



# **CS SERIES ELECTROCHEMICAL WORKSTATION**

## **USERS' MANUAL**

**Wuhan CorrTest Instruments Corp., Ltd.**  
**Wuhan China**

# Contents

<b>PART 1 INTRODUCTION OF CS SERIES POTENTIostat / GALVANostat.....</b>	<b>- 1 -</b>
<b>PART 2 CS STUDIO SOFTWARE.....</b>	<b>- 5 -</b>
<b>1. INTRODUCTION.....</b>	<b>- 5 -</b>
1.1 ELECTROCHEMICAL TECHNIQUES.....	- 5 -
1.2 SOFTWARE INSTALLATION.....	- 6 -
<b>2. MENU.....</b>	<b>- 13 -</b>
2.1 FILE.....	- 13 -
2.2 SETUP.....	- 13 -
<b>3. EXPERIMENT SETTING.....</b>	<b>- 15 -</b>
3.1 PSTAT/GSTAT(ECS)SETTING.....	- 15 -
3.2 CELL SETTING.....	- 17 -
<b>4. COMBINATION TEST.....</b>	<b>- 17 -</b>
<b>5. STABLE POLARIZATION.....</b>	<b>- 19 -</b>
5.1 OPEN CIRCUIT POTENTIAL.....	- 19 -
5.2 POTENTIOSTATIC.....	- 21 -
5.3 GALVANOSTATIC.....	- 22 -
5.4 POTENTIODYNAMIC.....	- 23 -
5.5 GALVANODYNAMIC.....	- 25 -
5.5 MULTI POTENTIAL STEPS.....	- 26 -
<b>6. TRANSIENT POLARIZATION.....</b>	<b>- 28 -</b>
6.1 MULTI-POTENTIAL STEPS.....	- 28 -
6.2 MULTI-CURRENT STEPS.....	- 29 -
6.3 POTENTIAL STAIR-STEP(VSTEP).....	- 30 -
6.4 GALVANIC STAIR-STEP(ISTEP).....	- 31 -
<b>7. CHRONO TECHNIQUES.....</b>	<b>- 31 -</b>
7.1 CHRONOPOTENTIOMETRY.....	- 31 -
7.2 CHRONOAMPEROMETRY.....	- 33 -
7.3 CHRONOCOULOMETRY.....	- 34 -
<b>8. VOLTAMMETRY.....</b>	<b>- 35 -</b>
8.1 CYCLIC VOLTAMMETRY.....	- 35 -
8.2 LINEAR SWEEP VOLTAMMETRY.....	- 37 -
8.3 STAIRCASE VOLTAMMETRY.....	- 39 -
8.4 SQUARE WAVE VOLTAMMETRY.....	- 40 -
8.5 DIFFERENTIAL PULSE VOLTAMMETRY.....	- 42 -
8.6 NORMAL PULSE VOLTAMMETRY.....	- 44 -
8.7 DIFFERENTIAL NORMAL PULSE VOLTAMMETRY.....	- 46 -
8.8 A.C. VOLTAMMETRY.....	- 47 -
8.9 2ND HARMONIC A.C. VOLTAMMETRY.....	- 49 -
8.10 FOURIER TRANSFORM AC VOLTAMMETRY (FTACV).....	- 50 -

<b>9. AMPEROMETRIC.....</b>	<b>- 51 -</b>
9.1 DIFFERENTIAL PULSE AMPEROMETRY (DPA).....	- 51 -
9.2 DOUBLE DIFFERENTIAL PULSE AMPEROMETRY (DDPA).....	- 52 -
9.3 TRIPLE PULSE AMPEROMETRY (TPA).....	- 54 -
9.4 INTEGRATED PULSE AMPEROMETRIC DETECTION(IPAD).....	- 55 -
<b>10. STRIPPING VOLTAMMETRY.....</b>	<b>- 57 -</b>
10.1 POTENTIOSTATIC STRIPPING.....	- 57 -
10.2 LINEAR STRIPPING VOLTAMMETRY.....	- 58 -
10.3 STAIRCASE STRIPPING VOLTAMMETRY.....	- 59 -
10.4 SQUARE WAVE STRIPPING VOLTAMMETRY.....	- 60 -
10.5 DIFFERENTIAL PULSE STRIPPING VOLTAMMETRY.....	- 62 -
10.6 NORMAL PULSE STRIPPING VOLTAMMETRY.....	- 62 -
10.7 DIFFERENTIAL NORMAL PULSE STRIPPING VOLTAMMETRY.....	- 63 -
<b>11. IMPEDANCE(EIS).....</b>	<b>- 64 -</b>
11.1 EIS VS. FREQUENCY(IMP).....	- 64 -
11.2 EIS VS TIME(IMPT).....	- 67 -
11.3 EIS VS POTENTIAL(IMPE).....	- 69 -
<b>12. CHARGING/DISCHARGING.....</b>	<b>- 70 -</b>
12.1 BATTERY CHARGING/DISCHARGING.....	- 70 -
12.2 GALVANOSTATIC CHARGING/DISCHARGING(GCD).....	- 71 -
12.3 POTENTIOSTATIC CHARGE AND DISCHARGE (PCD).....	- 73 -
<b>13. BIPOTENTIOSTAT.....</b>	<b>- 74 -</b>
13.1 HYDROGEN DIFFUSION TEST (HDT).....	- 74 -
13.2 ROTATING RING-DISK ELECTRODE (RRDE).....	- 77 -
<b>14. MISC.TECHNIQUES.....</b>	<b>- 79 -</b>
14.1 ELECTROCHEMICAL NOISE (EN).....	- 79 -
14.2 ELECTROCHEMICAL STRIPPING/DEPOSITION.....	- 80 -
14.3 ELECTROCHEMICAL POTENTIOKINETIC REACTIVATION(EPR).....	- 81 -
14.4 BULK ELECTROLYSIS WITH COULOMETRY (BE).....	- 81 -
14.5 SOLUTION RESISTANCE RS MEASUREMENT.....	- 82 -
14.6 CYCLIC POLARIZATION CURVE (CPP).....	- 83 -
14.7 MULTI POTENTIOSTATIC.....	- 84 -
<b>15. TIMING MEASUREMENT.....</b>	<b>- 85 -</b>
<b>16. GRAPH DISPLAY.....</b>	<b>- 86 -</b>
16.1 ".COR" DATA FILE GRAPHING.....	- 86 -
16.2 ".z60" IMPEDANCE DATA.....	- 89 -
<b>17. TOOLS.....</b>	<b>- 91 -</b>
17.1 DATA EXPORT.....	- 91 -
17.2 DATA FITTING.....	- 91 -
17.3 VOLTAMMETRY ANALYSIS.....	- 95 -

17.4 M-SCURVE ANALYSIS.....	- 99 -
17.5 FILTER.....	- 99 -
17.6 DELETE DATA.....	- 100 -
17.7 EIS ANALYSIS.....	- 101 -
<b>18. WINDOWS.....</b>	<b>- 107 -</b>
<b>19. HELP.....</b>	<b>- 107 -</b>
<b>20. FAQs.....</b>	<b>- 107 -</b>
<b>21. SERVICE &amp; CONTACT US.....</b>	<b>- 111 -</b>
<b>22. APPENDIX-ELECTROCHEMICAL ACCESSORIES.....</b>	<b>- 111 -</b>

## Part 1 Introduction of CS series potentiostat / galvanostat

CS Potentiostat / Galvanostat (electrochemical workstation) contains a fast digital function generator, high-speed data acquisition circuitry, a potentiostat and a galvanostat. With high performance in stability and accuracy with advanced hardware and well-functioned software, it is a comprehensive research platform for corrosion, batteries, electrochemical analysis, sensor, life science and environmental chemistry etc.



### Applications

- ①Electrosynthesis, electrodeposition (electroplating), anodic oxidation, etc.
- ②Electrochemical analysis and sensor;
- ③Battery (Li-ion battery, solar battery, fuel cell, supercapacitor), new materials, optoelectronic materials;
- ④Corrosion mechanism of metals in water, concrete and soil;
- ⑤Fast evaluation of corrosion inhibitor, water stabilizer, coating and cathodic protection efficiency.

### Specifications

- Support 2-, 3- or 4-electrode system
- Potential control range:  $\pm 10\text{V}$
- Current control range:  $\pm 2\text{A}$
- Potential control accuracy:  $0.1\% \times \text{full range} \pm 1\text{mV}$
- Current control accuracy:  $0.1\% \times \text{full range}$
- Potential resolution:  $10\mu\text{V} (>100\text{Hz})$ ,  $3\mu\text{V} (<10\text{Hz})$
- Current sensitivity:  $1\text{pA}$
- Potentiostat rise time:  $<1\mu\text{s} (<10\text{mA})$ ,  $<10\mu\text{s} (<2\text{A})$
- Reference electrode input impedance:  $10^{12}\Omega || 20\text{pF}$
- Current range:  $2\text{nA} \sim 2\text{A}$ , 10 ranges
- Compliance voltage:  $\pm 21\text{V}$
- Maximum current output:  $2.0\text{A}$
- CV and LSV scan rate:  $0.001\text{mV} \sim 10,000\text{V/s}$
- CA and CC pulse width:  $0.0001 \sim 65,000\text{s}$
- Current increment during scan:  $1\text{mA} @ 1\text{A/ms}$
- Potential increment during scan:  $0.076\text{mV} @ 1\text{V/ms}$
- SWV frequency:  $0.001 \sim 100\text{kHz}$
- DPV and NPV pulse width:  $0.0001 \sim 1000\text{s}$
- AD data acquisition:  $16\text{bit} @ 1\text{MHz}$ ,  $20\text{bit} @ 1\text{kHz}$
- DA Resolution: 16bit, setup time:  $1\mu\text{s}$
- Minimum potential increment in CV:  $0.075\text{mV}$
- IMP frequency:  $10\mu\text{Hz} \sim 1\text{MHz}$
- Low-pass filters: covering 8-decade
- Potential and current range: automatic

### EIS specs

#### Signal generator:

- Frequency range:  $10\mu\text{Hz} \sim 1\text{MHz}$

Frequency accuracy: 0.005%

AC signal amplitude: 1mV~2500mV

Signal resolution: 0.1 mV RMS

DC Bias: -10~+10V

Output impedance: 50Ω

Waveform: Sine wave, triangular wave and square wave

Wave distortion: <1%

Scan mode: Logarithmic/linear, increase/decrease

**Signal analyzer:**

Integral time: minimum: 10ms or the longest time of a cycle

Maximum: 10<sup>6</sup> cycles or 10<sup>5</sup>s

Measurement delay: 0~10<sup>5</sup>s

**DC offset:**

Potential automatic compensation range: -10V~+10V

Current compensation range: -1A~+1A

Bandwidth: 8-decade frequency range, automatic and manual setting

**System Requirements**

Operating System: Windows XP / Vista /7/ 8/10.

Communication between PC and instrument: USB2.0.

Dimensions(cm):36 ×30×14;weight: 6.5kg

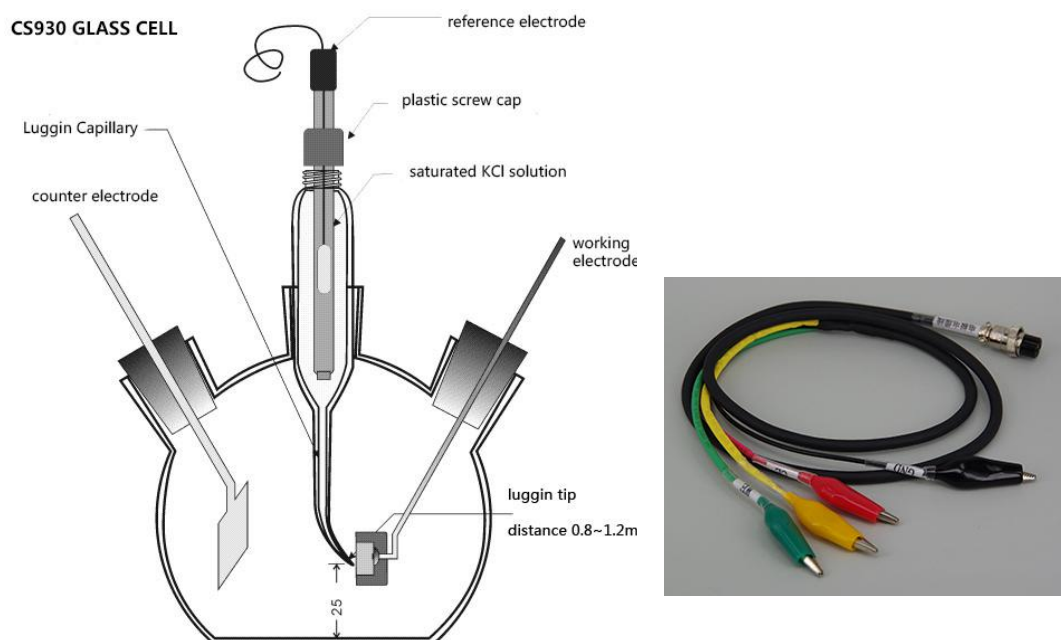


Front panel of CS single channel potentiostat/ galvanostat

Cell- This port is insert the cell cable to connect the instrument with the cell system. Each cell cable has 5 leads/clamps.

- ① Green clamp (WE) connects to working electrode (WE)
- ② Red clamp (CE) connects to counter electrode (CE)
- ③ Yellow clamp (RE) connects to reference electrode (RE)
- ④ Black (GND) connects to galvanic electrode WEII in electrochemical noise experiment. If use a Faraday cage, black GND and Shield connect the cage together.

LED screen: display the current range, load status, working mode, polarization status



## 2. Two electrodes system

The green lead connects to WE or anode; red lead & yellow lead together connect to another electrode or cathode.



Rear panel of CS single channel potentiostat galvanostat

**AC 220V or 110V:** AC 220V or 110V power socket with fuse, 1A fuse in the bottom box.

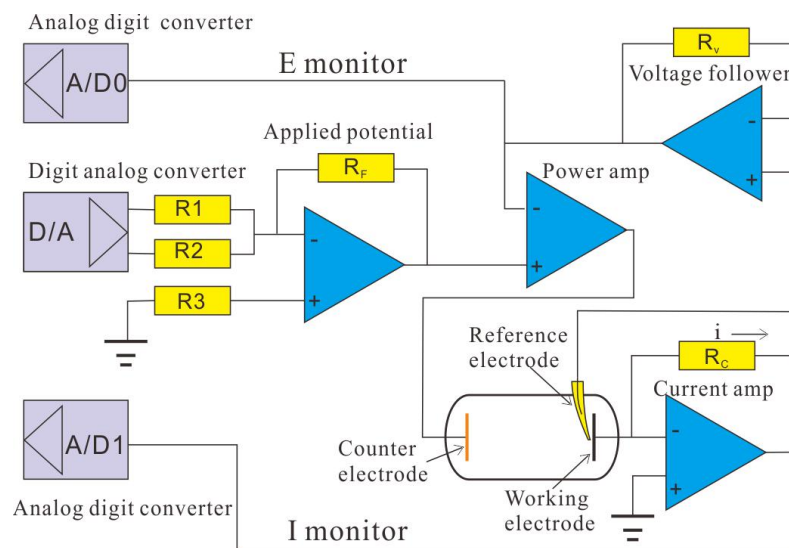
**External control interface:** used to synchronously control the external stirrer, motor rotating rate, etc., or as a frequency meter for frequency testing of external signals (can be connected to a quartz crystal microbalance QCM).

**USB:** using USB to connect the potentiostat with a computer.

**LAN:** using an Ethernet cable to connect the potentiostat with a computer.

**Analog input and output:** the analog input and output expansion port of the instrument.

## Schematic diagram



Schematic diagram of CS potentiostat

### Shipment list

For one set of CS potentiostat/galvanostat, supply list:

Instrument host×1

CS studio software ×1

Dummy cell×1

Power cable ×1

USB (or Ethernet) cable ×1

Electrode cable ×2

Manual×1



## Part 2 CS Studio Software

### 1. Introduction

CS Studio software shipped with the CS electrochemical workstation is an easy-to-use, flexible, and versatile electrochemical tool and can be applied in many research fields from corrosion, voltammetry, electroanalysis to battery test, etc. There is no special requirement for computer, a mainstream/ common one is OK.



Interface of CS Studio software

#### 1.1 Electrochemical Techniques

# There is the corresponding stripping method.

**Stable polarization:** Open Circuit Potential (OCP), Potentiostatic (I-T curve), Galvanostatic, Potentiodynamic (Tafel), Galvanodynamic, Potential Sweep-step

**Transient polarization:** Multi-Potential Steps, Multi-Current Steps, Potential Stair-Step (VSTEP), Galvanic Stair-Step (ISTEP)

**Chrono Methods:** Chronopotentiometry (CP), Chronoamperometry (CA), Chronocoulometry (CC)

**Voltammetry:** Cyclic Voltammetry (CV), Linear Sweep Voltammetry (LSV), Staircase Voltammetry (SCV)#, Differential Pulse Voltammetry (DPV)#, Normal Pulse Voltammetry (NPV)#, Square wave voltammetry (SWV)#, AC voltammetry (ACV)#, Differential Normal Pulse Voltammetry (DNPV)#, 2nd Harmonic A. C. Voltammetry (SHACV), Fourier Transform AC Voltammetry (FTACV)

**Amperometric:** Differential Pulse Amperometry (DPA), Double Differential Pulse Amperometry (DDPA), Triple Pulse Amperometry (TPA), Integrated Pulse Amperometric Detection (IPAD)

**Impedance:** EIS vs Frequency (IMP), EIS vs Time (IMPT), EIS vs Potential (IMPE)

**Corrosion testing:** Cyclic polarization curve (CPP), Linear polarization curve (LPR), Electrochemical Noise (EN), Zero Resistance Ammeter (ZRA), Electrochemical Potentiokinetic Reactivation (EPR)

**Battery testing:** Battery charge and discharge, Galvanostatic charge and discharge(GCD)

**Bipotentiostat:** Hydrogen diffusion (HDT), Rotating ring-disk Electrode(RRDE)

**Extensions:** Data Logger, Disc machine control, Bulk electrolysis with Coulometry

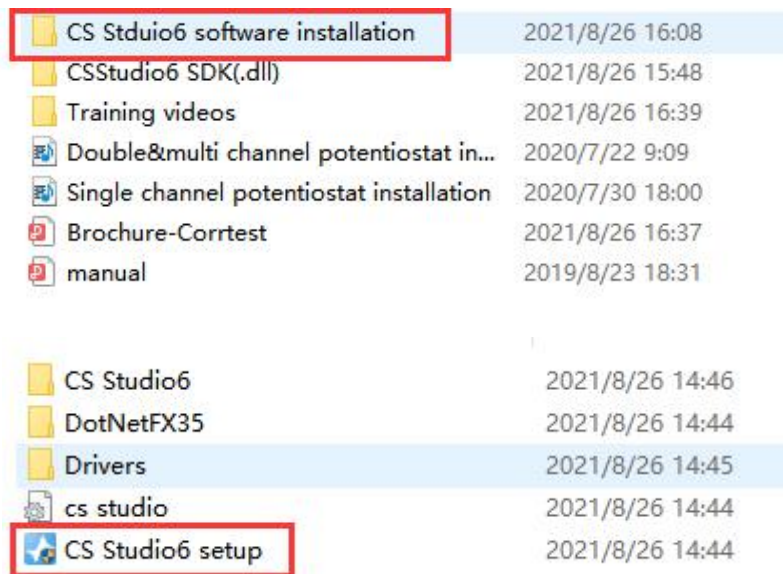
CS Studio software is also equipped with powerful corrosion analysis module. It can calculate the corrosion rate of the material by linear polarization and weak polarization, as well as polarization resistance ( $R_p$ ), Tafel slope ( $b_a$ ,  $b_c$ ), and corrosion current density ( $i_{corr}$ ) through the non-linear fitting of Tafel plots. In addition, by the built-in electrochemical impedance spectroscopy (EIS) technique, it can measure the double layer capacitance ( $C_{dl}$ ) and the solution/ concrete resistance ( $R_s$ ). Moreover, CS Studio software provides as a dual-channel data logger for pH, temperature and some physical quantities records.

## 1.2 Software Installation

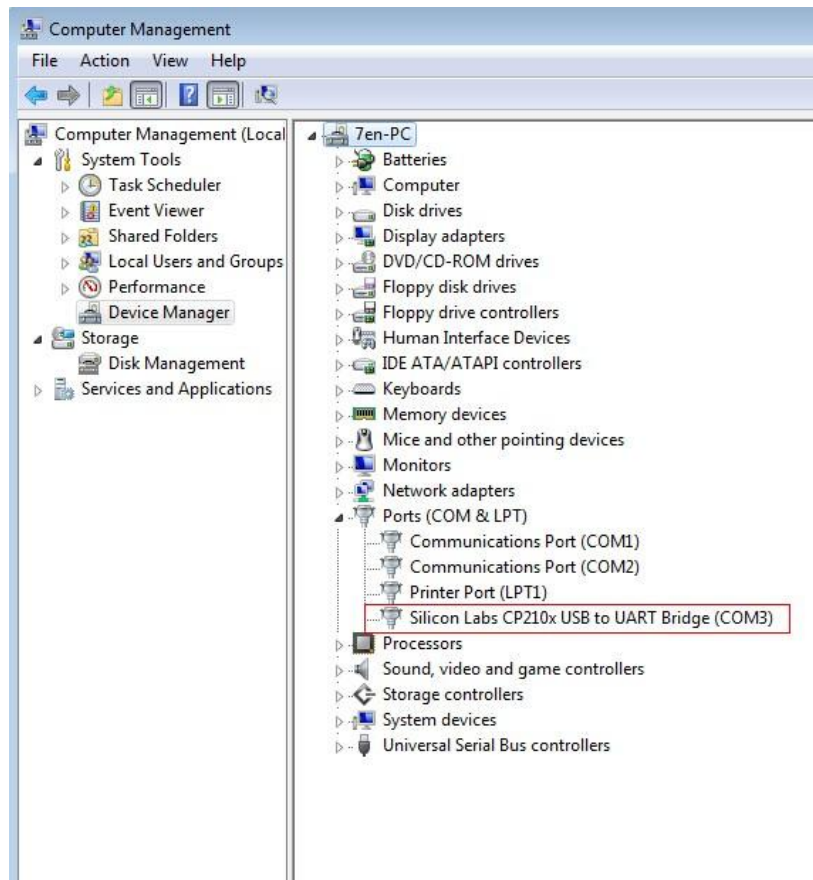
### 1.2.1 CS single channel models-USB(CS350/CS310/CS300/CS150/CS120)

1. Using the USB cable to connect the potentiostat with a computer.

2. Power on the instrument, open the “software installation” folder in the CD and USB flash disk., right click the “CS studio6 setup”, and run as administrator.



3. Firstly, install the drivers. After finishing it, go to the computer management → device manager → Ports (COM & LPT). There, it will appear “Silicon Labs CP210x USB to UART Bridge(COM x)”. As is shown below, the X is 3.



4. Secondly, install the runtime environment. If your computer has already installed it, there will be a prompt saying you have already installed.

If it hasn't been installed in your computer, just follow the steps to finish installation of runtime.

5. Click install CS Studio6. Created a shortcut is on the desktop.

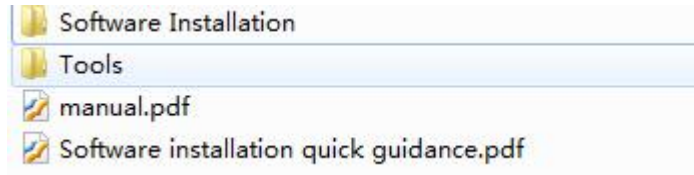


6. Run the software as administrator. Then the model and serial number will be shown. It means the instrument has been successfully connected.

## 1.2.2 CS2350 Bipotentiostat (Ethernet) and CS multichannel potentiostat

### Software installation

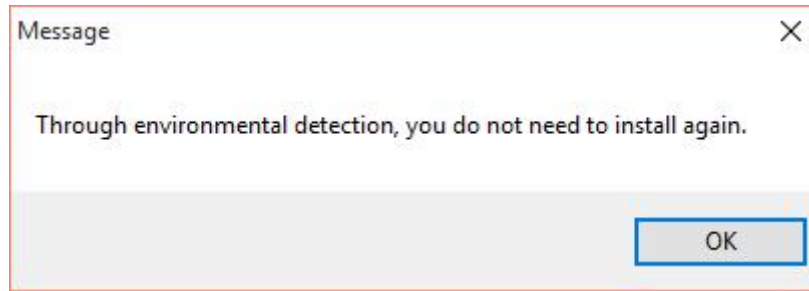
- (1) Use the Ethernet cable to connect the computer with the instrument. Power on the instrument.
- (2) Open the “software installation” folder, right click the “Setup.exe”, and run as administrator.



CS Studio5	2019/8/8 9:41	文件夹	
DotNetFX35	2019/8/8 9:41	文件夹	
Drivers	2019/8/8 9:41	文件夹	
DriversForXp	2019/8/8 9:41	文件夹	
SoConfig	2019/8/8 9:41	文件夹	
sxsForWin8	2019/8/8 9:41	文件夹	
sxsForWin10	2019/8/8 9:41	文件夹	
sxsForWin10-New	2019/8/8 9:41	文件夹	
clean	2017/3/23 9:27	Windows 批处理...	1 KB
<b>Setup.exe</b>	2019/8/7 15:52	应用程序	3,769 KB
Setup	2017/6/29 13:56	安装信息	1 KB
sxs8	2019/5/8 16:57	Windows 批处理...	1 KB
sxs10	2019/5/8 16:58	Windows 批处理...	1 KB
sxs10-New2-x64	2019/8/7 13:41	Windows 批处理...	1 KB
sxs10-New2-x86	2019/8/7 13:42	Windows 批处理...	1 KB
sxs10-New-x64	2019/5/8 17:58	Windows 批处理...	1 KB
sxs10-New-x86	2019/5/8 17:58	Windows 批处理...	1 KB

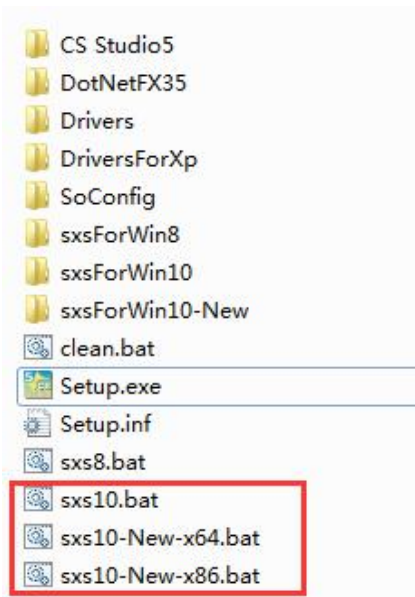


- (3) As it uses Ethernet communication, no need to install drivers. Firstly, install the .net 3.5. If your computer has already installed it, there will be a prompt as follows.

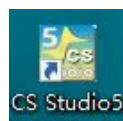


If it has not installed in your computer, just follow the steps to finish installation of .net 3.5.

Notice: If your operating system is windows 10 and it appears error prompt when you follow above step, then you have to install .net 3.5 through below tools. Please try one by one till you success. Remember to “run as administrator”.

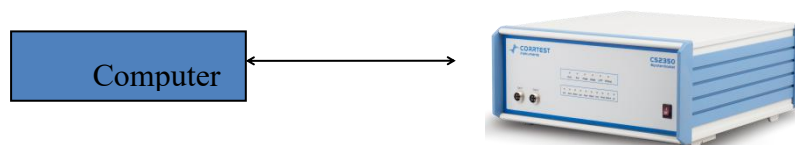


(4) Click install CS Studio5. Created a shortcut is on the desktop.

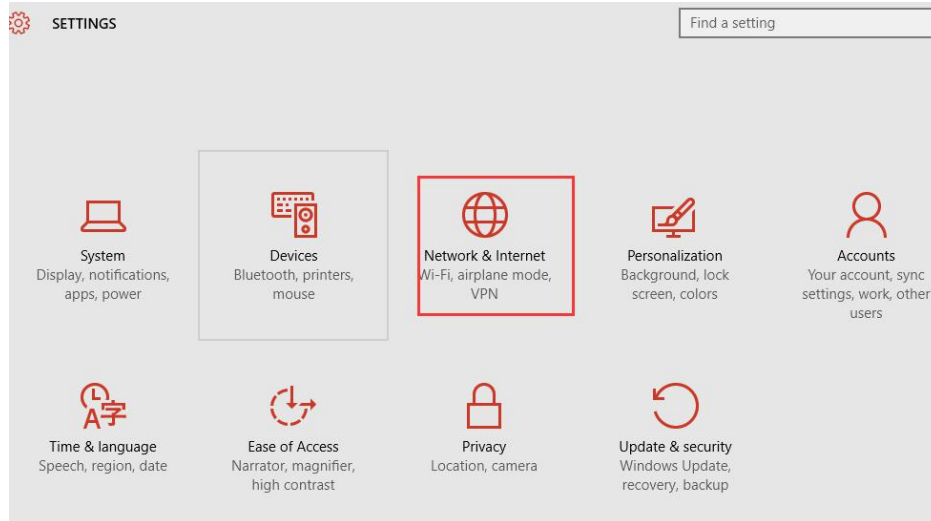


### IP address configuration

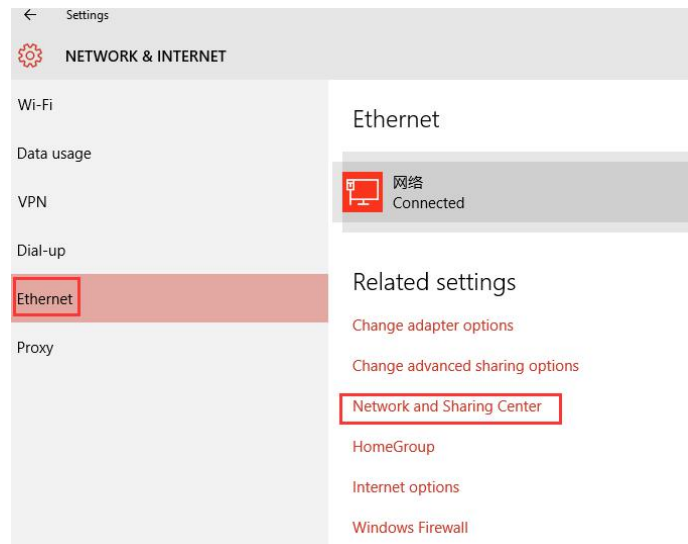
Connecting the instrument with computer by Ethernet cable, you should reset the IP address of the computer.



(1) Find the “Network and sharing center”



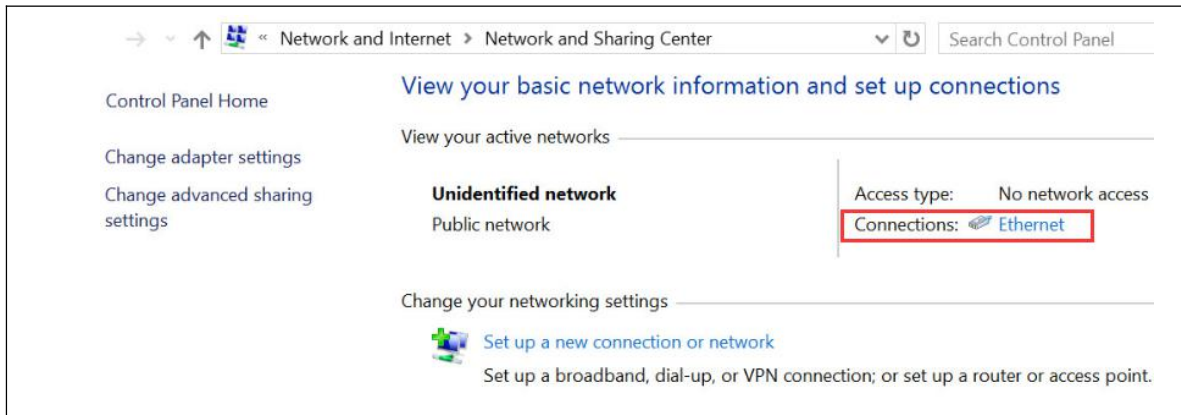
Then, Ethernet → Network and sharing center



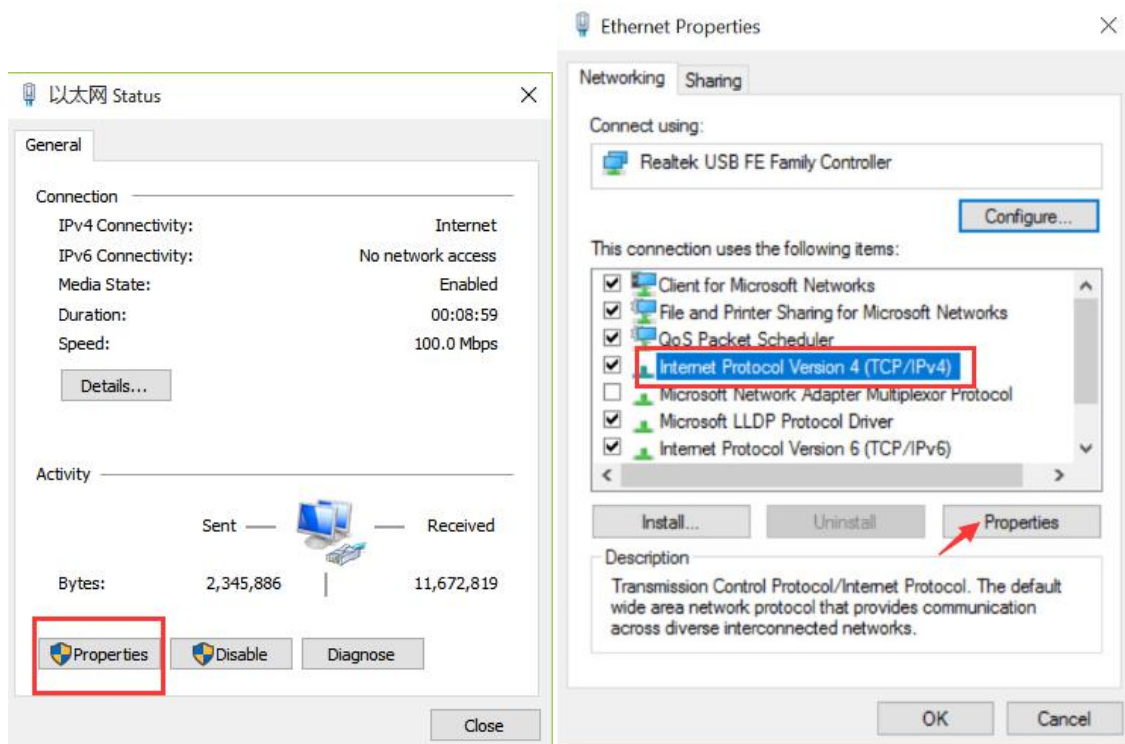
(Or  → Network and sharing center)

(2) Click “Ethernet” shown as below:

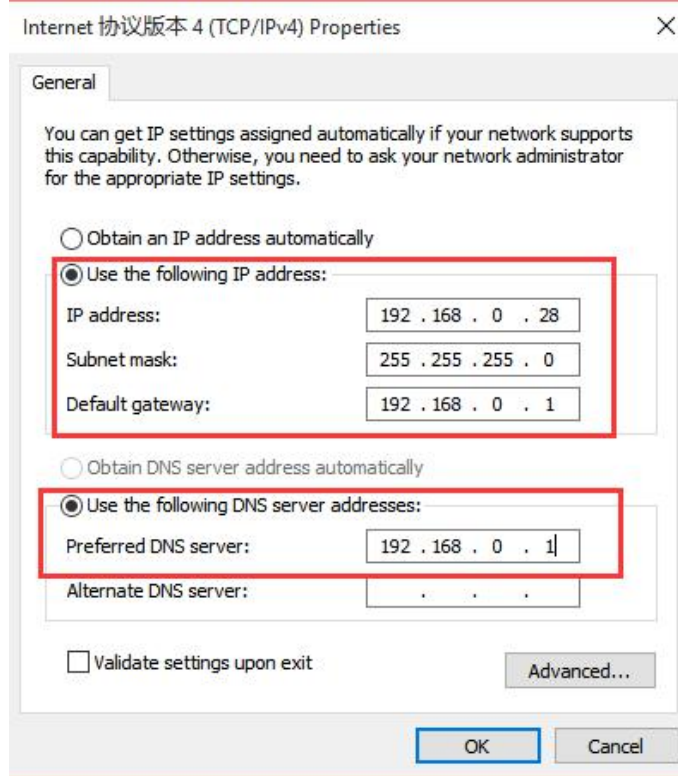




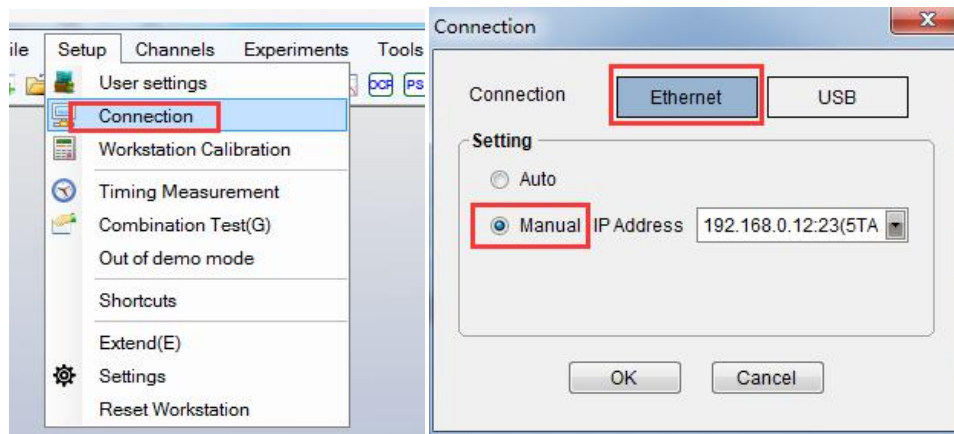
(3) Click “Properties”, then check “Internet Protocol version 4(TCP/IPv4)”



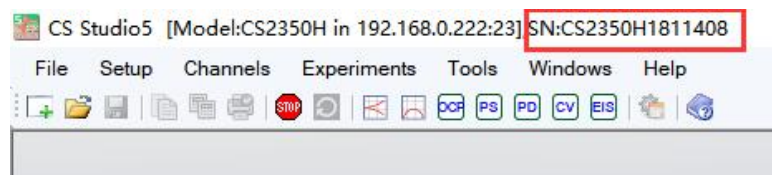
(4) Fill in the IP address exactly as below:



(5) Open CS Studio5 software, “Setup” → Connection→“Ethernet” →Manual



(6) When the bipotentiostat CS2350 is successfully connected with the computer, there will be model and serial number shown on the software interface, as is shown below.






## 2. Menu

There are key shortcuts for experiment techniques, such as “F2” for “Open Circuit Potential”, F4 for technique of “Potentiodynamic”.

There is a toolbar under the main menu, and it can achieve the same function as the main menu, and there will be a text message tip when you put the mouse on.

the “Experiments” will appear when you right-click the mouse on anywhere of the window. You can choose one technique to perform. Of course you can clicking main menu of “Experiments” and then click one technique..

The button  will be activated when a test is running. You can click it to stop the test. This button will gray out when you finish a test.

### 2.1 File

#### 2.1.1 *Open File*

Open a “.cor” data file. You can view data and do analysis. .

#### 2.1.2 *New Project*

Build a new project window. The original project window will not be closed or replaced.

#### 2.1.3 *Open Project*

Open a project file. You can view the file and do data analysis.

#### 2.1.4 *Save Project*

Save the project window file in project file format.

#### 2.1.5 *Save Project As*

Save data file or project file as a new project file.

#### 2.1.6 *Close Project*

Close an open project window. If no file is open, this menu is disabled.

#### 2.1.7 *Page Setup*

Set the format for printing output .

#### 2.1.8 *Print*

Output the graph of the open file to the printer.

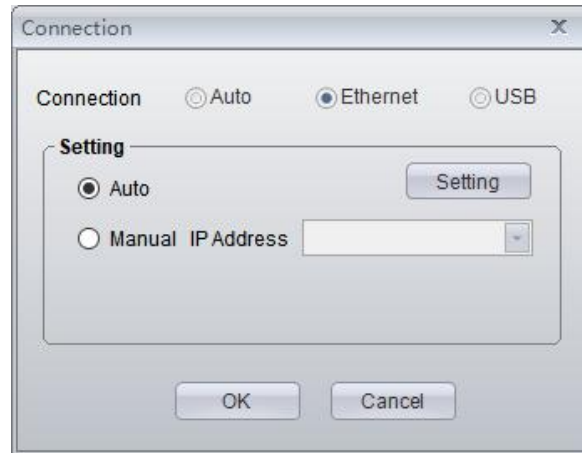
#### 2.1.9 *Exit*

Exit the CS studio software. When a test is being performed, there will be a prompt.

### 2.2 Setup

#### **Connection**

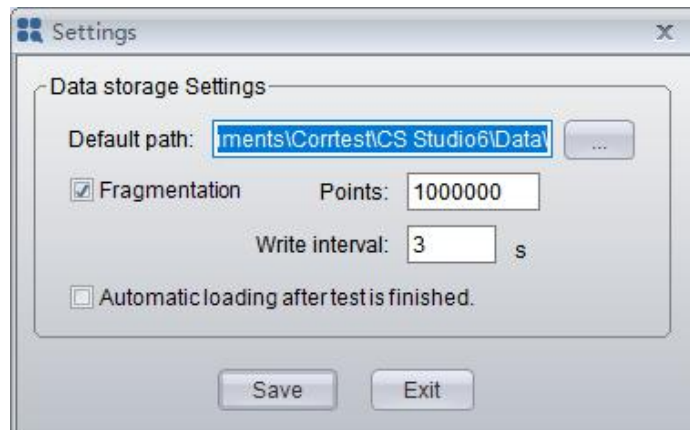
This menu is used to modify the communication way of the instrument connection.



## Settings

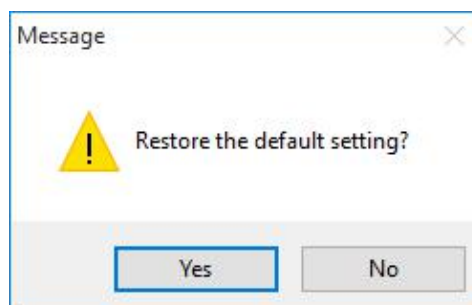
Here you can change the default place for data storage.

Fragmentation is used for big amount data. For each fragment the data points can be set. Default is 1000000.



## Restore default

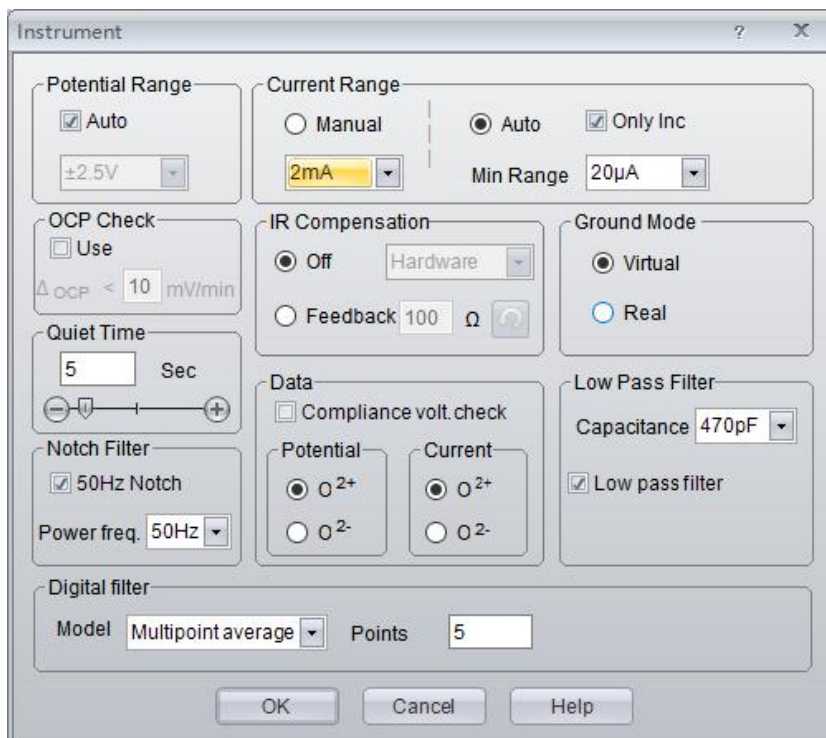
This is to restore to the factory default state. The stored experimental data will not be deleted.



### 3. Experiment Setting

#### 3.1 Pstat/Gstat(ECS)Setting

Open a technique, and you can do the instrument setting by clicking



#### Potential Range

Potential range can be  $\pm 2.5V$ ,  $\pm 5V$ , or  $\pm 10V$ . The default range is  $\pm 2.5V$ . The narrower the range is, the higher the input signal gain. Normally when the potential signal input is in the range of  $\pm 2.5V$ , “ $\pm 2.5V$ ” range is OK. But if the potential of the tested system is over  $\pm 2.5V$ , you must choose the range to be  $\pm 5V$ , or  $\pm 10V$ .

#### Current Range

You can choose either “Manual” or “Auto”. If check Manual, the drop-down box is activated, and you can choose a suitable current range. If the current in the experiment reaches 120% of the set range, then the software will automatically cut off the polarization of the potentiostat. “Auto” allows the instrument to select the suitable current range according to the polarization current.

“**Min Range**” - you can set a limitation for minimum current range to avoid possible extra noise in some high-resistance systems in case the current range is too small.

“**Only Inc**” means the current range will be switched only from lower range to higher range, just in this direction. This is particularly useful for CV experiment.

In the moment of current range switching, noise may be inevitable. Therefore, it is recommended to choose a fixed current range in fast measurements or when the data acquisition frequency is high.

#### OCP Check

If you check the radio button “Use”, the software will judge whether the open circuit potential is in the range that you set. If yes, the experiment will conduct automatically if you have set the data file save path.

#### Quiet Time

Enter a number or drag the slider, you can specify the duration of delay for scan. The maximum delay time is 1000s. Setting the quiet time can make the measuring current stable, especially when polarization doesn't start from OCP. As you know, transient polarization may cause a large current, and the value will decrease as time goes by. Therefore, there should be a quiet time before formally recording data.

Before this window appear, the potentiostat is already in the state of polarization, but doesn't start scan. If you think the polarization current is already stable, then you can click Run anytime to start testing. You can click cancel to quit the experiment.

When the countdown is completed, the scan will start automatically.

If you set "Auto" change current range, during this process, CS studio software will auto choose the suitable range according to the actual current. If the current range is set to be "manual", once the current is overloaded, the software will give you a prompt to change a larger current range. If you choose "No", then the software will control the instrument to change from polarization state to natural state.

### **IR Compensation**

In high-resistance system, the solution resistance( $R_s$ ) is large between the working electrode and the tip of Luggin capillary where the reference electrode is put, especially for concrete or coated samples, so it must be compensated.  $R_s$  measurement can be done with method of Potential Stair-Step (VSTEP). Enter the  $R_s$  value in the feedback for IR compensation in the subsequent measurements.

### **Ground mode**

There are two modes for the working electrode: virtual and real. The "virtual" mode is suitable for most stable test systems. As for electrochemical noise or galvanic corrosion measurement, you must choose "virtual" mode. Real mode is suitable for a system where the working electrode is connected to earth, such as the rebar in the concrete. For EIS test, you should choose real mode to increase the high-frequency response characteristic.

### **Low Pass Filter**

The frequency response bandwidth of the power amplifier in the potentiostat can be change by this setting. The higher the capacitance you choose is, the narrower the bandwidth of the potentiostat is.

If all the filters are closed, then the power amplifier has the best frequency response characteristics. But for some high-resistance systems, oscillation may appear. If you use the virtual mode and choose a low capacitance, it is very likely for the instrument to occur oscillation even positive feedback. You should decrease the bandwidth of the amplifier, i.e., increase the capacitance in the low pass filter.

When increasing the capacitance, the response frequency bandwidth will decrease, which equals to low-pass filtering the signals. Normally, for slow scan experiment, you can choose 10nF~100nF; for fast scan or transient measurements, you can choose 100pF~10nF; For EIS measurements, you may need to choose 100pF~10nF(virtual) or 0~1nF(real).

### **Data smooth**

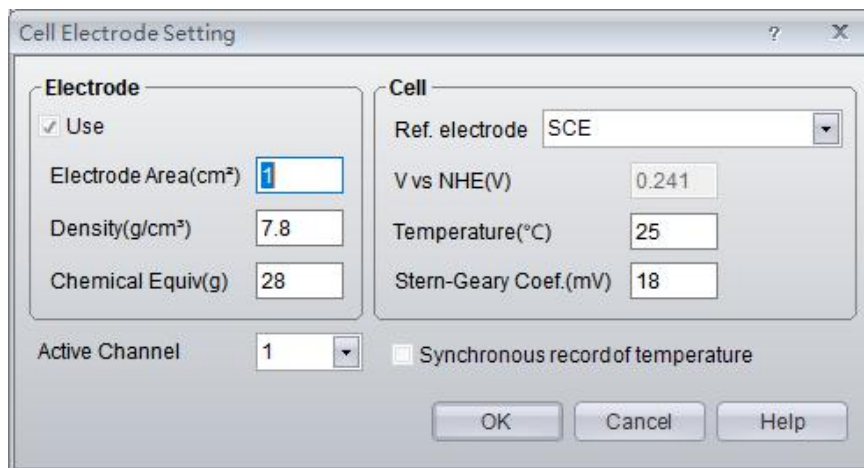
When choosing data smooth, the software will do real-time filtering of the data and automatically get rid of the burrs on the curves. Please note that when you do transient measurements, you don't need to use it because it can bring slight distortion for data.

### **Notch filter**

If you check the notch filter and choose the frequency, the interference can be restrained when the experiment is being conducted.

### 3.2 Cell Setting

You can enter related information of one or more working electrode(s) and electrolytic cell(s), eg. surface area, material, and temperature... The electrode area, density and chemical equivalent will affect the results of experiment and fitting. Temperature or type of RE will not affect the original data; they are just saved in each data file for info. Meanwhile, these parameters are needed for corrosion rate calculation.



#### Electrode

**Electrode Area:** the exposed area of the working electrode in the solution. It is the effective working area. Unit is  $\text{cm}^2$ . Default is 1. If it is 1, the current density will be the same as the measured current in value.

**Density:** the density of the material of the working electrode. Unit is  $\text{g/cm}^3$ .

**Chemical Equiv** = the molar mass/number of electrons transferred in a reaction. Take the reaction  $\text{Fe} \rightarrow \text{Fe}^{2+}$  for example, the molar mass of pure Fe is 55.84g, and the number of transferred electrons is 2, so the equivalent weight is  $55.84\text{g}/2=27.92\text{g}$ .

#### Cell parameters

**Reference electrode:** in the drop box you can choose SCE, Ag/AgCl, Hg/HgO, Hg/HgSO<sub>4</sub>, Cu/CuSO<sub>4</sub>... You can also choose "Custom" if your RE is not in the list, then you should specify the value of "V vs. NHE (normal hydrogen electrode)".

**V vs. NHE:** it is the relative potential of the selected reference electrode vs. NHE.

**Temperature:** it is the temperature for the electrochemical reaction at present.

**Stern- Geary Coef.:** in the range of 20~28mV.

#### Active channel

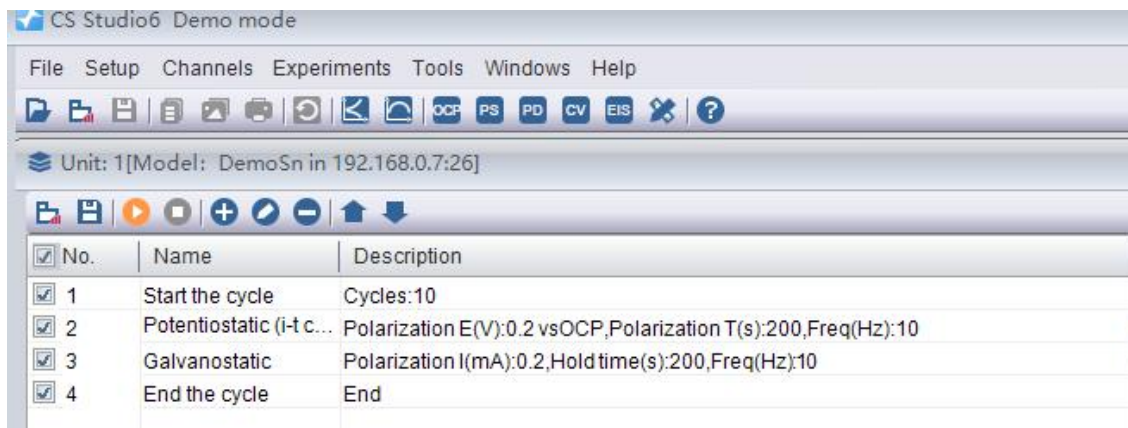
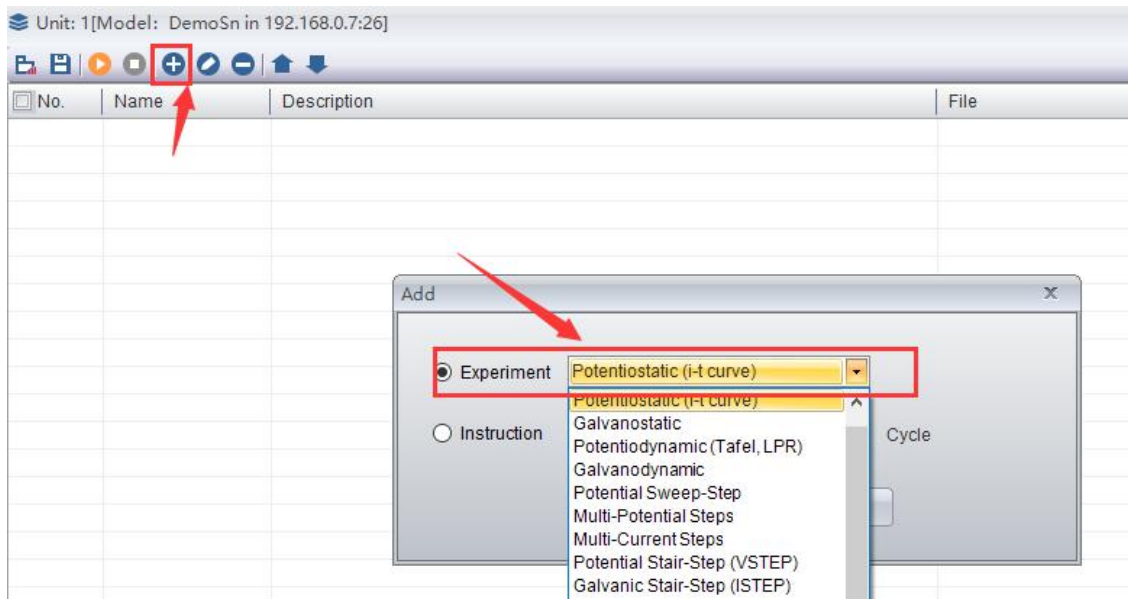
For single-channel CS potentiostat, there is only 1 channel. For multi-channel potentiostat, you can set the cell information independently.









### 4. Combination test

This is a very useful function.

You can add several experiments, for each test you can modify the parameters setting, and the number of cycles can also be set. After setting the experiments and control instructions, click the "OK" button, and the instrument will automatically test and save the data according

to the custom requirements. This function can achieved your unattended measurements. You don't need to wait in the lab and it will complete a series of experiments automatically. It will make the testings efficient and save your time.



-  Build a project
-  Save the project
-  Start
-  Pause
-  Add an experiment
-  Modify
-  Remove
-  Adjust the order of the instructions and experiments



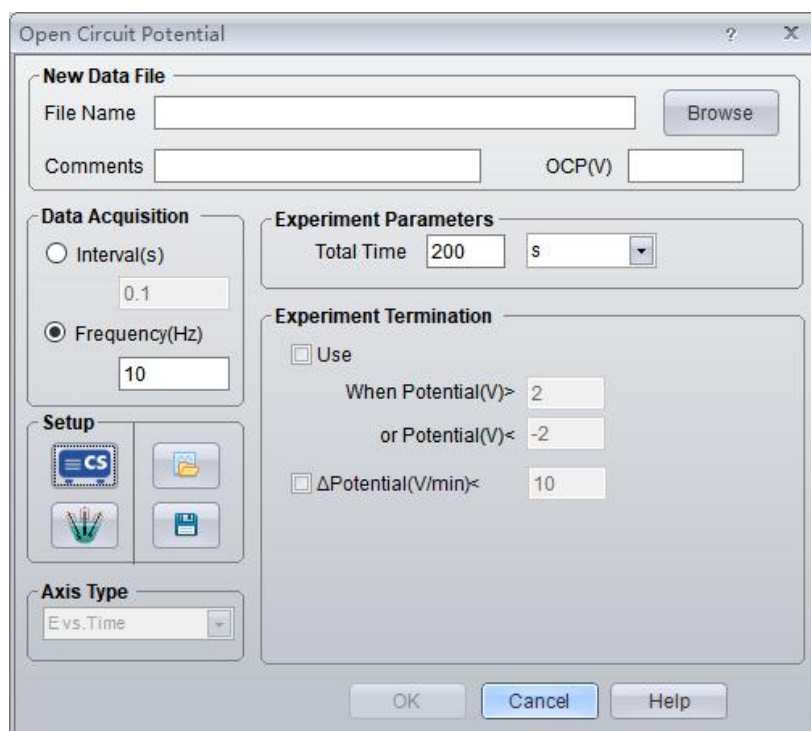
## 5. Stable Polarization

### 5.1 Open Circuit Potential

Experiments→Stable Polarization→Open Circuit Potential

This experiment aims at monitoring the open circuit potential (or free corrosion potential, i.e., the potential difference between WE and RE without any applied electric field) as a function of time. The experiment can be performed for a fixed duration or until a particular potential is reached.

Before test, the OK button is invalid. Only when you enter a file name can this button be activated. All the data will be saved in this file.

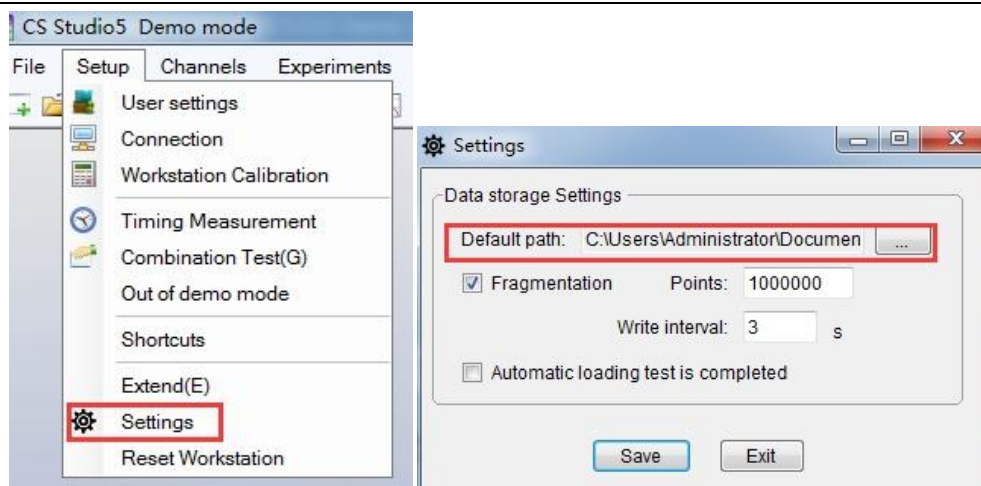


OCP (V) will display the current open circuit potential of the cell (update every second).

#### ***File Name***

You're suggested to build up a new folder for all the data files, then enter a file name before starting the test. You can click "Browse" and find the place where data files to be saved.

If you don't click browse and directly enter a name and confirm, then the default data storage path is as follows:



CS Studio will automatically append the suffix “.cor” to a file name. So if you input “tutor1”, the name of the data file will be shown as “tutor1.cor”.

The info in the Comments box will be saved in the data file. You can input info. such as the medium, the solution content, etc. Other info. such as the time when you perform the test, and all the related measurement parameters will be automatically saved in the data file. You don’t need to enter such information into comments.

### ***Experiment parameters***

**Total Time:** decides the total duration of the experiment.

### ***Data Acquisition***

Choose either “Interval” or “Frequency”.

**Interval** determines the time between each sampled data point. Frequency(Hz) specifies the data points sampled per second(acquisition rate). Please note that the interval cannot be set lower than 0.001s, i.e., the points/second cannot be higher than 1000. Otherwise the software will automatically set the frequency to be 1kHz (the maximum value allowed).

### ***Experiment Termination***

If the Use is checked, the experiment will be automatically terminated once the OCP goes above the high value (2V in the above dialog box for instance) or below the low value (-2V) .

### ***Axis Type***

You should set the Axis type for display of each dynamic graph. For OCP, the axis type is “E-Time”.

### ***Pstat/Gstat(ECS)***

See 3.1 Pstat/Gstat(ECS) Setting

### ***Cell Setup***

See Cell Setting 3.2.

Click OK to exit the parameter setting dialog box, and enter the “wait...” interface before testing. Meanwhile, CS Studio will save all the parameters that you set and remain the same the next time when you run this experiment.

Click “Cancel” also to exit the dialog box, not conducting the experiment. All the set parameters will be lost.

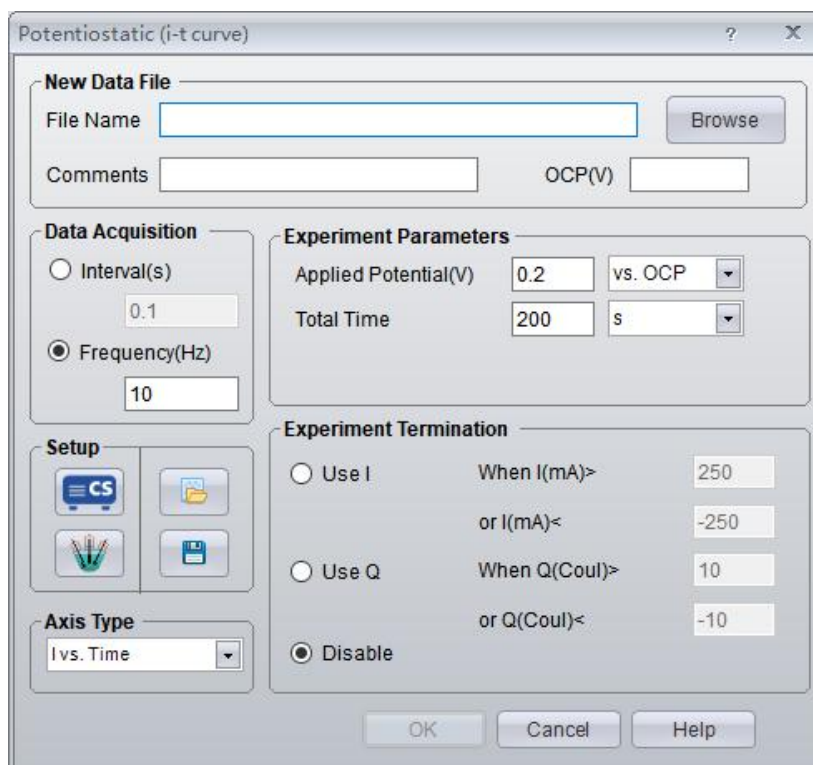
Click Help to access to the on-line help information on the setup of this experiment.



## 5.2 Potentiostatic

Experiments→Stable Polarization→Potentiostatic

In this experiment, the potentiostat applies a constant polarization potential on the working electrode and monitor the polarization current as a function of time. The polarization duration(Total Time) can be set by the user, or you can also let the experiment be automatically terminated when the polarization current or quantity of electric charge reaches to a certain value(change from the polarization state to OCP state).



OCP (V) will display the current open circuit potential of the cell (update every second).

### *Experiment Parameters*

**Applied Potential** is the potential applied on the measured system. It can be potential “vs. OCP” or “vs. RE”.

For CS series potentiostat, choosing potential “vs. OCP”, the input of a positive value means anodic polarization, negative value means cathodic polarization. Under potential “vs. OCP”, input of a positive value means anodic polarization, negative value means cathodic polarization. The actual potential applied on the WE is the algebraic sum of the input value and the current open circuit potential. For example, enter “0.2”, then the actual potential applied on the working electrode is “0.2V+OCP”. If selecting “vs. RE”, then the polarization potential applied on the working electrode is exactly 0.2V.

**Total Time** determines the total time of potentiostatic polarization. Unit is Second, minute or hour.

### *Experiment Termination*

If the Use I box is checked, the experiment of potentiostatic will be automatically terminated once the polarization current goes above the high value(anodic current, 250mA in above dialog box for instance) or below the low value (cathodic current, -250mA in above dialog box for instance) .

If Use Q is checked, the experiment of potentiostatic will be automatically terminated

once the total integral quantity of electric charge (coulombs) goes over maximum value(positive charge)or below minimum value(negative charge).

If the Disable is checked, the above two experiment termination prerequisites are ineffective. The experiment will not be terminated until the total time is reached.

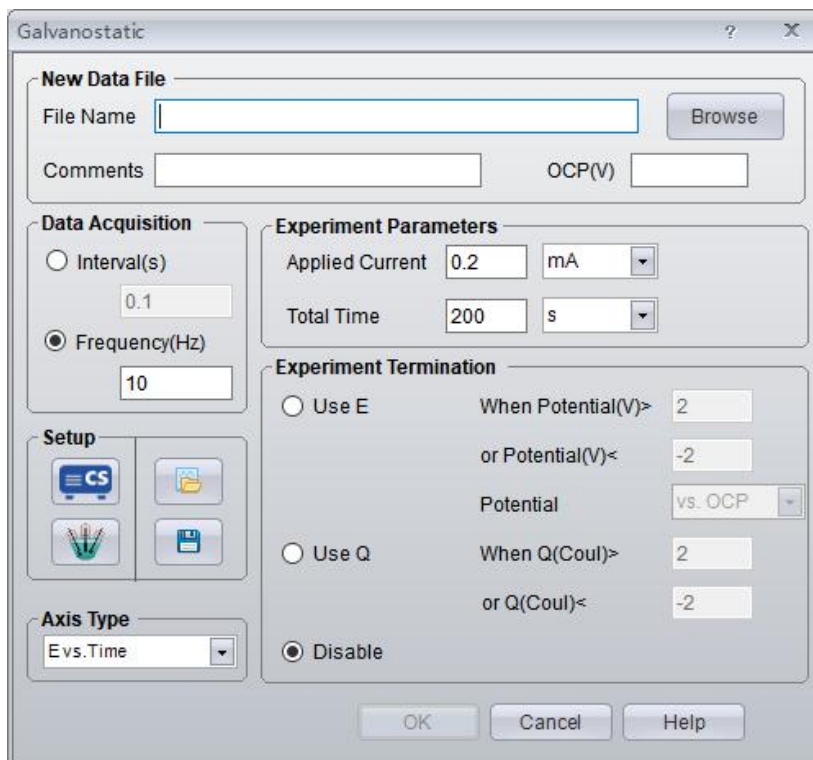
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats. For the experiment of Potentiostatic, the axis type is “I-Time”.

## 5.3 Galvanostatic

Experiments →Stable Polarization →Galvanostatic

In this experiment, the instrument applies a constant polarization current on the working electrode and monitor the polarization potential as a function of time. The polarization duration (Total Time) can be set by the user, or you can also let the experiment be automatically terminated when the polarization potential or quantity of electric charge reaches to a certain value.



OCP (V) will display the current open circuit potential of the cell (update every second).

### Experiment Parameters

**Applied Current** is the current applied on the measured system. Positive value means anodic polarization; negative value means cathodic polarization. This is the total current applied, not the current density. Units of  $\mu\text{A}$ , mA, A are available.

The Total Time determines the duration of the galvanostatic polarization process.

### Experiment Termination

If the Use E box is checked, the experiment of galvanostatic will be automatically terminated once the polarization potential goes above the high value(2V in above dialog box for instance) or below the low value (-2V in above dialog box for instance) .

If Use Q is checked, the experiment of galvanostatic will be automatically terminated once the total integral quantity of electric charge (coulombs) goes over maximum value or below minimum value.

If the Disable is checked, the above two experiment termination prerequisites are ineffective. The experiment will not be terminated until the total time is reached.

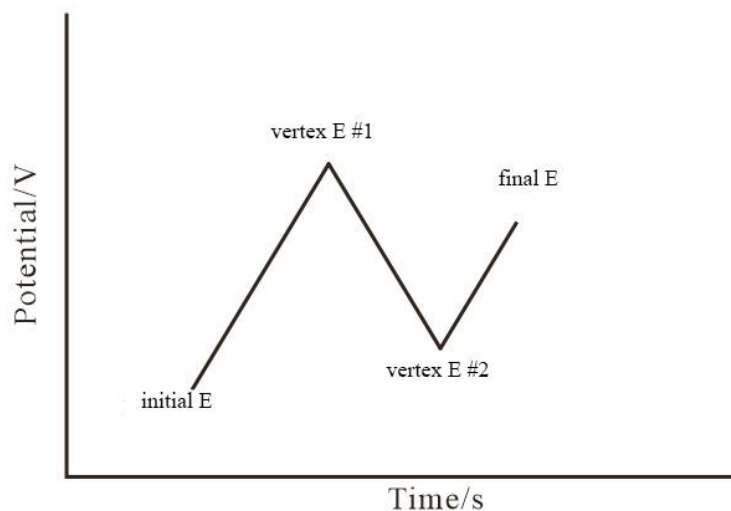
### ***Axis Type***

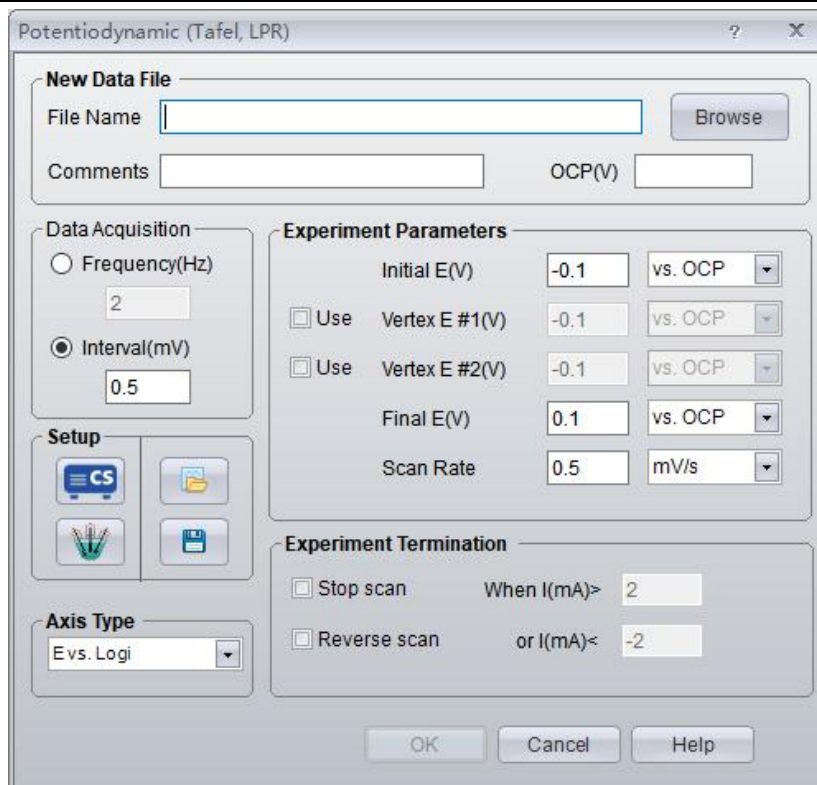
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats. For the experiment of Galvanostatic, the axis type is “E-Time”.

## **5.4 Potentiodynamic**

Experiments → Stable Polarization → Potentiodynamic

For potentiodynamic, there are up to four individual polarization potential set points. The scan starts from the “initial E” and goes through “vertex E #1”, “vertex E #2”, and finally reaches “final E”. The “vertex E #1” and “vertex E #2” can be both chosen, partly chosen or neither chosen. The scan can be stopped or reversed when current reaches to a certain value. The logarithm of current is recorded as a function of potential.





OCP (V) will display the current open circuit potential of the cell (update every second).

### ***Experiment Parameters***

If you check neither vertex E#1 nor vertex E#2, then the potential is scanned directly from Initial E towards Final E. For example, if you enter “-0.1” (vs. OCP) in the initial E, and “0.1” (vs. OCP) in the final E box, then the potential is actually scanned from cathodic polarization 100mV to anodic polarization 100mV. When the polarization current density has already met the condition to terminate the experiment before the potential reaches 100mV, the scan will stop, and the polarization state will be cut off. If potential is “vs. OCP”, then negative value means cathodic polarization, and positive value means anodic polarization.

Scan Rate: It can only be a positive value. Scan direction is determined by the sign of the applied potential. Scan time = scan amplitude/scan rate. Total measuring time =  $\sum(|\text{amplitude of polarization potential of each segment}|/\text{scan rate})$

### ***Experiment Termination***

If check “Stop scan”, when the polarization current density is higher than the maximum value (e.g. 2mA/cm<sup>2</sup>) or lower than the minimum set value (e.g. -2 mA/cm<sup>2</sup>), the experiment will be stopped automatically.

If check the “Reverse scan”, when polarization current reached the range that you set, the scan direction will be reversed, from current potential to initial potential. If the current density is lower than the minimum value you set during cathodic retrace scan, the scan will be automatically stopped.

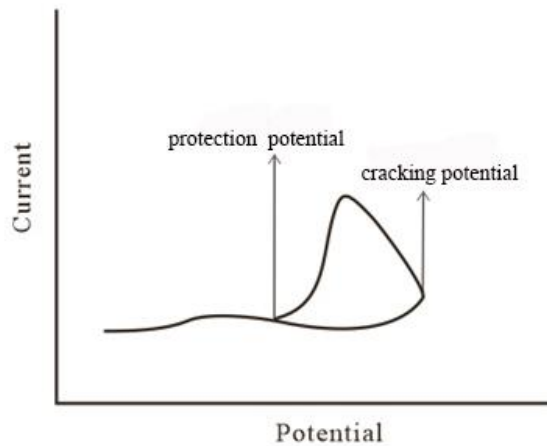
If neither is checked, the experiment will be conducted according to the potential settings. Normally, to protect the working electrode from excessively high current, you can choose Stop scan and set a maximum anodic current.

### ***Axis Type***

In the experiment of potentiodynamic, you can choose “E vs. Logi”.

### ***Passivation curve***

In potentiodynamic test, sometimes we need to measure passivation curves of some metals such as chromium, nickel, cobalt and their alloys in certain medium. It will produce a layer of passivation film on the surface of these metals when their potential is relatively positive. At this moment, they are similar to noble metals in behavior, with slight passivation current flowing. In order to evaluate their anti-corrosion performance, it is necessary to obtain the cracking potential and protection potential. Therefore, the passivation curve is graphed.



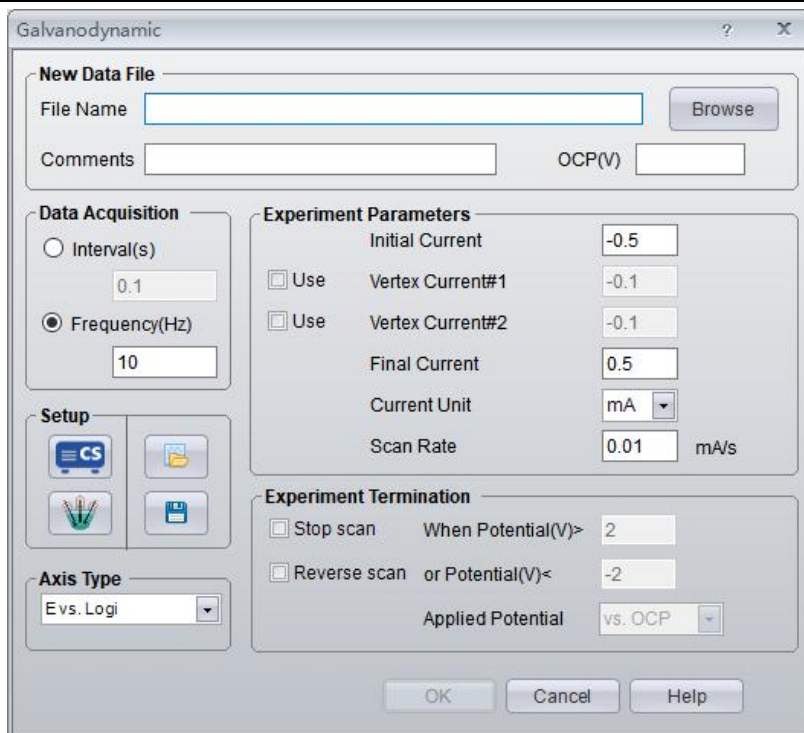
Typical passivation curve

When the polarization potential is scanned towards positive to a certain value, the passivation film will be cracked, then the polarization current will increase rapidly, this polarization potential is called cracking potential  $\phi_b$ . When the current exceeds a certain value (eg.  $100\mu A/cm^2$ ), the potential will immediately be scanned towards negative, there will be a hysteresis loop on the polarization curve. The intersection of the positive curve and the flyback curve is considered to be the protection potential of the metal in this medium  $\phi_p$ .

## **5.5 Galvanodynamic**

Experiments→Stable Polarization→Galvanodynamic

For technique of galvanodynamic, there are up to four individual polarization current set points. The scan starts from the “initial current” and goes through “vertex i #1”, “vertex i #2”, and finally reaches “final i”. The “vertex i #1” and “vertex i #2” can be both chosen, partly chosen or neither chosen by the **Use** box. The scan can be stopped or reversed when potential reaches a certain value.



OCP will display the current open circuit potential of the cell (update every second).

### ***Experiment Parameters***

If you check neither vertex  $i\#1$  nor vertex  $i\#2$ , then the current is scanned directly from Initial  $i$  towards Final  $i$ . For example, if you enter “-100” (unit:  $\mu$  A) in the initial  $i$ , and “100” in the final  $i$  box, then the current is actually scanned from cathodic polarization 0.1mA to anodic polarization 0.1mA. Of course when the polarization potential has already entered the range to terminate the experiment before current reaches 0.1mA, the scan will stop, and cut off the polarization state of the potentiostat.

Negative value means cathodic polarization, and positive value means anodic polarization.

Scan Rate: It can only be a positive value. Scan direction is determined by the sign of the applied current.

### ***Experiment Termination***

If check the “Stop scan”, when the final current is reached or the polarization potential meets the condition to terminate the experiment, the scan will be automatically stopped.

If check the “Reverse scan”, when polarization potential reaches the range that you set, the scan direction will be reversed, from current current to initial current, and when the polarization potential is lower than the minimum value you set, the scan will stop. .

If neither is checked, the experiment will be conducted according to the current settings.

### ***Axis Type***

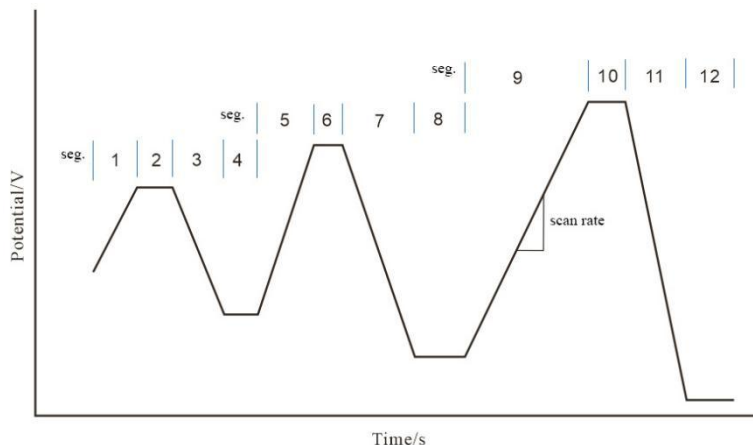
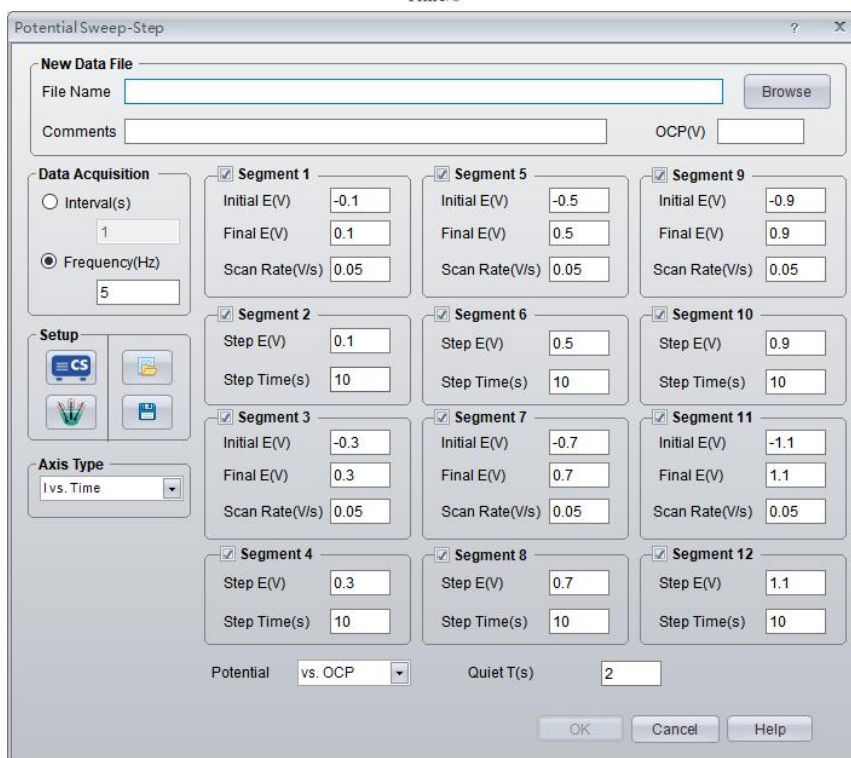
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **5.5 Multi Potential Steps**

Experiments→Stable Polarization→Potential Sweep Steps



In Potential Sweep Steps, the instrument alternates between six potential sweeps and six potential steps, somewhat like an arbitrary waveform generator. The following diagram shows the potential waveform applied as a function of time. One can skip any segment by setting parameters sufficiently small, allowing enhanced flexibility for waveform control. Current is recorded as a function of time; for sweep segments, it can also be presented as a function of potential.

Segment	Parameters	Range	Remarks
1, 3, 5, 7, 9, 11	Init E /V	-10~+10	Initial potential in sweep segment
	Final E /V	-10~+10	Final potential in sweep segment
	Scan rate /V • s <sup>-1</sup>	1E-6~50	Potential scan rate in sweep segment
2, 4, 6, 8, 10,12	Step potential /V	-10~+10	potential value in step segment

	Step time /s	0~10000	duration of step segment
1~12	Step potential/V	vs. RE or vs. OCP	choose the potential output mode

### Data Acquisition

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

### Axis Type

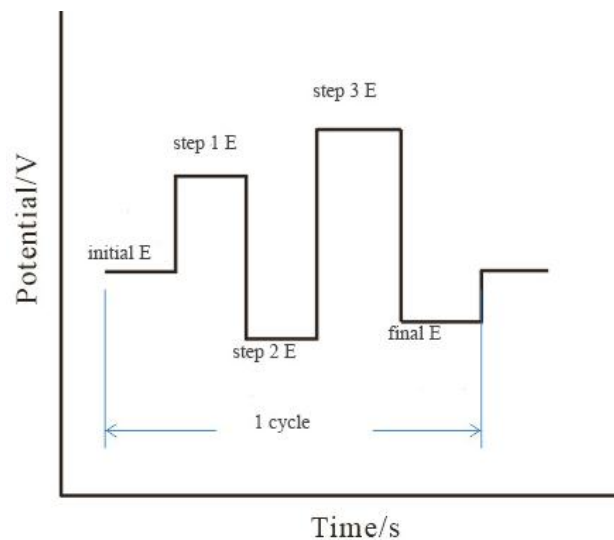
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 6. Transient Polarization

### 6.1 Multi-Potential Steps

Experiments→Transient Polarization→Multi-potential Steps

In the Multi-potential Steps technique, up to twelve potential steps can be applied and cycled. Current is recorded as a function of time.



Multi-Potential Steps ? x

---

**New Data File**

File Name  Browse

Comments  OCP(V)

---

**Data Acquisition**

Interval(s)

Frequency(Hz)

---

**Setup**

---

**Axis Type**

**Experiment Parameters**

Initial E(V)	<input type="text" value="0.01"/>	Time	<input type="text" value="100"/>	<input type="checkbox"/> Step 6 E(V)	<input type="text" value="0.04"/>	Time	<input type="text" value="100"/>
<input type="checkbox"/> Step 1 E(V)	<input type="text" value="-0.01"/>	Time	<input type="text" value="100"/>	<input type="checkbox"/> Step 7 E(V)	<input type="text" value="-0.04"/>	Time	<input type="text" value="100"/>
<input type="checkbox"/> Step 2 E(V)	<input type="text" value="0.02"/>	Time	<input type="text" value="100"/>	<input type="checkbox"/> Step 8 E(V)	<input type="text" value="0.05"/>	Time	<input type="text" value="100"/>
<input type="checkbox"/> Step 3 E(V)	<input type="text" value="-0.02"/>	Time	<input type="text" value="100"/>	<input type="checkbox"/> Step 9 E(V)	<input type="text" value="-0.05"/>	Time	<input type="text" value="100"/>
<input type="checkbox"/> Step 4 E(V)	<input type="text" value="0.03"/>	Time	<input type="text" value="100"/>	<input type="checkbox"/> Step 10 E(V)	<input type="text" value="0.06"/>	Time	<input type="text" value="100"/>
<input type="checkbox"/> Step 5 E(V)	<input type="text" value="-0.03"/>	Time	<input type="text" value="100"/>	Final E(V)	<input type="text" value="-0.01"/>	Time	<input type="text" value="100"/>

Potential

Time Unit

Cycles

---

OK Cancel Help



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Experiment Parameters***

The steps start from the Initial E, then to Step 1E, Step 2E, Step 3E,...towards Final E. If the time of a step is “0” or the box before it is unchecked, this segment will be skipped.

Potential can be specified as “vs. OCP” or “vs. RE”.

Cycles specifies how many times the potential is stepped between Initial E and Final E.

Time determines the duration of the step potential being held.

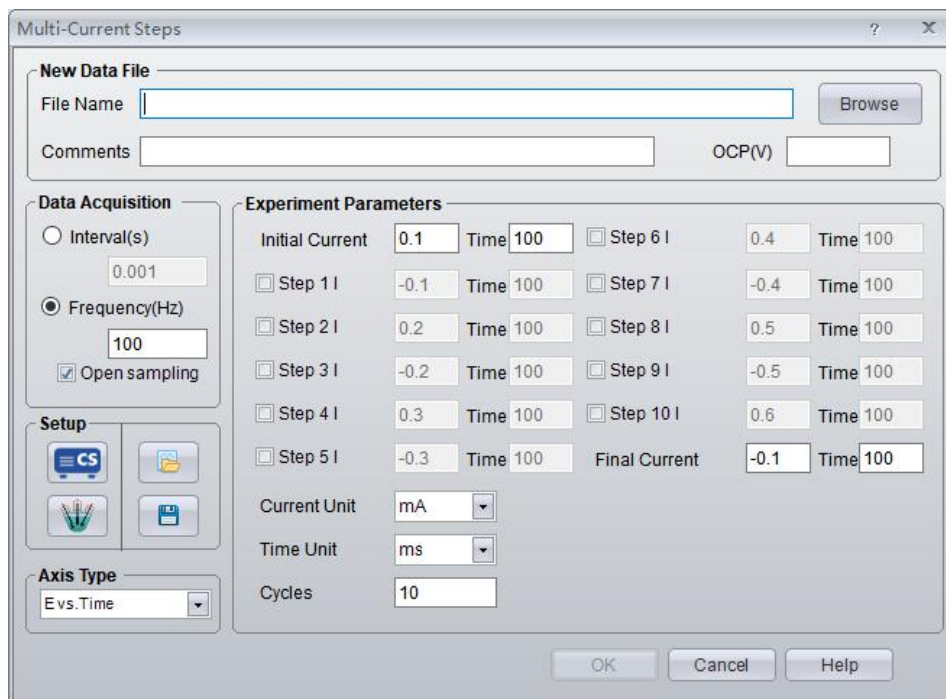
### ***Axis Type***

Axis Type is I vs. time for multi-potential steps.

## **6.2 Multi-Current Steps**

Experiments→Transient Polarization→Multi-Current Steps

In the Multi-Current Steps technique, up to twelve current steps can be applied and cycled. Potential is recorded as a function of time.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.

### ***Multi-Current Steps Parameters***

The steps start from the Initial i, then to Step 1i, Step 2i, Step 3i,...towards Final i. If the time of a step is “0” or the box before it is not checked, this segment will be skipped.

Cycles specifies how many times the current is stepped between Initial i and Final i.

Time determines the duration of the step current being held.

### ***Data Acquisition***

If **Frequency(Hz)** is chosen, the acquisition rate is set as Points/Second.

## Axis Type

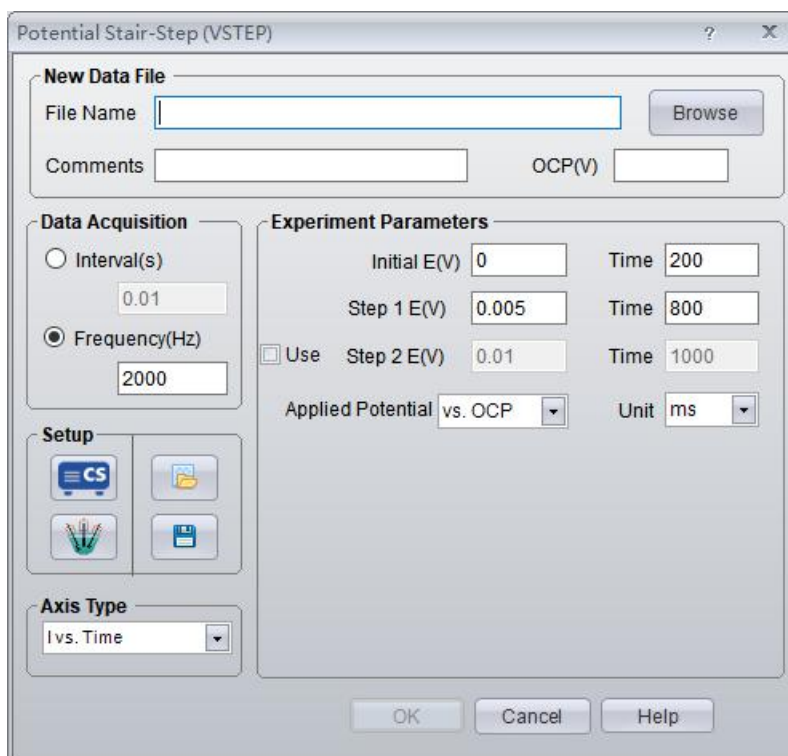
Axis type for multi-current steps is E vs time.

### 6.3 Potential Stair-Step(VSTEP)

Experiment→Transient Polarization→Potential Stair-Step

Potential Stair-Step can be used to measure the solution resistance  $R_s$  and polarization resistance  $R_p$ , it can also be applied to calculate the double-layer capacitance  $C_{dl}$ .

There are up to 3 individual potential setpoints for potential Stair-step. If the Use box is checked, the mode of the stair step is Initial E→Step1 E→Step2 E to finish two segments of stair step measurement.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.

#### **Experiment Parameters**

The steps start from Initial E, to Step E1, and then to Step E2. If “Use” box is unchecked, the segment of the Step E2 will be skipped.

Time determines the holding time of a step potential.

#### **Data Acquisition**

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified. Because the step process is fast, the data acquisition rate is also fast, 1~3KHz is recommended.

## Axis Type

Axis Type is I vs. time.

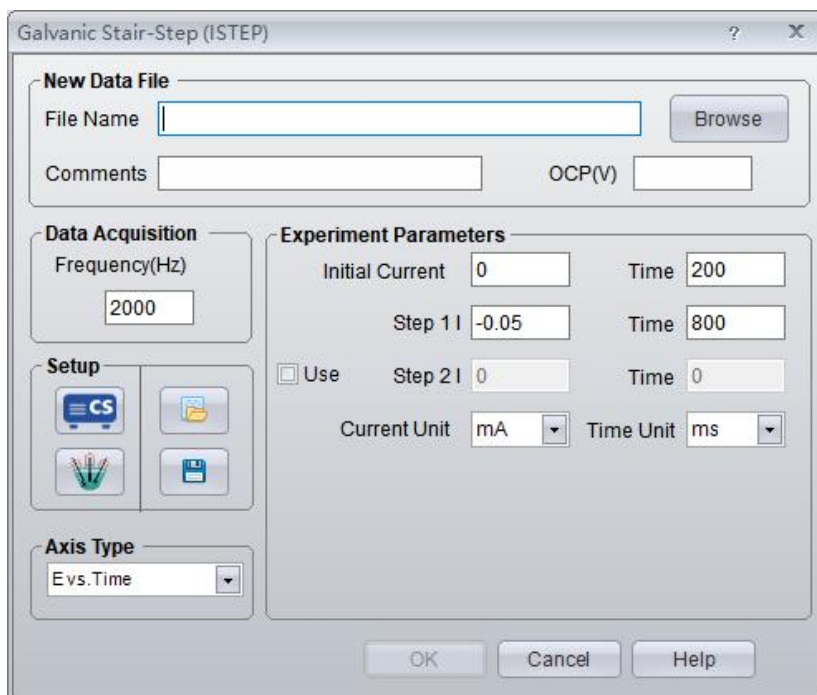
#### **Pstat/Gstat(ECS)**

In step test, because the measuring time is very short, the current range should only be chosen manually in advance, not determined by the software automatically.

## 6.4 Galvanic Stair-Step(ISTEP)

Experiments→Transient Polarization→Galvanic Stair-Step

There are up to 3 individual current setpoints for galvanic Stair-step. If the Use box is checked, the mode of the stair step is Initial current→Step1 E→Step2 E to finish two segments of stair step measurement.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.

### **Scan Parameters**

The steps starts from the Initial Current, to Step i#1, and then to Step i#2. If the Use is not checked, the segment of the Step i #2 will be skipped.

The Time determines how long the current will be held at each step.

### **Data Acquisition**

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified. Owing to the fast process of step, the data acquisition rate is fast too. The frequency is normally set between 1~3KHz.

### **Axis Type**

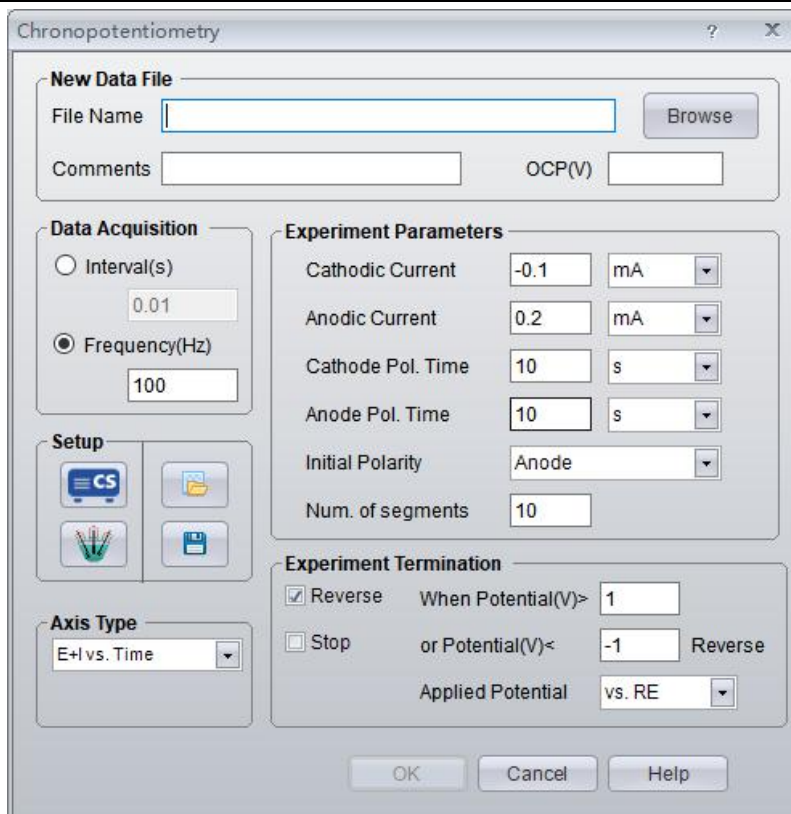
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 7. Chrono Techniques

### 7.1 Chronopotentiometry

Experiments→Chrono Techniques→Chronopotentiometry

In Chronopotentiometry (CP), two current levels can be specified to pass through the working electrode, with the switching between the two dictated by time or potential. Potential is recorded as a function of time.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Experiment Parameters***

Cathodic/anodic current is applied on the working electrode during the test. You can choose the unit of the current.

Cathodic/anodic time is the duration of the applied cathodic / anodic current. Second, minute and hour can be selected.

Num. of segments specifies how many times the current is cycled between cathodic and anodic current. When the number of current polarity switches (segments) is reached, the experiment stops.

<b>Parameters</b>	<b>Range</b>	<b>Description</b>
Cathodic current	-2A~+2A	The cathodic current applied on the working electrode
Anodic current	-2A~+2A	The anodic current applied on the working electrode
Cathodic time	>0	Duration of cathodic current
Anodic time	>0	Duration of anodic current
Initial polarity	Anode/ cathode	The polarity at the beginning of the experiment
Num. of segment	>0	The number of applied cathodic and anodic current

### ***Current Polarity Switching***

It's used to switch the anodic and cathodic polarization process. For example, as shown in

above parameters setting dialog box, if the potential reaches 1V in less than 10s, the polarity will be switched, proceeding the cathodic polarization. If the potential reaches -1V in less than 10s, anodic polarization is triggered.

### **Data Acquisition**

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### **Axis Type**

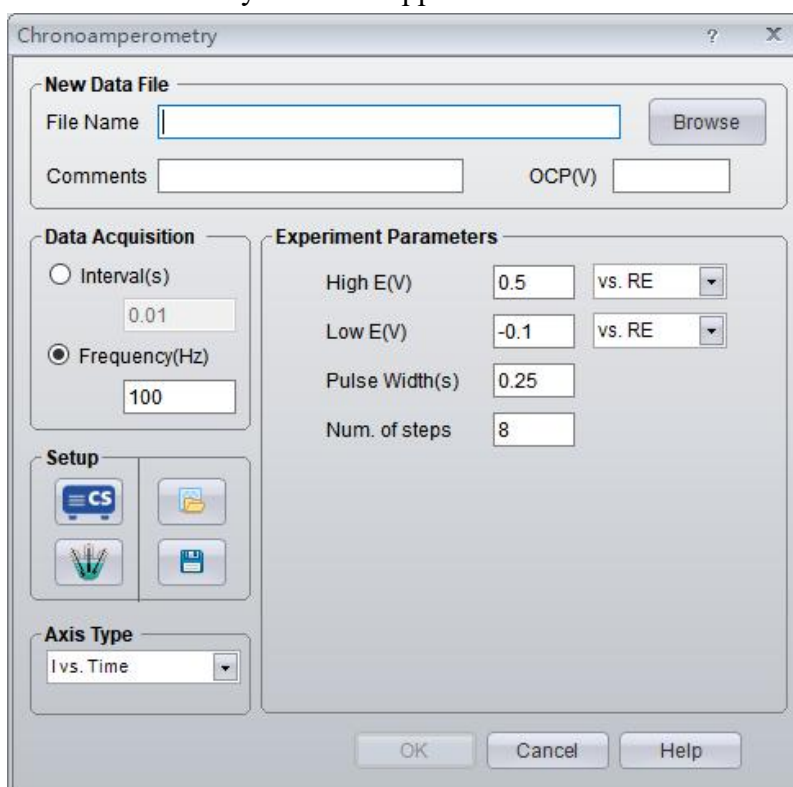
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **7.2 Chronoamperometry**

Experiments→Chrono Techniques→Chronoamperometry

Chronoamperometry method measures the current response as a function of time after applying a single or dual potential step on the working electrode. Electrodes of fixed area are often used in this method. This method is used to study the electrode process of coupling chemical reaction, especially the reaction mechanism of organic electrochemistry.

In Chronoamperometry (CA), the potential is stepped from Init. E to either High E or Low E depending on the Init. P/N and may then be stepped back.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### **Parameters setting**

The experiment starts at the Initial E, sweeps to High E, and then to Low E. The potential can be specified in several ways. If “vs.OCP” is chosen, the specified potential is added to the open circuit potential of the cell. If “vs.RE” is chosen, an exact potential is applied.

Pulse width specifies how long the potential is sustaining.

Number of Steps specifies how many potential cycles are formed between High E and Low E.

Parameters	Range	Description
Initial E (V)	-10~+10	Initial potential
High E (V)	-10~+10	Upper limit of potential step applied on the WE
Low E (V)	-10~+10	Lower limit of potential step applied on the WE
Pulse width (s)	>0	potential pulse width
Number of steps	>0	Number of potential steps

### Axis Type

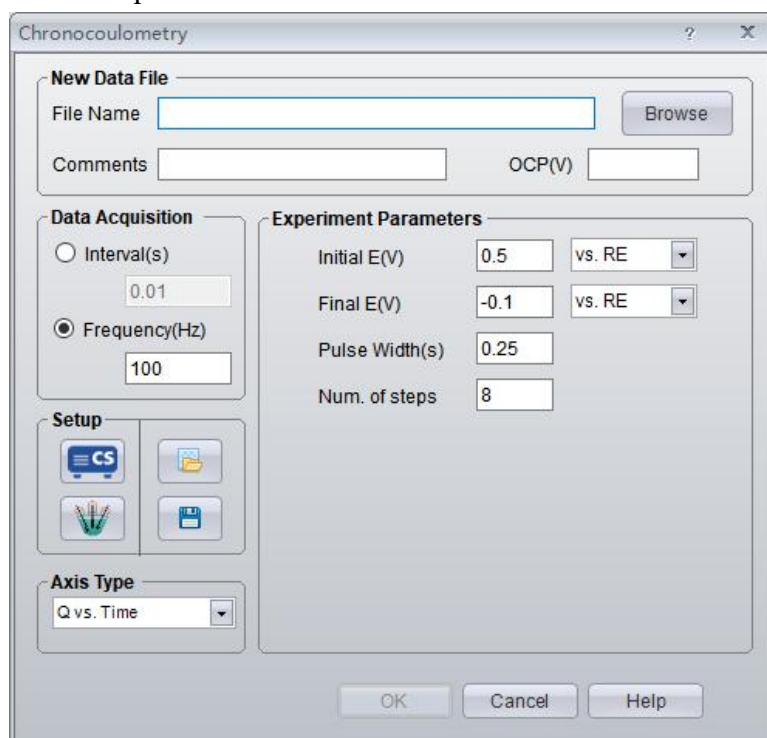
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 7.3 Chronocoulometry

Experiments→Chrono Techniques→Chronocoulometry

Chronocoulometry is a method to measure the quantity of electric charges as a function of time after a potential step is applied on the working electrode. It can study electrode process in all kinds of coupling reactions. It can also study the electroactive substance adsorption.

A fast-rising potential pulse is applied on the working electrode of an electrochemical cell. The current flowing through this electrode is measured and integrated, reporting coulombs as a function of time. Technique is also referred to as CC.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.



### Parameters setting

Parameters	Range	Description
Initial E (V)	-10~+10	The potential applied on the working electrode
Final E (V)	-10~+10	The potential applied on the working electrode
Pulse width(s)	0.001~10	Duration of the applied potential pulse
Number of steps	>0	Number of potential steps

The potential may be swept between up to 2 separate setpoints in this experiment. The experiment starts at the initial potential, and then to the final potential. A potential can be specified in several ways. If “vs. OCP” is chosen, the specified potential is added to the open circuit potential of the cell. “vs.RE” is chosen to select an exact potential to be applied.

Pulse width specifies how long the potential is sustaining.

Number of steps specifies how many times the potential is cycled between Initial E and Final E.

### Data Acquisition

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8. Voltammetry

### 8.1 Cyclic Voltammetry

Experiments→Voltammetry→Cyclic Voltammetry

CV technique is used for the theoretical study of redox couples. Cyclic Voltammetry is a special LSV that performs a triangular wave scanning on the working electrode. The potential is linearly swept from Initial E to High E (or Low E, depending on the Initial P/N polarity parameter). The potential is then swept back in the reverse direction.

CV curve usually consists of two parts: 1) the lower reduction/cathode part where the reduction waveform is generated from reduction process of the oxidation state of the electroactive material, 2) and the upper oxidation/anode part where the oxidation waveform is generated from oxidation process of reduction products. CV technique can directly measure the ratio of anodic peak current/cathodic peak current and the difference between anodic peak potential and cathodic peak potential.

CV technique is mainly used for basic electrochemical theoretical study, such as the electrode process, the absorption phenomenon of electrode etc.

For reversible system, if the cathodic reduction products are stable, then  $i_{pc}/i_{pa}=1$ .

To judge the reversibility of electrode process, the following formulas are employed:

$$E_{pa} = E_{1/2} + \frac{28.25}{n}$$

Where  $E_{pa}$  = anodic peak potential

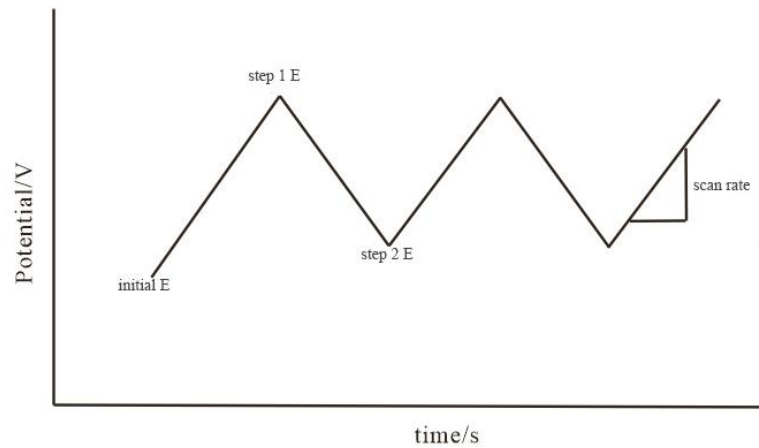
$$E_{pc} = E_{1/2} - \frac{28.25}{n}$$

$E_{pc}$  = cathodic peak potential.

$$\Delta E_p = E_{pa} - E_{pc} = \frac{56.5}{n}$$

Note:  $\Delta E_p$  is related to the reversing potential during CV scan. If  $n=1$ , and the reversing potential is  $-100\text{mV}$  vs.  $E_{pc}$ , the  $\Delta E_p$  will be  $59\text{mV}$ .  $\Delta E_p$  is also associated with the experiment environment, the value is in the range of  $55\sim 65\text{mV}(n=1)$ , we can judge it as a reversible process.

There are three individual setting points of potential. If use “initial E”, then the potential is scanned from “initial E” to “step 1 E”, to “step 2E”, and back to initial E, cyclically.



**Cyclic Voltammetry** [?] [X]

---

**New Data File**

File Name

Comments  OCP(V)

---

**Data Acquisition**

Frequency(Hz)

100

Interval(mV)

0.5

---

**Setup**

---

**Axis Type**

I vs. E

**Experiment Parameters**

Use Initial E(V)  vs. RE

Step 1 E(V)  vs. RE

Step 2 E(V)  vs. RE

Use Final E(V)  vs. RE

Scan Rate(mV/s)

Cycles

---

Parameters setting dialog box

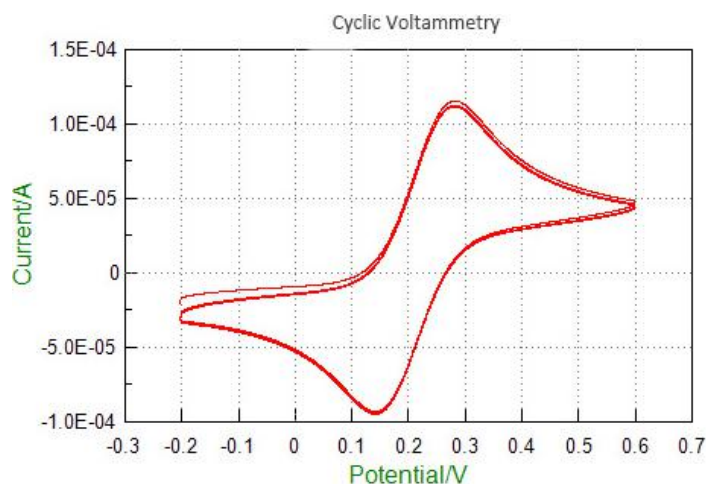
OCP displays the current open circuit potential of the cell (update every second).

### Scan Parameters



Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential of scan
Step 1E(V)	-10~+10	Initial potential of the scan(not checking “Use”) or the first vertex potential
Step 2 E(V)	-10~+10	the second vertex potential of the scan
Scan rate (mV/s)	$10^{-3}\sim 10^7$	The scan rate of the potential
Cycles	>0	The number of the cycles
Interval (mV)	> 0.001	Potential difference between two sampling points
Frequency (Hz)	0.01~1000	Sampling as per frequency, Either Interval or Frequency should be chosen.

The potential may be swept between upto 3 separate setpoints in this experiment. The experiment starts at the Initial E, sweeps to Step 1E, to Step 2 E, and then back to the Initial E. Check “Use” to turn on or turn off the Initial E setpoint.



CV curve of glassy carbon electrode in  $K_4[Fe(CN)_6]$  solution

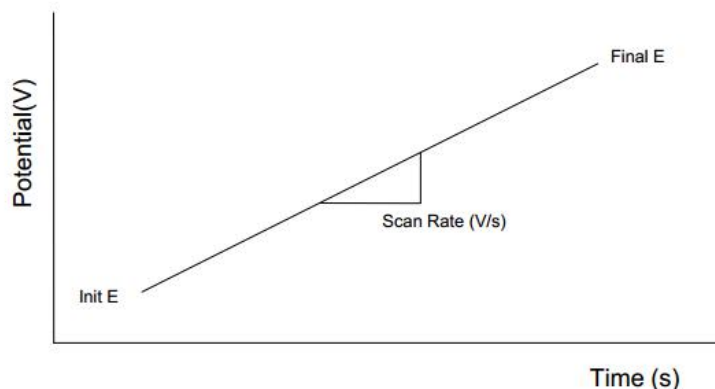
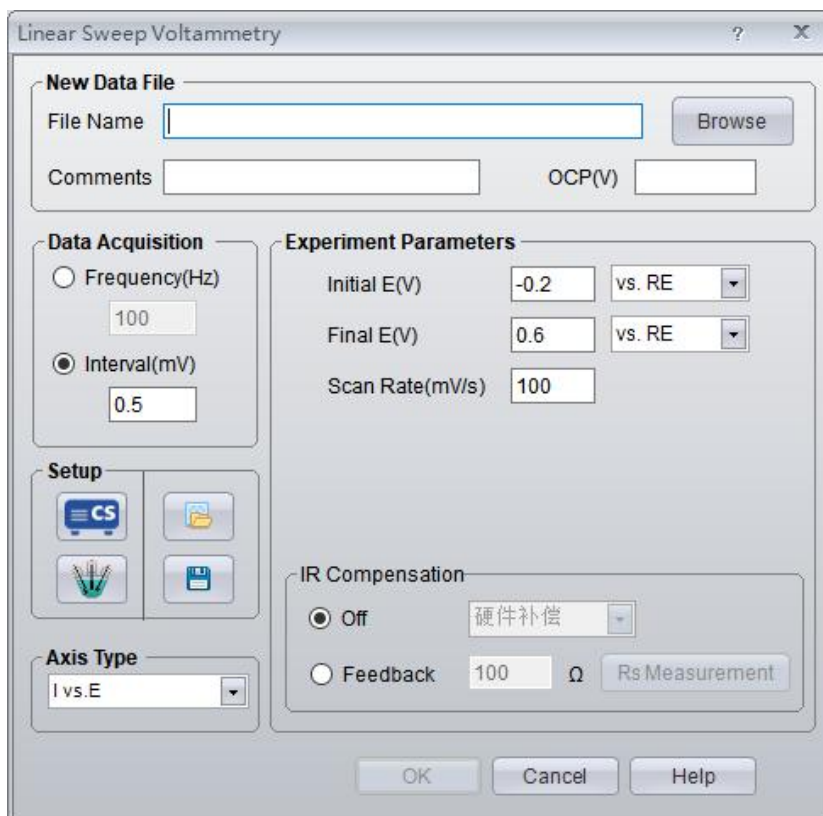
### Axis Type:

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.2 Linear Sweep Voltammetry

Experiments → Voltammetry → Linear Sweep Voltammetry

In Linear Sweep Voltammetry (LSV), the potential is scanned from Initial E toward Final E. The following diagram shows the potential waveform applied as a function of time. Current is recorded as a function of potential. Normally, the scan rate of the instrument can be from several mV to 1V per second.

OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.

### Scan Parameters

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential of scan, “vs. OCP” can be chosen.
Final E(V)	-10~+10	Final potential
Scan rate(mV/s)	$10^{-3} \sim 10^7$	The scan rate of the potential
Interval (mV)	> 0.001	Potential difference between two sampling points
Frequency (Hz)	0.01~1000	Sampling as per frequency, Either Interval or Frequency should be chosen

Up to 2 separate potentials can be set during the experiment. The scan starts at the Initial E, and to the Final E.

If the Initial/Final E is “vs.OCP”, and you enter “0.2” in initial E, it means the scan is from

the potential OCP+0.2V. Positive value means anodic polarization, and negative value means cathodic polarization.

If the Initial/Final E is “vs. RE”, and you enter “0.2” in initial E, it means the scan starts from 0.2V, which has nothing to do with OCP.

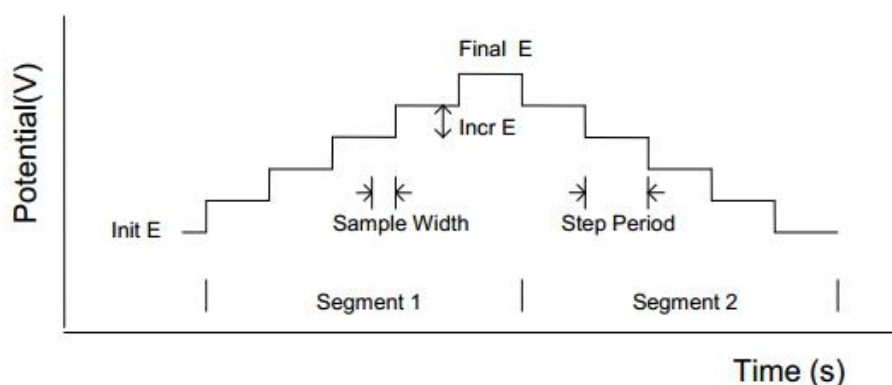
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.3 Staircase Voltammetry

Experiments → Voltammetry → Staircase Voltammetry

In Staircase Voltammetry (SCV), the potential is incremented from Initial E toward Final E, and it may be scanned back. Current is sampled after every potential increment and recorded as a function of potential. The following diagram shows the potential waveform applied as a function of time.



Staircase Voltammetry

---

**New Data File**

File Name  Browse

Comments  OCP(V)

---

**Data Acquisition**

Interval(s)

Frequency(Hz)

**Experiment Parameters**

Initial E(V)  vs. RE ▾

Final E(V)  vs. RE ▾

Inc. E(V)

Cycles


Step Period (s)


Sample width  ms


Powerfreq. period


---

**Setup**









---

**Axis Type**

▾

---

OK    Cancel    Help

OCP will display the current open circuit potential of the cell (update every second). If the

instrument is turned off, this value will display “Not Available”.

### Scan Parameter

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential of scan.
Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Incremented potential of each step
Cycles	1~10,000	The number of cyclic staircase waveform
Sample width(ms)	1~ half of step period	Data sampling width for each point
Step period(s)	0.001~100	Potential step period or dropping time

Initial E and Final E should be at least 0.01 V apart. If the sampling width is over half of the step period, there will be prompt from the software to adjust the sampling width within range. Data will be acquired at the end of each step. In general, potential is chosen to be vs. RE.

### Data Acquisition

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

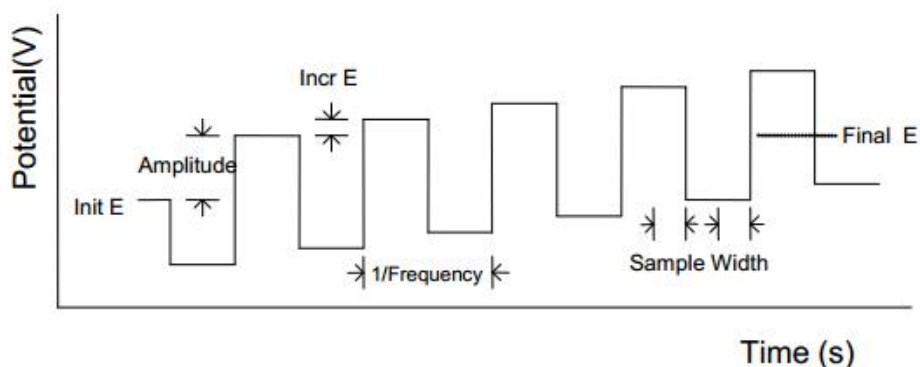
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.4 Square Wave Voltammetry

Experiments→Voltammetry→Square Wave Voltammetry

In Square Wave Voltammetry (SWV), the base potential is incremented from Init E towards Final E. A square wave potential is superimposed onto the base potential, which increments after each cycle of the square wave. Current is sampled at the second half of the forward and reverse steps. The current difference is recorded as a function of the base potential. The following diagram shows the potential waveform applied as a function of time and the current sampling scheme.



Square Wave Voltammetry
?
X

**New Data File**

File Name  Browse

Comments  OCP(V)

**Data Acquisition**

Interval(s)

Frequency(Hz)

**Experiment Parameters**

Initial E(V)  vs. RE

Final E(V)  vs. RE

Inc. E(V)

Amplitude(V)

Frequency(Hz)

Sample width  ms

Powerfreq. period

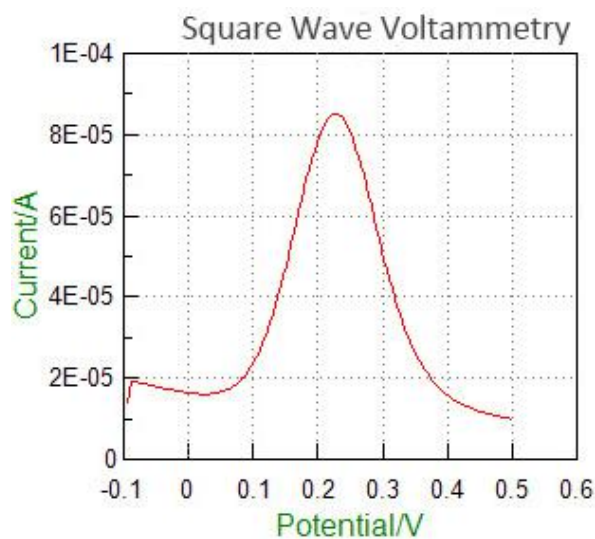
**Setup**

**Axis Type**

I vs. E

OK Cancel Help

OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.



SWV curve in  $K_3Fe(CN)_6$  system

### Scan Parameters

Parameters	Range	Description
Initial E (V)	-10~+10	Initial potential of scan.
Final E (V)	-10~+10	Final potential
Inc. E (V)	0.001~0.05	Incremented potential of adjacent two square wave
Amplitude (V)	0.001~0.5	The amplitude of each square wave
Frequency(Hz)	1~100,000	Square wave output frequency

Initial E and Final E should be at least 0.01V apart. “vs.RE” is usually chosen to specify the exact potential range.

Inc.E is the increment potential of each pulse; it can be chosen from 0.001V to 0.05V.

Amplitude can be chosen from 0.001V to 0.5V.

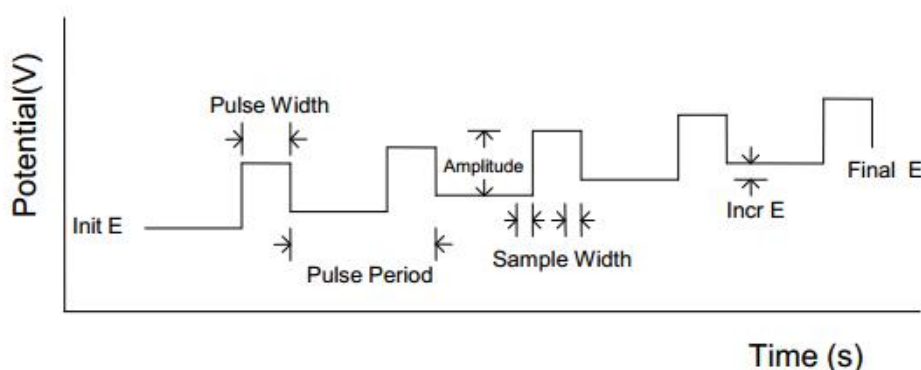
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.5 Differential Pulse Voltammetry

Experiments→Voltammetry→Differential Pulse Voltammetry

In Differential Pulse Voltammetry (DPV), the base potential is incremented from Init E toward Final E. A potential pulse is applied. Current is sampled before the potential pulse and at the end of the pulse. The difference between these two current samples is recorded as a function of potential. The following diagram shows the potential waveform applied as a function of time and the current sampling scheme.



For the reversible system, the curve is symmetric, and the peak current and the measured substance concentration is proportional. When the amplitude of the pulse is small, the relationship can be expressed by the following equation:

$$IP = \frac{n^2 F^2}{4RT} A \Delta E \sqrt{\frac{D}{\pi t_m}} C$$

Where,  $\Delta E$  is the amplitude, A is the electrode area,  $t_m$  is the interval of pulse applying and current sampling. D is the diffusion coefficient of the measured material. From the equation, it can be seen that the peak current is related to pulse amplitude. But too large amplitude will influence the resolution. Generally speaking, 25~50mV in amplitude and 5mV/s in scan rate are suitable.

DPV technique can effectively eliminate the effect of the background current, which enhances sensitivity dramatically. The minimum measured concentration can be as low as  $10^{-8}$ mol/L.

There is relationship between peak potential( $E_p$ ) of DPV curve and polarograph half-wave potential( $E_{1/2}$ ) as follows:

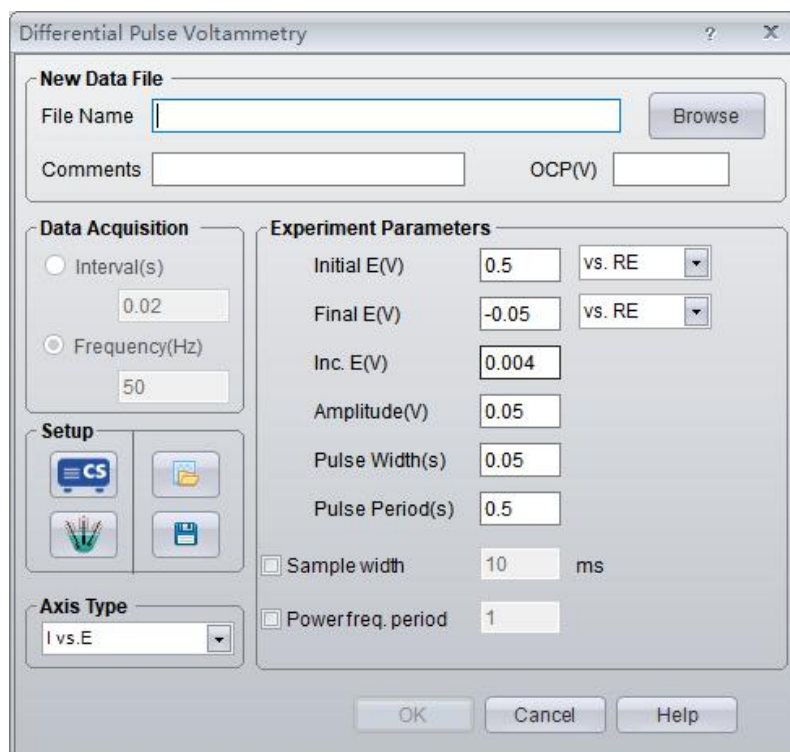
$$E_p = E_{1/2} - \frac{\Delta E}{2}$$



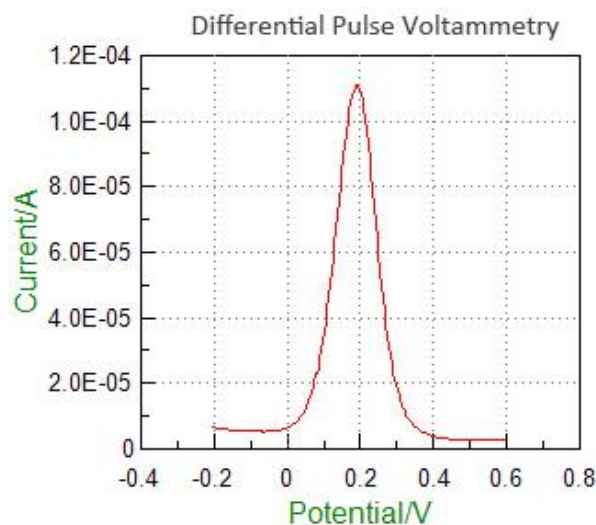
There is a useful parameter, the half-peak width( $W_{1/2}$ ) when  $I=I_p/2$ . When the amplitude is relatively small,

$$W_{1/2} = 3.52 \frac{\Delta E}{nF},$$

Measuring the  $W_{1/2}$  can be a supporting measure to calculate the number of transferred electron in reactions.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.



DPV curve in  $K_3Fe(CN)_6$  system

### Scan Parameters

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential

Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Incremented potential of adjacent two pulses
Amplitude(V)	0.001~0.5	Potential pulse amplitude
Pulse width(s)	0.001~10, or less than half of the pulse period	Potential pulse width
Pulse period(s)	0.01~50	Potential pulse period or dropping time
Sample width(ms)	1~ half of pulse width	Data sampling width

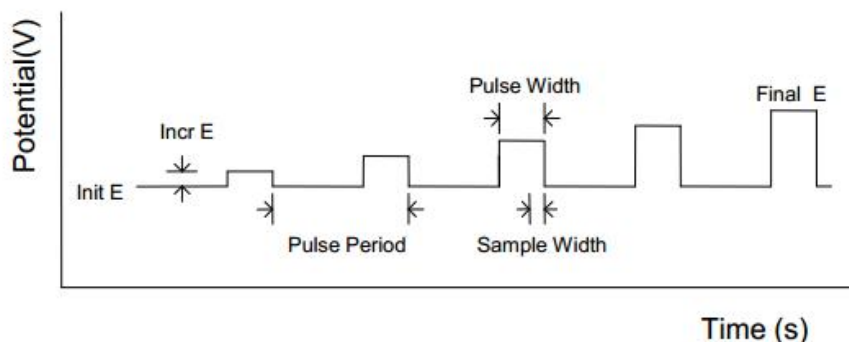
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in any of the other formats.

## 8.6 Normal Pulse Voltammetry

Experiments→Voltammetry→Normal Pulse Voltammetry

In Normal Pulse Voltammetry (NPV), the base potential is held at Init E, and a sequence of potential pulses with increasing amplitude is applied. The current at the end of each potential pulse is sampled and recorded as a function of the pulse potential. The pulse always starts from the initial potential. In such a way a discrete, digitized curve is obtained. The initial potential is a very important parameter. It determines the electrode surface state before the Faraday current flows.



**Normal Pulse Voltammetry**

New Data File

File Name  Browse

Comments  OCP(V)

**Data Acquisition**

Interval(s)

Frequency(Hz)

**Experiment Parameters**

Initial E(V)  vs. RE ▼

Final E(V)  vs. RE ▼

Inc. E(V)


Pulse Width(s)


Pulse Period(s)


Sample width  ms


Powerfreq. period

**Setup**







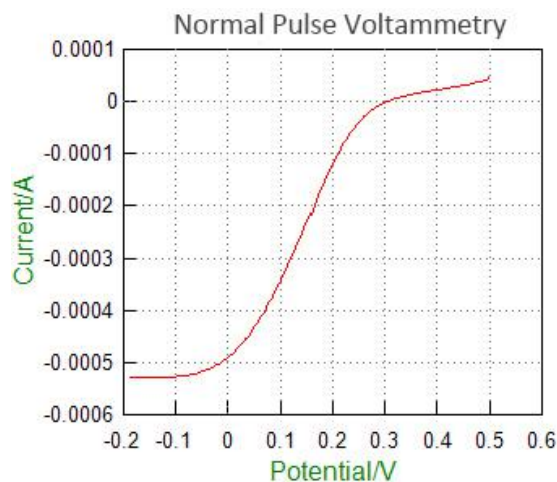


**Axis Type**

I vs. E ▼

OK Cancel Help

OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.



### Scan Parameters

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential
Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Incremented potential of adjacent pulses
Pulse width(s)	0.001~10, or less than half of the pulse period	Potential pulse width
Pulse period(s)	0.01~50	Potential pulse period or dropping time
Sample width(ms)	1~ half of pulse width	Data sampling width

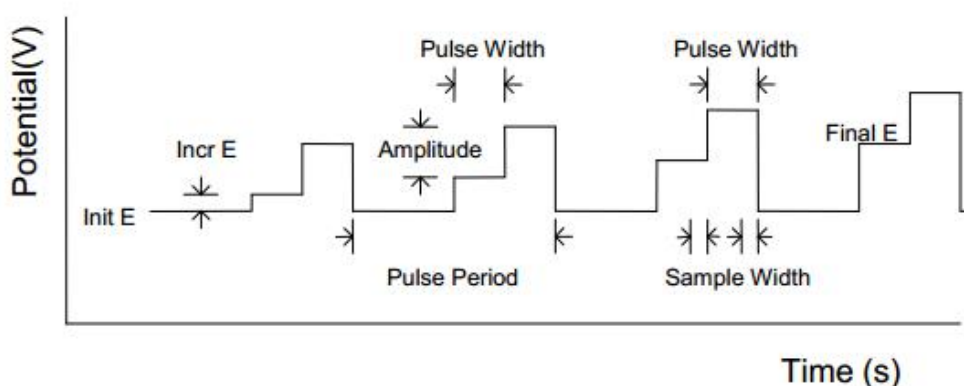
## Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in any of the other formats.

## 8.7 Differential Normal Pulse Voltammetry

Experiments → Voltammetry → Differential Normal Pulse Voltammetry

In DNPV, the base potential is held at Initial E, and a sequence of dual potential pulses is applied. The magnitude of the first pulse increments after every iteration, and the second pulse has a constant amplitude relative to the first. Current is sampled at the end of both potential pulses, and the difference of these two values is recorded as a function of the first pulse potential. The following diagram shows the potential waveform applied as a function of time and the current sampling scheme:



Differential Normal Pulse Voltammetry
?
×

**New Data File**

File Name  Browse

Comments  OCP(V)

**Data Acquisition**

Interval(s)

Frequency(Hz)

**Experiment Parameters**

Initial E(V)  vs. RE ▼

Final E(V)  vs. RE ▼

Inc. E(V)

Amplitude(V)

1st Pulse Width(s)


2nd Pulse Width(s)


Pulse Period(s)


Sample width  ms


Powerfreq. period

**Setup**







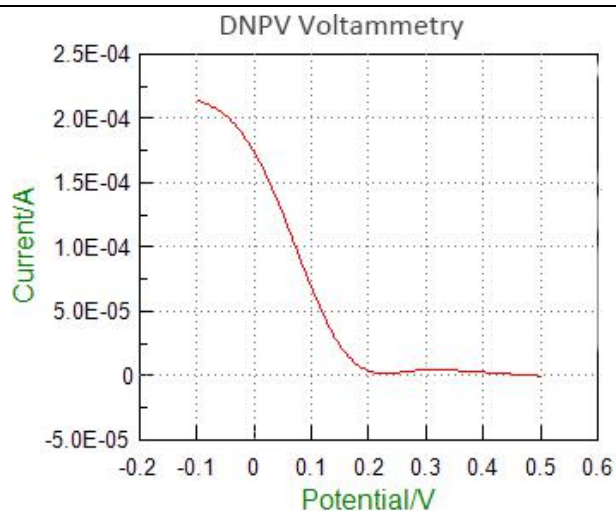


**Axis Type**

I vs. E ▼

OK Cancel Help

OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will be “Not Available”.



### Scan Parameters

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential
Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Incremented potential of adjacent pulses
Amplitude(V)	0.001-0.5	Potential pulse amplitude
1 <sup>st</sup> pulse width(s)	0.001~0.02	First potential pulse width
2 <sup>nd</sup> pulse width(s)	0.001~0.02	Second potential pulse width
Pulse period(s)	0.05~50	Potential pulse period or dropping time
Sample width(ms)	1~half of pulse width	Data sampling width

Init E and Final E should be at least 0.01V apart.

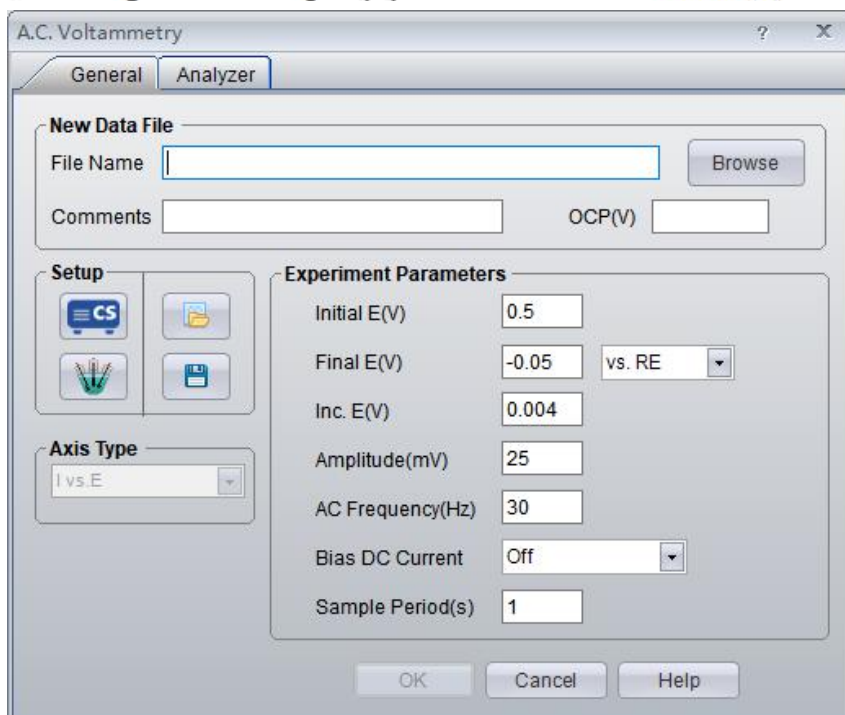
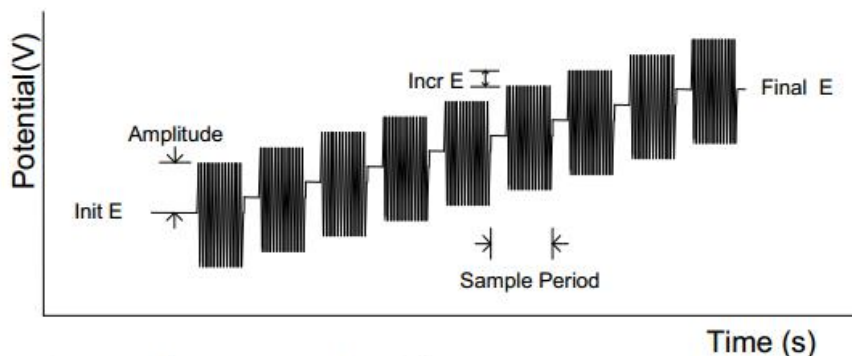
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.8 A.C. Voltammetry

Experiments→Voltammetry→A.C. Voltammetry

In A.C. Voltammetry, the base potential is incremented from Initial E to Final E, and a sequential sine waveform is superimposed. Current is sampled when the AC signal is applied, and it is analyzed by using a software lock-in amplifier. During the experiment, only the absolute AC current is displayed.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### Scan Parameters

Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential
Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Potential difference between adjacent waves
Amplitude (mV)	1~500	AC amplitude of each waveform
AC frequency(Hz)	0.1~10000	AC frequency
Bias DC	Off-range-On	Enable DC current bias during run
Sample period(s)	1~50	Data sampling period or dropping time

Initial E and Final E should be at least 0.01V apart.

Inc.E is the increment potential of each pulse;it can be chosen from 0.001V to 0.05V.

When the AC frequency is 2Hz or lower, the sample period parameter should be at least 2 seconds.



Bias DC Current, check off or on, enables DC current bias during run.

### Data Acquisition

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

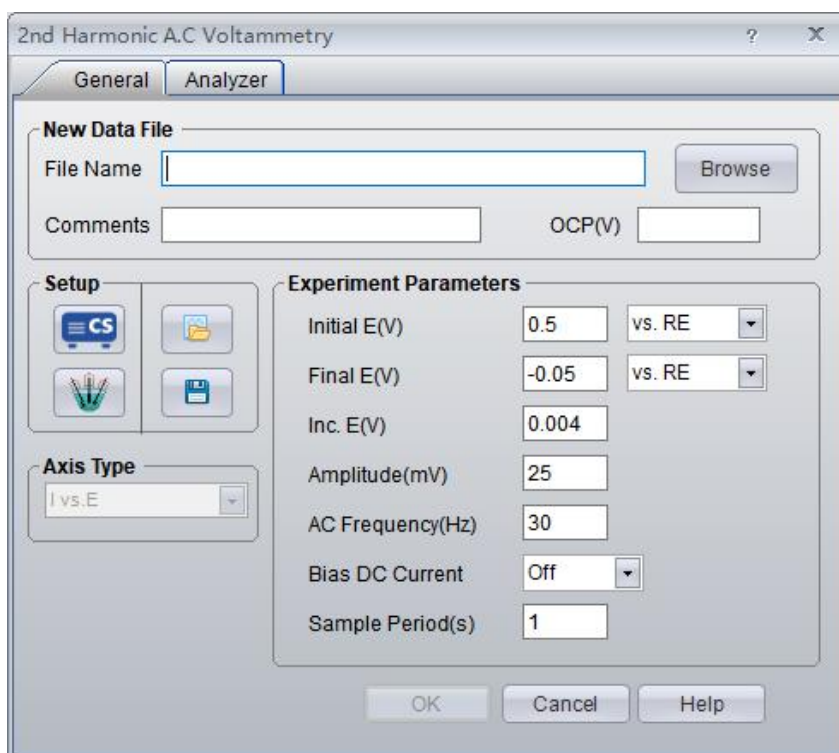
### Axis Type

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 8.9 2nd Harmonic A.C. Voltammetry

Experiments→Voltammetry→2nd Harmonic A.C. Voltammetry

In Second Harmonic AC Voltammetry, the base potential is incremented from Initial E toward Final E, and a sequential sine waveform is superimposed. Current is sampled when the AC signal is applied, and its second harmonic component is analyzed by using a software lock-in amplifier. During the experiment, only the absolute second harmonic AC current is displayed.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### Scan Parameters

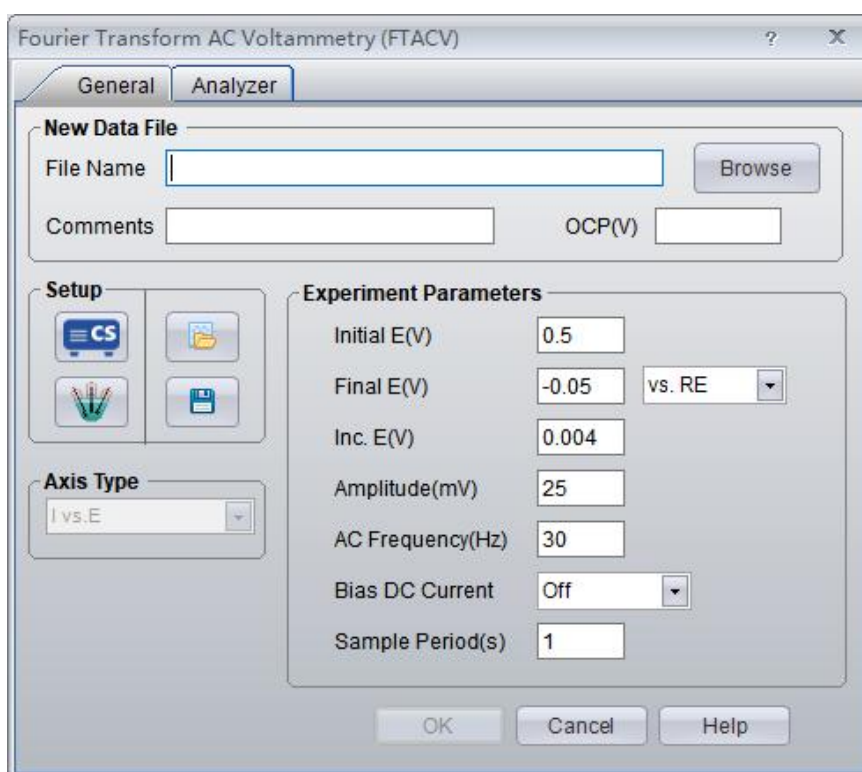
Parameters	Range	Description
Initial E(V)	-10~+10	Initial potential
Final E(V)	-10~+10	Final potential
Inc. E(V)	0.001~0.05	Potential difference between adjacent waves
Amplitude (mV)	1~500	AC amplitude of each waveform
AC frequency(Hz)	0.1~5000	AC frequency

Bias DC current	Off-range-On	Enable DC current bias during run
Sample period(s)	1~50	Data sampling period or dropping time

## 8.10 Fourier Transform AC Voltammetry (FTACV)

Experiments→Voltammetry→Fourier Transform AC Voltammetry

For FTACV, the way of testing, parameters setting and data acquisition are the same as ACV. The difference lies in post-processing of the data. After the test, the software will automatically do the Fourier conversion with the original data, meanwhile obtaining the 2nd, 3rd, 4th, 5th, and 6th harmonics ACV data.

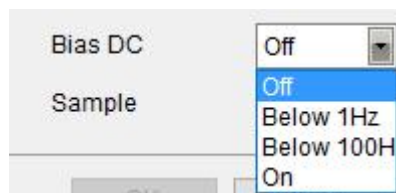


### *Experiment parameters*

Parameter	Range	Description
Initial E(V)	-10~+10	Initial potential
Final E (V)	-10~+10	Final potential
Inc. E (V)	0.001~0.05	Potential difference between adjacent waves
Amplitude (mV)	1~2500	AC amplitude for every waveform
AC frequency(Hz)	0.1~5000	AC frequency
Bias DC current	Off-range-On	Superimpose bias DC current on AC signal
Sample period (s)	1~50	Time of sampling

Initial E and Final E should be at least 0.01 V apart.

For parameter of Bias DC current, the user can choose among Off, Below 1Hz, Below 100Hz, On.

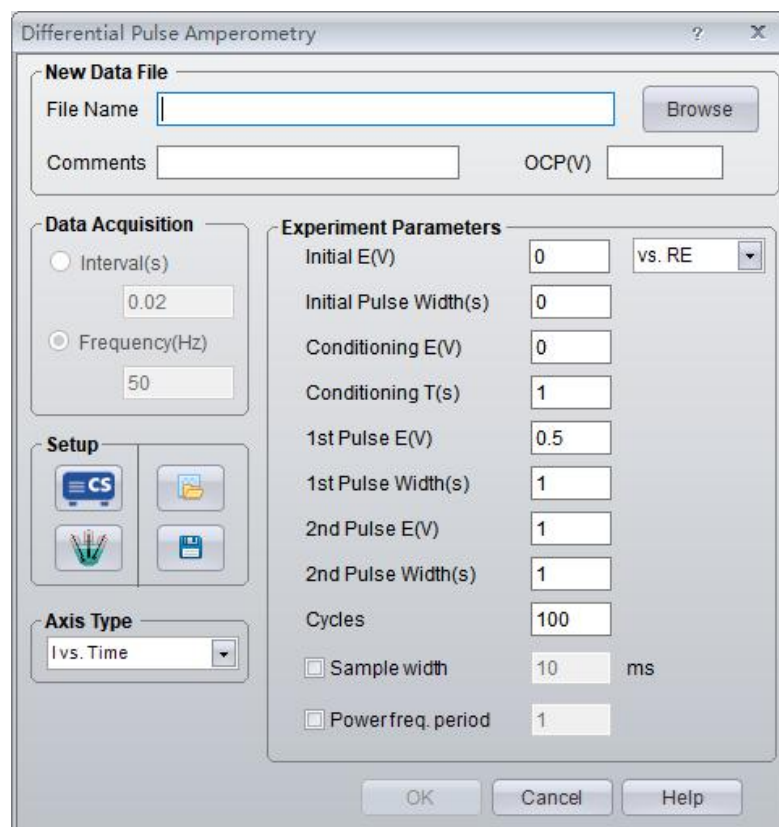
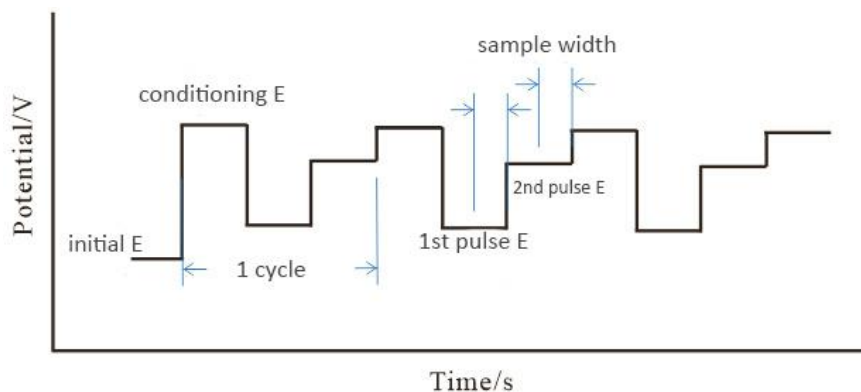


## 9. Amperometric

### 9.1 Differential Pulse Amperometry (DPA)

Experiments → Amperometric → Differential Pulse Amperometry (DPA)

In Differential Pulse Amperometry (DPA), a conditioning potential can be applied for electrode conditioning, during which current is not sampled. Two potential pulses are applied after the conditioning step, and the current at the end of each pulse is recorded as a function of time.



## Parameter setting window for DPA

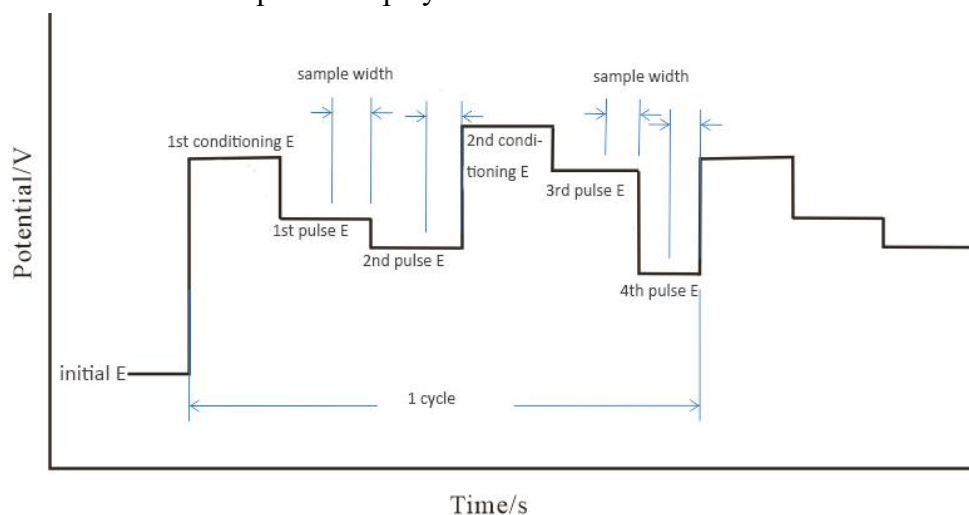
**Experiment parameters**

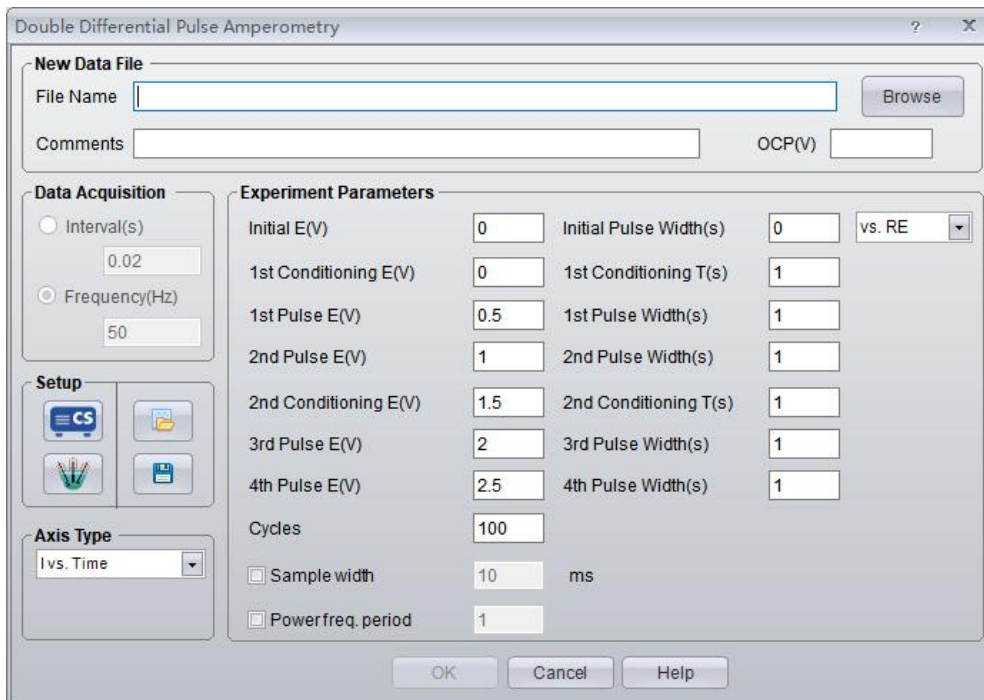
Parameters	Range	Description
Initial E(V)	-10~10	initial potential
Initial pulse width (s)	$\geq 0$	The duration of the initial potential. No data acquisition
Conditioning E(V)	-10~10	The electrode conditioning potential
Time(s)	$\geq 0$	The duration of the conditioning potential. Current is not sampled.
1 <sup>st</sup> pulse potential(V)	-10~10	The 1 <sup>st</sup> pulse potential in each cycle.
1 <sup>st</sup> pulse width (s)	0.01~100	The duration of the 1 <sup>st</sup> pulse potential. Current is sampled.
2 <sup>nd</sup> pulse potential (V)	-10~10	The 2 <sup>nd</sup> pulse potential in each cycle.
2 <sup>nd</sup> pulse width (s)	0.01~100	The duration of the 2 <sup>nd</sup> pulse potential. Current is sampled.
Cycles	10~100,000	The total number of cycling.
Sample width(ms)	1~ half of pulse width	The sampling width of the 1 <sup>st</sup> and 2 <sup>nd</sup> pulse potential in each pulse.

**9.2 Double Differential Pulse Amperometry (DDPA)**

Experiments→Amperometric→Double Differential Pulse Amperometry(DDPA)

Double Differential Pulse Amperometry (DDPA) alternates between two instances of differential pulse amperometry, with two sets of data recorded and displayed. In each instance, a conditioning potential applied for electrode conditioning, during which current is not sampled. Two potential pulses are applied after the conditioning step, and the current at the end of each pulse is recorded as a function of time. During the experiment, only the difference between the two current samples is displayed.





Parameter setting window for DDPA

### Experiment parameters

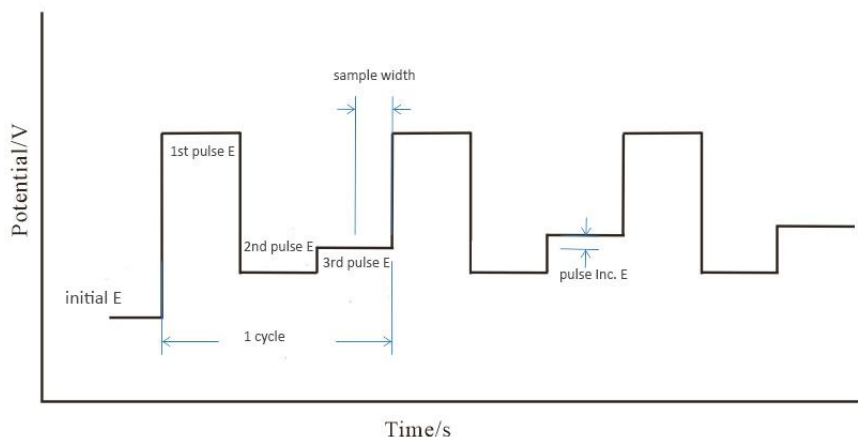
Parameter	Range	Description
Initial E(V)	-10~10	Initial potential
Initial pulse width (s)	$\geq 0$	Duration of the initial potential. The current is not sampled.
1 <sup>st</sup> Conditioning E(V)	-10~10	the 1 <sup>st</sup> cleaning potential
1 <sup>st</sup> Conditioning T(s)	$\geq 0$	The duration of the 1 <sup>st</sup> cleaning potential. Current is not sampled.
1 <sup>st</sup> pulse E (V)	-10~10	The 1 <sup>st</sup> pulse potential in each cycle
1 <sup>st</sup> pulse width(s)	0.01~100	The duration of the 1 <sup>st</sup> pulse potential. Current is sampled.
2 <sup>nd</sup> pulse E (V)	-10~10	The 2 <sup>nd</sup> pulse potential in each cycle
2 <sup>nd</sup> pulse width(s)	0.01~100	The duration of the 2 <sup>nd</sup> pulse potential in each cycle. Current is sampled.
2 <sup>nd</sup> Conditioning E(V)	-10~10	The 2 <sup>nd</sup> cleaning potential of the experiment
2 <sup>nd</sup> Conditioning T(s)	$\geq 0$	The duration of the 2 <sup>nd</sup> cleaning potential. In this process the current is not sampled
3 <sup>rd</sup> pulse E(V)	-10~10	the 3 <sup>rd</sup> pulse potential in each cycle
3 <sup>rd</sup> pulse width (s)	0.01~100	The duration of the 3 <sup>rd</sup> pulse potential in each cycle. Current is sampled.
4 <sup>th</sup> pulse E (V)	-10~10	The 4 <sup>th</sup> pulse potential in each cycle
4 <sup>th</sup> pulse width(s)	0.01~100	The duration of the 4 <sup>th</sup> pulse potential in each cycle. The current is sampled in this process.
Cycles	10-100,000	Total number of cycling
Sample width(ms)	1~half of	The sampling width of pulse potential 1,2,3,4.

	pulse width	
--	-------------	--

### 9.3 Triple Pulse Amperometry (TPA)

Experiments → Amperometry → Triple Pulse Amperometry (TPA)

In Triple Pulse Amperometry (TPA), three potential pulses are applied. The first two pulses are for electrode conditioning. Current is sampled at the end of the third potential pulse and recorded as a function of time. The third potential pulse can be constant or incremented after each cycle.



#### 8.3.1 Experiment parameters

Triple Pulse Amperometry
?
X

**New Data File**

File Name  Browse

Comments  OCP(V)

**Data Acquisition**

Interval(s)

Frequency(Hz)

**Experiment Parameters**

Initial E(V)  vs. RE ▼

Initial Pulse Width(s)

1st Pulse E(V)

1st Pulse Width(s)

2nd Pulse E(V)

2nd Pulse Width(s)

3rd Pulse E(V)

3rd Pulse Width(s)

Pulse Inc. E(V)

Final E(V)

Cycles

Sample width  ms

Powerfreq. period

**Setup**

**Axis Type**

▼

OK Cancel Help

Parameter setting window for TPA

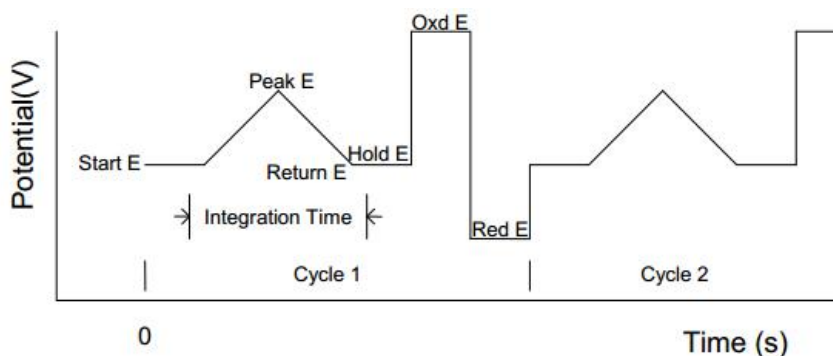


Parameter	Range	Description
Initial E(V)	-10~10	The initial potential
Initial pulse width (s)	$\geq 0$	The duration of the initial potential. The current is not sampled.
Final E(V)	-10~10	The final potential
1 <sup>st</sup> pulse E(V)	-10~10	the 1 <sup>st</sup> pulse potential in each cycle
1 <sup>st</sup> pulse width(s)	$\geq 0$	The duration of the 1 <sup>st</sup> pulse potential in each cycle.
2 <sup>nd</sup> pulse E(V)	-10~10	The 2 <sup>nd</sup> pulse potential in each cycle
2 <sup>nd</sup> pulse width(s)	$\geq 0$	The duration of the 2 <sup>nd</sup> pulse potential in each cycle. The current is not sampled.
3 <sup>rd</sup> pulse E(V)	-10~10	the 3 <sup>rd</sup> pulse potential in each cycle
3 <sup>rd</sup> pulse width(s)	0.01~100	The duration of the 3 <sup>rd</sup> pulse potential in each cycle. The current is sampled.
Pulse inc. E(V)	0~0.02	Potential difference of the 3 <sup>rd</sup> pulse of adjacent cycles
Cycles	10-100,000	Total number of cycling
Sample width(ms)	1~ half of 3 <sup>rd</sup> pulse width	The sampling width of the 3 <sup>rd</sup> pulse potential in each cycle

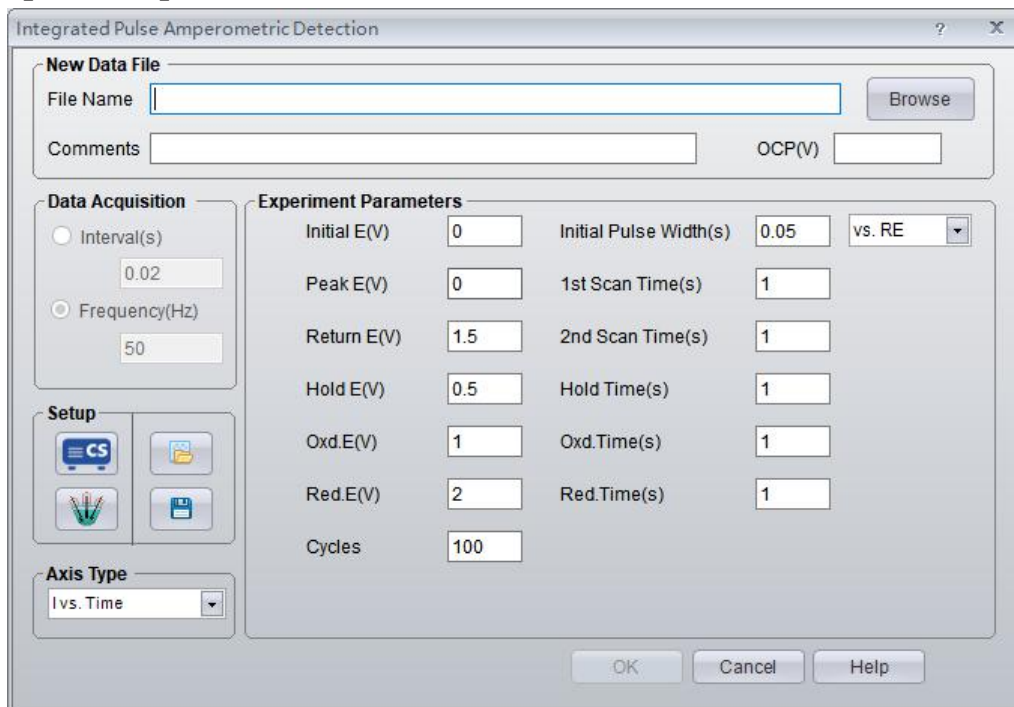
#### 9.4 Integrated Pulse Amperometric Detection(IPAD)

Experiments→Amperometric→Integrated Pulse Amperometric Detection(IPAD)

In Integrated Pulse Amperometric Detection (IPAD), six segments of potential sweeps or steps are applied. Current is sampled and integrated during the first four segments. Electrode conditioning or cleaning occurs during the last two steps. The integrated current is averaged and recorded as a function of time.



### 8.4.1 Experiment parameters



Parameter setting window for IPAD

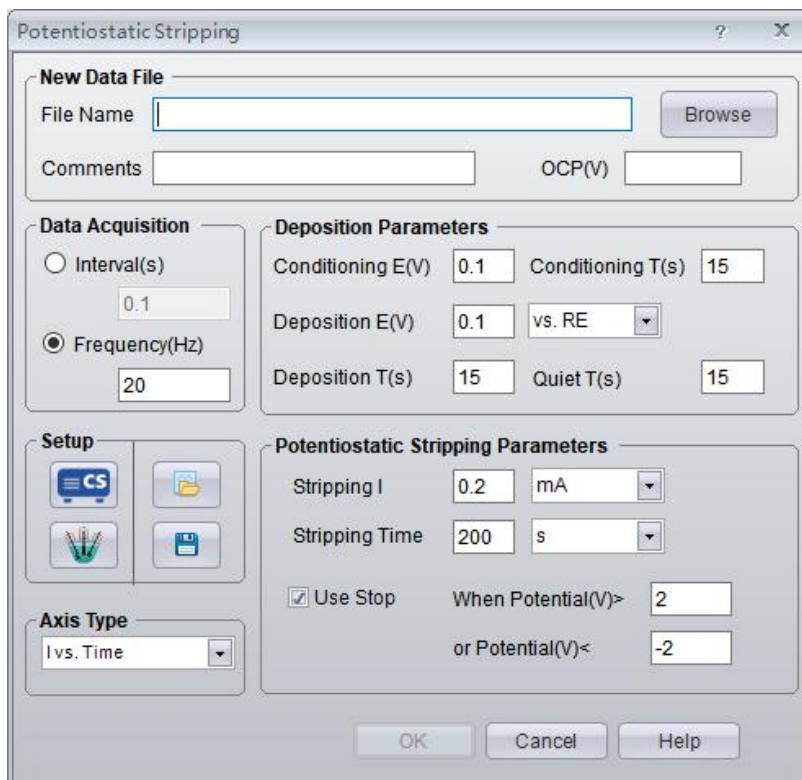
Parameters	Range	Description
Initial E(V)	-5~5	The initial potential
Initial pulse width(s)	0.05~1	Duration of initial potential (current is sampled and integrated for the last 10ms)
Peak E(V)	-5~5	Peak potential
1 <sup>st</sup> scan time(s)	0.1~1	Scan time from Initial E to peak E;The current is sampled and integrated.
Return E(V)	-5~5	Return potential in each cycle
2 <sup>nd</sup> scan time(s)	0.1~1	Scan time from peak E to Return E;The current is sampled and integrated.
Hold E(V)	-5~5	Hold potential of each cycle
Hold Time(s)	0.05~1	Duration of hold potential (current is sampled and integrated for the first 10ms)
Oxd. E(V)	-5~5	Oxidation potential for electrode treatment
Oxd. Time(s)	0.05~1	Oxidation time duration; The current is not sampled
Red. E(V)	-5~5	Reduction potential for electrode treatment
Red. Time(s)	0.05~1	Reduction time duration.The current is not sampled
Cycles	5-100,000	Total number of cycling

## 10. Stripping Voltammetry

### 10.1 Potentiostatic Stripping

Experiments→Stripping Voltammetry→Potentiostatic Stripping

In Potentiostatic Stripping, a constant potential deposition step is first applied, after which the species accumulated at the electrode surface are stripped out by applying a constant current. Potential is recorded as a function of time.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

Parameters	Range	Description
Conditioning E(V)	-10~10	Cleaning/conditioning potential
Conditioning T(s)	$\geq 0$	Cleaning potential duration; the current is not sampled
Deposition E(V)	-10~10	Deposition potential is usually 0.3~0.5V more negative than the redox standard potential, which makes it easy to reduce the tested metal ions.
Deposition Time(s)	$\geq 0$	The time of the deposition process
Quiet Time(s)	$\geq 0$	Waiting time between deposition and stripping
Stripping I(mA)		Constant current is applied on the working electrode.
Deposition Time(s)	$> 0$	the time of potentiostatic stripping process

#### Data Acquisition

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

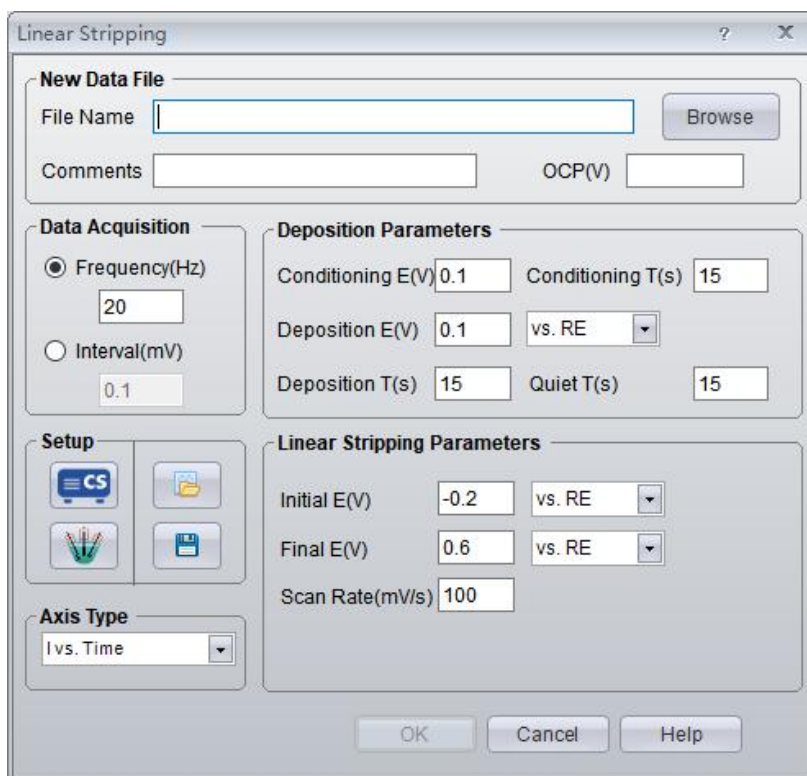
### Axis Type:

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 10.2 Linear Stripping Voltammetry

Experiments→Stripping Voltammetry→Linear Stripping

Voltammetry stripping technique is a high-sensitivity electrochemical method for trace elements analysis. In Linear Stripping, a constant potential deposition step is first applied. After that, the species accumulated on the electrode surface are stripped out by applying a linear potential, which is scanned from an initial potential to a final potential that progresses at a defined scan rate.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

Parameter	Range	Description
Conditioning E(V)	-10~10	Cleaning/conditioning potential
Conditioning T(s)	$\geq 0$	Cleaning potential duration; the current is not sampled.
Deposition E(V)	-10~10	Deposition potential is normally 0.3~0.5V more negative than the redox standard potential, which makes it easy to reduce the tested metal ions.
Deposition Time(s)	>0	The time of the deposition process
Quiet Time(s)	>0	Waiting time after deposition and before stripping

Initial E(V)	-10~10	Initial potential in stripping
Final E(V)	-10~10	Final potential in stripping
Scan Rate(mV/s)	0.01~1000	Scan rate in stripping process

### ***Deposition Parameters***

Before the experiment, the surface of working electrode needs cleaning by this conditioning step.

A constant potential deposition step is applied to accumulate species on the working electrode surface. This potential can be specified to choose either “vs. OCP” or “vs. RE”.

The deposition time determines how long the potential will be held at this step. After deposition, the experiment can be quiet for some time.

### ***Linear Stripping Parameters***

A potential can be specified in several ways. If “vs.OCP” is chosen, the specified potential is added to the open circuit potential of the cell. “vs.RE” means selecting an exact potential.

### ***Data Acquisition***

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

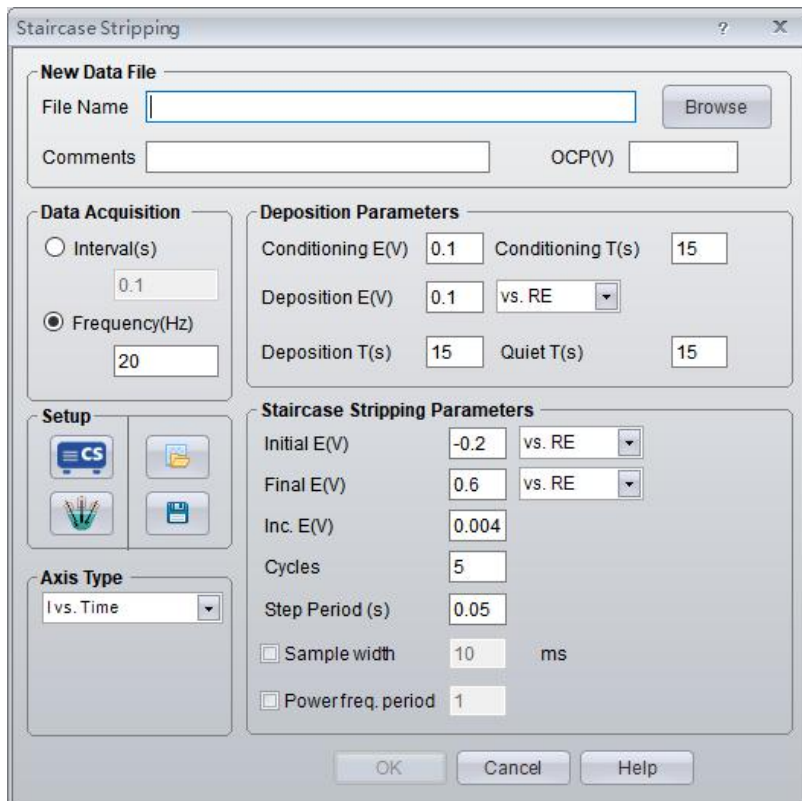
### ***Axis Type***

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **10.3 Staircase Stripping Voltammetry**

Experiments→Stripping Voltammetry→Staircase Stripping

In Staircase Stripping, a constant potential deposition step is applied. After that the species accumulated on the electrode surface are stripped out by applying a staircase potential, which is incremented from Initial E toward Final E that progresses at a defined increment. It is similar to linear stripping. Staircase stripping is considered to be a derivative of linear sweep stripping.



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Staircase Stripping Parameters***

Before the experiment, the surface of working electrode needs cleaning by this conditioning step.

A constant potential deposition step is applied to accumulate species on the working electrode surface. This potential can be specified to choose either “vs. OCP” or “vs. RE”.

The deposition time determines how long the potential will be held at this step. After deposition, the experiment can be quiet for some time.

### ***Data Acquisition***

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

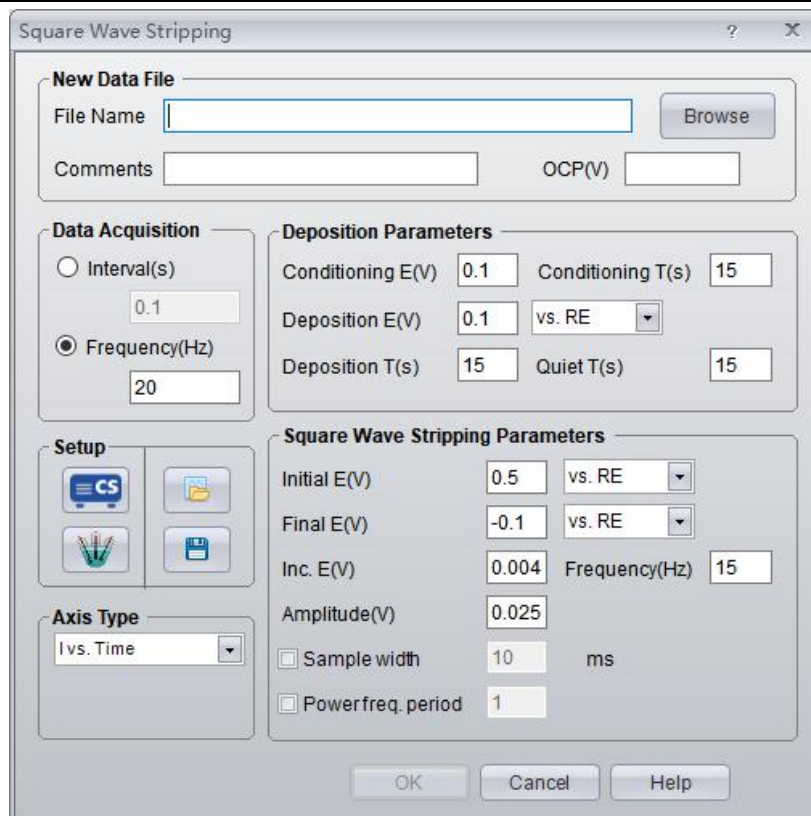
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **10.4 Square wave stripping Voltammetry**

Experiments→Stripping Voltammetry→Square Wave Stripping

In square wave stripping voltammetry, the potential applied on the working electrode is linearly varied in the mode of square-wave in stripping process. The stripping process applies the technique of substantial differential, and the potential applied on the working electrode is in the mode of a symmetric square wave being superimposed on a base step potential. High sensitivity and fast scanning are its advantages, which reduces the analysis time.





OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Deposition Parameters***

Conditioning E: Before deposition, the conditioning potential is applied on working electrode to remove impurities. working electrode surface state is automatically updated.

Conditioning T: the duration of conditioning potential.

Deposition E: Deposition potential is normally 0.3~0.5V more negative than the redox standard potential, which makes it easy to reduce the tested metal ions.

Deposition time: the duration of deposition potential.

Quiet time: Stop stirring, the potential is not applied on the working electrode.

### ***Square wave stripping Parameters***

Initial E: the minimum potential for stripping process to begin.

Final E: final potential is generally higher than the oxidation potential of analyte ions.

Inc.E: the incremental potential of each step.

Amplitude: Square wave amplitude

The potential can be specified in several ways. If “vs. OCP” is chosen, the specified potential is added to the open circuit potential of the cell. For example, “0.1V vs.OCP” means applying a potential 0.1V above the open circuit potential. “vs.RE” means selecting an exact potential.

### ***Data Acquisition***

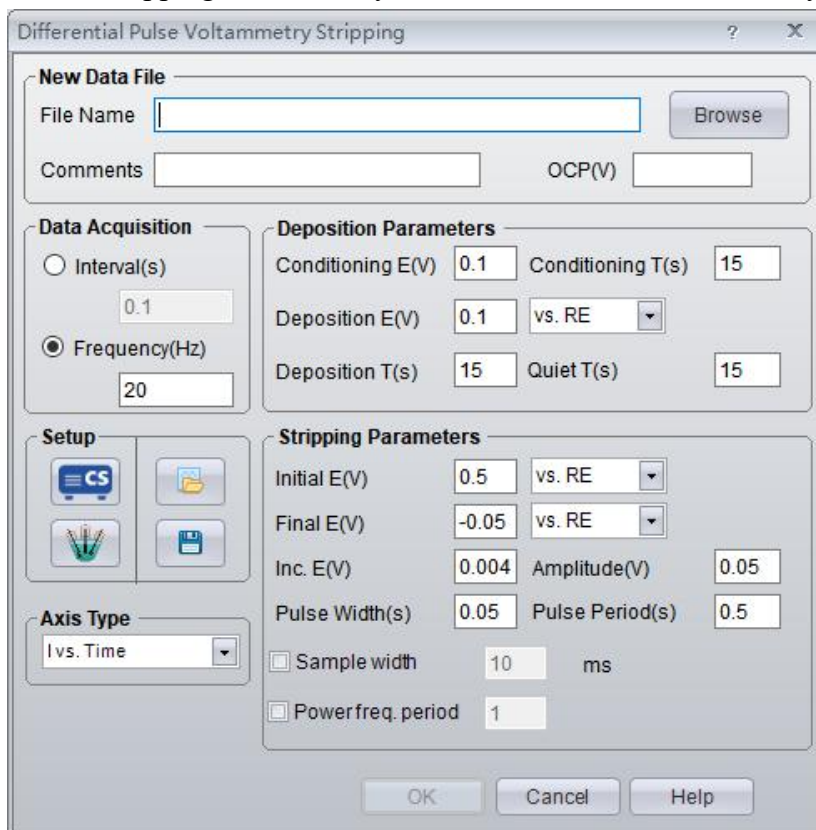
If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 10.5 Differential Pulse Stripping Voltammetry

Experiments→Stripping Voltammetry→Differential Pulse Voltammetry Stripping



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### **Data Acquisition**

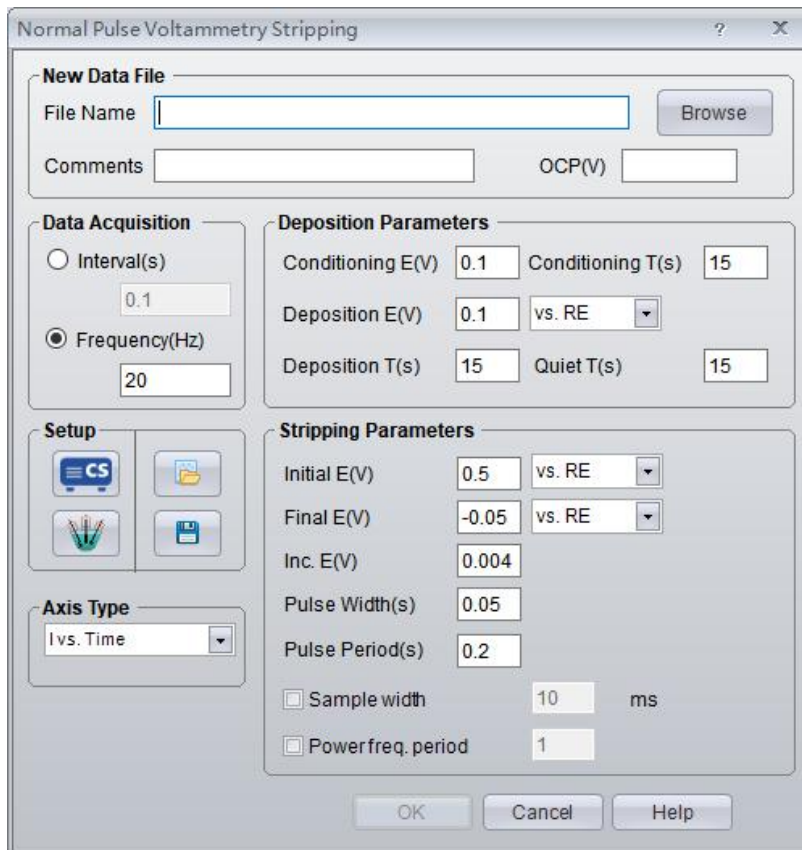
If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### **Axis Type**

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 10.6 Normal Pulse Stripping Voltammetry

Experiments→Stripping Voltammetry→Normal Pulse Voltammetry Stripping



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Data Acquisition***

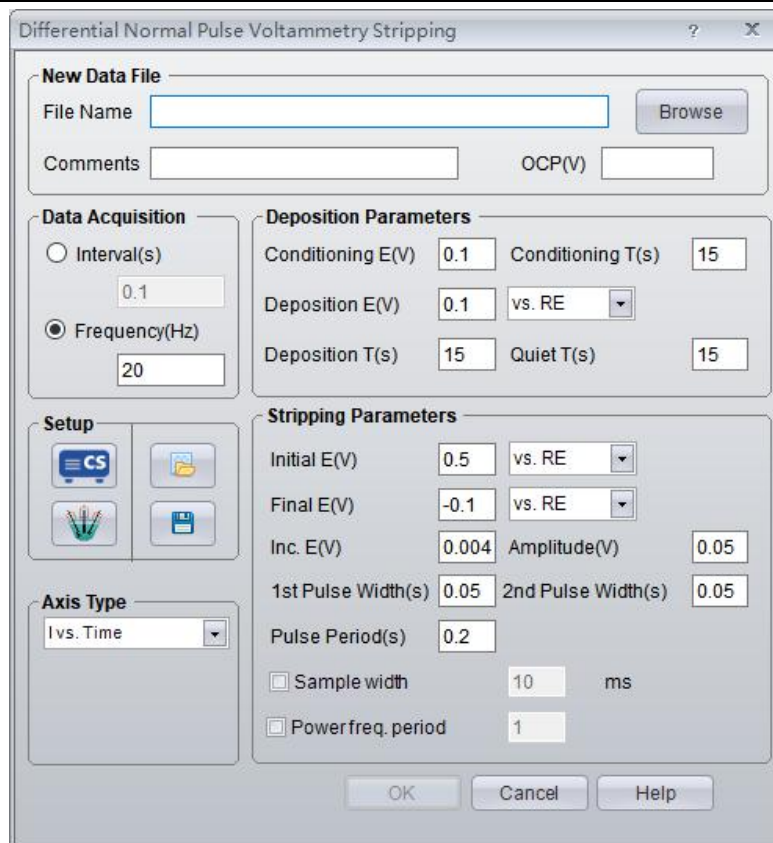
If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **10.7 Differential Normal Pulse Stripping Voltammetry**

Experiments→Stripping Voltammetry→Differential Normal Pulse Voltammetry Stripping



OCP will display the current open circuit potential of the cell (update every second). If the instrument is turned off, this value will display “Not Available”.

### ***Data Acquisition***

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

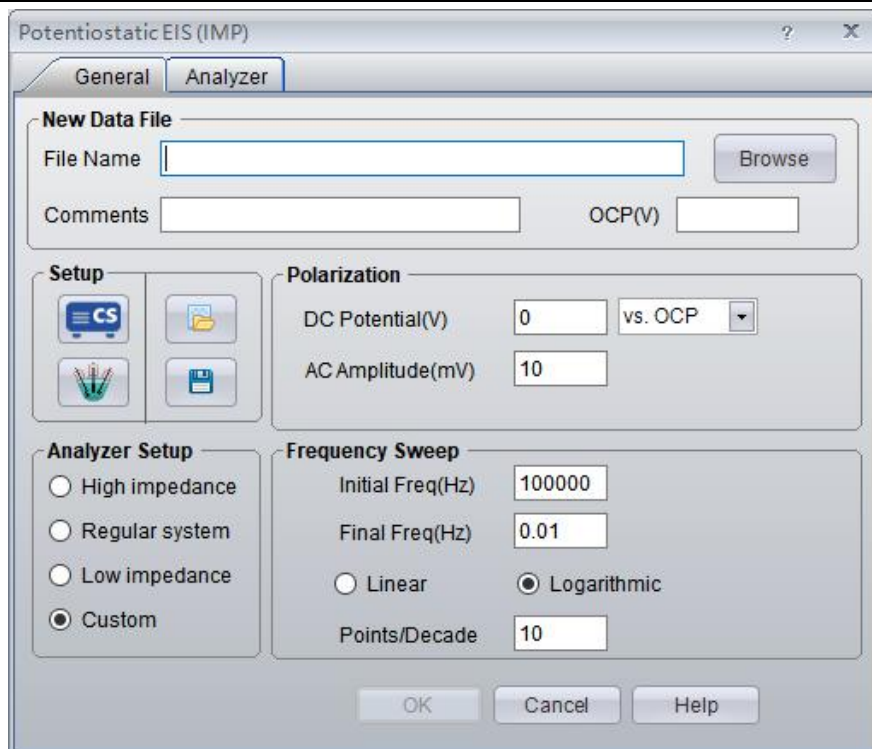
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **11. Impedance(EIS)**

### **11.1 EIS vs. Frequency(IMP)**

Experiments→Impedance→EIS vs. Frequency

In EIS vs. Frequency technique, it measures the impedance spectroscopy of the electrochemical system in difference frequency. Nyquist and Bode plot is obtained.



OCP will display the current open circuit potential of the electrolytic cell (update every second). It is useful for the users to judge whether the working electrode is stable for impedance test.

### ***File Name***

The user should enter a file name to save data before starting the test. At the first time, when You input a name and click OK, you will see the default data storage path on the top of the testing window. Or you can click the Browse, and choose the storage path as you want. This is particularly useful if you forget the file names that you already use.

CS Studio will automatically append the suffix “.z60” to a file name. For example, if you input “tutor1”, the name of the data file will be shown as “tutor1.z60”.

### ***Polarization***

**DC potential:** the DC polarization potential of the working electrode during impedance test. If the test needs to be conducted under open circuit potential, the user should enter “0” and select “vs. OCP” here. At this moment, the potentiostat will automatically give an output of OCP+ DC potential on the working electrode. For example, if you need to do the impedance test under 50mV DC potential of anodic polarization, you can enter “0.05”.

If the test needs to be carried out at a certain potential (such as -0.5V vs. SCE), you can select “vs. RE” and enter “-0.5”, then the potentiostat will polarize the working electrode to be -0.5V.

**AC amplitude** is the amplitude of the electrochemical impedance excitation signals. For example,  $E=0.012\sin(\omega t)V$  means AC signal amplitude is 12mV. Under high frequency, the actual polarization amplitude of the working electrode may be lower than this value due to rate limitation of the amplifier and high-frequency transmission loss of the conducting wires.

### ***Frequency Sweep***

The user should choose the mode of frequency sweep. Frequency sweep starts from the initial frequency to the final frequency, and the mode can be both linear and logarithmic.

If you choose linear mode, the measured points will be evenly distributed between the initial frequency and final frequency. For example, if the frequency range is from “1kHz to



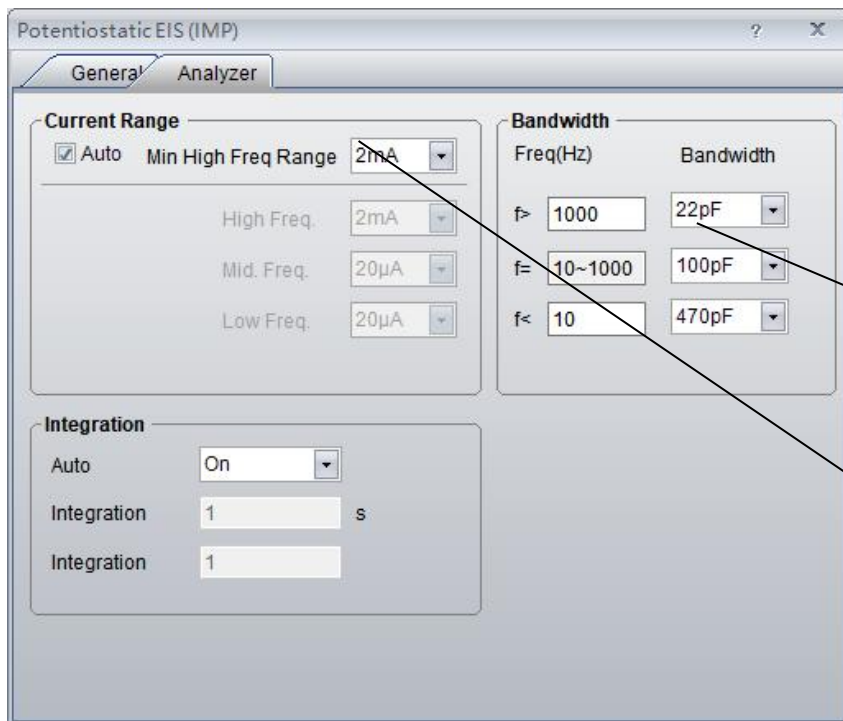
1Hz”, and you set “10” measured points, the frequencies will be “1Hz, 99.9Hz, 2×99.9Hz ...” Generally speaking, this mode is not usually selected unless for special requirements.

If you choose logarithmic, the sampling data points will be evenly distributed in frequency logarithmic axis (Bode plot). It is particularly useful when frequency range is between 2 to 5 orders of magnitude. For example, if the frequency range is from 100kHz to 0.01Hz, and you set 10 points/10 decade, then the measured points will be evenly distributed between initial and final frequency, 70 points in total. The users usually choose this mode.

### ***Pstat/Gstat(ECS)***

For regular electrochemical impedance system, in ground mode the “real” mode is recommended. The bandwidth of filter can be 2.2pF~1 μ F.

## ***Analyzer***



For stable system, you can select “off”. For high impedance system (e.g.coating), you can choose 22~100pF to reduce the noise of the plot. But there may be a small additional capacitor ring in the high impedance region of the spectroscopy.

For low impedance system, you can choose 2mA. For high impedance system, you can choose 20μA~200μA. If the range is not properly set, noise may appear on the EIS plot.

### **Current range**

The user can set current range automatically/manually. If select “auto”, you need to set a minimum current range in high frequency. In the above dialog for example, when the measuring frequency is over 1000Hz, the auto current range will be no lower than 2mA.

The high frequency is defined by the user. In the above picture,  $f > 1000\text{Hz}$  is high frequency region,  $f < 10\text{Hz}$  is low frequency region, and  $10\text{Hz} \sim 1000\text{Hz}$  is middle frequency region.

If auto current range cannot meet the need, then manual setting is recommended. For example, in above picture, under manual setting, the current range is 2mA( $f > 1000\text{Hz}$ ), 200 μ A ( $f < 10\text{Hz}$  and  $f = 10\text{Hz} \sim 1000\text{Hz}$ )

To improve measurement accuracy, the setting for current range should be varied. The user should select suitable current range according to frequency band. In general, current range at low frequency should be smaller than that at high frequency. If the current range is set inappropriately, the EIS plot may appear large noise. If the current range is changed frequently,



there will be obvious bent points on the curve. By observing signal amplitude of the waveform, the user can judge if the current range is suitable.

### **Bandwidth**

The higher the selected capacitance value is, the narrower the bandwidth of the potentiostat will be. The performance in high-frequency will weaken, but stability will be improved.


Bandwidth is set based on the critical frequency  $f_c$ . If the measurement frequency is higher than  $f_c$ , normally you should choose a small capacitance (or turn it off) to avoid false impedance spectra in high frequency region. But for high impedance system, it may result in oscillation. You may have to increase the capacitance. To check if oscillation occurs, you can observe the signal amplitude of the waveform.

### **Integration Time**

The impedance measurement accuracy can be improved by increasing the integration time. You can set the integration time to be the number of cycles or seconds. It specifies the time spent on each frequency point. The longer the integration time is, the higher the measurement accuracy will be, and the more time it will take.

**Delay time** is the waiting time between measurement of two frequency points.

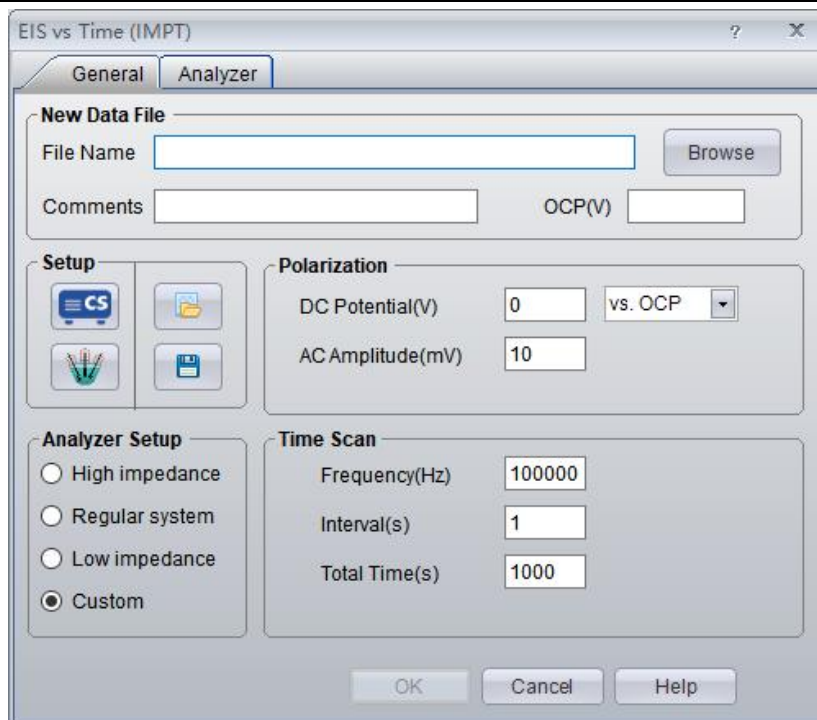
### ***The impedance spectroscopy analyzing***

Impedance data file (.z60) is fully compatible with Zview software which is the tool to analyze impedance spectroscopy and draw graphics. After data acquisition in impedance test, you can click “Tools”→“EIS Analysis” or directly click Zview icon  to analyze data.

## **11.2 EIS vs Time(IMPT)**

Experiments→Impedance→EIS vs. Time(IMPT)

IMPT measures the impedance characteristics of the electrochemical system as a function of time at a fixed frequency. It tracks the dynamic processes of some systems, such as conductivity.



OCP will display the current open circuit potential of the electrolytic cell (update every second). This is particularly useful for the user to judge whether the working electrode is stable for impedance test.

### ***Polarization***

**DC potential** is the DC polarization potential of the working electrode during impedance test. If the test needs to proceed under open circuit potential (OCP), then you can enter “0” and select “vs. OCP”. At this moment the potentiostat will automatically give an output of the sum of OCP and the DC potential to the working electrode. If you do the impedance test at anodic polarization 50mV DC potential, you can enter “0.05” here.

If the test needs to be carried out at a certain potential (such as -0.5V vs. SCE), you can select “vs. RE” and enter “-0.5”. The potentiostat will polarize the working electrode to be “-0.5V”, instead of “-0.5+OCP”.

**AC amplitude** is the amplitude of the electrochemical impedance excitation signals. For example,  $E=0.012 \sin(\omega t) V$  means AC signal amplitude is 12mV. At high frequency, the actual polarization amplitude of the working electrode may be lower than this value due to rate limitation of the amplifier and high-frequency transmission loss of the conducting wires.

### ***Time Scan***

In Impedance~ Time scan, frequency of sine wave is constant. It measures the impedance of some electrochemical systems at a frequency point as a function of time.

Interval - interval for measurement at each frequency point.

Total time- the total time of measurement.

### ***Pstat/Gstat(ECS)***

Click this button, and open the window for instrument setting. You can choose the instrument model, set the switching way of current range, signal gain/loss, ground mode, filter bandwidth, digital smoothing, quiet time (scan delay). For regular electrochemical impedance measurement system, real ground mode is recommended, and 2.2pF~1μF is OK for filter bandwidth.

## Cell Setting

You can enter related information of one or more working electrode(s) and electrolytic cell(s), eg. surface area, material, and temperature... The electrode area, density and chemical equivalent will affect the results of experiment and fitting. Temperature or type of RE will not affect the original data; they are just saved in each data file for info. Meanwhile, these parameters are needed for corrosion rate calculation.

### 11.3 EIS vs Potential(IMPE)

Experiments→Impedance→EIS vs. Potential

This method is used to measure impedance characteristics at different DC polarization potential. The potential is stepped from initial potential to final potential. It can obtain Mott-Schottky (M-S) plot which has been widely used to study the semiconductor characteristics of passivation film on the metal. It can determine the carrier type, concentration and the flat band potential of the semiconductor passivation film.

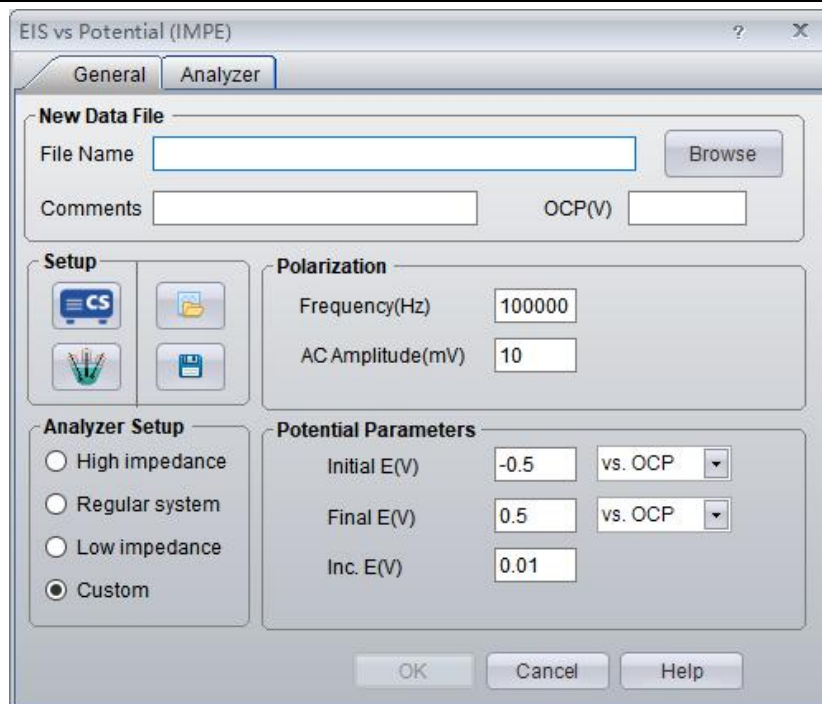
When the passivation film is in contact with the solution and the space charge of the semiconductor passivation film is in the state of depletion, for the space charge capacitance ( $C_{sc}$ ) and the measured voltage ( $V_m$ ), there is the following linear relationship:

$$C_{sc}^{-2} = \frac{2}{eN_d\epsilon\epsilon_0A^2} \left( V_m - V_{fb} - \frac{kT}{e} \right) \quad \text{n-type semiconductor} \quad (1)$$

$$C_{sc}^{-2} = \frac{-2}{eN_a\epsilon\epsilon_0A^2} \left( V_m - V_{fb} + \frac{kT}{e} \right) \quad \text{p-type semiconductor} \quad (2)$$

Where,  $V_{fb}$  is flat band potential,  $N_d$  and  $N_a$  are the carrier concentration of donor and acceptor respectively,  $\epsilon$  is the relative permittivity,  $\epsilon_0$  is the vacuum permittivity,  $A$  the electrode surface area,  $k$  is Boltzmann constant,  $T$  is absolute temperature,  $e$  is the quantity of electric charge.

Passivation film is of a double layer structure. Because the composition and crystal structure are different for the inner and outer layer of the passivation film, semiconductor type is also different. Therefore, two space charge layers are formed inside the passivation film, that is, the space charge layer on solution/passivation film interface, and the inner layer /outer layer interface pn junction capacitance. Because pn and passivation film capacitance are small, in the impedance~potential sweep, high-frequency sine wave is generally used for measurement.



OCP will display the actual open circuit potential of the electrolytic cell (update every second). This is particularly useful for the user to determine whether the working electrode is stable for impedance test.

### ***EIS Parameters***

Frequency and AC Amplitude specify the frequency and amplitude of sine wave during the impedance measurement.

### ***Potential Parameters***

**Initial E** is the initial DC level of the working electrode in impedance ~ potential sweep.

**Final E** is the final potential in impedance ~ potential sweep.

**Inc. E** is the potential increment. Potential is increased with the form of steps.

### ***Pstat/Gstat(ECS)***

Click on this button, and open the window for instrument setting. You can choose the instrument model, set the switching way of current range, signal gain/loss, ground mode, filter bandwidth, digital smoothing, quiet time (scan delay). For regular electrochemical impedance measurement system, real ground mode is recommended, and 10pF~100pF is OK for filter bandwidth.

### ***Cell Setting***

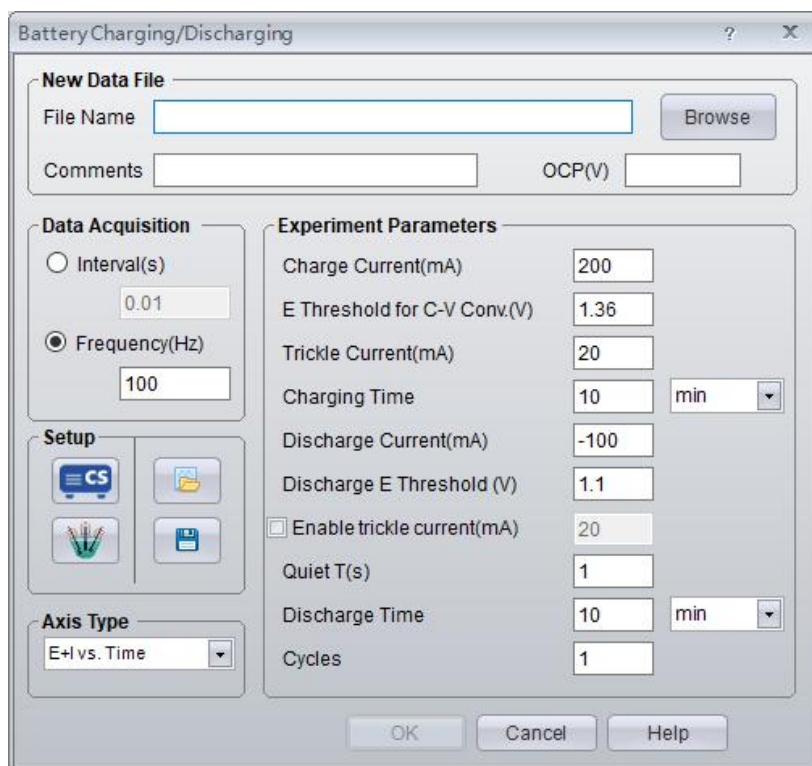
You can enter related information of one or more working electrode(s) and electrolytic cell(s), eg. surface area, material, and temperature... The electrode area, density and chemical equivalent will affect the results of experiment and fitting. Temperature or type of RE will not affect the original data; they are just saved in each data file for info. Meanwhile, these parameters are needed for corrosion rate calculation.

## **12. Charging/Discharging**

### **12.1 Battery Charging/Discharging**

Experiments → Charging/Discharging → Battery Charging/Discharging

It is used to test the charge and discharge characteristics of rechargeable battery and its lifetime.



### Experiment parameters

**Charge current**--According to different connecting ways of the electrodes, the sign of charge current will be different. Connect the working electrode to anode, and the reference & counter electrodes to the cathode, if the open circuit potential is positive, then a positive value entering means charging process. .

**E-Threshold for C-V Conv.** is the critical voltage where charge process is changed from constant current mode to constant voltage mode. Normally in the early stage of charge, it is constant current charge mode. Once the battery voltage is higher than the critical voltage, it will convert to constant voltage mode. At this moment, the charge current will gradually decrease with time. When it falls to the **trickle current** (usually 10% ~20% of the charge current), the software will automatically stop charging.

**Discharge current**--Connect the working electrode to anode, and the reference & counter electrode are connected to cathode, if the OCP is a positive value, then it means discharging if you enter a negative value here.

**Discharge threshold voltage**--During discharge process, when the voltage drops to this threshold voltage, the battery will stop discharge.

**Quiet time**--it specifies the interval from the state of charging to discharging. The battery is in the open circuit during this time.

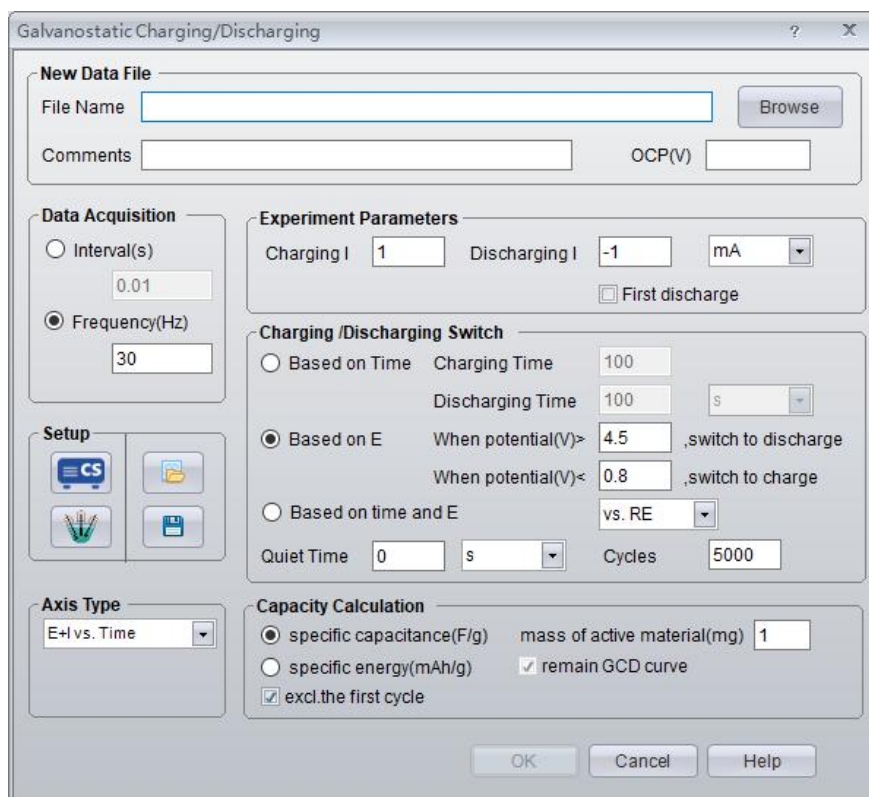
**Charge/ Discharge time**--When the charge/discharge time is reached, even the specified threshold voltage hasn't been reached yet, the charge / discharge process will stop, and turn to discharge/charge. You can select second, minute or hour.

**Cycles**-- a complete cycle includes a charging & discharging process. This parameter specifies the total number of cycles throughout the experiment. When the number is reached, the experiment will be stopped.

## 12.2 Galvanostatic Charging/Discharging(GCD)

Experiments→Charging/Discharging→Galvanostatic Charging/Discharging

It measure cyclic charge-discharge characteristics of the electrode materials, such as secondary battery or supercapacitor electrode material, under a constant current. It tests the cycle lifetime of the electrode material.



### **Charge/Discharge Current**

**Charging I-** if the anode is connected to the working electrode, entering a positive value means charge.

**Discharging I-** if the anode is connected to the working electrode, entering a negative value means discharge.

### **Condition for switch of Charging/Discharging**

#### **Based on Time**

It specifies the duration of the process of charge /discharge. Charging process will be stopped and it will turn to discharge if the charging time reaches the set value. After the time of discharging, a cycle is finished. It will go to the charging process again. You can select “seconds”, “minute” and “hour.”

#### **Based on Time and E**

Either condition is met, the charge/discharge process switch.

**Cycles-** a complete cycle includes a charge and a discharge process. It specifies the total number of cycles conducted throughout the experiment. When this number is met, the experiment will be stopped.

#### **Capacity calculation**

Specific capacitance is calculated according to the following formula:



$$C = \frac{I \Delta t}{m \Delta V}$$

Where I is charging(discharging) current.  $\Delta t$  is discharging(charging) time,  $\Delta V$  is discharging(charging) potential difference, m is the mass of electrode active materials(note: m cannot be 0, otherwise the software will give an error prompt.)

Through many times of cyclic measurement, we can evaluate the lifespan of the capacitors. By symmetry of the charging and discharging curve, we can judge whether capacitor charging and discharge, and the electrochemical reactions are reversible or not.

Charge-discharge efficiency( $\eta$ ) is calculated according to:

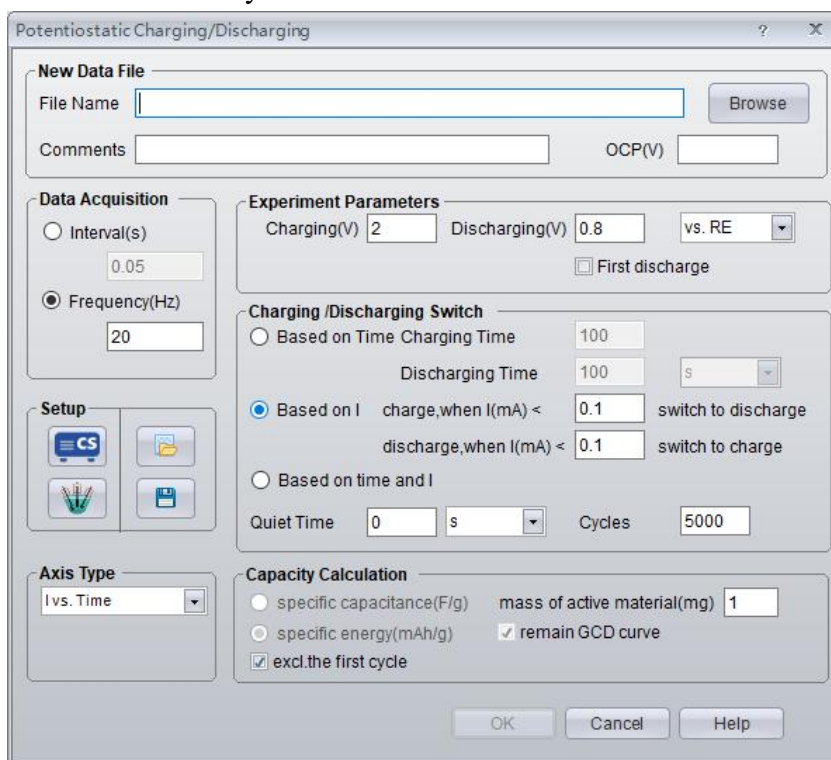
$$\eta = \frac{C_{dis}}{C_{ch}} \times 100\% \quad \eta = \frac{\Delta t_{dis}}{\Delta t_{ch}} \times 100\%$$

Where,  $C_{ch}$ ,  $C_{dis}$  is the charging capacitance and discharging capacitance, respectively.  $\Delta t_{ch}$ ,  $\Delta t_{dis}$  is charging time and discharging time, respectively, they are displayed on the software.

**Excl. the first cycle**—Normally error is relatively big for the data of the first cycle. You can check it to not save the data of the first cycle.

### 12.3 Potentiostatic charge and discharge (PCD)

This technique aims to checking the charge and discharge characteristic of the battery, and test the service life of the battery.



**Charging Voltage (V):** charge under a constant voltage.

**Discharging Voltage (V):** discharge under a constant voltage. You can check the First discharge to let the system be under discharge.

**Charge / discharge switch conditions**

**Based on Time:** You can set the time for each process. When the time is up it will change from charge to discharge or from discharge state to charge.

**Based on Current:** When current meets the conditions for switch, it will go to a different process.

**Quiet time:** the intervals when battery turns to discharge from charge. During the quiet time the battery is under open circuit state.

**Cycles:** A cycle includes a charge and discharge process. When the number of charge-discharge process reaches this number you set, the whole battery test will end.

**Capacity calculation:** Specific capacitance and specific energy not check as default. After the test, you can find the related calculation result in the data .dat

## 13. Bipotentiostat



### 13.1 Hydrogen Diffusion Test (HDT)

Experiments → Bipotentiostat → Hydrogen diffusion Test

CS2350 bipotentiostat can do hydrogen diffusion test.

Hydrogen Diffusion Test (HDT) requires a set of H-cell which consists of two cells connected in serial. For each cell, there is a set of reference & counter electrode, and they share a working electrode which is a thin metal plate clipped in the middle of the two cells. (See the right picture).

On the hydrogen-charging surface of the working electrode, the square wave cathodic current is applied. By alternatively changing the current value, the atoms will diffuse into the metal and gradually reach the other side (detection surface) of the working electrode. By measuring the amplitude of the current waveform and the delay time, the hydrogen diffusion rate and diffusion coefficient can be calculated.

Connect the double electrolytic cells in the way as shown below, add 0.1 mol/L NaOH solution into the anodic cell (right cell). Connect the electrode cable to the main channel on the front panel, and the cathodic cell to the slave channel. Firstly, set the anodic polarization potential of the main channel to be 0.2 V vs. Hg / HgO, then start the polarization. The anodic current will decline dramatically at the beginning, then slowly remain a stable value, i.e. the anodic residual current which is generated by the residual hydrogen inner the steel plate or the impurities that can be oxidized in solution of the diffusion surface. When the residual current is lower than the set value, the user can add experimental medium (such as dilute hydrochloric acid) into the cathodic cell, and then start galvanostatic polarization of the slave channel. The initial current is the peak current, e.g. 10 mA (see the figure). At this moment hydrogen ions on cathodic surface of cathodic cell will be reduced to hydrogen atoms, some of which will permeate into the metal disc and arrive on anodic surface of the anodic cell, then

these arrived hydrogen atoms will be oxidized into ions under anodic polarization in the main channel,, forming oxidation current.

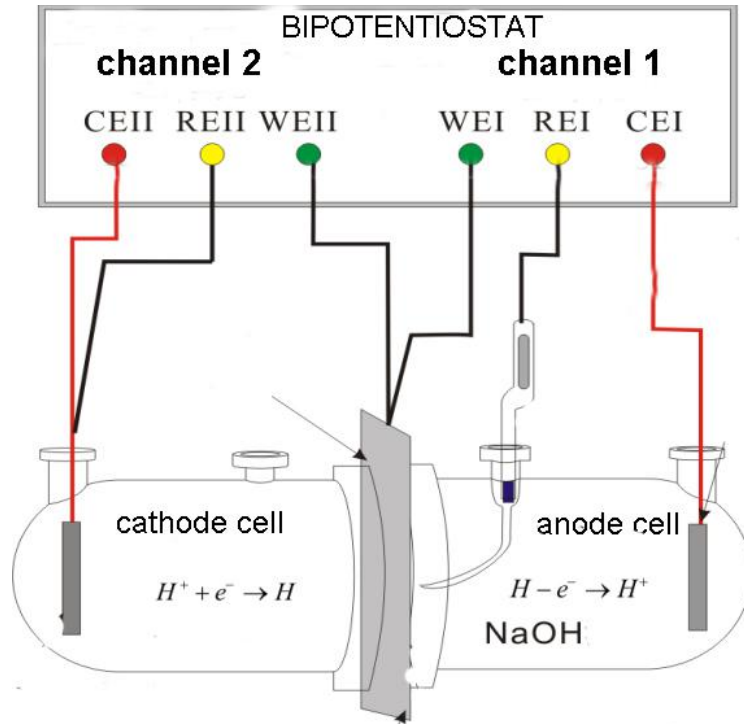
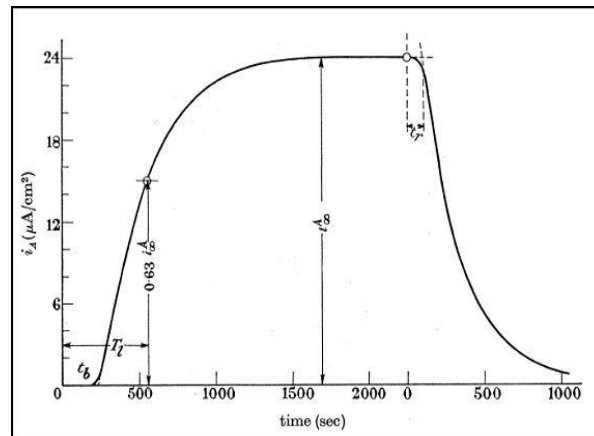
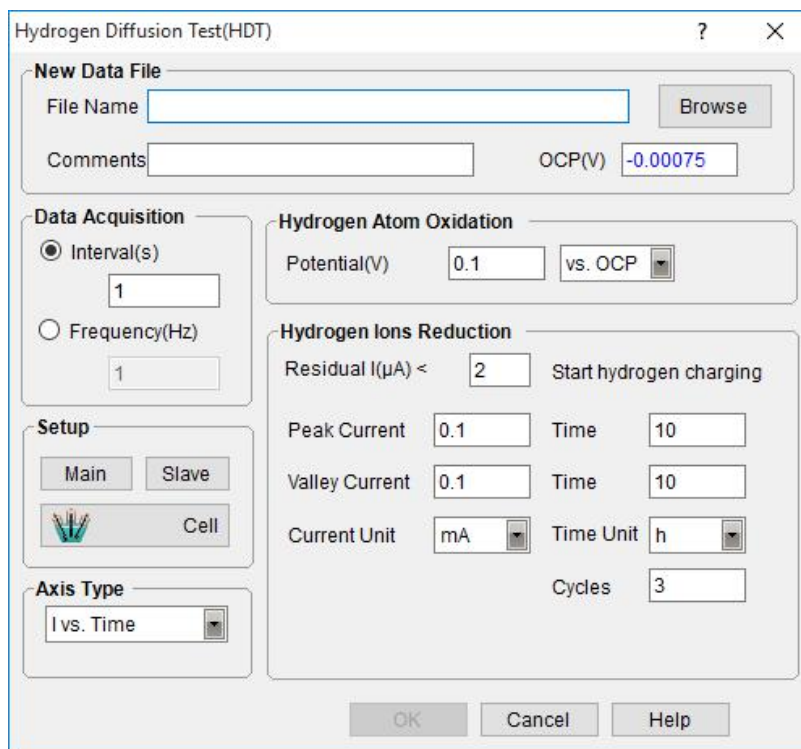


Diagram for Hydrogen diffusion cells



Current vs time curve in hydrogen diffusion test

Because hydrogen atoms diffusion rate is limited, current at the hydrogen detecting side delays, taking the form that anodic current increases (rising edge) or decreases (falling edge) gradually with time. According to the delay time of the hydrogen detecting current and its value, we can calculate the hydrogen concentration and diffusion rate in the metal, and further, we also can evaluate some inhibitors' effect on hydrogen diffusion.



### ***Hydrogen Atoms Oxidation (main channel)***

Potential (V) — it is the polarization potential applied on the working electrode at the hydrogen current detection side. This potential should make the working electrode (metal disk) in anodic polarization. That is, a positive value should be entered to allow hydrogen atoms to be oxidized to ions.

### ***Hydrogen Ions Reduction (slave channel)***

Please set peak current and valley current of the square wave of hydrogen charging current as well as time. Hydrogen charging current can only be the cathodic direction so that the hydrogen ions are reduced to be atoms and pass through the working electrode (metal disk in the middle). Number of cycles of hydrogen charging current is the number of square wave.

**Residual current** — With the potentiostatic polarization going on, residual hydrogen current in the metal will gradually decrease. When it is lower than the set residual current, the software will start galvanostatic polarization for hydrogen charging.

At the beginning, the main channel will firstly start potentiostatic polarization, letting the hydrogen atoms in the metal fully diffuse onto the oxidation surface and be oxidized. It takes a relatively long time. Normally when the residual current is lower than  $1\sim 2\mu\text{A}/\text{cm}^2$  (threshold of residual current), it's considered that hydrogen atoms in the metal are totally oxidized. Once the oxidation current is lower than the threshold value, the slave channel will start galvanostatic hydrogen charging. Hydrogen charging current varies between the peak current and the valley current. In general, 10~20 minutes later (depends on the material and thickness of the metal), the anodic current detected in the main channel will increase gradually and finally keep stable, as hydrogen atoms diffuse and reach to the opposite side of the metal and are oxidized to form anodic current.

### ***Data Acquisition***

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

When the experiment is performed, the data will be displayed as specified by the Axis

Type. CorrView can be later used to display the data in other formats.

### Main/Slave settings

For bipotentiostat, the “main channel” and “slave channel” settings can be same or different. Please choose “real” in ground mode.

## 13.2 Rotating ring-disk Electrode (RRDE)

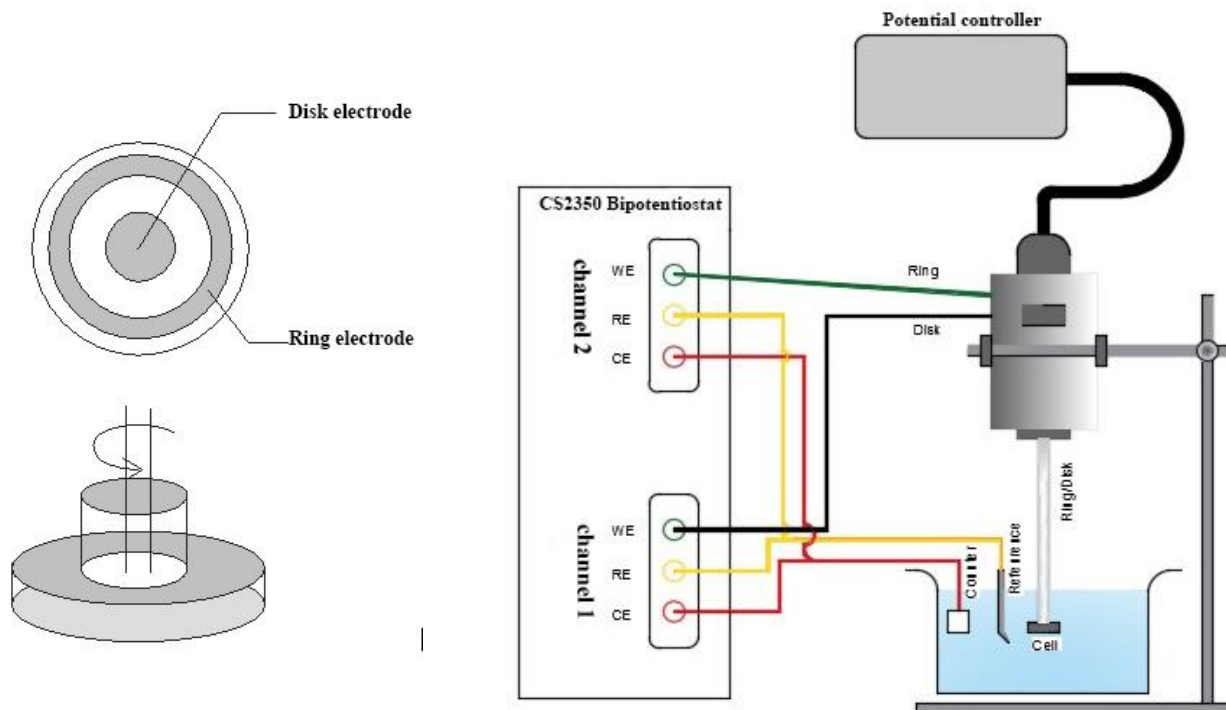
Experiments → Bipotentiostat → Rotating ring-disk electrode

CS2350 bipotentiostat can conduct rotating ring-disk electrode.

Compared with stationary electrodes, the rotating disk electrode is more stable in terms of concentration polarization. It has better polarization curve stability; and can measure rapid electrochemical reactions. Therefore, measuring the polarization curve of the rotating disk electrode has wide applications, especially in diffusion coefficient measurement, electron gain & loss in reactions, the reactant concentration, leveling effect of electroplating additives, and the kinetic parameters of electrode reactions, etc. With the help of ring electrode, it can also detect reaction intermediate products on the disk electrode.

In the following picture, disk working electrode (DW) and ring working electrode (RW) are two independent WE in concentric circle. DW and RW should be controlled at different polarization potential to ensure that electrochemical reaction product on DW can arrive in ring electrode for further redox reactions and be detected.

RRDE setup should be connected to the bipotentiostat with main channel (channel 1) and the slave channel (channel 2). The slave channel controls the potential difference between DW and RW.



The main channel applies the common three-electrode mode: CE clamp connects to the counter electrode; RE clamp connects to the reference electrode; and WE clamp connects to the disk electrode.

The slave channel also applies three-electrode potentiostatic mode: WE clamp connects to the ring electrode, CE clamp connects to the counter electrode, and RE clamp connects to the

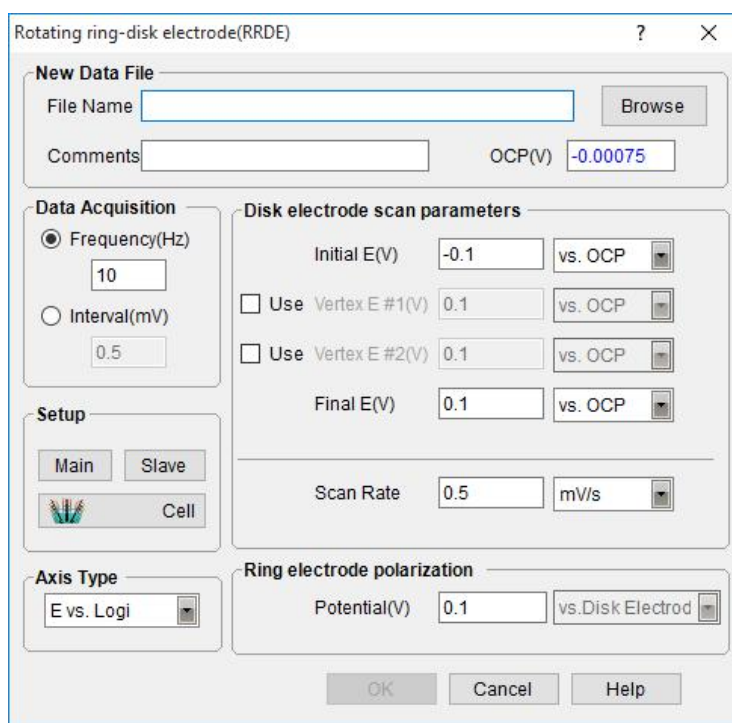


reference electrode. That is, RE clamp and CE clamp of each channel connects to a common reference electrode and counter electrode.

The intermediate product generated during disk electrode polarization further will be oxidized or reduced on the ring electrode due to the potential difference between the ring-disk electrode. Current on the ring electrode is measured and displayed by slave channel potentiostat.

For RRDE test, the disk electrode is the main working electrode, and the ring electrode is mainly used to detect the intermediate product on the disk electrode. Therefore, potentiodynamic test is usually conducted on disk electrode, and the potential difference between ring and disk electrode is set to be a constant value.

There are two groups of measured data: one is the polarized potential  $E_d$  and polarized current  $I_d$  on the disk electrode(main channel /channel 1). The second group is the polarized potential  $E_r$ (fixed) and the polarized current  $I_r$  on the ring electrode(slave channel /channel 2).



parameters setting for rotating ring-disk electrode test

### ***Disk electrode scan parameters***

Similar to potentiodynamic scan, up to 4 independent polarization potentials can be set on disk electrode.

### ***Ring electrode polarization***

Potential —polarization potential of ring electrode vs. the disk electrode, with unit of V.

### ***Data Acquisition***

If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

### ***Main/Slave settings***

For bipotentiostat, you need to do settings for the main & slave channel respectively.



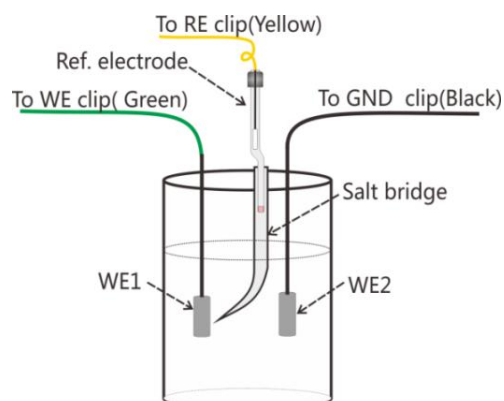
## 14. Misc. Techniques

### 14.1 Electrochemical Noise (EN)

Experiments → Misc. Techniques → Electrochemical Noise

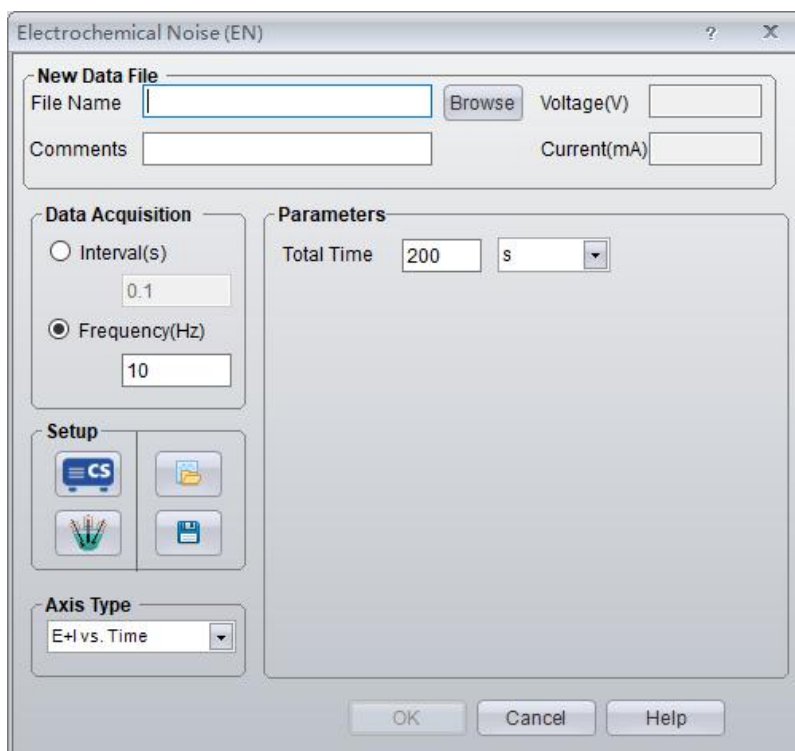
This method is mainly used to monitor noise potential and the noise current (zero resistance current or galvanic current) as a function of time. Monitoring duration can be set.

For CS series electrochemical workstation, the noise signals (or galvanic current) measurement is different from other methods in that it doesn't need to be in the state of polarization. In the noise/galvanic current measurement, the working (galvanic) electrode I is connected to the green clamp of the electrode cable, and working (galvanic) electrode II is connected to the black clamp, and the reference electrode is connected to the yellow clamp. (See the picture on the right.)



Run the CS Studio software, select electrochemical noise measurement, on the software dialog box, it will appear coupling potential and galvanic current. If the current value is positive, it means the working /galvanic electrode I is anode and the working (galvanic) II is cathode. The current flows from electrode I to electrode II.

During measurement, the potentiostat will automatically switch current range according to the current.



#### **Data Acquisition**

If **Frequency (Hz)** is chosen, the acquisition rate in points/second is specified.

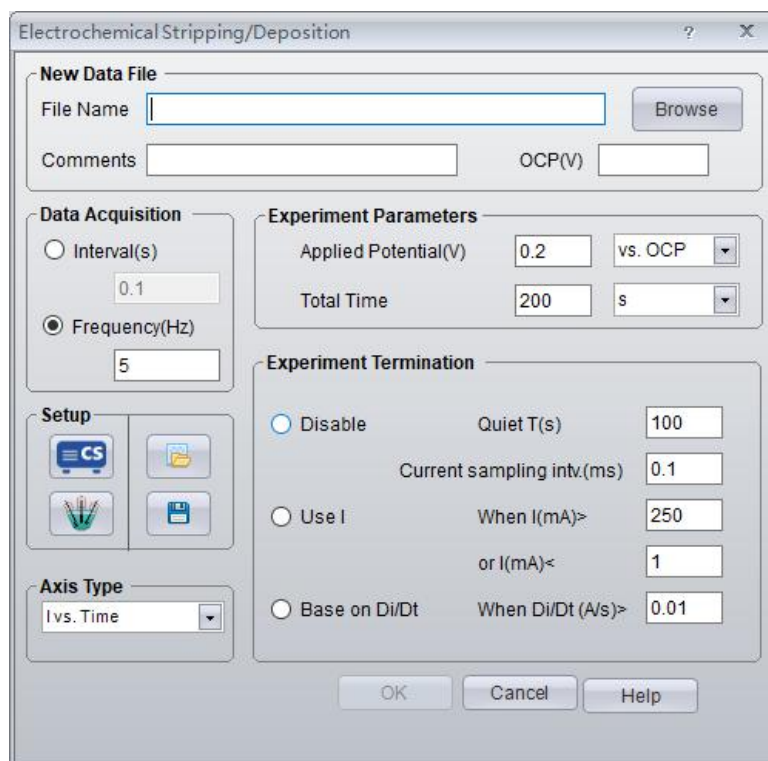
#### **Axis Type**

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## 14.2 Electrochemical Stripping/Deposition

Experiments → Misc. Techniques → Electrochemical Stripping/Deposition

A constant polarization potential is applied on the working electrode, and monitor the polarization current as a function of time. The polarization total time can be specified by the user, and it can also be set as that when the polarization current achieves a certain value, test is automatically terminated.



### **Deposition Parameters**

Applied potential (V)—it is the potential applied to the measured system. For CS series electrochemical workstation, if the polarization potential is “vs. OCP”, then negative value means cathodic polarization, and positive value means anodic polarization. By clicking on the drop-down box, users can choose the applying way of polarization potential.

Total time— you can specify the duration of potentiostatic polarization; time unit can be “second”, “minute” or “hour”.

### **Experiment Termination**

If you select “Use I” and set the quiet time and current sampling interval, the software will automatically terminate potentiostatic polarization test once the polarization current is higher than the specified maximum value (anodic current) or lower than the specified minimum value (cathodic current).

If you choose “Based on Di/Dt”, the program will automatically terminate potentiostatic polarization test once the Di/Dt is higher than the set value.

If you choose “Disable”, neither of the two conditions to terminate the test works.

### **Data Acquisition**

If **Frequency(Hz)** is chosen, the acquisition rate in points/second is specified.

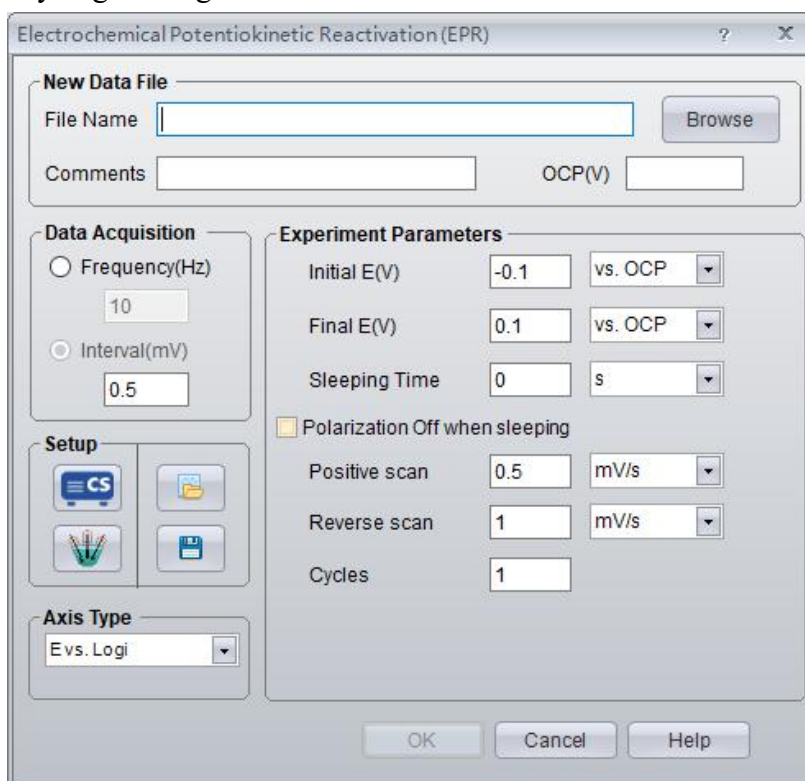
### **Axis Type**

When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

### 14.3 Electrochemical Potentiokinetic Reactivation(EPR)

Experiments→Misc.Techniques→Electrochemical Potentiokinetic Reactivation

This technique can be applied to evaluate susceptibility to intergranular corrosion. It can be determined by  $I_a/I_r$ (activation peak current/reactivation peak current). It can also be obtained by the ratio  $Q_a/Q_r$ . When the experiment is finished, the measured data can be analyzed and obtain the value of  $I_r$ ,  $I_a$ ,  $Q_r$ , and  $Q_a$  through“EPR index calculation” of voltammetric analyzing&fitting.



#### **Parameters setting**

Initial E/Final E/Scan Rate: please refer to the parameter setting in technique Potentiodynamic.

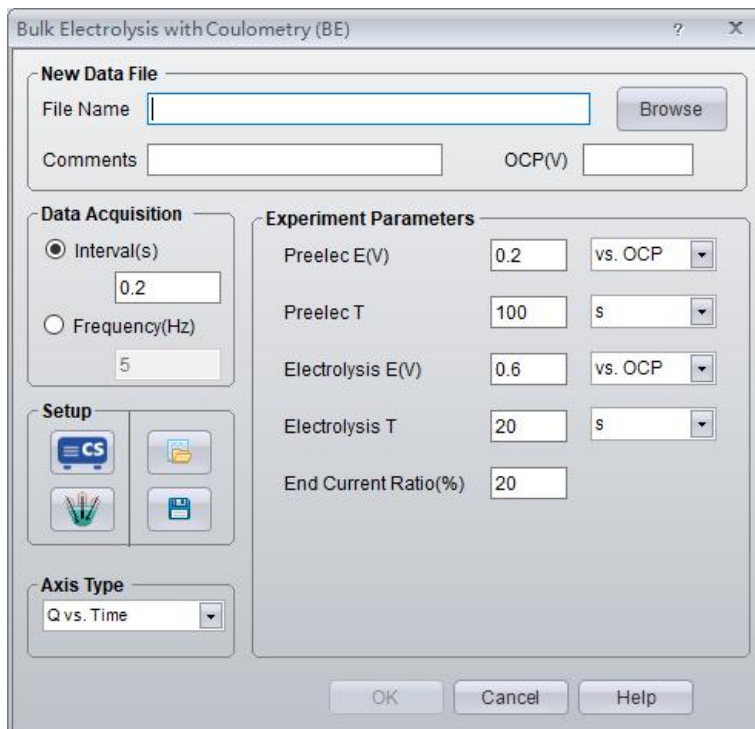
Sleeping Time: the time staying at final potential.

Cycles: The number of cycles can be set. A complete cycle is finished scanning from the initial E to final E.

### 14.4 Bulk Electrolysis with Coulometry (BE)

Experiments→Misc.Techniques→Bulk Electrolysis with Coulometry

In Bulk Electrolysis with Coulometry(BE), a constant potential is applied and the integrated charge is recorded as a function of time.



### ***Parameters setting***

Preelec E(V): the potential in pre-electrolysis process.

Preelec T: duration of the pre-electrolysis process.

Electrolysis E(V): the potential in electrolysis process.

Electrolysis T: duration of the process of electrolysis.

End current ratio (%): One condition to terminate the electrolysis process.

Electrolysis T and End current ratio jointly determine the termination of electrolysis.

### ***Data Acquisition***

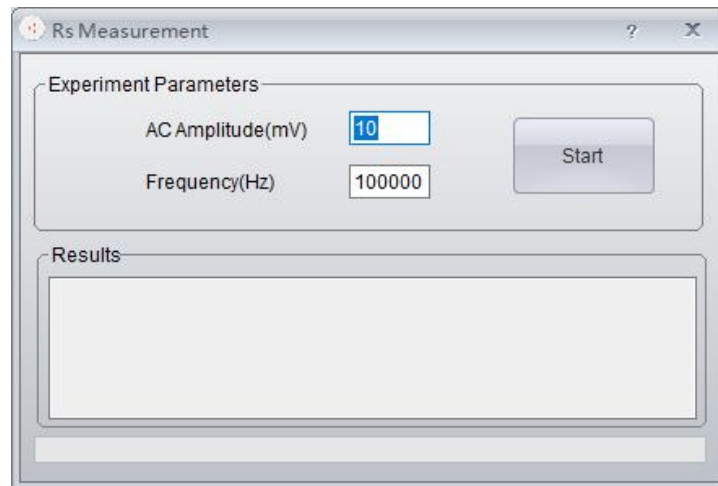
If Frequency(Hz) is chosen, the acquisition rate in points/second is specified.

### ***Axis Type***

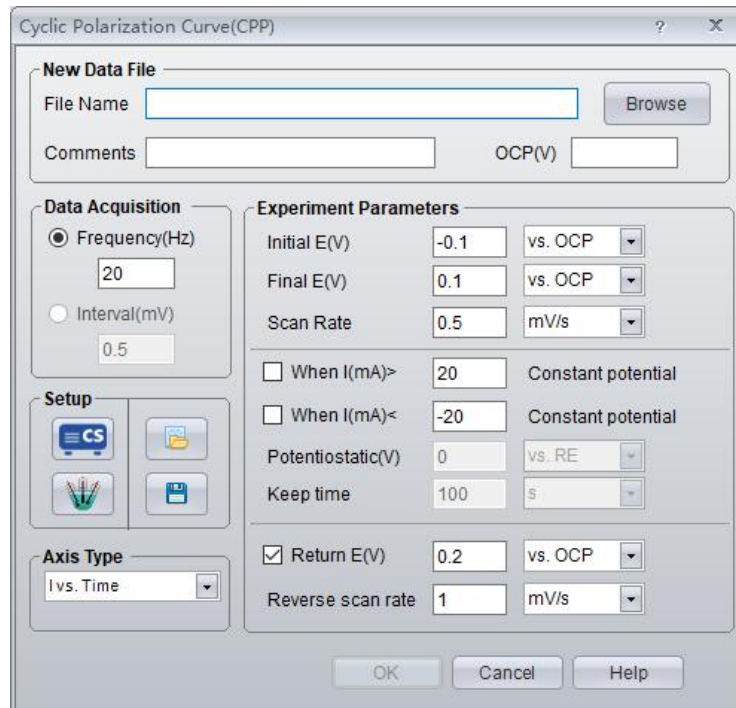
When the experiment is performed, the data will be displayed as specified by the Axis Type. CorrView can be later used to display the data in other formats.

## **14.5 Solution resistance $R_s$ measurement**

Set the AC amplitude and test frequency, and click "Start". After the test, the software will display the value of the solution resistance  $R_s$ . Repeat three times to get the average value of the solution resistance.



## 14.6 Cyclic Polarization Curve (CPP)



Initial E, final E and scan rate: you can refer to contents in potentiodynamic

**Return potential:** the reverse scan final potential

**Reverse scan rate:** the scan rate from final potential to initial potential

### Constant potential conditions

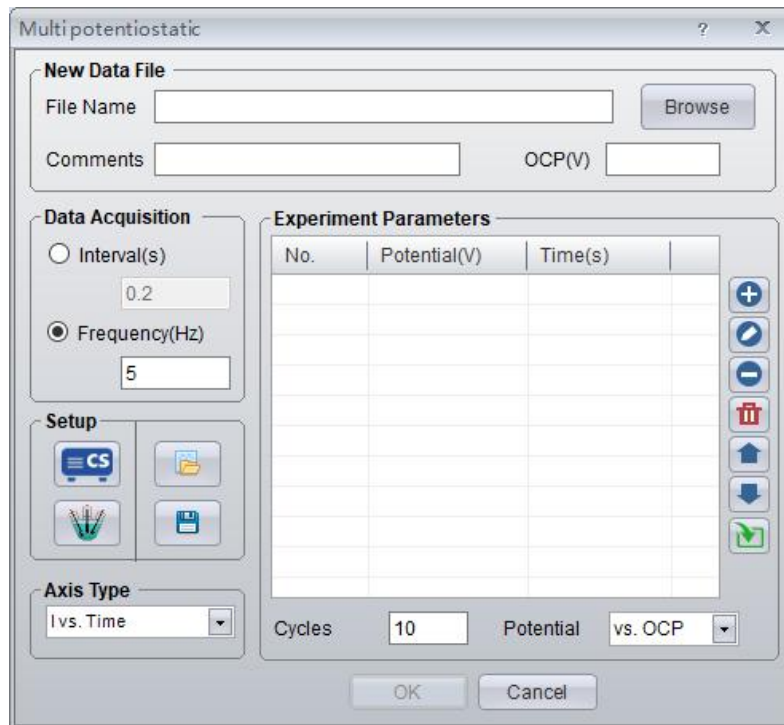
When you check the first condition, it means, when the response current is higher than your set value, the instrument will apply a constant potential. You can set this constant potential and the duration/keep time. The logic is similar for second condition.

If you don't choose any condition, it will not proceed the potentiostatic process.


Potentiostatic: if you set vs. Meas, the potential the instrument actually apply is the sum

of the instantaneous potential when potentiodynamic stage turns to potentiostatic and the setting value here in potentiostatic. If vs. OCP, the potential the instrument actually apply is the sum of OCP and the setting value. If vs. RE, the potential the instrument actually apply is the setting value.






## 14.7 Multi potentiostatic



It aims to achieving custom measurement that multi potentials, multi duration for each potential can be set.

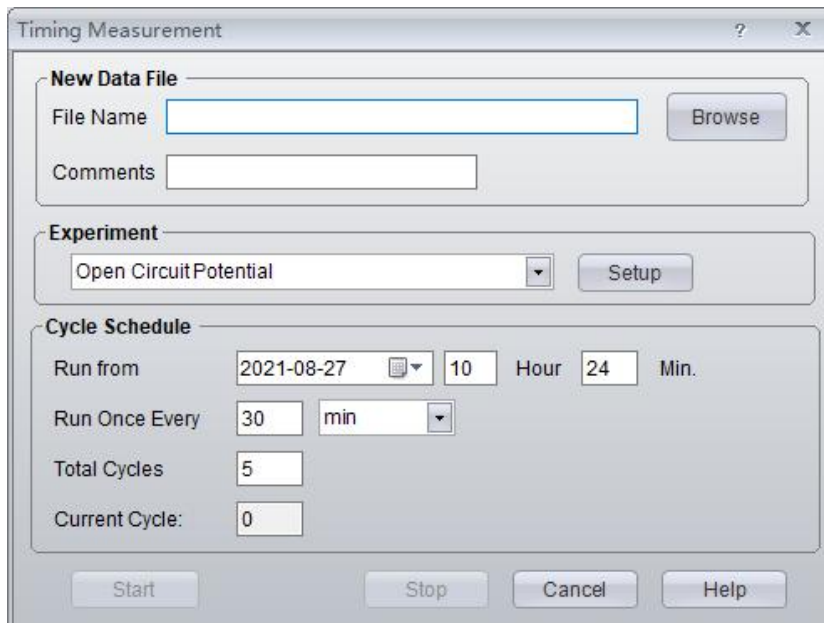
-  Set the value of the potential and applied duration/step time



-  Modify potential and step time
-  Remove the selected project
-  Remove all
-  move up and down to adjust the order
-  You can import several parameter settings at one time



## 15. Timing measurement



The screenshot shows a 'Timing Measurement' dialog box with the following fields and controls:

- New Data File:**
  - File Name:
  - Comments:
  - Browse:
- Experiment:**
  - Open Circuit Potential:
  - Setup:
- Cycle Schedule:**
  - Run from:   Hour  Min.
  - Run Once Every:
  - Total Cycles:
  - Current Cycle:

Buttons at the bottom:

It aims to setting the running mode of a certain experiment. This function allows the user to perform automatic measurement at a set time interval after a specified time. It facilitates the user to track the time change characteristics of a certain testing system.

After a file name is specified, the start will be activated.

You can specify the exact time the experiment will run from and the intervals for each measurement and the total cycles of the measurement. It also displays the current cycles it has run.

For the experiment involves polarization (such as potentiodynamic, cyclic voltammetry, EIS), after each cycle, the instrument will automatically cut off the polarization and let the cell be in the status of OCP till the next measurement/cycle.

When the times of the measurement reach the total cycles, the window will exit automatically to end the project. The user can judge the measurement time according to the serial number at each data file name.

## 16. Graph Display

### 16.1 “.cor” Data file Graphing

Data file format:

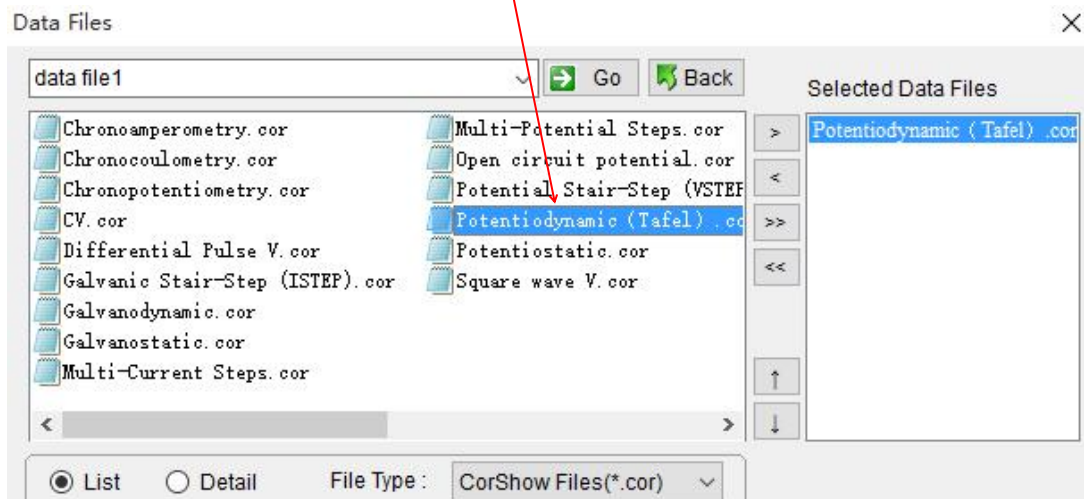
EIS: .z60

Others: .cor

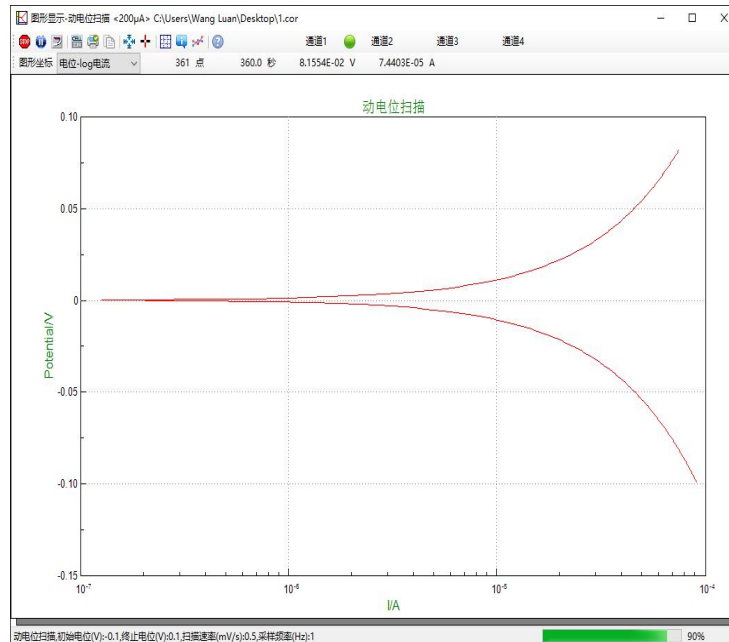
The data file can be open by notepad in txt format. And it can be copied and pasted to Excel for drawing.



Double-click to import a data file



For all the techniques based on constant potential, constant current, galvanic current, the window displays real-time data in the form of graphs, and can “stop”, “pause”, or “reverse”.

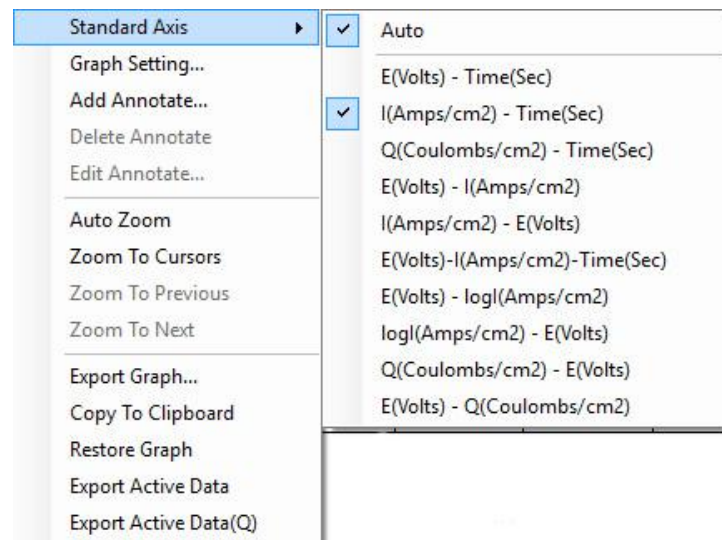


dynamic graph display window

The file name is shown at the top of the window. The techniques such as potentiostatic, potentiodynamic, parameters such as the scan rate, measuring time, working status, total data amount, etc., and test completion percentage will be shown at the bottom.

CS Studio will automatically find the best beginning and end point in the coordinate and refresh the graph in real time.

### Coordinate



E vs. time- the abscissa is time in “second”; the Y- axis is potential of the electrode.

I vs. time- the abscissa is time in “second”; the Y- axis is current.

E vs. I- the abscissa is current; the Y- axis is the potential of the electrode.

I vs. E- the abscissa is the potential of the electrode ; the Y- axis is current.

E vs. LogI- the abscissa is the logarithm of the absolute current; the Y- axis is the potential of electrode.

E+I vs. time- The abscissa is time, and the Y- axis is electrode’s potential and polarization

(galvanic) current.


Q vs. Time - the abscissa is time and the Y- axis is the integral quantity of electric charges.

### **Zoom In**


If you want to zoom in a local position, you can left-press the mouse button on the target area, and drag it to the lower- right side, and then release the button. The selected graph will be immediately zoomed in and fill up the entire window. The graph will not be updated, but CS studio is still scanning and acquiring data signals. If you want to go back to the previous state , please just double click the mouse anywhere on the graph or click “zoom out”.

### **Buttons**


#### **Stop**

Click  to stop the ongoing test.

#### **Pause/Start**

Click  to pause the test, re-click to resume the testing.

#### **Reverse**

Click  button then the scan direction will be reversed. It is only used in potentiodynamic and cyclic voltammetry test. A single click will let the scan direction reverse, and the scan rate keeps unchanged. Click again, then the direction will be returned to the original.


#### **Polar off**

Click  then you can change the state of the electrode polarization anytime.

#### **Print**

Click , then the real-time graph in the window will be output to the printer immediately.


#### **Copy**

Click  then the real-time graph in the window can be copied and pasted.


#### **Auto zoom**

Click  then the real-time graph will zoom in and fill up the entire graph window.


#### **Data reader**

It shows the real -time data, from left to right they are: data points, time(s), potential(V), current(A). If you want to know the value of a certain point, you can click the  icon and move the mouse cursor on that specific point on the graph. The value will be displayed immediately. For example, if you set coordinate to be “E-T”, then the text will be the time and potential; and if you select “E-I”, then the text will be current density and potential.


#### **Show Grid**

Click , the coordinate grids will be shown, click it again not to show the grids.


#### **Show Parameters**

Click  then the testing parameters can be shown, click it again not to display.

#### **Show Mark**

Click  button to display the mark. Click it again to cancel display.


## Help

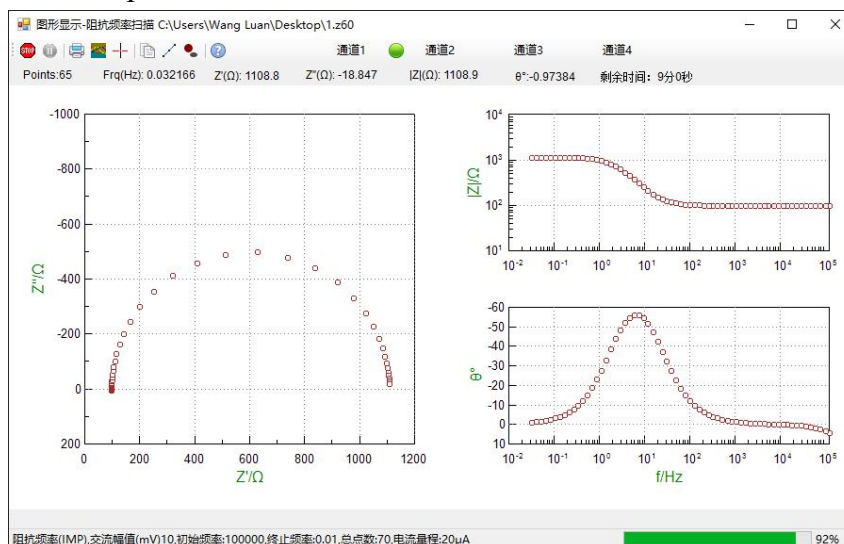
Click  to get help info. of the test at present.

## 16.2 “.z60” Impedance Data

CS studio will display the real-time impedance data. The real part, the imaginary part, the impedance modular, phase angle and frequency will be displayed. The measuring data will be automatically saved .

### Data reader

If you want to know the value of a certain data point on the graph, you can click  and move the cursor to the graph area, then the data will be displayed immediately. You can read the real part, imaginary part, frequency, impedance modular and phase angle of a data point in “Nyquist” or “Bode” plot, as shown in below.



EIS vs. Frequency testing window

### Zoom in

If you want to zoom in a local position, you can left-press the mouse button on the target area, and drag it to the lower- right side, and then release the button. The selected graph will be immediately zoomed in and fill up the entire window. The graph will not be updated, but CS Studio is still scanning and acquiring data signals. If you want to go back to the previous state , please just double click the mouse anywhere on the graph or click “zoom out”.

Note:Due to the large amount of data during the test, you’d better use the zoom in function after the measurement.

### Stop

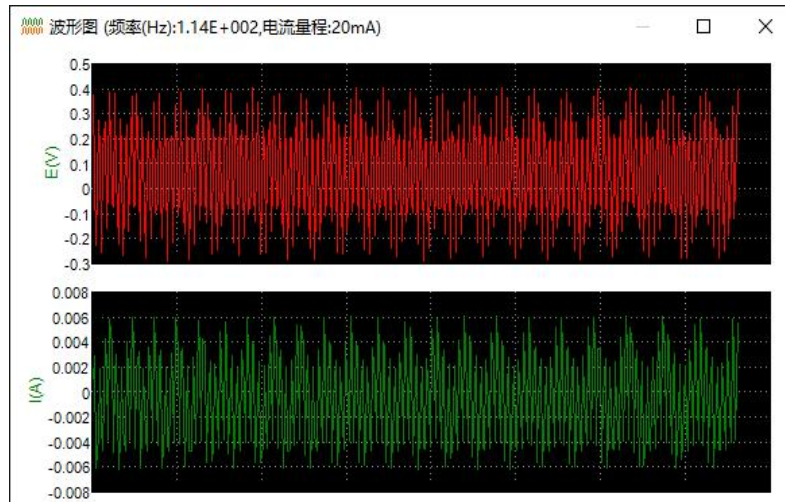
Click  button to stop the testing and change from polarization status to natural status.

### Waveform

The waveform window shows the acquired potential and current waveform during EIS test, and guide the user to choose the suitable “Min. High Freq. range” and “Bandwidth” in the

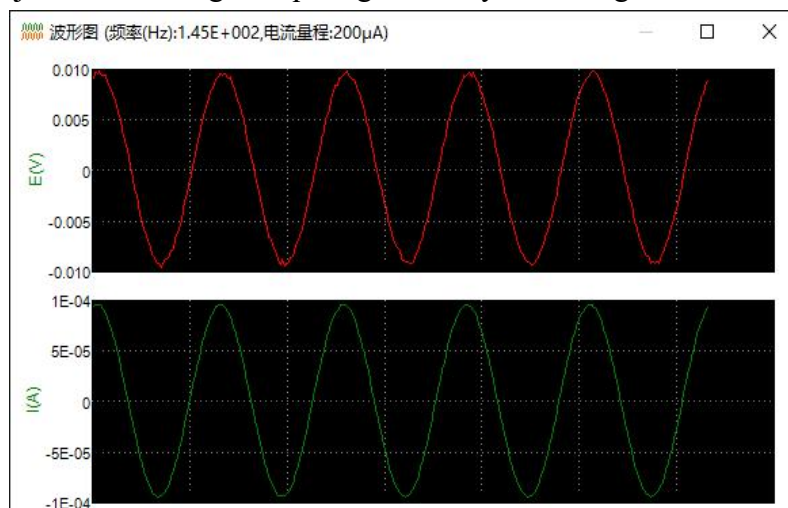
analyzer setting. If the noise is big, you should probably increase capacitance of the bandwidth filter, and prevent measuring system oscillation.

For EIS test of high-impedance system, if you don't open the bandwidth response capacitor in analyzer setting, oscillation may happen, as shown in below. In this picture, you can't see sine signals, and the amplitude is not 10mV, meaning there is oscillation in the testing system.



(close bandwidth capacitor) acquired potential / current waveform(oscillation appears)

Choose the bandwidth capacitance to be “22pF” in analyzer setting, then you can see the normal sine wave signals, suggesting that the instrument can response to the applied sine wave signals, and works properly. As shown in below picture, the amplitude of the potential signals is 10mV, in accordance with the amplitude of the applied signals. Meanwhile, the current signal is around 100 $\mu$ A, matching the selected current range 200 $\mu$ A. If the current amplitude is too big or too small, there will be relatively big error in the measured impedance spectroscopy. You should re-adjust the min. high freq. range in analyzer setting.



(selecting 22pF capacitor) acquired potential/current waveform(normal sine wave signals)

If just current signals noise is big, the cause may be high input impedance of the reference electrode loop (eg. high-impedance coating). You should increase the capacitance of the bandwidth filter to improve the stability.



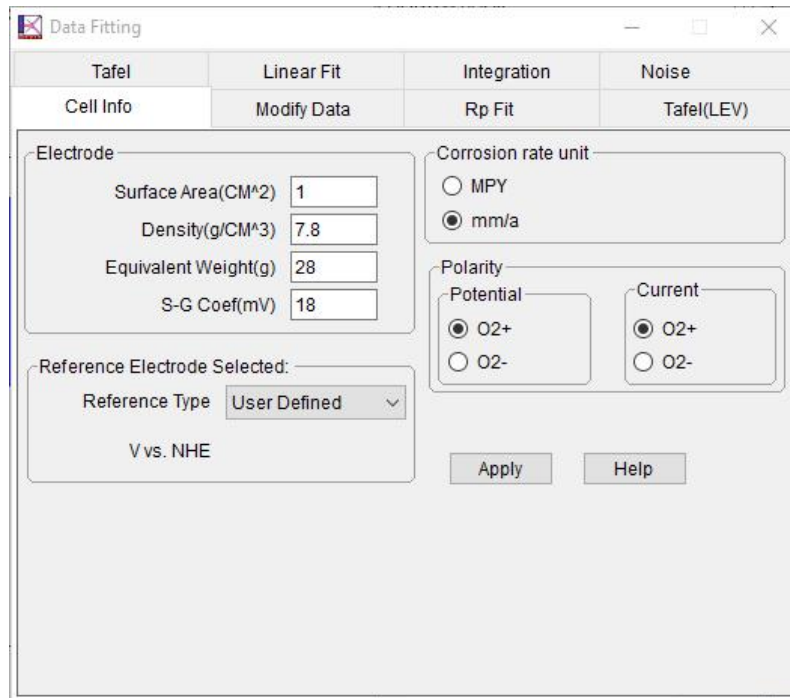
## 17. Tools

### 17.1 Data Export

This command is to export the data file of the active window, and save as data file suffixed with “.cor”. The data format is “.csp” if you choose “save project as”.

### 17.2 Data fitting

There are: Tafel fitting, linear fit, integration, Noise, cell information, modify data,  $R_p$  fit, Least square method etc.



Data Fitting

#### **Modify Data**

This is used to change the original data for data / graph offset and flipping. After modification, all data is changed. During switch, there will be a prompt to ask if you want to save the data.

If you want to do subtraction, you only need to enter a negative value in Addition. If you want to do division, you just need to change the corresponding relationship.

#### **Cell info.**

See Cell Setting 3.2.

Electrode area is the area of the working electrode. If it is 1, the current density will be the same as the measured current in value.

CS studio employs material density or the chemical equivalent for corrosion rate calculation. Chemical equivalent = atomic weight / the number of electrons transferred in the reaction. For example, for reaction  $\text{Fe} - 2e \rightarrow \text{Fe}^{2+}$ , the number of transferred electrons is 2, then the chemical equivalent is  $55.8/2 = 27.9$ .

If such values are not entered, then the software only calculate the polarization resistance

$R_p$  or the Tafel slope, and cannot calculate corrosion rate.

“Polarity” determines how the positive/negative potential/current is interpreted. When choose the normal “ $O^{2+}$ ”, a more positive potential will produce a bigger oxidation driving force, meanwhile the generated current is positive. If you choose “ $O^{2-}$ ”, a more negative potential will produce a bigger oxidation driving force, the oxidation current value is negative.

### ***R<sub>p</sub> fitting***

Polarization resistance is the slope of the E-I curve near the open circuit potential.

If the data range is set to be “auto”, CS Studio will automatically find the open circuit potential(current is around 0), and choose data range of 20mV at each side of the OCP. If you don't think this is an appropriate range, you can re-position the mouse on the curve to select a desired data range, or directly enter a max. and min.potential.

Fitting results:

$R_p$ (Ohms/cm<sup>2</sup>):slope of the curve

$E_0$ (V): The potential where polarization current changes direction. They usually keep in accordance with the OCP of the system.

$I_0$ (A/cm<sup>2</sup>): current density is computed based on the Stern-Geary equation (Stern-Geary, J. Electrochem.Soc. 104,561957)

$$i_{corr} = \frac{\beta_a \times \beta_c}{\beta_a + \beta_c} \times \frac{1}{R_p}$$

Because the Tafel slope( $E_p$ & $b_c$ ) cannot be obtained directly in linear polarization area, CS studio program assume it to be 0.12V/dec, thus for Stern Geary coefficient:

$$B = \frac{\beta_a \times \beta_c}{\beta_a + \beta_c} = \frac{b_a \times b_c}{2.303(b_a + b_c)}$$

Normally, assign the  $B$  to be 18mV(it can also be set in cell info.), then,

$$I_{corr}(\text{mA/cm}^2) = \frac{18\text{mV}}{R_p}$$

Corrosion rate is calculated according:

MPY =  $I_{corr}(\text{A/cm}^2) \times \text{chemical equivalent (g/mol)} \times 393.7(\text{mil/cm}) \div \text{density}(\text{g/cm}^3) \times 365 \times 24 \times 3600(\text{s/Y}) \div 96500(\text{C/mol})$ ;

mm/a = MPY  $\div$  39.37(mil/mm).

For carbon steel, 1mm/a =  $11.73 \times I_{corr}(\text{mA/cm}^2)$ , 1MPY =  $462.2 \times I_{corr}(\text{mA/cm}^2)$

Therefore, only after the electrode parameters are set can the corrosion rate of metal be calculated.

### ***Tafel fitting***

It provides four methods. The anodic/cathodic fitting is based on linear fitting principle:

$$i = i_0 \left[ 10^{\frac{E-E_0}{B_a}} - 10^{\frac{-(E-E_0)}{B_c}} \right]$$

If fit  $B_a$ , then  $i = i_0 \times [10^{(E-E_0)/B_a}]$  can be simplified as:  $\lg i = E/B_a + \lg i_0 - E_0/B_a$ . Then it becomes a standard linear equation.  $i_0$  and  $B_a$  can be calculated.

Using the same method, you can calculate  $B_c$ . If fit the  $B_a$  and  $B_c$  respectively, then we can

calculate  $E_0$  and  $i_0$  more accurately.

### Auto fitting

By auto fitting, the software will automatically find the data in range of 200mV around open circuit potential, and then do the anodic and cathodic fitting respectively, obtaining two equations and the intersection of the two lines. The more accurate  $i_0$  and  $E_0$  will be obtained, then we can calculate the corrosion rate.

### Least square method

This method is usually used to do fitting of multi parameters, such as 4-, or 5- parameters fitting. It employs Levenberg-Marquardt fitting. If  $i_L$  is not used, then the equation is:

$$i = i_0 \left[ 10^{\frac{E-E_0}{B_a}} - 10^{\frac{-(E-E_0)}{B_c}} \right]$$

If using the  $i_L$ , then the fitting equation is as follows:

$$i = i_{corr} \left[ e^{\frac{E-E_0}{\beta_a}} - \frac{e^{\frac{E-E_0}{\beta_c}}}{1 - \frac{i_0}{i_L} \left( 1 - e^{\frac{E-E_0}{\beta_c}} \right)} \right]$$

During fitting, you must assign an initial value to the program.

After obtaining  $B_a$ ,  $B_c$ , Stern-Geary coefficient is calculated according to the following formula:

$$B = \frac{\beta_a \times \beta_c}{\beta_a + \beta_c} = \frac{b_a \times b_c}{2.303(b_a + b_c)}$$

If the data range is set “Auto”, CS studio software will automatically find the OCP, then choosing 250mV range for anodic and cathodic part. If you don't think it's a suitable range, you can re-choose a range by locating the cursor in the curve. Then only data points between the two cursors are involved in the computing. You can also enter max. and min. value to directly specify the range.

### Linear fit

There are six types of fitting we provide, but the latter five methods are based on the first type, i.e., according to linear equation:  $y = a + bx$ .

#### Linear fit principle

The linear fitting is based on the least square method.

$$\theta(a, b) = \sum_{k=1}^n (y_k - a - bx_k)^2$$

By computing the acquired data points, we can obtain the value of a, b to make the minimum  $\theta(a, b)$ .

$$\begin{cases} \frac{\partial \theta(a, b)}{\partial a} = -2 \sum_{k=1}^n (y_k - a - bx_k) = 0 \\ \frac{\partial \theta(a, b)}{\partial b} = -2 \sum_{k=1}^n (y_k - a - bx_k)x_k = 0 \end{cases}$$

Expand the equation:

$$\begin{cases} na + \left(\sum_{k=1}^n x_k\right)b = \sum_{k=1}^n y_k \\ \left(\sum_{k=1}^n x_k\right)a + \left(\sum_{k=1}^n x_k^2\right)b = \sum_{k=1}^n x_k y_k \end{cases}$$

### Other linear fittings

Take the function:  $i = i_0 \times 10^{E/B}$  for an example:

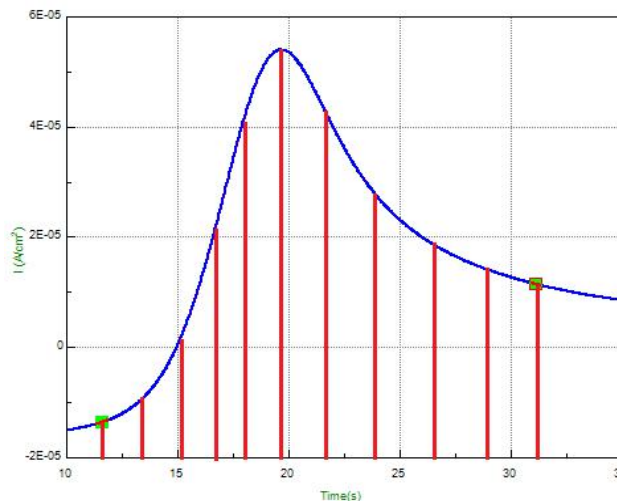
Firstly you should judge the sign of the  $i$ ; it can be either all positive or all negative. Convert the equation to be  $\lg i = \lg i_0 + E/B$ . Assume  $\lg i = y$ ,  $\lg i_0 = a$ ,  $1/B = b$ , then it's simplified to be a standard linear equation. Find the value of  $\lg i_0$  and  $1/B$ , then calculate the  $i_0$  and  $B$  indirectly. The value of  $i_0$  is determined by the sign of  $i$ .

### Integration

There are two kinds of integration, with background and without background. The calculation way is basically the same, using trapezoidal integration.

#### Q(Quantity of electric charges)

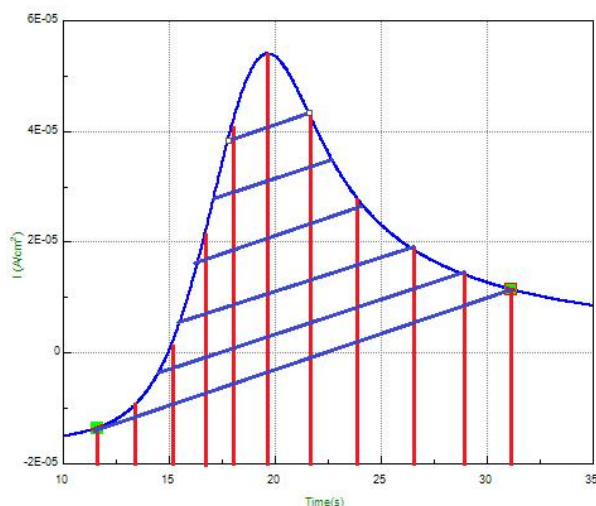
Trapezoidal integration means to calculate the area of the trapezoid constituted by two adjacent points, that is, to do trapezoidal integration for every data point on the I-T graph. The current value is the bottoms, and the time difference ( $\Delta t$ ) is the height (see the picture as below). The sum of each trapezoidal area is the quantity of electric charges.



Q integration area diagram

#### Q (with background)

If the Q is with background, then we should find the area between two points and the connection line of them. As shown in below picture, the area of the grid is to be obtained. It equals to the difference between the area constituted by points collection and the area of the lines.



Q integration(background) area

### Noise

We can use the method of root-mean-square (RMS) to calculate the noise between cursors, and show the results.

E\_RMS represents the RMS value of the potential noise after removing the background drift.

I\_RMS represents the RMS value of the current noise after removing the background drift.

The formula is as follows:

$$\text{RMS} = \sqrt{\frac{\sum_{i=1}^n x_i^2}{n}}$$

Where, n is the number of data involved in the calculation,  $x_i$  is the #i data value.

Note: The results of the calculation strongly depend on the quality of data, sampling rate, influence of filter and ambient noise etc. The validity of results depends entirely on the user's judgment.

### 17.3 Voltammetry Analysis

In the menu of voltammetry analysis, there are: CV, DPV, NPV and EPR index calculation.

#### Cyclic Voltammetry

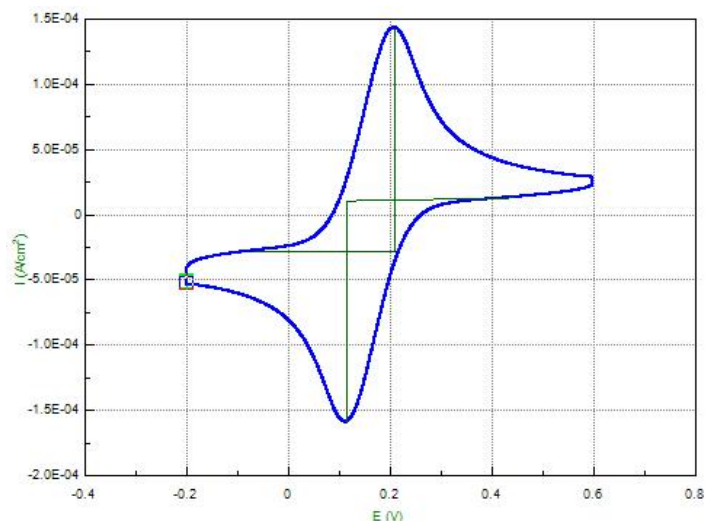
##### CV graph Display

In the data file, there is mark of cycle, so it can display each cycle. If the number of cycles is more than 2, then there is a radio button "Show". Check it, you can adjust the graph display, from which cycle to which cycle, as you wish.

Cycles:	<input type="text" value="10"/>	<input checked="" type="checkbox"/> Show	From	<input type="text" value="1"/>	To	<input type="text" value="10"/>	Cycle
---------	---------------------------------	--	------	--------------------------------	----	---------------------------------	-------


### Auto

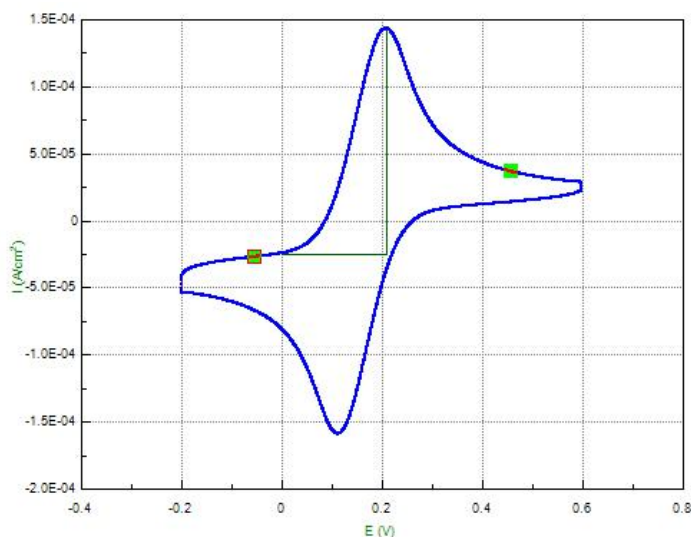
The program provides a method to find the peak: divide the data points cycle by cycle, then find the peak and valley of each cycle, and find a baseline which parallels to the X axis most, obtaining the peak height and half-peak area. You can also find the peak and baseline manually.



CV auto analysis


### Anodic peak between cursors

By swapping cursor , you can locate the beginning and end position for the anodic peak. The software will make the scan direction as baseline, and find the highest point as the peak. The peak height and half-peak area can be calculated.

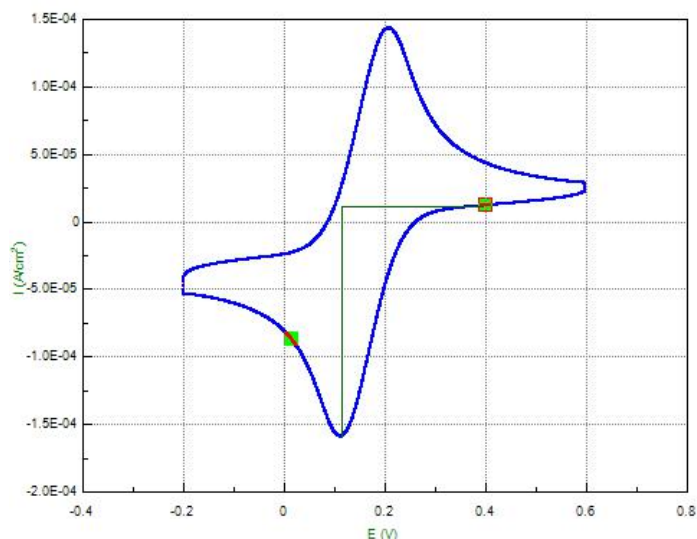


Anodic peak interface between cursors

### Cathodic peak between cursors

Through swapping cursor , you can locate the beginning and end position for the cathodic peak. Then the software will find the peak height and the half-peak area according to the baseline and the bottom point.





Cathodic peak interface between cursors

In CV analysis, in order to show the height line, the coordinate axis must be I vs. E.

### Capacitance calculation

For CV graph, you can calculate the capacitance according to the following formula:

$$C = \frac{\int_{E_1}^{E_2} i dE}{2v\Delta E}$$

Where  $E_1$ ,  $E_2$  is the minimum, maximum potential value in CV scan;

$\Delta E = E_2 - E_1$ ,  $v$  is the scan rate

The result is shown like this:

Segment 2:

Area = 1.6438E-05 W

$\Delta E = E_2 - E_1 = 0.79803$  V

Scan rate = 0.05 V/s

$C = 0.00020598$  F

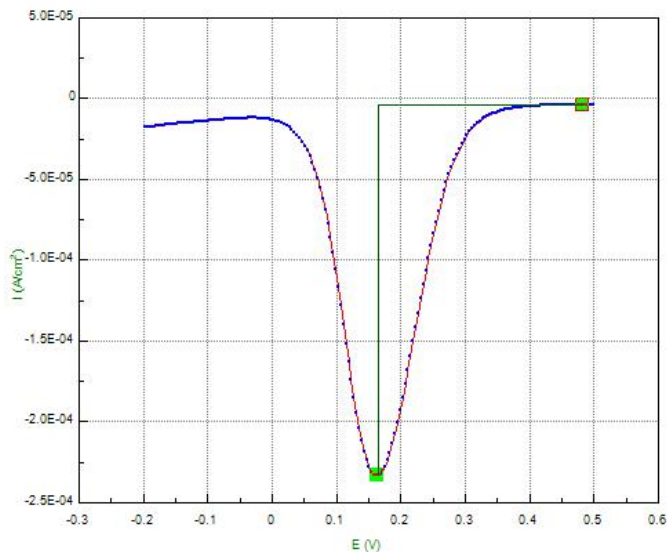
### Differential Pulse Voltammetry (DPV)

It provides two methods: Auto and Peak between cursors.

Two methods are supplied for DPV: auto and peak value between the cursors.

#### Auto

The software will automatically find the maximum current value as the peak height, and find the place where the slope is near to zero to be the baseline, then calculate the peak height and half-peak area.


 DPV curve in  $K_3Fe(CN)_6$  system

### Peak between cursors

Because there will be error or what you obtain is not what you want by auto method, we supply manual method. By swapping the cursors to determine the beginning and ending points, the software will then find the peak height and half-peak area based on the baseline and highest point.

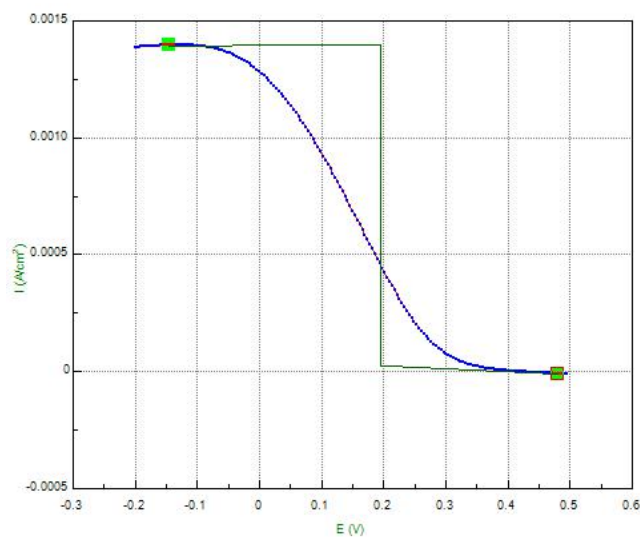
In voltammetric analysis, in order to show the height line, the coordinate must be I-E.

### Normal Pulse Voltammetry(NPV)

It supplies two methods: Auto and Peak between the cursors.

#### Auto

Firstly you should find the median current, and then make the line that most parallels to X-axis as the baseline, then calculate the height.




 NPV curve in  $K_3Fe(CN)_6$  system

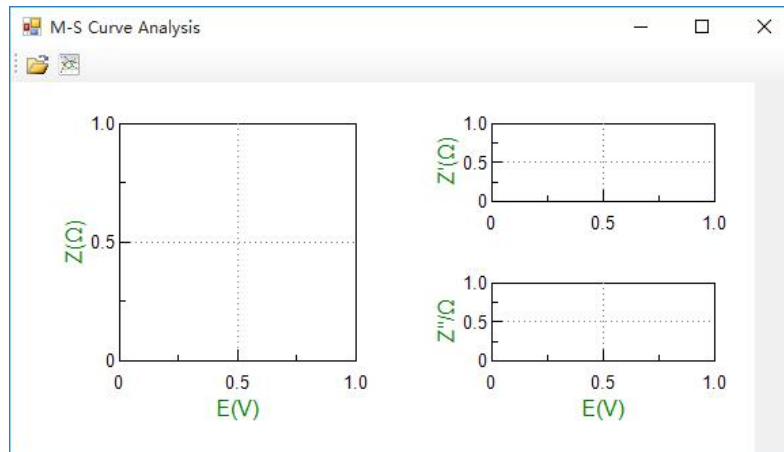
### Peak between the cursors(manual)

Find the median current of the data points of a whole segment, and make the baseline of the point where the cursor is on, then calculate the height between two baselines.


## 17.4 M-Scurve analysis

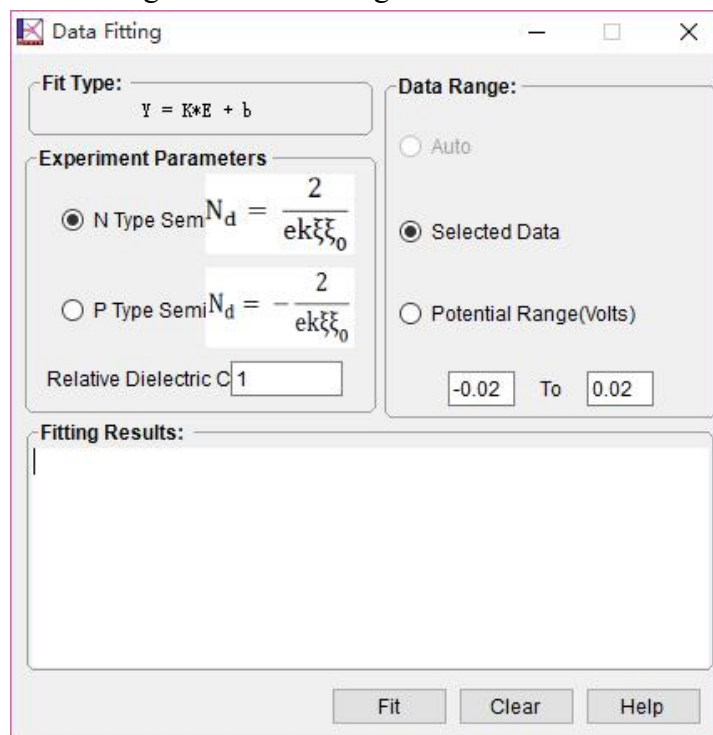
“Tools ”→M-S curve analysis

The generated EIS data file (.z60) is compatible to ZView software, but ZView cannot do Mott-Schottky analysis. After data acquisition, you should click “Tools”→M-S curve analysis to open the M-Scurve analysis. Click  to import a data file, click  to open M-S curve fitting interface.



M-S curve analysis interface

Click  to get the following M-S curve fitting interface:



**Data Fitting**

Fit Type:  $Y = K * E + b$

Experiment Parameters

- N Type Semi  $N_d = \frac{2}{ek\xi\xi_0}$
- P Type Semi  $N_d = -\frac{2}{ek\xi\xi_0}$

Relative Dielectric C:

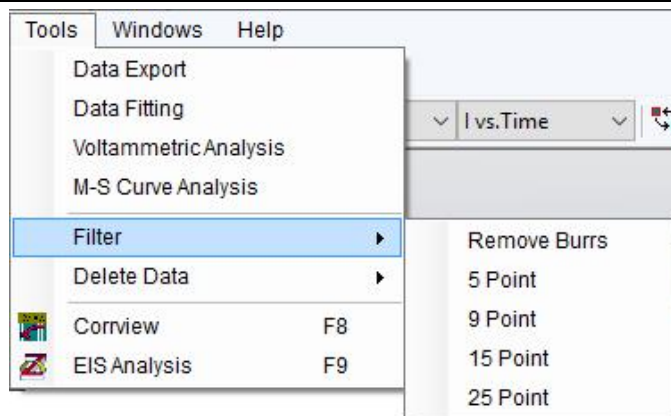
Data Range:

- Auto
- Selected Data
- Potential Range(Volts)

To

Fitting Results:

## 17.5 Filter



Two different digital filtering methods are available to eliminate burrs or noise in the data file. You should find the suitable method according to the type of noise.

The first type is “Remove burrs”. It is especially suitable to data file that includes abnormal burrs. For every data point in the file, you can firstly choose 5 points (current point, the 2 points before it, and 2 points after it), delete the maximum and minimum one, then make the average of the left three points as the new value. Using this method to handle every data point, you can effectively remove the burrs resulted from range change of the potentiostat and the interference noise caused by repeated on-off of the temperature controller, or the discrete noise signals.

The second type is “5 to 25 point smoothing”. This method employs Savitzky Golay (SG) smoothing algorithm to remove the random noise. (“Smoothing and Differentiation of Data by Simplified Least Squares Procedures”, Analytical Chemistry, Vol. 36, No. 8, July 1964, page 1627).

If you need to use both of the two methods, you must first use “Remove burrs”.

These smoothing methods do not change the saved data file. But if you use filter and then switch to another data file (via the active data selection box), you will be prompted to save the modified data as a new file.

If you need to return to the original data, you can select the same file from the active data selection box. When the software prompts you to save the modified data file, click “No”.

Note: Please use the filter with cautiousness. The better way is to resolve the noise problem instead of covering it. Improper usage of the filter may lead to missing of some important information (such as the potential and current peak formed by passivation film rupture on the surface of the electrode). Before using the digital filter, it is suggested that you check the actual noise level of the potentiostat output signals by an oscilloscope so as to determine whether to use the filter.

## 17.6 Delete Data

It supplies three methods: delete data point, delete data between cursors, and delete data outside cursors. After the data is deleted, the source file will be unchanged. The data after modification can also be saved via “Tools” → “Data Export”.

### Delete Data Point

Considering that there may be an abnormal data point in a data file, you can use this

command to delete it. After the data point is deleted, the source file will be unchanged. The data after modification can be saved via “Tools”→ “Data Export”.

**Delete data between cursors**

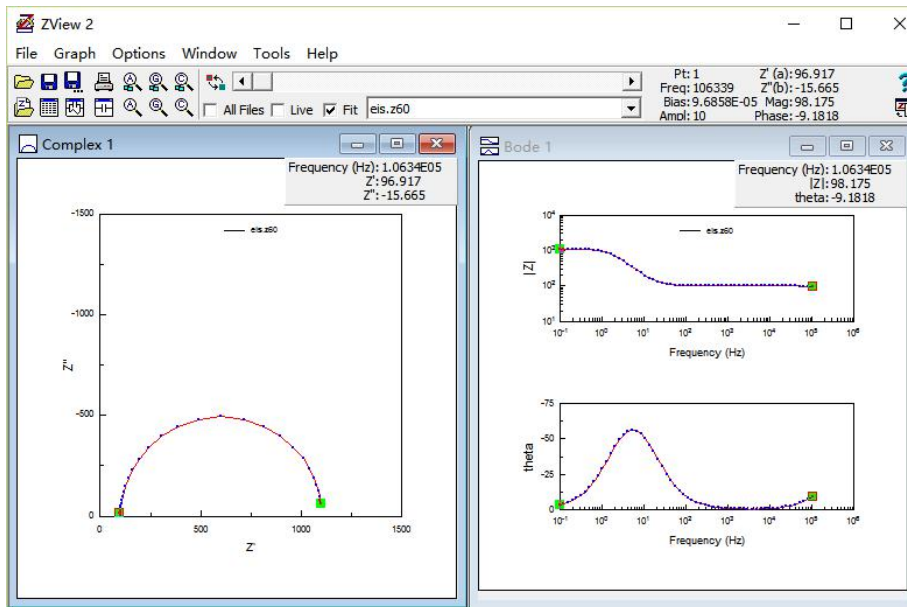
You can use this command to delete all data points between two cursors. After the data segment is deleted, the source file will be unchanged. The data after modification can also be saved via “Tools” → “Data Export”.

**Delete Data outside cursors**

In an experiment (eg. Voltammetry stripping test), it is possible that there is only a segment of data that is valid, then using this command, all the invalid data points (outside the two cursors) can be selected and deleted. After deletion, the source file will be unchanged. The data after modification can also be saved via “Tools” → “Data Export”.

**17.7 EIS Analysis**

ZView is a powerful EIS analysis and graphing software. It can do various electrochemical parameters computing, and do smoothing and digital filtering to the original potential and current data. It can also compensate solution resistance by software. ZView interface is clear, and the data, graphs can be easily printed and saved, and output to Word in vector mode.




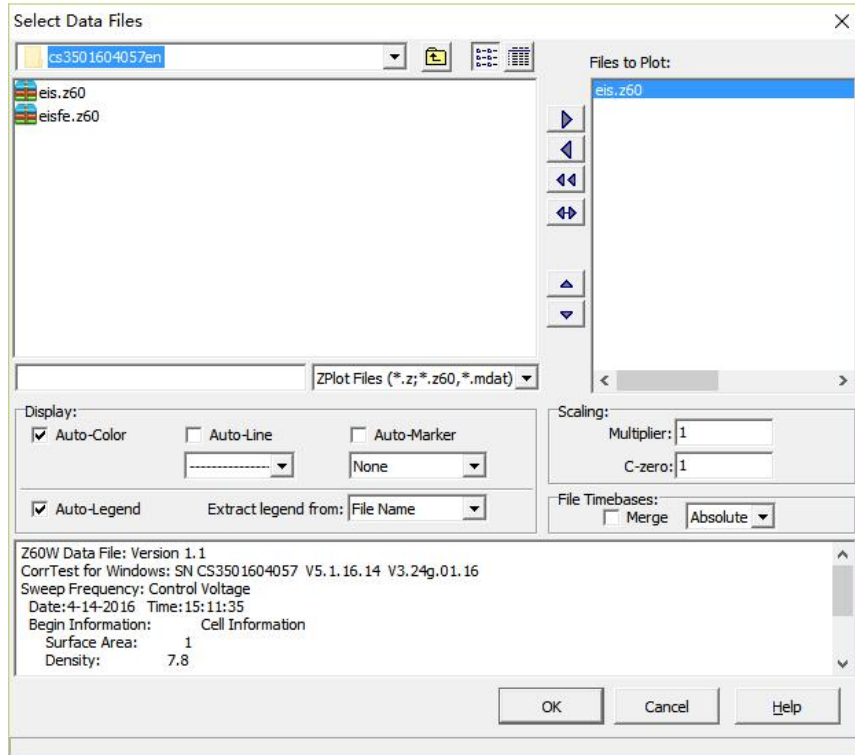
ZView impedance analysis interface

Toolbar is the shortcut keys of the menu. If you locate the mouse cursor on the icon, there will be explanation of the icon.



**Open data files**

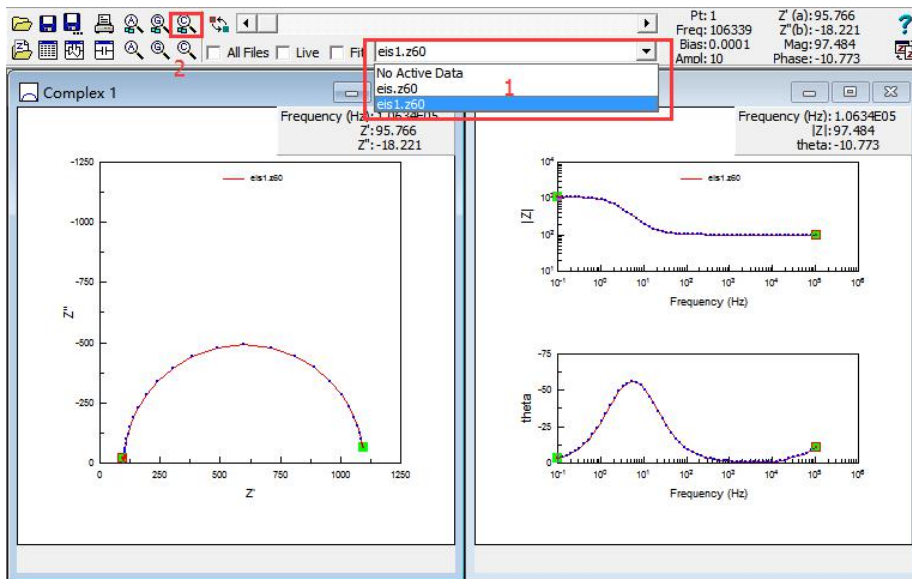
Click “File”→“Data Files”(or directly ) to import the EIS data file, as shown in below:



ZView data import window

### Activate data

Choose the data file which is to be analyzed (marked 1).

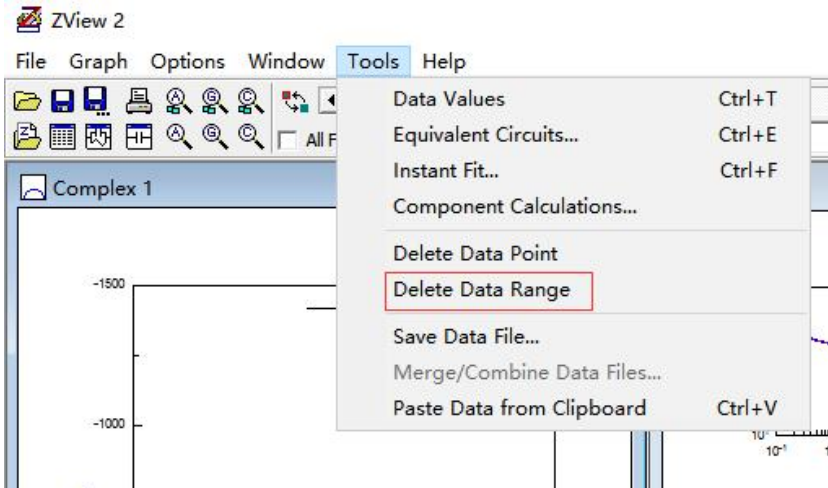


ZView: choose the active data file

### Delete data range

Select the unwanted data range ( the part cannot be fitted by ZView) by the mouse cursor, and then delete them through Tools →Delete Data Range.

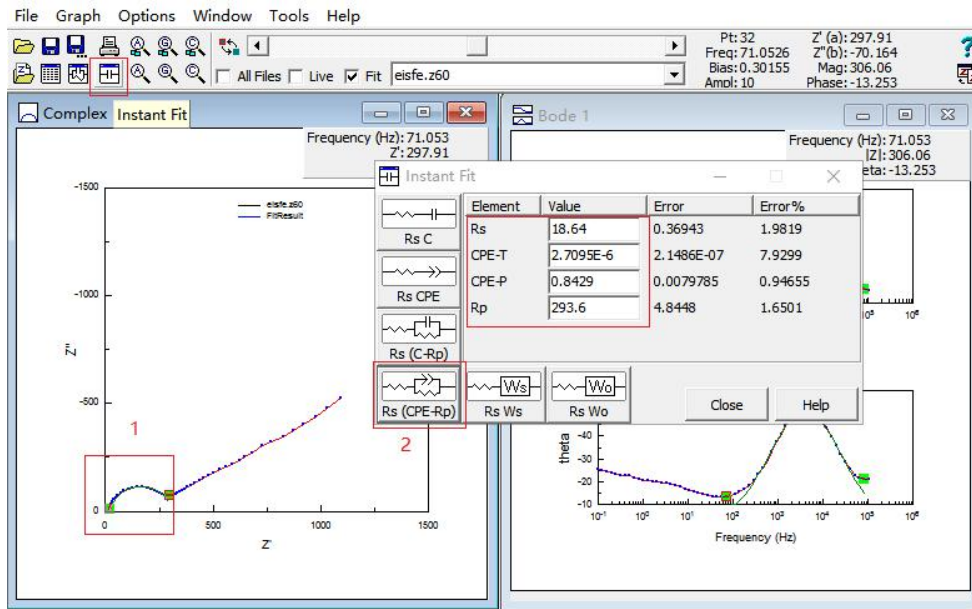





ZView : delete data range

### Instant fit

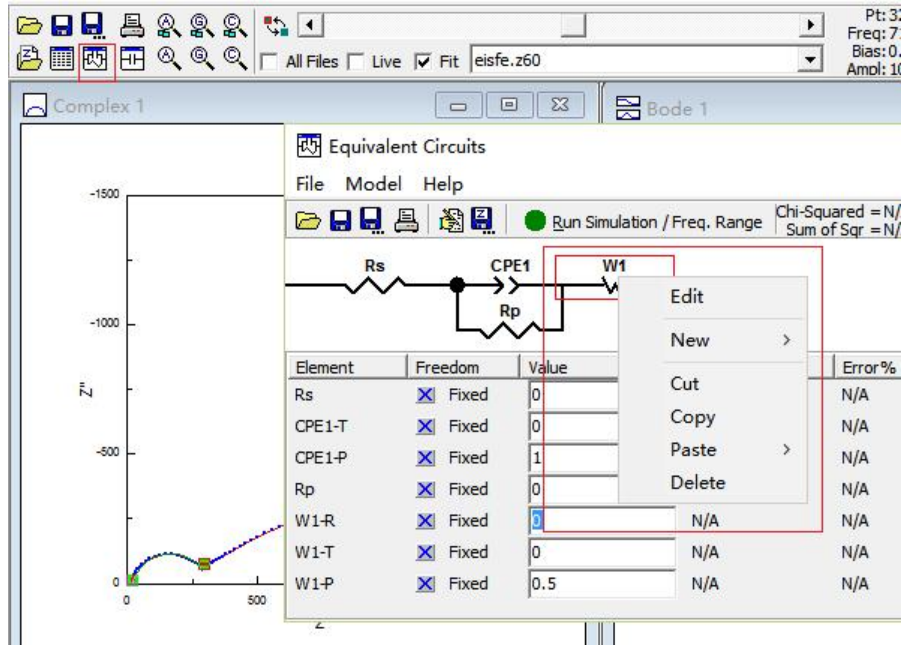
Instant fit is to obtain the initial value, a preparation for the formal fitting afterwards.



- (1) Choose the element one by one for instant fitting individually.
- (2) Click  for instant fitting.
- (3) Choose the suitable equivalent element(eg. the one marked 2), and obtain the initial value of the equivalent circuit.

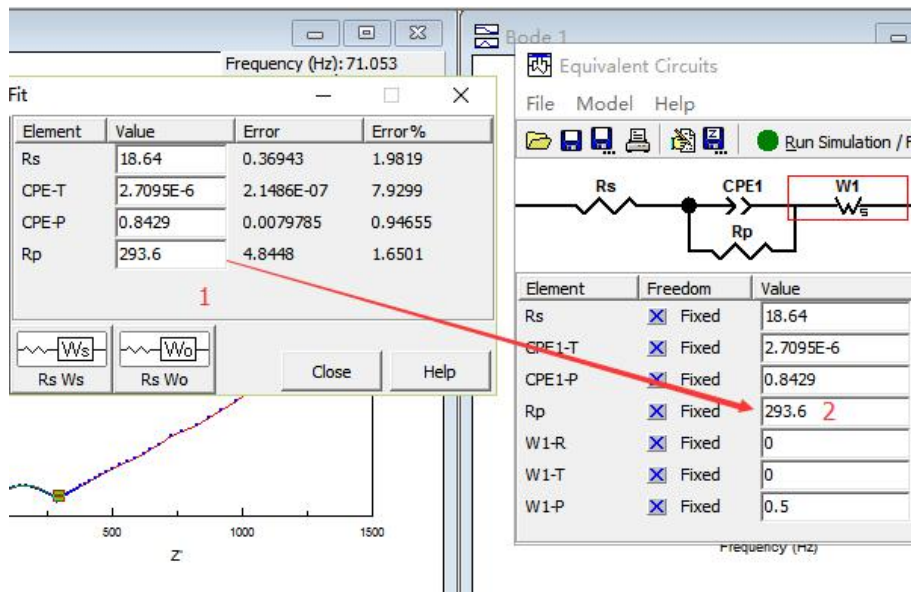
### Complex equivalent circuit fitting

Build the suitable equivalent circuit based on the instant fit(see the below picture as an example). It depends on the actual testing system.



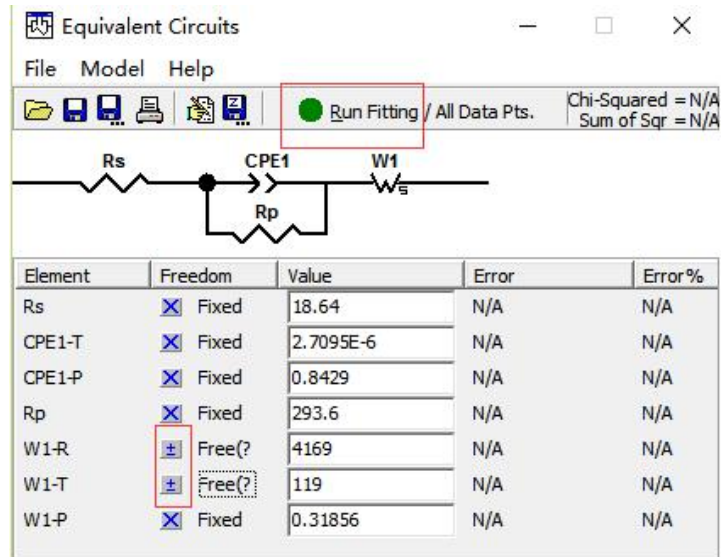
Choose the suitable equivalent circuit from ZView for formal fitting

Drag the data in place “1” to place “2”, as shown below:



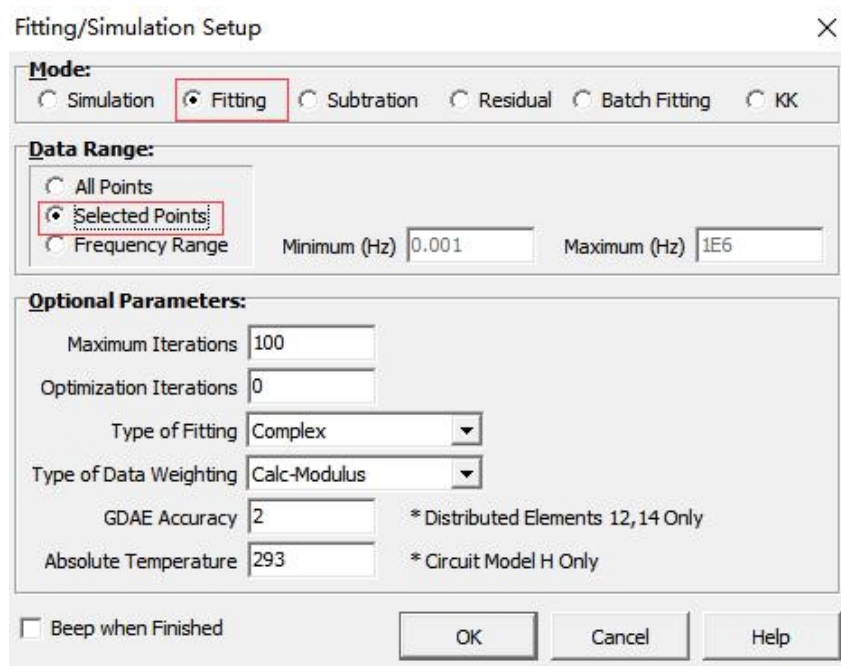
Drag the data from the instant fit window to the initial value entering box

Change “fixed” to “free”, shown in the following picture:




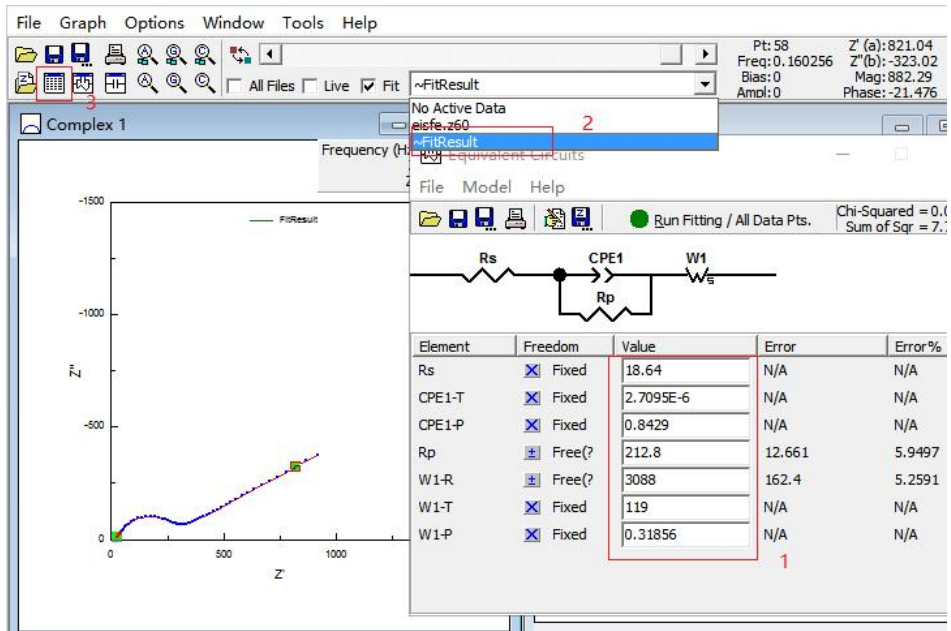
Data fitting based on equivalent circuit

And change the mode from “Simulation” to “Fitting”



Parameters setting dialog box

The place marked with “1” are the fitting results. If you want to re-graph for the results, choose “fit result” in place “2”, and click  to show the data. After copying them to the clipboard, they can be copied to Excel or Origin software.



Fitting results and fitting curve

## 18. Windows

This option is used to manage all current project subforms.

Cascade

All project subforms are displayed in the form of Cascade

Tile

All project subforms are displayed in the form of Tile

Arrange

All project subforms are rearranged.

Close all

Close all project subforms.

## 19. Help

Index and search: manual

Language: English and Chinese optional

Contact us: click to go to our company website, showing the contact info.

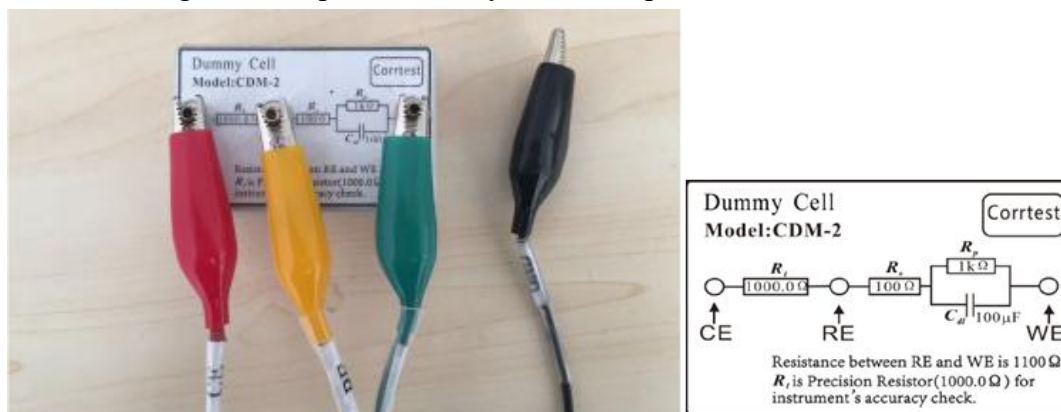
Check for update: click to update the software to the latest version

About: the version of the software, hardware, the serial no. etc of the instrument.

## 20. FAQs

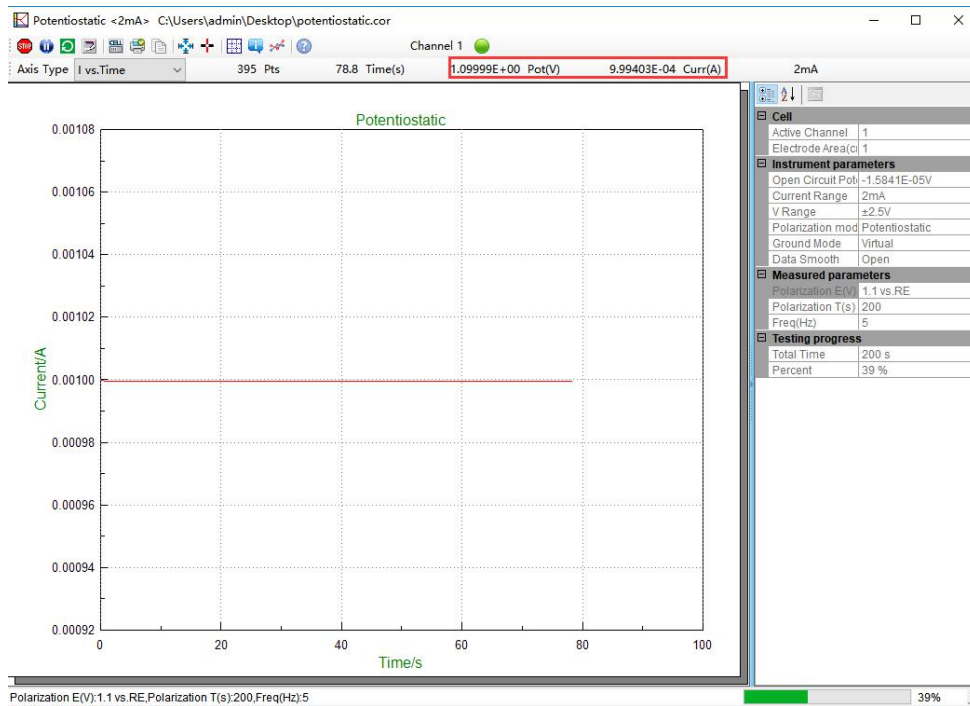
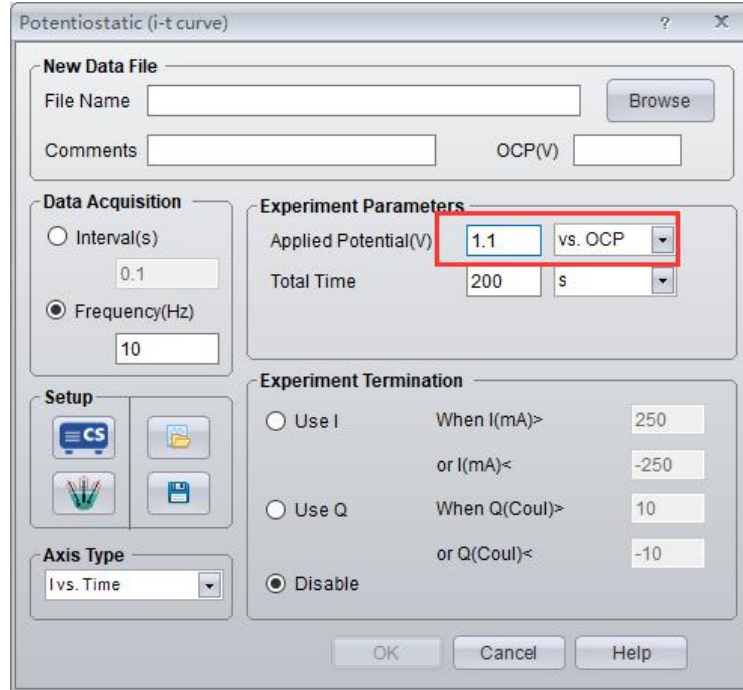
### 20.1 How to use dummy cell to check the instrument?

Connect the green clamp to WE, the yellow clamp to RE, and the red one to CE.



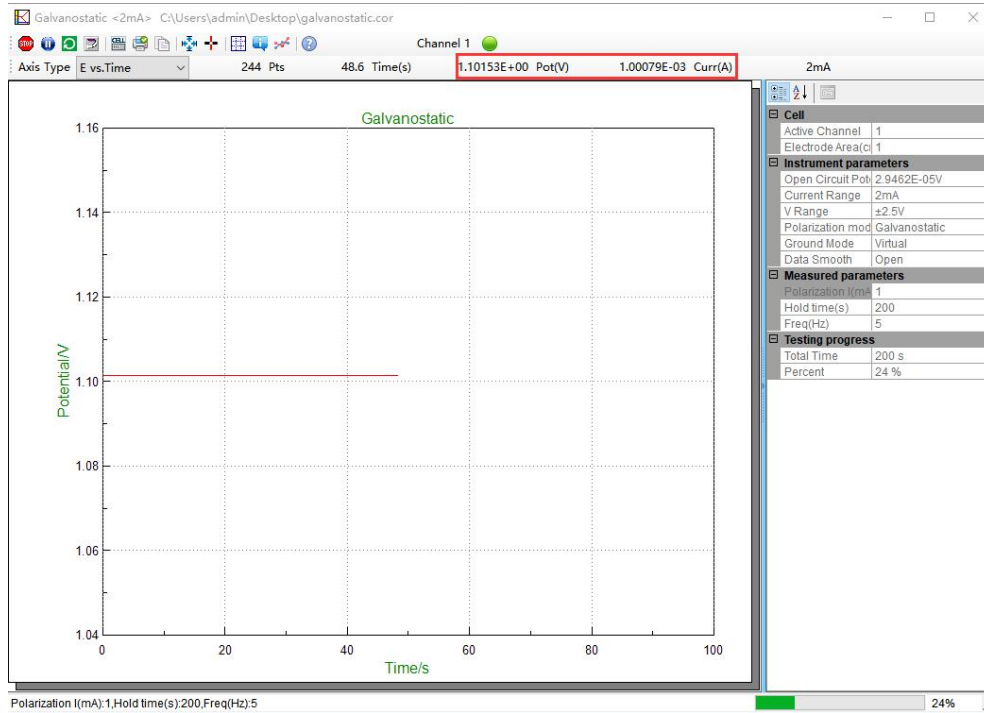
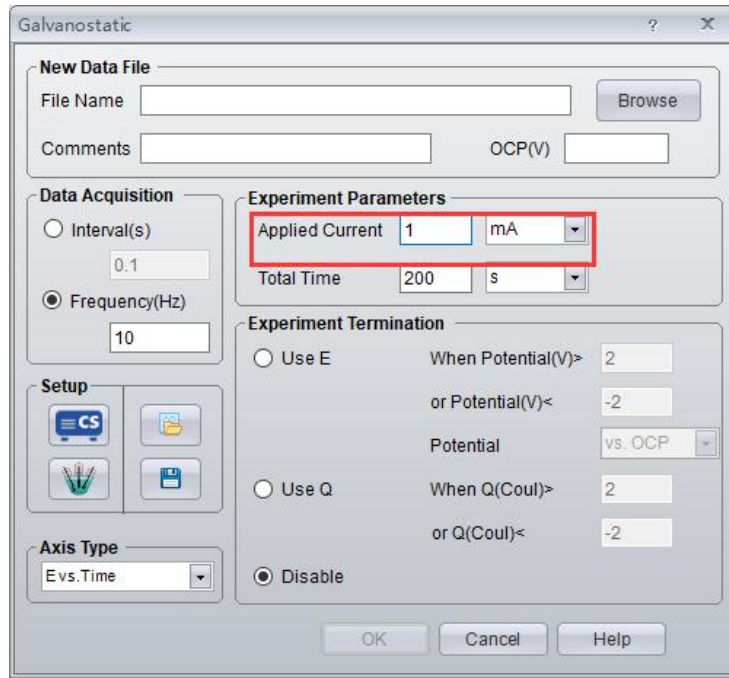
Open the software, Click setup  $\rightarrow$  Reset Workstation. During experiment, the potential and current value should always obey the Ohm law:  $I = E / R$

Click Experiments  $\rightarrow$  Potentiostatic, set the applied voltage to be 1.1V, start the test. If the displayed potential value is 1.1V, and the current is 1mA, it means the instrument potential output is normal.



The same way, click Experiments → Galvanostatic, set the applied current to be 1mA, start the test. If the displayed current value is 1mA, and the potential value is 1.1V, it means the instrument current output is normal.





Combining the results, we can say the electrode cable is no problem.

20.2 How can I use the data to draw in Excel

The data file can be open directly in notepad in TXT. And data can be copied

### 20.2 What may cause potential overload?

- (1) Max.potential difference between the RE and WE is higher than 10V
- (2) WE is unconnected.
- (3) Low impedance system (fuel cell, battery) in galvanostat mode.
- (4) Compliance voltage is over than 21V.
- (5) Broken RE or poor RE connection.
- (6) High-impedance system.

### 20.3 How to reduce the noise in electrochemical experiment?

1. Make sure the solution in salt bridge is conductive, and that the tip of the RE is down in the agar and connected well with the working solution. To make sure the microporous ceramic is well soaked, so as to reduce the RE impedance.
2. Open the filter to improve system stability.
3. Give a serial capacitor (100nF) between the RE and CE if the noise resulted from the solution resistance is unavoidable.
4. For corrosion test, add a 1  $\mu$  F capacitor between WE and machine shell of the potentiostat.
5. For impedance test, make a parallel connection of a Pt wire and RE. Dip one end of the Pt wire into solution and connect the other end to RE output port by a 100nF capacitor.
6. All of the equipment in the experiment incl. the PC must be connected to the ground using individual ground wire. If there is no suitable ground wire, you can use a thick copper wire to connect the PC with a nearby metal conductive water tap.
7. Shut down all the possible environmental interference source, such as high-power power supply, computer monitor, stirrer, and fluorescence light etc.
8. Use the Faraday cage, and connect it to the ground.

## 21. Service & Contact us

### After-sales Service:

1. Warranty period: 5 years. During this period, all service including repair is TOTALLY FREE. You need to pay freights if return instrument to us for repair.
2. Provide installation guidance and manual, software installation video.
3. Lifetime free software upgrading of the same model and technical service

### Sales Center

Email: [sales@corrtest.com.cn](mailto:sales@corrtest.com.cn)

[sales2@corrtest.com.cn](mailto:sales2@corrtest.com.cn)

Tel.: (+86) 27 67849450,(+86)13971066778

### Technical Support Center

Email: [service@corrtest.com.cn](mailto:service@corrtest.com.cn)

Tel.: (+86) 18086482080, (+86) 18086482081, (+86) 18086482082,  
(+86) 27 67849890 ext.35/36/32

**Address:** Room 505, Jinfeng Building A, International Enterprise Center, Optics valley Ave.,East Lake High-tech Development Zone, Wuhan, China, 430074




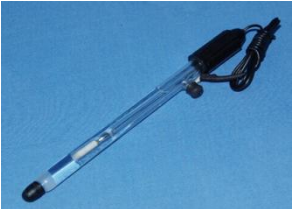


**Website:** [www.corrtest.com.cn](http://www.corrtest.com.cn)



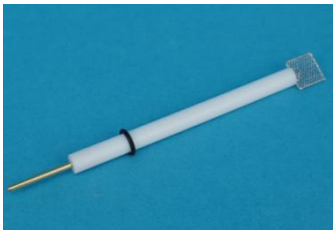

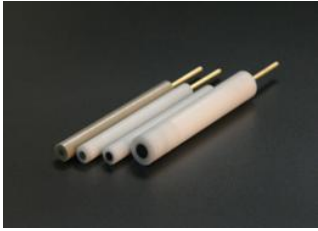

[www.csechem.com](http://www.csechem.com)

## 22. Appendix-electrochemical accessories

## Appendix





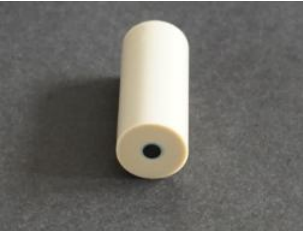

### Electrochemical Accessories






Model	Product	Picture	Specification
CS900	CS900 Saturated Calomel Electrode		Saturated KCl refilling solution
CS901	Ag/AgCl reference electrode		Ø4mm/Ø6mm 3.5M KCl refilling solution
CS902	Hg/HgO reference electrode		Suitable for alkaline/base solution 1M KOH refilling solution
CS903	Mercury/Mercurous sulfate electrode		suitable in acid solution Saturated K <sub>2</sub> SO <sub>4</sub> refilling solution
CS905	Non-aqueous Ag/Ag <sup>+</sup> reference electrode		Ø4mm/Ø6mm
CS910	Platinum conductivity electrode		

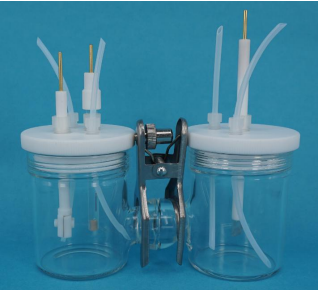
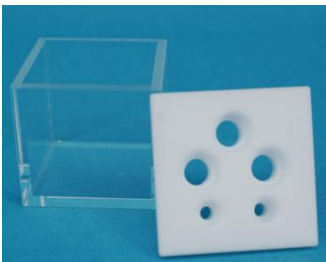

CS911	Platinum plate electrode **Size can be customized		99.95%,10x10x0.1mm
			99.95%,10x10x0.2mm
			99.95%,20x20x0.1mm
			99.95%,20x20x0.2mm
			99.95%,20x20x0.3mm
CS912	Platinum wire counter electrode		99.95%, Ø 0.5x37mm(wire)
CS913	Platinum mesh electrode		10*10mm
			20*20mm
CS915	Graphite rod		Φ4 / 6mm, length 150mm
CS916	Graphite electrode		Ø2~ Ø5mm
CS920	Glassy carbon working Electrode		Ø3mm
			Ø2mm
			Ø4mm/Ø5mm
			Ø6mm
CS920L	L-shape glassy carbon		Ø3mm

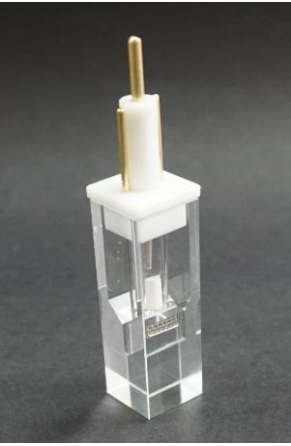

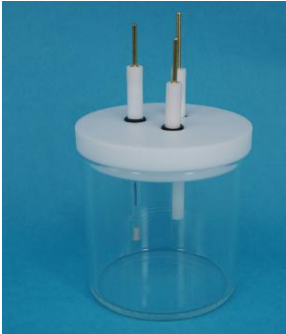

	working electrode		Ø2mm
			Ø4mm/Ø5mm
CS921	Metal Electrode		Carbon steel, stainless steel, copper Working area: 0.5cm <sup>2</sup>
CS922	Platinum working electrode		99.95%, Ø2mm
			99.95%, Ø3mm
CS923	Gold working electrode		99.95%, Ø2mm
			99.95%, Ø3mm
CS924	Silver working electrode		Ø2mm / Ø3mm
	Titanium WE		Ø2mm / Ø3mm
	Copper WE		Ø2mm / Ø3mm
	Aluminum WE		Ø2mm / Ø3mm
	Nickel WE		Ø2mm / Ø3mm
	Zinc WE		Ø2mm / Ø3mm
	Cadmium WE		Ø2mm
	Iron WE		Ø2mm
	Palladium WE		Ø2mm/ Ø3mm
CS925	Pt micro electrode		10µm/25µm




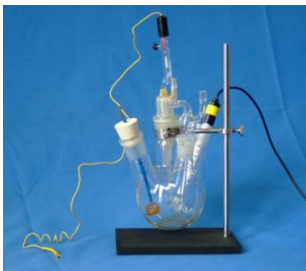
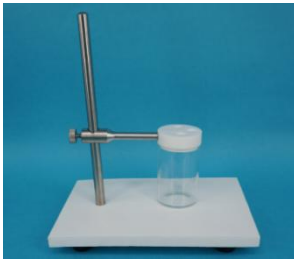


CS926	Gold micro electrode		12.5µm/25µm
CS927	PINE RDE Glassy carbon disk electrode 3mm/4mm/5mm		<p>Electrode is internal-screw type. Compatible to PINE's RDE equipment with external-screw rod Pt/Au disk electrode also available</p>
			<p>Electrode is external-screw type. Compatible to PINE's RDE equipment with internal-screw rod. Pt/Au disk electrode also available</p>
	PINE RRDE		<p>RRDE- Glassy carbon disk, Pt ring electrode Compatible to PINE's RRDE equipment</p>
	ALS RDE		<p>Glassy carbon disk electrode- Disk diameter 3mm, Insulator diameter 12mm, length 25mm</p>
ALS RRDE		<p>Glassy carbon disk working electrode OD of ring electrode 7mm, Inner diameter 5mm; disk diameter 4mm, Insulator diameter 12mm, length 25mm</p>	

	ALS Pt Wire		Platinum counter electrode φ 0.5*230mm
CS930	Glass electrolytic Cell, 4 ports  **Include salt bridge and gas inlet/outlet pipe		150ml
			250ml
			500ml
			1000ml
CS9305	Corrosion Cell, 5 ports 500mL  Includes all the electrodes		The cell kit includes: A specimen holder (1cm <sup>2</sup> working area) * 1 Graphite rods *2 Pt plate electrode*2 (10*10*0.1mm) Saturated calomel electrode *1 Salt bridge*1 F-shape gas inlet and outlet*1
CS931	Jacketed glass cell (None-sealed)  **Holes on the lid can be tailored. No include the electrodes shown in the pic.		50ml
			100ml
			150ml
CS931S	Jacketed glass cell (Sealed)  **Holes on the lid can be tailored. No include the electrodes shown in the pic.		50ml
			100ml
			150ml

CS932	H- cells (None-sealed)		None-sealed Volume:50~250mL (each cell, PTFE caps. The two cells are separated by ion membrane which is prepared by user.
CS932S	H- cells (sealed)  **Holes on the lid can be tailored. No include the electrodes shown in the pic.		Sealed 50~250 mL (each cell) PTFE caps The two cells are separated by ion membrane which is prepared by user.
CS933	Photoelectrochemical cell(quartz)  **Holes on the lid can be tailored.		30*30*30mm
			35*15*45mm
			40*40*40mm
			50*50*50mm
CS9331 None- sealed	Photoelectrochemical cell  **Holes on the lid can be tailored. No include the electrodes shown in the pic.		*Glass cell, Teflon cap, Quartz light window (dia. 24mm).
CS9331S (Sealed)	For working electrode, you're recommended to use L-shape electrodes, or the CS945 electrode clamp. 50ml 100ml 150ml		

CS9330	Spectroelectrochemical cell (cuvette cell kit)		<p>This kit includes:          Quartz cuvette          12.5*12.5*42mm,          Teflon cap,          Pt mesh(WE),          Pt wire counter          electrode(CE), Ag/AgCl          reference electrode(RE),          Purge tube          optical path: 8*6.5*1mm</p>
CS934	Coating evaluation cell (Paint test cell)		<p>10mL          Working area is 1cm<sup>2</sup></p>
CS935	<p>Electrolytic cell (None-sealed)</p> <p>**Holes on the lid can be tailored. No include the electrodes shown in the pic.</p>		<p>50mL/100mL</p> <hr/> <p>150mL/200mL/250mL</p>
CS935S	<p>Seal electrolytic cell</p> <p>** Holes on the lid can be tailored. No include the electrodes shown in the pic.</p>		<p>50mL</p> <hr/> <p>100mL</p> <hr/> <p>150mL</p> <hr/> <p>250mL</p>

CS936	Flat corrosion cell -None-jacketed		working area is 1cm <sup>2</sup> including: Ag/AgCl reference electrode Counter electrode: Pt mesh*1 (20*20mm)
	Flat corrosion cell -Jacketed		Jacketed, water circulation for temperature control working area is 1cm <sup>2</sup> including: Ag/AgCl reference electrode *1 counter electrode: Pt mesh *1 (20*20mm)
CS937	Glass cell + Teflon cap		Glass cell: 10ml Diameter of the three holes: φ6.35mm, φ6.35mm, φ6mm
CS940	Cell stand 1		Match CS930 glass cell Base material: carbon steel. Not included the cell and electrodes which are for demonstration
CS941	Simple Cell Stand		Base material: PTFE provide 2 pieces cells (30ml)

CS942	Electrode polishing kit		<p>Alpha alumina powder 0.05μm,0.3μm,1μm, 10g each</p> <p>Nylon polishing pad (Ø200mm) *1</p> <p>Microcloth polishing pad (Ø200mm)*1</p> <p>Carbimet disks (1200-4000 grit, Ø200mm)*1</p> <p>-Glass plate*2</p>
CS942	Faraday cage		25*25*30cm
CS945	<p>Specimen clamp</p> <p>**The price is for one electrode</p>		<p>Suitable for plate specimen with thickness: &lt; 1mm.</p>
CS946	Specimen holder		<p>Effective Working area is 1cm<sup>2</sup>.</p> <p>Round specimen: diameter: 11.5~15mm, Thickness 0.1 ~ 5mm.</p> <p>Only One face of the sample contacts with the solution.</p> <p>PVDF rod diameter 10mm, length 100mm</p>



**Wuhan Corrtest Instruments Corp., Ltd.**

**Rm 501, Dingye Hall B, International Enterprise Center,  
Optics valley Ave., East Lake High-tech Dev. Zone, Wuhan, China, 430074**

**TEL: 027-67849450**

---

<http://www.corrtest.com.cn>