Development of Helium Direct Current Discharge Ultraviolet Light Source

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Abstract. Ultra-violet (UV) light source is one of the important components of ultraviolet photoelectron spectroscopy (UPS). A Helium direct current discharge ultraviolet light source is mainly composed of anode, quartz capillary, gas inlet pipe, differential exhaust assembly and heat sink. At 80Pa working pressure and 30mA discharge current, the test sample shows 1nA photoelectron current. Photoelectron current increases proportional with discharge current. The results show that the He DCDUV light source is working well and can be used as the light source in UPS.

1. Introduction

UV light source in the field of science refers to the generation of UV radiation as the main purpose of non-lighting source. UPS can directly obtain the valence electron band structure of molecules/atoms[1-4]. Having a stable and strong UV light source is one of the key techniques for UPS. Typical UV light sources are mercury lamp, synchrotron radiation and inert gas discharge. Mercury lamp is widely used in semiconductor industries, but it is not suitable for UPS because of the low energy and intensity. Synchrotron radiation can produce wide range electromagnetic waves, but it is mainly used in the range of soft and hard X-rays with extremely high running cost. The inert gas discharge UV lights are the most reasonable light sources for laboratory UPS. There are two ways for inert gas discharge, one is direct current discharge, the other is microwave discharge[5]. Although the direct current discharge UV (DCDUV) light has weaker intensity than that the microwave discharge UV light has, the low cost and easy to use make DCDUV light source very important for UPS. Considering the sputter influence, we developed a Helium DCDUV.

In this paper, we main introduce the design and test results of the He DCDUV light source.

2. Principles and Design

2.1. Principles

The principle of the He UV light sources is shown in Figure 1. A neutral He atom has two electrons in its 1s orbit. When the He atom receives energy by high voltage or electromagnetic waves, the electrons in the 1s orbit will transit to a higher energy orbit or fly out as a photoelectron. He atom with electron in the higher orbit is unstable, UV light is then emitted when the electron transits back to the stable 1s orbit.
Basing on the selection rule of energy level transition $\Delta l=\pm 1$, the He electron transition occurs between the $1s$ orbit and the $2p$, $3p$ or $4p$ orbits. The corresponding UV lights are called He I, He II, and He III, lights, respectively. If one electron of the He atom is excited as a photoelectron, the left electron of the He$^+$ ion can also transit between the $s$ and the $p$ orbits, and then produces the He II$\alpha$, He II$\beta$, and He II$\gamma$ UV lights. The main UV lights from the He atoms are the He I$\alpha$ (58.43nm, 21.22eV) and the He II$\alpha$ (30.38nm, 40.81eV), the corresponding energy widths are only several mV which guarantees the UV lights suitable for UPS without using any monochromators. The intensity of the He I$\alpha$ is about 4 times higher than that of the He II$\alpha$. The other $\beta$ and $\gamma$ lights are less than 2% of the total intensity.

![Fig 1. Principle of the He I$\alpha$ and He II$\alpha$ UV light generation.](image)

2.2. Basic Design

The core structure of the He DCDUV light source is shown in Figure 2(a), it consists mainly of anode, quartz capillary, gas inlet pipe, differential exhaust assembly and heat sink. A CF16 gas inlet flange is on the side of the anode assembly, which is connected to a He gas tank through a variable gas flow valve. In order to prevent the He gas in the UV light source chamber from entering the ultra-high vacuum analysis chamber, two differential exhaust ports are prepared on the UV light source. There are three knobs and a short bellows on the light source, which are used for the fine-adjustment of the UV light direction. Two quartz capillaries having several millimeters gap are placed at the center of the light source. The inner and outer diameter of the quartz capillary are 1mm and 5mm, respectively. The small inner diameter of the quartz capillary and the two cutting faces facing to the two differential exhaust make it possible to realize differential pumping between the UV light source and the ultra-high vacuum analysis chamber.

Pure copper is used as the heat sink because of the high thermal conductivity and low sputtering rate. The material for the complete UV light source is fully compliant for the use of ultra-high vacuum environment and capable of 200℃ baking temperature. The He DCDUV light source can be installed to any other vacuum chambers through a CF35 flange.

We use Comsol software to simulate the electron density dispersion in the discharge chamber to verify the rationality of the He DCDUV light source design. He gas discharge is a short and steady process that can be achieved in just one second, and figure 2(b) is the simulated electron density map at one second. From the electron density dispersion, we can see that the He discharge produces the UV light and the intensity is the highest in the center of the discharge chamber. There are many factors influencing the He gas discharge including electric field, temperature, gas pressure and the size of the discharge chamber. Comsol software is used to find the optimized structural parameters of the He DCDUV light source.
During operation, we first apply current to the He gas in the discharge chamber, and then apply direct current voltage to the anode as ignition. The high voltage terminal of the anode is energized, and the He discharge occurs throughout the discharge chamber. The discharge becomes stronger with higher He gas pressure in the discharge chamber (usually at 50–200Pa). The discharge voltage of the He is between 400 and 700V\cite{6}. After the discharge, UV light generated in the discharge chamber is directed by the quartz capillary to the sample surface in the ultra-high vacuum analysis chamber. Changing the lengths of the quartz capillary, UV light can be forwarded and focused to any sample\cite{7}.

The quartz capillary works not only for the UV light guidance and focus, but also for higher UV light intensity and lower impurity influence. Usually, the average energy of the glow discharge electron for the inert gas is less than 3eV, and only very few high-energy electrons can transit to emit the He I and He II UV lights. Moreover, the current density of the glow discharge and the concentration of ions are low. Therefore, reducing the diameter of the discharge tube and then the He pressure can increase the strength of the axial electric field. The increasing average energy of the discharge electrons causes the increase of the high-energy electrons to emit the He I and He II UV lights. Smaller the discharge chamber diameter, higher the discharge current and ion densities, so we can obtain stronger He UV lights.

The circuit schematic of the He DCDUV light source is shown in figure 3. The power supply includes an adjustable current source, a voltage source, an ammeter and a voltmeter. Connect the power supply to the He DCDUV light source electrode, first adjust the current source to supply a discharge current, and then turn off the ignition 12kV voltage source switch. The He gas is then start to discharge and forms a circuit. The discharge current and discharge voltage of the He gas can be measured by the ammeter and voltmeter.
3. UV light source testing

The energy of the He UV light is high enough to emit photoelectrons when irradiating any metals. During the UV light irradiation, the photoelectrons will be released because of the photoelectric effect, and the metal sample will be positively charged. We made a simple mechanism to detect the UV light. The test sample is an isolated stainless plate on the tip of a linear motion. The linear motion is used to change the distance between He DCDUV light source and the metal sample, while the isolated stainless plate is connected to a micro-ampere meter through a coaxial BNC feedthrough to display the photoelectron current[8-9].

During the experiment, we installed the test sample and the He DCDUV light source face to face to an ultra-high vacuum chamber at a working distance 10mm. The UHV chamber can reach to 10^-6Pa pumped by the combination of molecular pump and rotary pump. The He DCDUV light source was differentially pumped by using a separate rotary pump, and the pressure in the discharge chamber was calculated from the gas mass flow meter[10]. When the He pressure in the discharge chamber reaches to 100Pa, we ignited the He gas discharge by applying high voltage. The He gas discharge can also be confirmed by a purple glow light through a view port directly. At the working pressure 80Pa and 30mA discharge current, we obtained the photoelectron current as figure 4. The tested photoelectron current increases proportional with the discharge current. At the discharge current 100mA, the tested photoelectron current reaches to around 5nA. The results show that the He DCDUV light source is working well and can be used as the light source in UPS.

![Fig. 4 Test result of the relationship between the photoelectron current and the discharge current.](image)

4. Conclusion

We designed a compact and easy to use He DCDUV light source. The test results show that the UV light source is good to excite photoelectrons from metal samples and can be used as the light source for UPS. The photoelectron current is proportional to the He gas discharge strength.

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