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Effect of Plasma Surface Treatment of Semiconductor Emitter on Photon Enhanced Thermionic Emission
光支援熱電子放出における半導体エミッタのプラズマ表面処理の効果

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Energy converter using photon enhanced thermionic emission is a device to convert solar and thermal energy to electrical power. To develop the PETE devices, reducing electron affinity χ and work function ϕ of the semiconductor emitter is particularly effective. In this study, the effects of plasma surface treatment for Cs adsorption and surface oxidation on reducing χ to improve electron emission characteristics was investigated. The effective ϕ of untreated and etched surfaces decreased from 1.52 eV to 1.10 eV ($\Delta\phi$=0.42 eV) and from 1.46 eV to 1.19 eV ($\Delta\phi$=0.27 eV), respectively.

1. Introduction

The photon enhanced thermionic emission (PETE) device will convert thermal energy and photon energy simultaneously to electric energy with high efficiency. The theoretical efficiency for ideal thermionic energy converter using PETE effect exceeds 40% [1], which is higher than the theoretical limit of the single junction photovoltaic solar cell. The PETE device driven by solar energy is designed to use the whole wavelength of solar light as the energy source [2], i.e., an emitter heating is mainly carried out by the longer solar light wavelength, while the photo excitation is accomplished by the shorter solar light wavelength. In the energy conversion using the PETE process, the electrons in the valence band of a semiconductor emitter can be excited into the conduction band by photons with the energy higher than band gap. The excited electrons are thermalized to the equilibrium thermal distribution of the emitter temperature T_E, and then thermally emitted in the vacuum by overcoming the electron affinity energy barrier χ. PETE using a semiconductor emitter has a possibility that a lot of electron emission can be obtained at considerably lower T_E than usual electron emission from metal surfaces. The emitted electrons are collected by collector and flow into the emitter passed through load resistance, and electricity will be brought.

To improve the performance of PETE converter, reducing electron affinity χ and work function ϕ is particularly effective. The χ depends on the emitter surface properties, especially, first atomic layer on the surface, and is reduced by adsorption of alkali metals such as Cs and Li to emitter surface [3]. In this study, the effects of plasma surface treatment and surface oxidation for Cs adsorption on reducing χ was investigated.

2. Experimental methods

The electron emission characteristics of p-type Si emitters were measured in a vacuum chamber. The schematic of electrodes setting is shown in Fig. 1. The estimated concentration of doped boron of the Si emitter is around 10^{18} cm^{-3}. The emission area of Si was 3 cm^2 in the experiment. The surface of semiconductor emitter was treated by low pressure plasma with Ar and H_2 mixture gases. The effect of plasma treatment on the surface was examined with

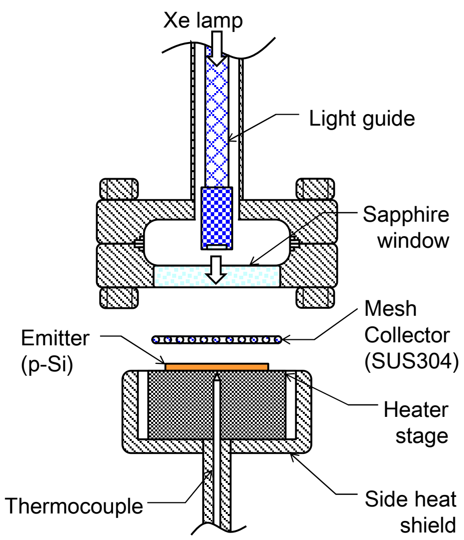

Fig.1. Schematic of the electrodes setting for testing the emission from p-Si emitter.

X-ray photoelectron spectroscopy (XPS). Then, the treated emitter was installed on the heater stage in vacuum chamber for the emission measurement. The collector electrode was the stainless steel mesh electrode. The both electrodes were installed closely. After the chamber was evacuated and baked at 725 K for 1 h, the vacuum level in the chamber was kept at a pressure below 3×10^{-5} Pa. Then, the emitter surface was activated by cesium evaporated from the cesium dispenser. A monolayer of a low work function material such as cesium decreases χ. The xenon short arc lamp was used as the light source for the photo excitation. The power density and the photon flux of the lamp radiation were 230 mW·cm^{-2} and 6.3×10^{17} cm^{-2}·s^{-1} on the emitter surface, respectively. The emission current from the semiconductor surfaces was collected and measured with an ammeter.

3. Results and discussion

Figure 2 shows the typical XPS spectra in Si 2p of Si emitter surface before and after Ar plasma treatment for 2 min. The spectra of the surface treated by HF wet etching was also shown. The peak intensities assigned to the component of SiO_2 decreased compared to untreated surface.

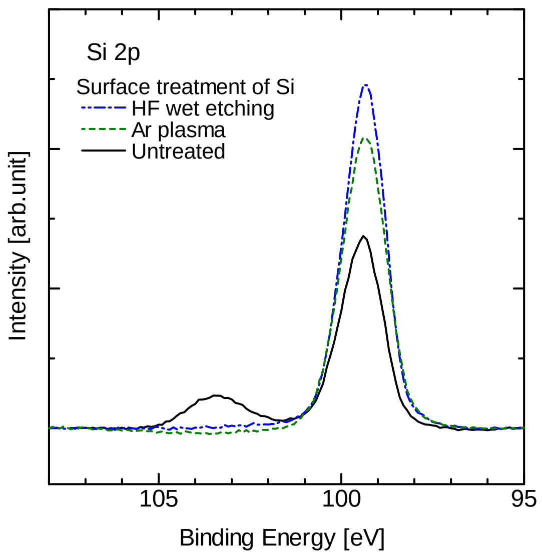

Fig.2. XPS spectra in Si 2p region of untreated and plasma treated Si emitter surfaces.

Figure 3 shows the experimental results of PETE current I and the effective ϕ for untreated and etched Si surfaces at T_E = 473 K. The ϕ can be calculated from Richardson equation and measured I. The Cs adsorption onto Si surface was performed by flowing Cs dispenser current I_{Cs} through the dispenser. As the degree of cesium coverage on the

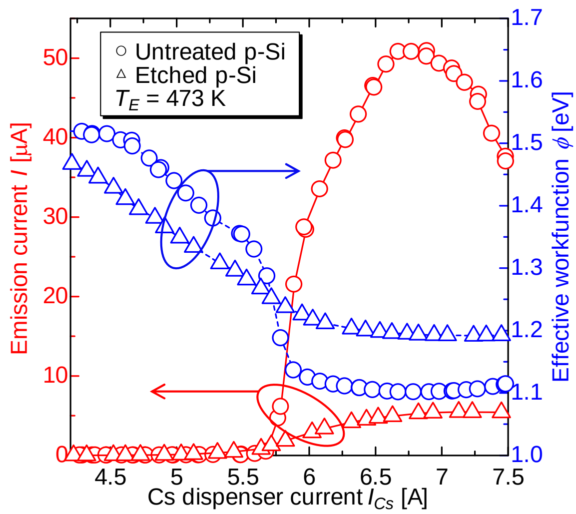

Fig.3. Measured emission current I and effective work function ϕ as a function of Cs dispenser current I_{Cs} at T_E = 473 K.

surface increases, the effective ϕ initially decreases and reaches a minimum value. After the minimum the ϕ increases with increasing the degree of cesium coverage. The ϕ of untreated and etched surfaces decreased from 1.52 eV to 1.10 eV ($\Delta\phi$=0.42 eV) and from 1.46 eV to 1.19 eV ($\Delta\phi$=0.27 eV), respectively. On the heated surfaces, the dependence between the adsorption energy and the surface temperature are important. Since the adsorption energy of cesium on Si surfaces are not so high, it is difficult to keep low ϕ at higher T_E around 700 K. The combination between other alkali metals and plasma treated surfaces are investigating.

4. Conclusion

To improve the performance of PETEC, the effects of plasma surface treatment for alkali metal adsorption and surface oxidation on reducing χ was investigated. The $\Delta\phi$ for etched Si surface was lower than untreated one. It is speculated that the oxygen atom onto the surface modified by plasma treatment plays a role in the degree of $\Delta\phi$.

Acknowledgments

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