

Significant enhancement of ion-induced secondary electron current by photons in plasma immersion ion implantation

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Abstract

This paper describes effects of vacuum ultraviolet (VUV) optical emission on the secondary electron emission coefficient (SEEC) in plasma immersion ion implantation (PIII) processes. To examine this, time-resolved in situ SEEC measurements were carried out for square wave-modulated Ar discharges. The SEEC in the activeglow was enhanced in proportion to the SEEC in the afterglow regardless of the ion-bombarding energy. The SEEC enhancement in the activeglow was caused by photon effects, and was explained by synergistic effects of photon irradiation and ion bombardment. Oxygen addition to the Ar discharge also caused a significant increase in the SEEC, and enhanced both ion-induced SEEC and photon enhancement factor.

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1. Introduction

Plasma immersion ion implantation (PIII) has been developed for three-dimensional materials processing, and many efforts have been made for various practical applications [1,2]. In the PIII processes, negative pulse voltages are applied to a processed target, and the ions accelerated at the sheath are implanted onto the target surface. Simultaneously, at the surface, secondary electron emission is induced by ion bombardment. Since a sheath around the target has a potential structure to accelerate the secondary electrons away from the target, a large secondary electron flux flows away from the target.

From the secondary electron point of view, sheath diagnostics has been performed [3,4], and new techniques for measuring sheath-accelerated energetic secondary electrons have been developed [5]. Especially, the semiconduc-

tor detector has enabled us to precisely measure the flux and energy of the energetic secondary electrons, and the technique has been pointed out to be applicable to end-point detection based on monitoring of the secondary electron emission coefficient (SEEC) of the ion-implanted surface [6]. The SEEC measurements have also revealed that the measured SEEC during PIII is rather high compared to that obtained by beam studies in clean vacuum environment [5]. The SEEC enhancement has been explained by formation of surface oxidation [6] layer as well as vacuum ultraviolet (VUV) optical emission from the plasma [7]. Especially, in a square wave-modulated discharge, the SEEC drastically decreased in early afterglow where VUV emission disappeared.

In this paper, the photon effects on the SEEC enhancement are quantitatively examined from the dependence of ion-bombarding energy on the SEEC in argon discharges, and the synergy effect of ion bombardment and photons on the SEEC is investigated. Influences of oxygen addition on these effects are also examined.

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2. Experimental

The present experiments are carried out with an apparatus that has been previously reported [7]. An argon gas was fed into an evacuated 36-cm-diameter and 50-cm-long grounded stainless steel cylindrical chamber at a typical pressure of ~ 1.3 Pa. Inductively coupled plasma (ICPs) was generated inside the chamber by supplying a 13.56-MHz RF power with a 20-cm-diameter one-turn loop internal antenna. The RF powers were modulated with a 400- μ s period and 50% duty ratio square wave in 100% modulation depth. The afterglow of the discharge is defined to begin at $t=0$ when the discharge is turned off. VUV photons from the plasma were introduced through a ~ 1 -cm-diameter capillary plate (hole diameter: 12 μ m; aspect ratio: ~ 167) into a VUV spectrometer differentially pumped down to $\sim 1 \times 10^{-5}$ Torr in pressure, and spectrometric measurements are carried out. Ten-microsecond-long negative high-voltage pulses were applied to a 2-cm-diameter spherical copper target set in the chamber with a repetition rate of 5 pps synchronously to the modulated discharge. The amplitude of the pulse voltages was adjusted in the range from -5 to -8 kV, and the target voltage V_t directly gives the ion-bombarding energy E_i as eV_t in electron volts for the amount of electron charge e since the plasma potential of ~ 20 V was negligible with respect to the target potential. The rise time of the voltage pulse was shorter than 1 μ s. A semiconductor detector with a thin beryllium window installed was located ~ 20 cm far from the target, and the sheath-accelerated secondary electrons were measured to obtain the SEEC $\tilde{\alpha}$ of the target. Details on the principles of the SEEC measurements are described in Refs. [3,4].

3. Results and discussions

3.1. VUV optical emission

When spectra of VUV optical emission from the plasma were examined in the Ar discharge, two spectra peaks were clearly observed and identified as transitions to the ground state in neutral Ar atoms of $3p^{61}s \rightarrow 4s'$ [$1/2$] $^\circ$ for 104.82 nm and $3p^{61}s \rightarrow 4s'$ [$1/2$] $^\circ$ for 106.66 nm. The emission intensity ratio between 106.66 and 104.82 nm was almost independent, and the 106.66-nm emission intensity hardly depended on the target voltage, as shown in Fig. 1. Therefore, photon irradiation intensity at the target is almost constant under the present conditions.

3.2. Synergy of ion bombardment and photon irradiation on SEEC

As reported in a previous work, the SEEC had an ion-induced component that is still existing with no photons irradiated and a photon-induced component proportional to the photon intensity [7]. Here, for the Ar discharge, it is

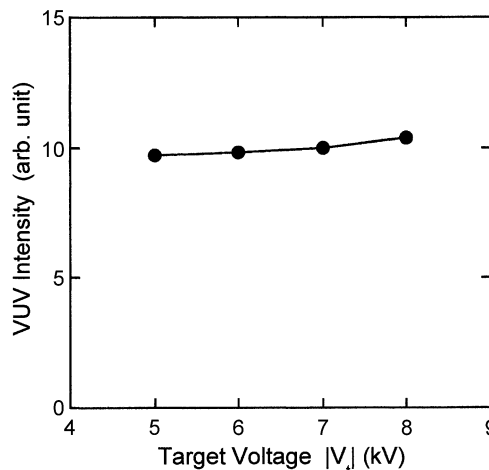


Fig. 1. VUV emission intensity as a function of ion-bombarding energy.

examined whether the photon irradiation has a synergy effect on the SEEC with ion bombardment.

The overall SEEC γ_{all} is composed of an ion-induced SEEC γ_i and a photon-induced SEEC γ_p such as:

$$\gamma_{\text{all}} = \gamma_i + \gamma_p, \quad (1)$$

and should be given by a function of ion-bombarding energy E_i and photon intensity I_p as $\gamma_{\text{all}}(E_i, I_p)$ because both ion bombardment and photon irradiation strongly affect the overall SEEC. The overall SEEC γ_{all} was given by the SEEC measured in the activeglow of the square wave-modulated discharge at $t \sim 15$ μ s, where the plasma was in steady state, and the data were plotted in Fig. 2 with closed circles. On the other hand, since the ion-induced SEEC γ_i is a component still existing with no photons irradiated, the ion-induced SEEC γ_i is given by a function of only E_i independently of I_p as $\gamma_i(E_i)$. The ion-induced SEEC γ_i is experimentally obtained by the SEEC measured in the afterglow of the modulated discharge at $t \sim 5$ μ s immediately after the discharge was turned off, where the VUV intensity was sufficiently decayed. The ion-induced SEEC $\gamma_i(E_i)$ (i.e., SEEC in the afterglow) is shown in Fig. 2 with open circles as a function of the target voltage V_t . Under the present conditions, the ion-induced SEEC exponentially increases with V_t .

If the photon-induced SEEC γ_p is independent on ion bombardment, the photon-induced SEEC would be just given by a function of only I_p , as $\gamma_p(I_p)$. However, if there is a synergy of ion bombardment and photon irradiation, the photon-induced SEEC γ_p would be given by a function of both E_i and I_p , as $\gamma_p(E_i, I_p)$. From Eq. (1), the photon-induced SEEC γ_p is experimentally obtained by subtracting from the overall SEEC $\gamma(E_i, I_p)$ in the afterglow, and the data of γ_p are plotted in Fig. 3a with open circles as a function of the target voltage V_t . Even for the approximately constant photon intensity I_p (see Fig. 1), the subtracted SEEC $\gamma - \gamma_i$ significantly depends on the target voltage V_t corresponding to the ion-bombarding energy E_i , suggesting that the

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