Dependence of ion sheath collapse on secondary electron emission in plasma immersion ion implantation

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The collapse of the ion sheath in front of a dielectric substrate during argon plasma immersion ion implantation is investigated using a Langmuir probe. The probe signals during the buildup and collapse of the ion sheath are recorded from a lime glass substrate with a magnesium metal plate placed on top. The collapsing speed of the ion sheath is shown to strongly depend on the secondary electron emission coefficient of the substrate. The authors’ results show that it is possible to derive secondary electron emission coefficients from insulating materials based on the probe signals.


When a high negative voltage is applied to a substrate in contact with a semi-ionized plasma in which ions are at room temperature and electrons have a temperature of a few eV, the light electrons will be repelled away from the substrate surface leaving the heavy ions forming an ion sheath. The positive ions within the ion sheath are then accelerated and bombard the sample surface. This process is referred to as the plasma immersion ion implantation (PIII).\textsuperscript{1} Positive ions implanted into the substrate cause the emission of secondary electrons. The secondary electron emission coefficient (SEEC) or yield increases nonlinearly with the impact energy of the incident particles (ions). If the substrate is an insulator placed on top of a conducting sample stage, positive charges will accumulate on the surface reducing the net negative surface potential. The accumulated positive charges result from the implanted ion charges that cannot be dissipated readily as well as the emitted secondary electrons. Since the absolute surface potential of the insulator is reduced, the ion sheath will start to collapse. The negative surface potential will finally be neutralized by the accumulated positive charges enhanced by the secondary emission electrons. Without the negative voltage, the ion sheath will collapse back to the insulator surface. Oates \textit{et al.}\textsuperscript{2} and Anders\textsuperscript{3} measured the collapse of the ion sheath due to surface charging of an insulator in a drifting plasma by an electrical probe. In their experimental setup, a drifting Ti plasma was generated by a cathodic arc. A positively biased Langmuir probe was inserted in front of the substrate to pick up the negative electron current from the bulk plasma. The probe was positively biased at 90 V such that ions with a drifting velocity of $1.3 \times 10^4$ m s\textsuperscript{-1} were repelled. When the ion sheath develops, the probe will not pick up any signal since all the plasma electrons are repelled away from the substrate. When the surface potential is completely neutralized by the surface accumulated charges, the ion sheath collapses back to the insulator surface and the Langmuir probe will pick up the electron current again.

The dependence of the SEEC on the collapse of the ion sheath cannot be reflected accurately in a drifting metal plasma because the material surface is contaminated by deposited metal. In a drifting metal plasma, the SEEC represents that of the deposited metal but not the original insulating substrate. Therefore, in the work reported here, the CISC is measured in a nondrifting argon gas plasma. Our results show that it takes a longer time for the ion sheath to collapse in the gas plasma because gas ions do not have a large drifting velocity. In addition, the CISC is found to depend largely on the SEEC of the materials.

The experimental setup has been described elsewhere.\textsuperscript{4,5}

The apparatus consisted of a cylindrical chamber of 60 cm in diameter and 30 cm tall connected to a bigger chamber with a diameter of 76 cm and height of 100 cm. The gas plasma was generated mainly in the smaller chamber equipped with four radio frequency (rf) planar inductive coils placed on the insulator surface and the Langmuir probe will pick up the electron current again. Figure 1 illustrates the experimental apparatus. The probe signal shown on the right bottom in Fig. 1 records the buildup and collapse of the ion sheath with time and is defined as the collapse ion sheath current (CISC) curve.

FIG. 1. Experimental apparatus and the measurement of a collapse ion sheath current (CISC) curve are illustrated.

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The traditional method to measure the SEEC is to shoot a continuous beam of charged particles such as electrons or ions toward a metal surface. A hemispherical stainless steel chamber is used to collect the secondary electrons released from the surface. The target current ($I_p$) and the collector current $I_c$ can be measured by picoammeters with $I_p$ being the primary beam current. The SEEC can be calculated as $I_c/I_p$ at different impact energies.  

An approach to determine the SEEC of a dielectric substance is proposed here. Instead of preventing surface charging, the surface charges are used to determine the SEEC at
The dependence of the SEEC $\gamma(E_p)$ on the energy of the incident ions $E_p$ can be described more generally by a power law $\gamma(E_p) = (E_p/E_1)^\alpha$, where $E_1$ corresponds to $\gamma=1$ and $\alpha$ depends on the materials. When the plasma density, substrate thickness, substrate dielectric constant, and high voltage bias, and so on are fixed, the collapse time of the ion sheath will depend on the values of $E_1$ and $\alpha$ for the materials under consideration. By fitting the numerical simulated CISC curve with the experimentally measured CISC one, $E_1$ and $\alpha$ can be determined. However, the low energy dependence of the SEEC of most materials is not well known. There may be a threshold impact energy corresponding to the release of a secondary electron. It is not necessary to assume a quadratic dependence, but to describe the dependence by a matrix, i.e., $(\text{SEEC}_i, E_i)$ for $i=1$ to $N$. Initially, a quadratic dependence can be assumed to provide a starting matrix which can subsequently be refined using some optimizing procedures.

In summary, the collapse of ion sheath in front of an insulator has been experimentally measured in a gas plasma. The CISC curves at different sample voltages are recorded for a lime glass substrate with a magnesium plate placed on top of the lime glass. Our results show that the ion sheath collapses faster for a material with a higher SEEC such as Mg. Our work suggests a viable means to determine the SEEC of a material based on the CISC.

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