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Plasma immersion ion implantation in arc and glow discharge plasmas submitted to low magnetic fields

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Abstract

The influence of low magnetic fields ($B \leq 130$ G) on the plasma parameters of a DC nitrogen glow discharge is investigated with a double Langmuir probe. The discharge was optimized for maximum plasma density for different values of a magnetic field, and a condition was found in which density was enhanced by an order of magnitude. In this condition partial suppression of secondary electron emission was obtained during ion implantation experiments. Silicon samples implanted in this optimum density condition showed larger retained dose and penetration depth compared with samples treated in non-magnetized plasmas as shown by Auger electron spectroscopy depth profile analysis. These results were compared with previous similar experiments in much denser magnetized vacuum arc plasmas, in which total suppression of secondary electrons (SE) was obtained, corroborating the theory that the maintenance of a virtual cathode for SE suppression is favored by higher plasma density. Silicon samples implanted in magnetized magnesium plasmas exhibited much larger doses (as expected) and penetration depths (not so obvious) than the ones treated in non-magnetized plasmas. The deeper ion penetration obtained in magnetized gaseous and vacuum arc plasmas indicates that an enhanced diffusion may be taking place induced by the large ion bombardment in dense plasmas.

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1. Introduction

Plasma immersion ion implantation (PIII) is a widely used technique for implanting ions into substrates without the use of ion beam accelerators. Gaseous plasma ions generated in several reactor types as well as condensable materials such as metals and carbon produced by vacuum arcs can be implanted for numerous applications [1,2].

The use of a magnetic field for plasma confinement increases electron temperature and density, resulting in higher implantation flux and consequently faster PIII treatment and higher retained dose (RD). Higher RD, on the other hand, could lead to improved mechanical, tribological, and corrosion resistance properties of the treated materials.

The use of strong magnetic fields is not desirable in PIII, since it could affect ion trajectories to the substrate. In fact, the improvement of plasma parameters occurs mainly due to electron magnetization. Although the ions are not magnetized, they cannot move independently, and are confined because they are bound to the motion of the magnetized electrons, and even a very slight charge separation generates plasma electric fields, keeping electrons and ions together. In vacuum arc discharges, the increase in plasma density due to the magnetic field is more dramatic than in gaseous plasmas, reaching two orders of magnitude. As in the gaseous case, only moderate magnetic field intensities are necessary, since ions do not need to be magnetized for plasma confinement [3].

PIII in magnetized plasmas has also been studied to reduce or suppress completely the emission of secondary electrons (SE) [4]. Suppression of SE implies higher implantation efficiency and suppression of X-rays, present and hazardous when high energy is used. The magnetic suppression of SE was proposed by Rej et al. [5] and is based on the formation of a virtual

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cathode near the target surface, due to the confinement of emerging SE by a magnetic field parallel to the surface. This electron layer decreases the local electric field, inhibiting the emission of further electrons.

In this paper the effects of a moderate magnetic field in a gaseous nitrogen plasma will be described, in terms of plasma parameters enhancement, suppression of secondary electron emission and implantation characteristics of treated silicon samples. The results will be discussed and compared with previous works made on the same subjects in aluminum and magnesium plasmas generated by vacuum arc discharges.

2. Experimental set-up

Fig. 1 shows schematics of the equipment used. A large cylindrical vacuum vessel 1.05 m long and 0.22 m in diameter is equipped with a coil system wound around it that produces an axial magnetic field. From $z=10$ cm to $z=70$ cm, where z is the distance from the one end of the chamber where the plasma source is introduced, the magnetic field is axially uniform to within 5%. In order to produce gaseous plasmas (nitrogen in this case), a cylindrical stainless steel rod 0.5 cm in diameter is typically biased to 450 V, while the chamber walls are grounded, generating plasma currents of (0.2–0.5)A at operating pressures around 2×10^{-3} mbar. An electron shower from a tungsten filament is introduced for the start-up of the discharge and in order to decrease the plasma potential from about 350 V to approximately 100 V. A decrease in plasma potential is necessary in order to decrease the target sputtering between the high voltage pulses during implantation experiments [6]. For this DC glow discharge plasma, the magnetic field coils are powered by a DC current supply, so that a field of 107 G at the axis is generated for coil currents of about 25 A. Higher fields are not presently possible due to power supply limitation.

Metal arc plasmas were produced in the same equipment, but with an arc source (Fig. 1b) replacing the cylindrical rod and filament. The cathode consists of a metal rod with a detachable tip and an anode made of a tungsten grid placed 15 mm from the cathode. Arc triggering is made with an auxiliary electrode biased with a high voltage pulse. In order to make the arc current constant for a few milliseconds the cathode is biased using an LC network instead of a capacitor bank, which results in a constant arc current of approximately 16 ms duration. The magnetic field is produced by pulsing the coils with a capacitor bank. This system is able to produce up to 3 kA of arc currents with magnetic fields up to 1 kG, although much lower values were used in the described experiments [7].

Due to the large plasma potentials in DC glow discharge plasmas, changes in plasma parameters (electron temperature and density) were monitored by a 6 mm long and 0.5 mm diameter cylindrical double Langmuir probe [8]. A voltage ramp

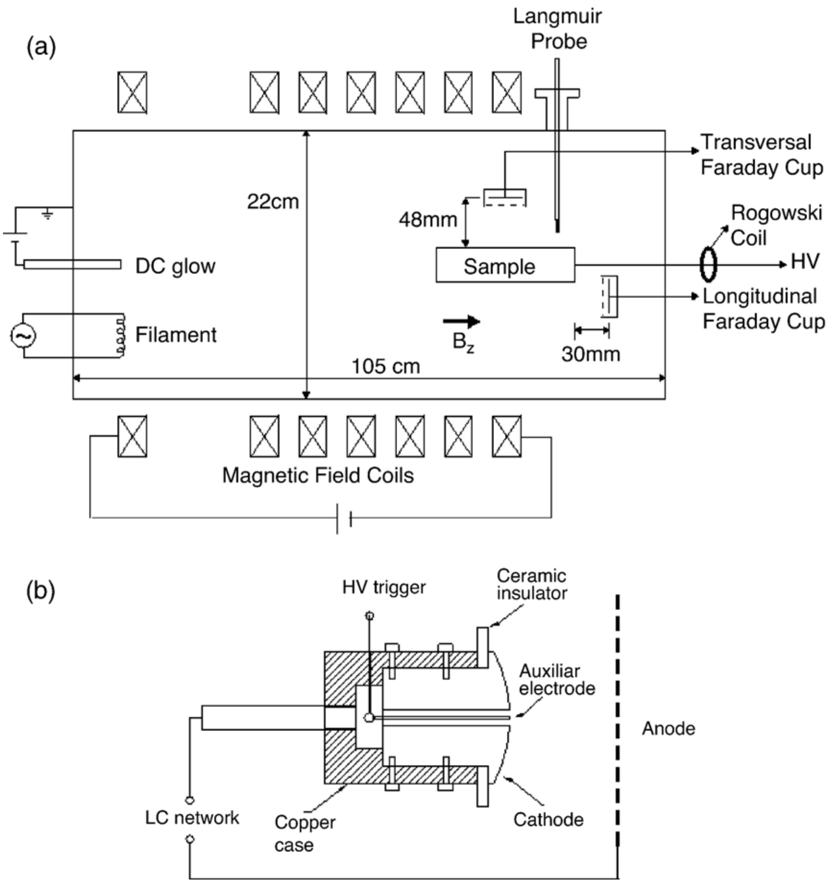

Fig. 1. Experimental set-up showing the vacuum chamber, magnetic field coils, double Langmuir probe, ion implantation target electrode, Faraday cups, and plasma sources for (a) DC glow discharge and (b) vacuum arc discharge.