Negative Ion Beam Focusing in a Plasma Sputter-type Negative Ion Source

Miguel Yambot*, Alexander Mendenilla[1], Nico Valmoria[1], Henry Ramos[1], and Alipio Garcia[2]
[1]Plasma Physics Laboratory, National Institute of Physics
[2]Condensed Matter Physics Laboratory, National Institute of Physics
College of Science, University of the Philippines, Diliman, Quezon City 1101 Philippines

ABSTRACT

The ion beam produced from a plasma sputter-type negative ion source with Zr target was analyzed, and the negative ion beam current was increased by focusing with an electrostatic Einzel lens. An Ar-N2 plasma at 7.0 x 10-3 Torr (20% N2) with discharge current voltage=-20 V and discharge current =1.0 A was produced for sputter formation of negative ions in the ion source. The Zr target immersed in the plasma was biased at -200 V. The ion beam was analyzed with a retarding potential electrostatic energy analyzer. Lens potentials of 20.0 V for the outer electrodes and -80.3 V for the inner electrode resulted in the highest negative ion beam current, increasing the ion current to 0.5 nA (from 0.28 nA when not using the lens), and reduced the beam spot size to 25 mm (from 35 mm for the unfocused beam).

Keywords: negative ion source, electrostatic einzel lens

INTRODUCTION

The plasma sputter-type negative ion source (PSNIS) facility of the Plasma Physics Laboratory is designed to grow thin films through ion beam deposition. In the PSNIS, a negatively biased metallic target, e.g., Zr, is immersed in an Ar plasma to produce Zr^- ions by sputtering. The Zr^- ions are extracted to form a beam that is collimated into a reaction chamber, where these ions will be combined with N_2 near the substrate area to form thin nitride films, e.g., ZrN.

So far, problems preventing thin film formation by the aforementioned mechanism have been encountered. One major problem is brought about by divergence of the ion beam. The ion beam is divergent because of the ions' transverse thermal velocities and mutual repulsion. Since the beam must travel the large distance separating the ion source and reaction chambers, beam current densities obtained at the reaction chamber are very low. This would lead to poor substrate coverage and non-uniformity of the deposited film. Thus, there is a pronounced need to focus the ion beam in order to increase the beam current density and have a beam spot size comparable to the surface dimension of the substrate.

METHODOLOGY

A diagram of the PSNIS facility is shown in Fig.1. At the left side of the system is the ion source where the negative ion beam originates, while at the right end is the reaction chamber where the ion beam should hit the substrate for thin film deposition to occur. Located between these two chambers is the diagnostic chamber,

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**Corresponding Author*

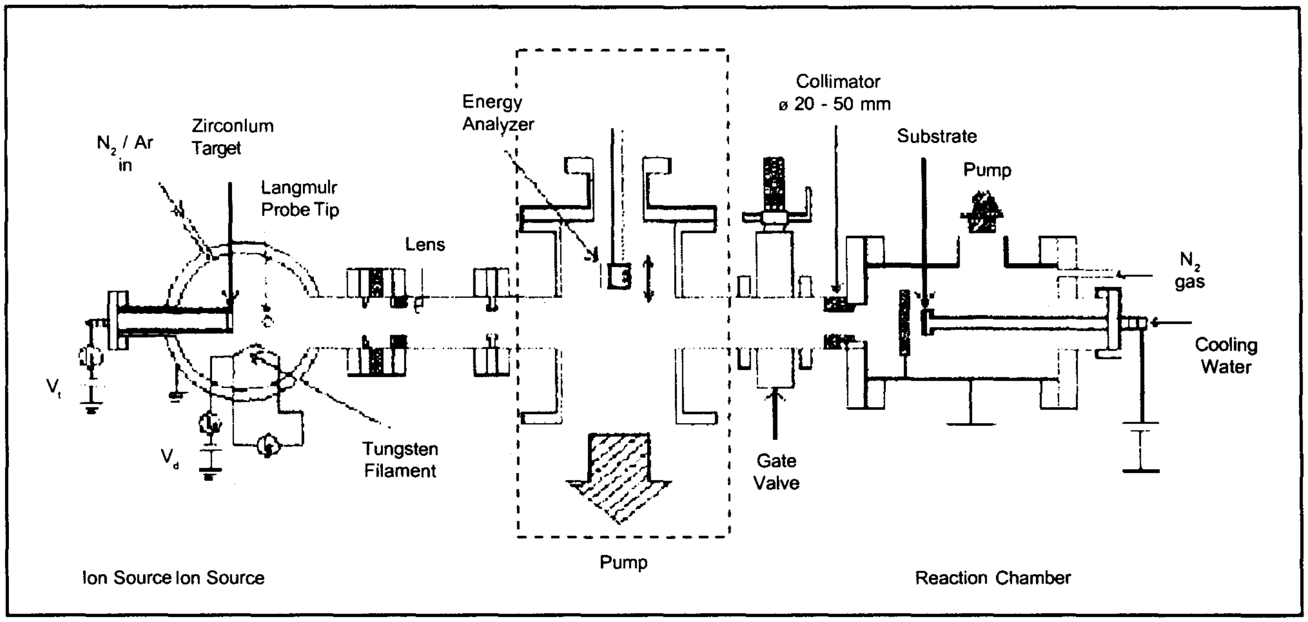

Fig. 1. Diagram of the PSNIS facility. The Diagnostic chamber is enclosed by dashed lines.

where the beam is characterized with an electrostatic energy analyzer (ESA). Focusing is achieved through the use of an Einzel lens placed along the beam path in between the ion source and the diagnostic chamber.

A turbo molecular pump backed by a rotary pump evacuated the ion source to a base pressure of 5.0 x 10^{-6} Torr. A 20% N_2 in Ar gas mixture is introduced into the ion source chamber for a total chamber pressure of 7.0 x 10^{-3} Torr. The plasma is ignited when an electrical current is introduced into the ϕ0.5 mm, 8.0 cm long tungsten filament. The filament serves as cathode while the chamber wall serves as the anode for the discharge. Constant discharge voltage and current of -20 V and -1.0 A, respectively, were used for the experiments. Plasma parameters such as electron density, electron temperature, and plasma potential were determined with a Langmuir probe.

The Zr target was constantly biased at -200 V. The energy provided by the potential difference accelerates the Ar^+ ions through the plasma sheath and into the Zr target. Various species are produced by this mechanism, but due to the negative bias of the target, negative ions are accelerated out of the ion source chamber via Coulombic repulsion. The resulting ion beam passes through a ϕ10-mm collimator and into the focusing lens system, the Einzel lens. The Einzel lens is comprised of three coaxial cylindrical electrodes. Each electrode has 15.8 mm apertures and are held at different potentials (V_O for the two outer electrodes and V_I for the central electrode) which give rise to electric fields having a net focusing effect on the negative ion beam. The focal length of the lens depends on V_O and V_I. After passing through the lens, the beam was characterized in the diagnostic chamber with an ESA capable of moving in a transverse direction with the beam axis. The ESA is used to determine the negative ion current and energy spread. The values of the lens electrode potentials V_O and V_I are varied and the corresponding beam current densities, beam spot sizes, and ion energy spreads are taken.

RESULTS, DISCUSSIONS, AND CONCLUSIONS

The transverse profile of the ion beam current without using the lens system was acquired. Then, the lens voltages were varied and the beam currents taken at the beam axis (ESA displacement 30 mm). The lens voltages (among the values tested) which resulted in the highest negative ion beam current were $V_O = 20.0$, and V and $V_I = -80.3$ V. At these lens potentials, the transverse profile of the ion beam current was taken. A comparison between the transverse scans of the unfocused ($V_O=V_I=0$) and focused ($V_O = 20$ V, $V_I = -80.3$ V) ion beams is shown in Fig. 2. With the use of the lens, the ion current obtained at the axis was 0.5 nA, an almost 80% increase from the 0.28 nA taken at the same position when the lens was not used. Furthermore, measurements of the full width at half maximum of both beam profiles in Fig. 2 show that the beam diameter of the unfocused beam is 35 mm while that of the focused beam is reduced to 25 mm.

The majority of the negative ions have measured energies near the target potential, 200 V. The energy spread is an indication of the uniformity of the energies of the ions in the beam. The energy spread as a function of transverse position for both beams in Fig. 2 were also taken and these are shown in Fig. 3. The energy spreads slightly increased when the lens was used, but the energy spreads approach some average value that is spatially independent within the ion beam cross section. This means that the uniformity of deposition using the focused beam may not be adversely affected.

The marked increase in the negative ion beam current and narrowing of the beam when the Einzel lens is properly configured indicate that the lens can significantly aid towards ion beam deposition. It remains to be seen, however if the beam is indeed composed mainly of Zr ions, or if there are other ions, what species these are. A mass analyzer could address this problem. Furthermore, thin film deposition should now be initiated since the characterization of the grown films will provide more information regarding the facility.

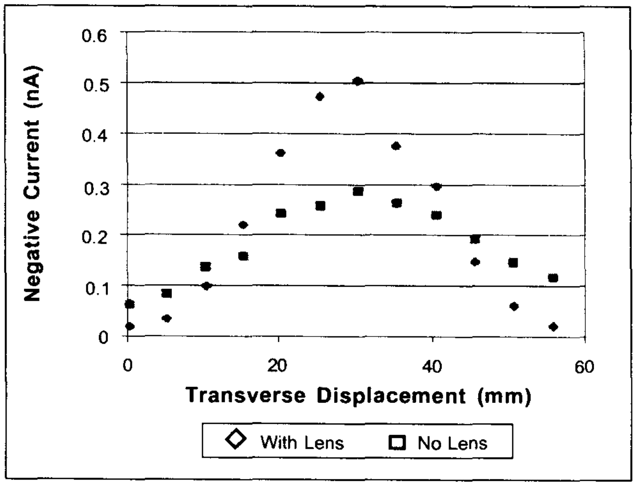

Fig. 2 Ion current vs. displacement for unfocused and focused (Vo=20V, Vi=-80.3 V) beams

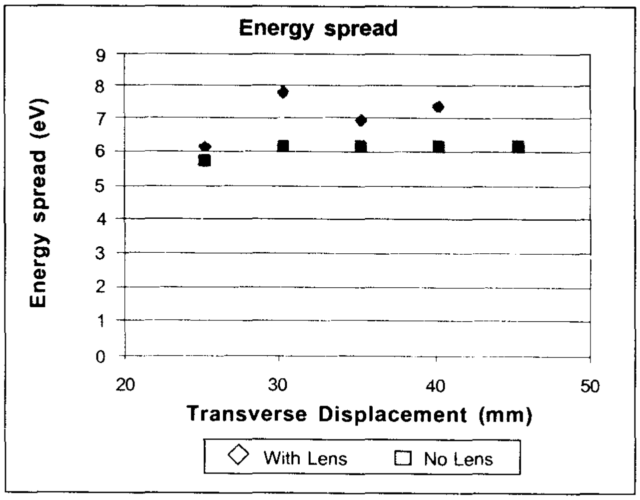

Fig.3 Energy profiles of the unfocused and focused ion beams

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