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Stability of N_2 Plasmas in an Aluminum Made Planar Magnetron Device

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A plasma operation procedure to stabilize a glow discharge by applying a short duration high voltage pulse was investigated using an aluminum made planar magnetron device equipped with 160 mm diameter sputtering target. When the device was operated only with dc power supply, it was not possible to maintain a steady state N_2 discharge. As a train of pulses of 800 V peak voltage and with several microseconds duration was imposed onto a dc power, stable operation of N_2 plasma up to 900 W could be maintained by increasing the repetition rate of pulse voltage up to 2 kHz. The plasma tended to be more stable by increasing the repetition rate, and the formation of passivating film of AlN created by N_2-Al interaction was considered as the cause of plasma instability. A series of probe measurements had clarified a strong inhomogeneity existed in the plasma, indicating concentrated current flow onto the sputtering target. The erosion area of the target was found to be a thin ring of about 10 mm width, and deposition of AlN was found at the rest part of the sputtering target.

Key words : sputtering, planer magnetron, aluminum nitride, film deposition, glow discharge

Introduction

Aluminum nitride (AlN) can be a suitable substrate material for electronic circuits integration of group III nitride materials because of it's small difference in lattice constant [1]. There are several methods to prepare an AlN film, which include planar magnetron sputtering technique [2]. It produces far much higher particle flux compared with molecular beam epitaxy devices, but may include impurities in the formed film.

Preparation of films of AlN had been already attempted using planar magnetron device with Ar-N_2 mixed plasma conditions [3]. In the most experiments, Ar is added to N_2 as pure N_2 plasma can make plasma operation unstable as they form an insulating AlN film on an Al sputtering target. Even with Ar, plasma operation can often become unstable. Pure metallic Al exposed to a plasma containing N_2 adsorbs N_2 to reduce pressure inside the discharge device. This reduction of pressure elevates the discharge voltage necessary to ignite the plasma. The higher discharge voltage then triggers local arcing, and terminate stable discharge.

In this research, we attempt to realize a stable sputtering system for AlN deposition with pure N_2 plasma. We have taken the approach to stabilize a glow discharge by applying a trigger voltage with a fixed time interval. The performance of the device is evaluated by measuring the plasma parameters with a Langmuir probe.

2. Experimental Set up

Figure 1 shows the experimental apparatus. The discharge chamber is made of aluminum and the size is 400 mm wide, 400 mm deep and 160 mm high. A 160 l/s turbo molecular pump evacuates the chamber. A substrate for film deposition is located 50 mm above the sputtering target. The diameter of the Al sputtering target is 160 mm, and the inner diameter of the arc prevention shield is 140 mm. Inside the sputtering target, Nd-Fe magnets are arranged to create planar magnetron magnetic field geometry to generate plasma near the sputtering target.

The power supply system consists of a DC power source (600 V, 12.5 A), and a voltage pulse generator (max 4 kV voltage, 10μs pulse width, and 10 Hz to 4.0 kHz frequency). Discharge gas is introduced into the chamber through a piezoelectric gas regulating valve to enable feed back control of gas pressure.

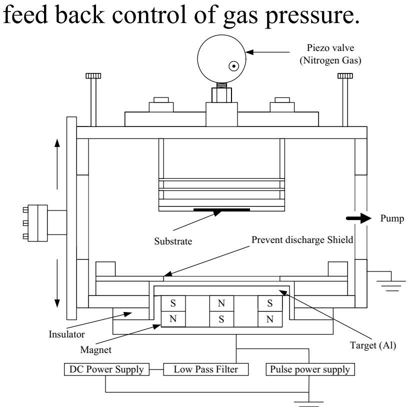

Fig. 1 Schematic drawing of experimental apparatus.

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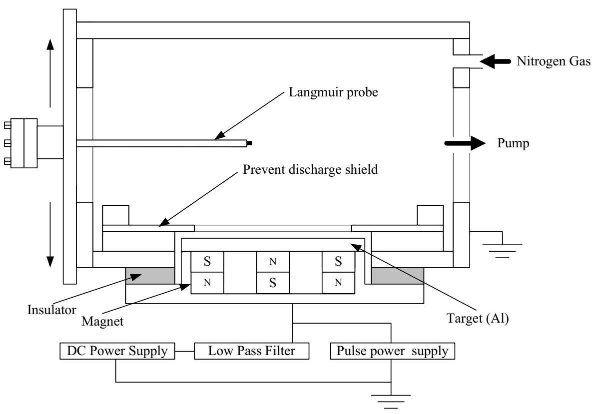

Fig. 2 Schematic showing electrical circuit, magnet arrangements, and Langmuir probe location.

Figure 2 shows the electrical circuit connection for the discharge operation. The entire chamber wall is grounded. A Langmuir probe having a Mo tip of 2 mm diameter and 1 mm long is inserted into a discharge in region above the sputtering target to measure plasma parameters. The electrical connection employed for the probe measurement is shown in Fig. 3. As probe current often shows fluctuations, the signals are integrated by digital oscilloscope, and the data is stored on a PC.

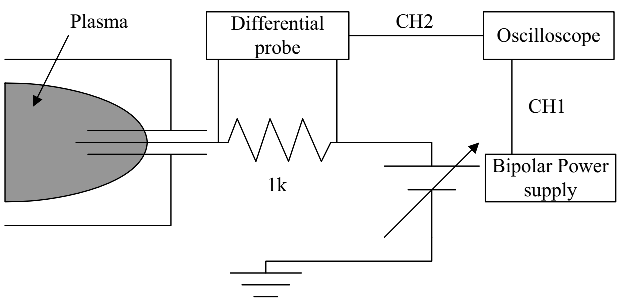

Fig. 3 Electrical circuit diagram of a Langmuir probe.

3. Plasma stabilization

In the following experiment, the Al sputter target served as the cathode, while the entire chamber wall served as the anode. The maintenance of pure N_2 plasma was impossible with an operation only with the DC power supply. The stability of pure N_2 plasma through applying a train of voltage pulses was investigated by changing the repetition rate of the pulse voltage imposed on the DC power supply. The N_2 gas pressure was kept constant at 0.2 Pa. Height of the voltage pulse was fixed at 0.8 kV, while the discharge current was kept at 0.5 A throughout the experiment.

Typical oscilloscope traces showing the discharge voltage and current are shown in Fig. 4(a) and (b). Note that dc current of 0.5 A flows through the cathode in addition to the pulse current shown in Fig. 4(b). Meanwhile, the voltage between the cathode and the anode is determined with the DC power supply set constant at 260 V, and with 0.8 kV pulse voltage supplied from the pulse power supply. The pulse height of the voltage can be adjusted by capacitor charging duration of the pulse power supply. Change of the pulse height causes little difference in the voltage and current of the DC phase as can be seen in the waveforms of Fig. 4.

The formation of thin insulating layer of AlN on the top of pure Al cathode target is the most probable reason for observing the unstable plasma behavior in the present device. A short high voltage pulse makes the temporal current to maintain a steady state discharge for a duration short enough not to cause arc transition of the discharge. The plasma becomes unstable if the interval between the pulses becomes longer, and the discharge current becomes larger. Pressure of N_2 is another important factor as it determines the nitrogen flux touching down to the Al sputtering electrode.

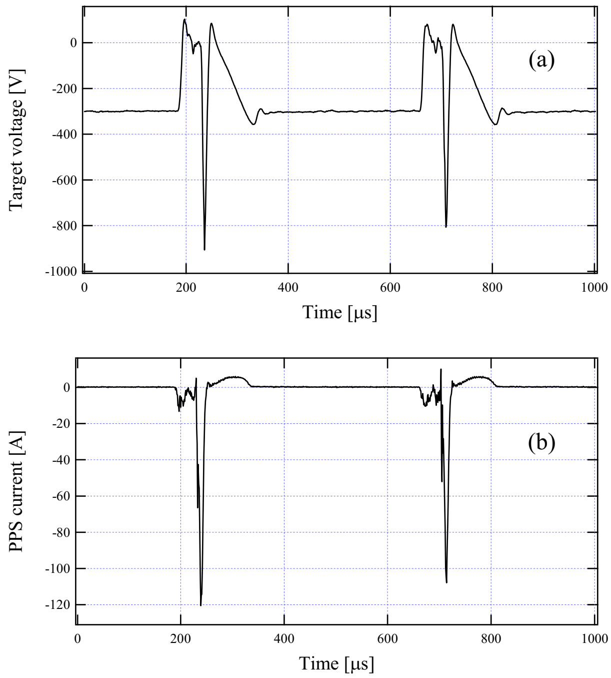

Fig. 4 Waveforms of (a) target voltage, and (b) pulse power supply (PPS) current during discharge operation.

In Fig. 5, the threshold discharge currents at which the plasma becomes unstable are plotted as functions of frequency to generate pulses for different N_2 pressure. In the figure, any operational area above the plot is unstable. The result is consistent with the assumption that formation of AlN insulating layer destabilizes the plasma. The plasma can be more stably operated at higher frequency, as the insulating layer is removed before it gets thicker by a high voltage pulse. Higher pressure and larger discharge current results in lager number of nitrogen atoms forming AlN layers on the sputtering target. Thus, the plasma is stable for higher frequency and higher pressure, for fixed discharge current.

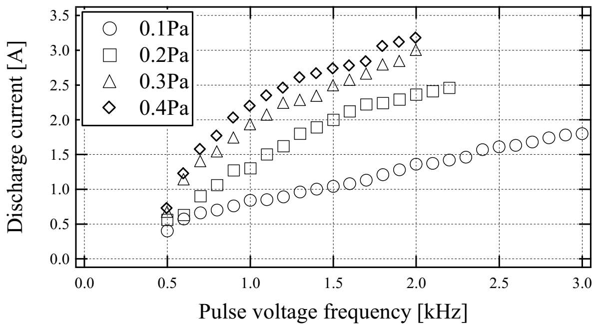

Fig. 5 Plots of current at which the plasma becomes unstable as functions of frequency of pulse voltage for different N_2 pressure.

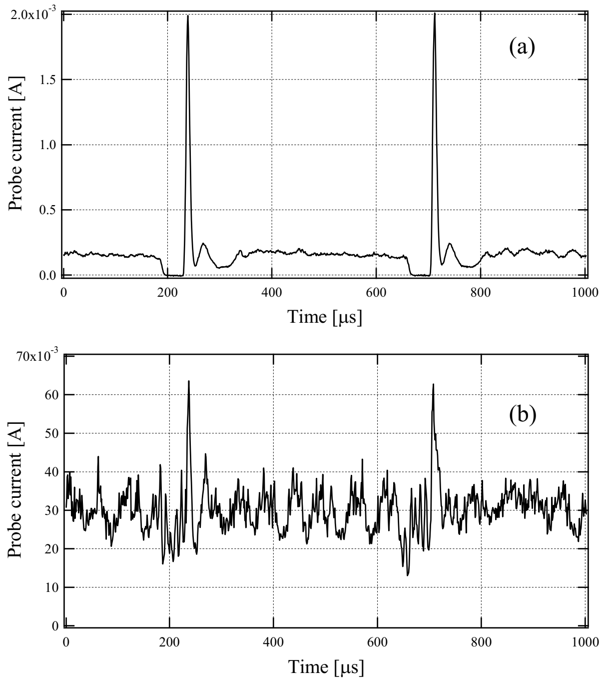

Fig. 6 Oscilloscope traces of electron current to a Langmuir probe for (a), stable plasma operation, and (b), unstable operation leading to discharge termination.

Figure 6 (a) and (b) show the oscilloscope traces of electron current flowing into a Langmuir probe for stable and unstable plasma conditions. The electron current increases by a factor of about 100, while clear indication of plasma fluctuation appears in the unstable condition. After reaching this condition, plasma extinguishes in a short time. Usually, the arcing occurs toward the end of the unstable period, which results in particle contamination onto the substrate.

4. Plasma parameter distributions

Spatial distributions of N_2 plasma parameters inside the discharge chamber were measured with a movable Langmuir probe set up. To help understanding of the experimental geometry, precise dimensions of the discharge chamber and the probe position are schematically illustrated in Fig. 7. The experimental conditions are again 0.2 Pa N_2 pressure in the chamber, 0.8 kV voltage height for the 7 μs pulse width, and 2.1 kHz repetition rate. The discharge current was kept at 0.5 A. As shown in Fig. 7, probe vertical position was limited from 41 mm to 91 mm due to the opening of the port.

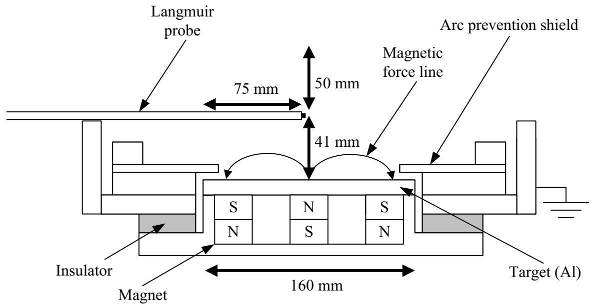

Fig.7 Geometry for the probe measurement.

The probe trace had to be recovered from noisy electron saturation current data, and spatial distributions of ion saturation current and floating potential are measured for most cases. Typical electron temperature of the bulk plasma obtained for quiet plasma condition was about 4 eV. The *I-V* trace exhibited the presence of high energy electrons.

The radial profile of ion saturation current measured at the distance of 46 mm and 56 mm from the sputtering target surface are displayed in Figs. 8(a) and 8(b), respectively. As can be seen in the graph, the profile at 46 mm shows a peak near at 42 mm from the center, while the profile was more homogeneous at 56 mm, or just 10 mm away from the 46 mm position.

The floating potential profile exhibited clearer structures as shown in Fig. 9. As the probe was put at a distance closer to the sputtering target, the floating potential had become more negative. Meanwhile the radial distance at which the floating potential becomes the most negative at a fixed distance from the sputtering target, increased with increasing distance from the target. This indicates the presence of high energy electrons emitted from the sputtering target acting as the cathode.

As the probe was separated by 90 mm from the target, no distinct dependence of ion saturation current, or the floating potential against radial position was observed. Thus, highly concentrated plasma production by the magnetron magnetic field is confirmed. Meanwhile, the ion flux can be the highest at some radial position from 20 mm to 40 mm right on the target surface.

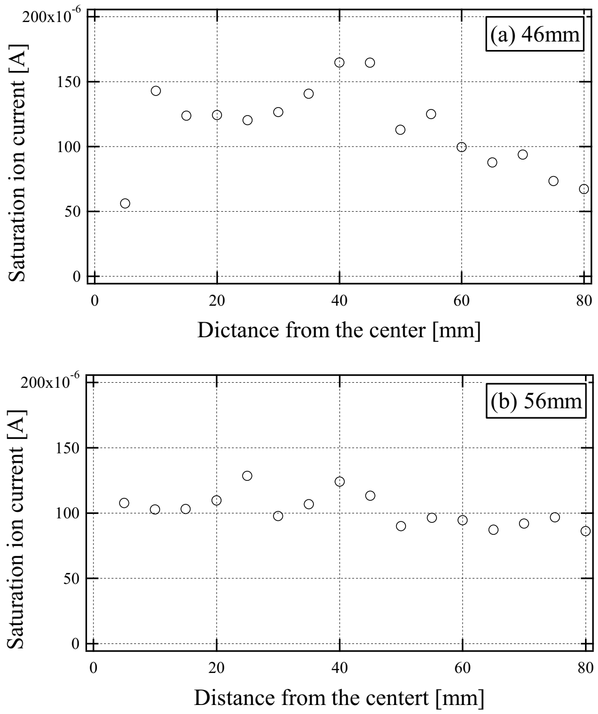

Fig. 8 Radial distributions of ion saturation current at (a), 46 mm from the sputtering target and (b), 56 mm from the sputtering target.

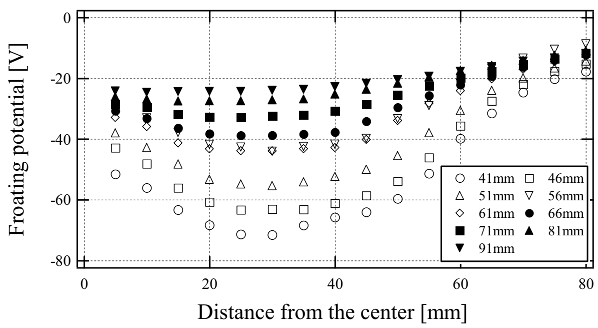

Fig. 9 Radial distributions of probe floating potential for different distances from the sputtering target.

5. AlN deposition profile

Occasionally, the probe measurement had to be terminated as insulating AlN was deposited on the surface of the probe. To investigate the deposition rate of AlN on the target, Al collector plates of 5 mm by 5 mm were placed on the target with 10 mm interval. The experimental conditions are 0.2 Pa N_2 pressure, 0.8 kV pulse voltage, 1.5 kHz pulse frequency with 7 µs pulse width, and 0.5 A discharge current. The discharge was run for 5 hrs to evaluate the amount of deposition.

The result is shown in Fig. 10. Except at the radial position of 40 mm from the center, deposition was observed on surface of sputtering target. From this result, very small area of the sputtering target is irradiated to N_2 plasma, and the discharge current can be concentrated in a very narrow region. The narrow cathode area subject to a rapid formation of insulating film can easily make discharge unstable.

Composition of the deposit was investigated by X-ray diffraction (XRD). As shown in Fig. 11, the XRD spectrum showed peak at 36° which correspond to insulating AlN.

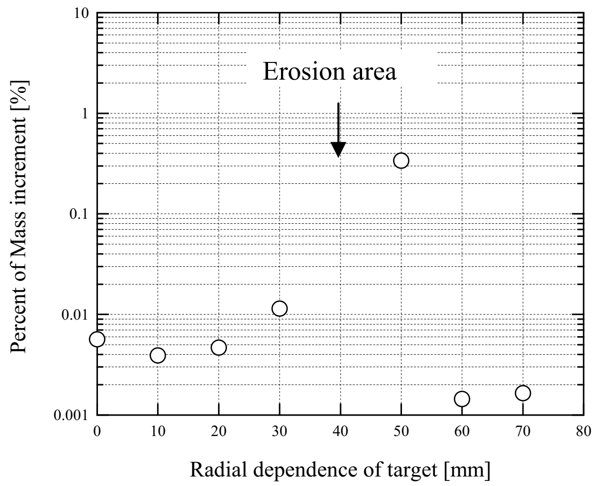

Fig. 10 Deposition of AlN on Al samples put on the sputtering target.

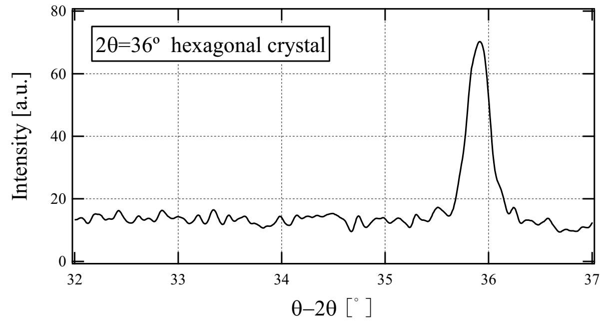

Fig. 11 XRD spectrum of AlN on Al plate.

6. Summary

Nitrogen plasmas easily form insulating AlN on Al surface of magnetron sputtering target immersed in the plasma. Induction of short duration high voltage pulses at high frequency was effective to stabilize the plasma operation, but the area eroded due to sputtering was very narrow. Most of the surface area of the Al sputtering target was found covered by AlN.

Acknowledgements

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