DEVELOPMENT OF 30-cm LONG LINEAR SPUTTERING SOURCE USING ECR DISCHARGE

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Abstract

A 30-cm class long electron cyclotron resonance plasma was generated for plasma sputtering with large area. It achieved by using permanent magnets and slot antennas on a rectangular waveguide. The generated plasma density was $1.04 \times 10^{17}\,m^{-3}$ beyond the cutoff density at 0.146 Pa of Ar and 600 W of microwave power. The spatial plasma uniformity was ± 7.8 % within 180 mm on the discharge chamber exit. For plasma sputtering, a sputtering target was set within the discharge chamber along the waveguide, and substrate was set on the discharge chamber exit. It successfully deposited titanium nitride films by reactive sputtering method with a Ti target and a mixture of Ar and N_2. The deposited film thickness uniformity was ± 11.4 % within 160 mm. A stoichiometric TiN film deposited at 700 W of microwave power and mass flow ratio of N_2/Ar=1.5.

Introduction

Microwave discharge is widely used and studied in various fields, such as electric propulsion in space [1-3], and plasma processing [4-7]. Since microwave discharge has no electrodes within the discharge chamber, it achieves long life of plasma source and generate no contaminant plasma. Especially, microwave discharge using resonance magnetic field, electron cyclotron resonance (ECR) discharge, is attractive for its high-density plasma under low-pressure environment. ECR plasma sources widely used as ion sources application [4]. Recently, the ECR ion source attracts much attention as an electric propulsion, that is an ion thruster [2,3].

Also, ECR plasma sources are useful for plasma processing, such as plasma enhanced chemical vapor deposition (PCVD) [5], and plasma sputtering [6,7]. ECR discharge generates high-density plasma with highly reactive species. It achieves deposition of high quality film at low substrate temperature. In sputter process, reactive sputter deposition of nitride and oxide materials becomes important. Moreover, there are increasing demands for large area deposition, such as large-scale wafers, flat panel displays and structural materials. In comparison with sputtering source using DC or RF discharge, sputtering sources using ECR discharge has an advantage in reactive sputter deposition of films. However, conventional ECR plasma sources are difficult to achieve these demands. Linear sputtering process achieves large area deposition by a linear substrate motion on a conveyor system as shown in Fig.1. A long ECR plasma source enables to

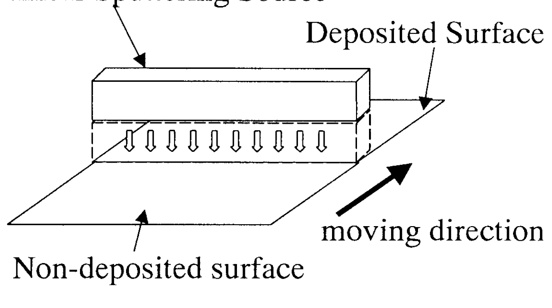

Fig.1 Linear sputtering process for large area deposition.

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deposit large area by linear sputtering process. The linear sputtering source using ECR discharge improves throughput and reduces production cost.

For long plasma generation, configuration of a microwave launcher and a magnetic circuit are important. We developed a long ECR plasma source using slot antennas on a rectangular waveguide with T-shaped ridge as the microwave launcher, and permanent magnets for the magnetic circuit. The plasma source achieved simple system and easy operation for 30-cm class long plasma generation. For plasma sputtering, a sputtering target was placed along the waveguide, and substrate holder was placed on the discharge chamber exit.

This paper presents the configuration of the long ECR plasma source for plasma sputtering and plasma generation characteristics. Finally, its deposition characteristics were examined by reactive sputter deposition of titanium nitride.

30-cm class long ECR plasma source for linear sputtering

Figures 2 shows the configuration of the long ECR plasma source for linear sputtering. The discharge chamber (268×45 ×30 mm) is placed along the rectangular waveguide. The working gases are injected into the discharge chamber from eight gas ports on the side wall.

The magnetic circuit has three ring-shaped magnetic fields in the discharge chamber. Figure 3 shows a calculated profile of magnetic field. Two rings of them on the exit of slot antennas produce ECR layer (87.5 mT) near the slot, and two rings of them on the discharge chamber side wall produce ring cusp magnetic fields and confine plasma in the central region of the discharge chamber. They are cooled by water from its behind.

The microwave launcher is composed from a rectangular waveguide with a T-shaped ridge, a quartz glass microwave window and slot antennas on the waveguide. Microwaves of 2.45 GHz are transmitted in the TE_{10} mode into the rectangular waveguide. Through the quartz glass, microwaves are radiated from the slot antennas into the discharge chamber. The slot antennas are on the E-side of the rectangular waveguide, and the T-shaped ridge is on the opposite side of the waveguide. For efficient microwave

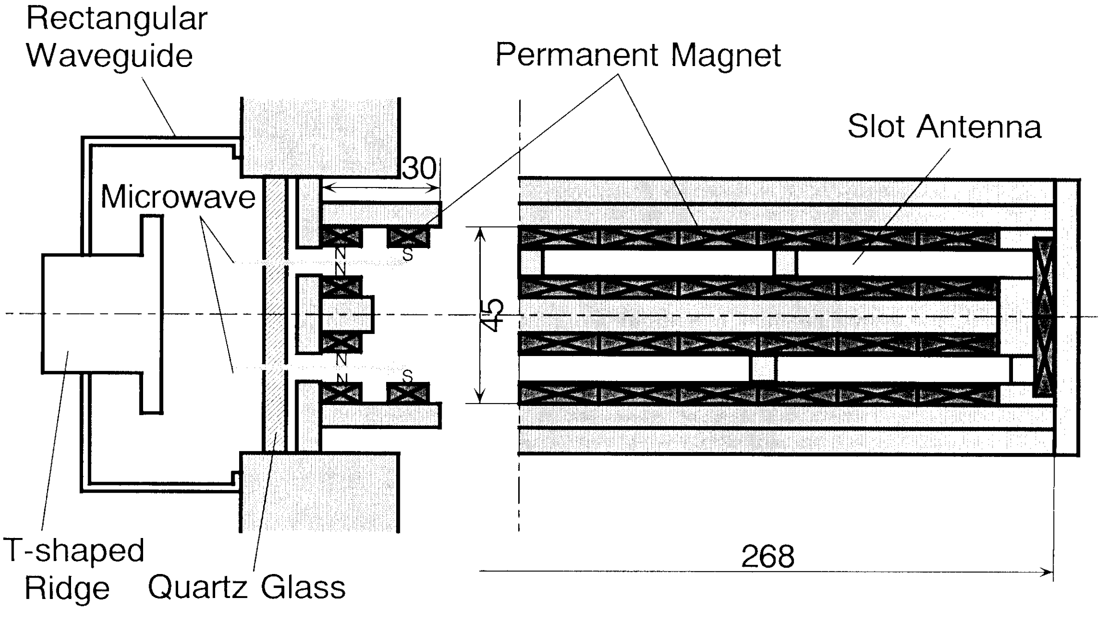

Fig.2 Long ECR plasma source using permanent magnets and slot antennas.

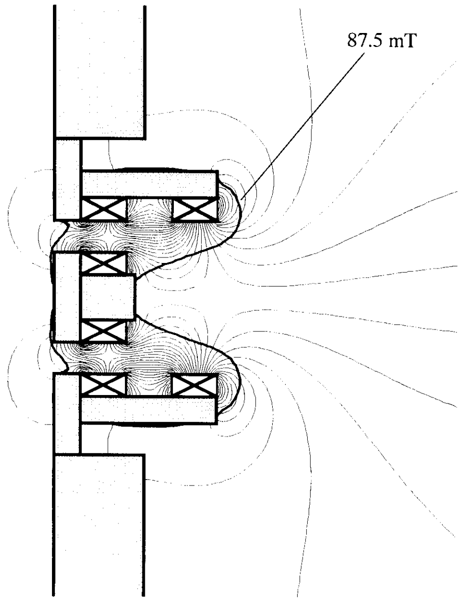

Fig.3 Cross sectional view of calculated magnetic field profile.

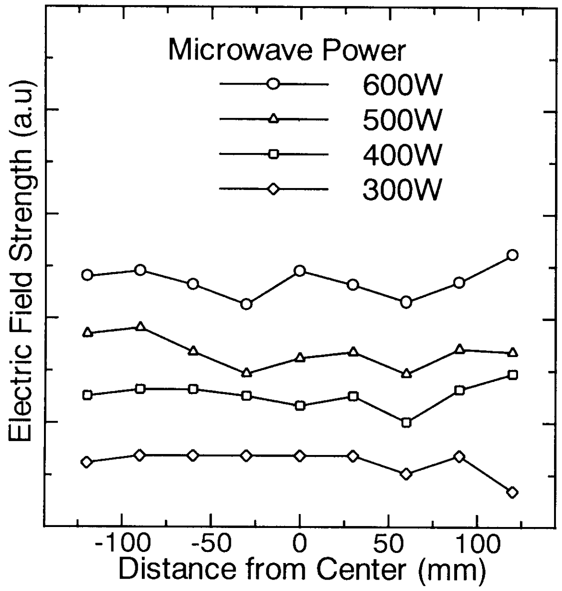

Fig.4 Radiated electric field profiles on the exit of the discharge chamber.

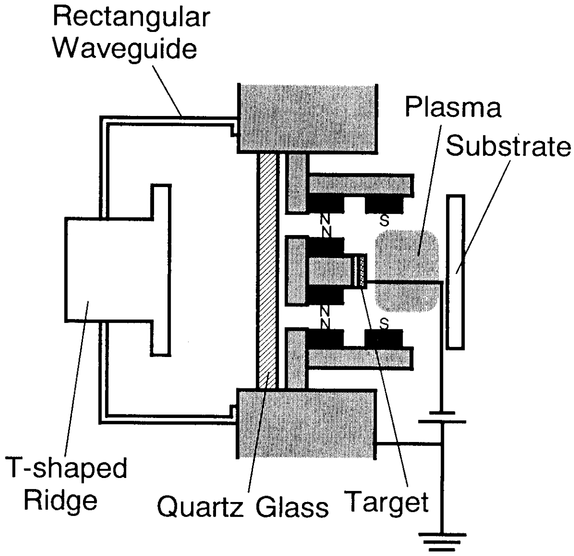

Fig.5 Sputtering target and substrate arrangement.

coupling with plasma and uniform plasma generation, the radiated electromagnetic field profiles are adjusted by using the T-shaped ridge and a plunger at the end of the waveguide. Figure 4 shows the radiated electric field profiles from the slots antennas at substrate position without plasma. The radiated electric fields strength increases with microwave power. However, the distributions are non-uniform with three peaks. It attributed to the generation of standing wave within the waveguide. Though the generation of the standing wave is unavoidable by this launcher, it achieve stable operation of plasma source.

For linear sputtering, a linear sputtering target (240 mm x 10 mm) is placed on the discharge chamber center, as shown in Fig.5. The target is isolated from the discharge chamber wall, and biased at negative potential. The discharge chamber and substrate holder are connected to ground potential. The target cannot see the microwave window directly. This placement prevents the microwave window contamination by sputtered particles. Also, it achieves high deposition rate by dense plasma. These enables stable operation during sputter deposition. The distance between a substrate holder and target is 35 mm in this experiment.

Operational characteristics of long ECR plasma source

Figure 6 shows the spatial distribution of generated plasma. The spatial plasma uniformity was measured by ion

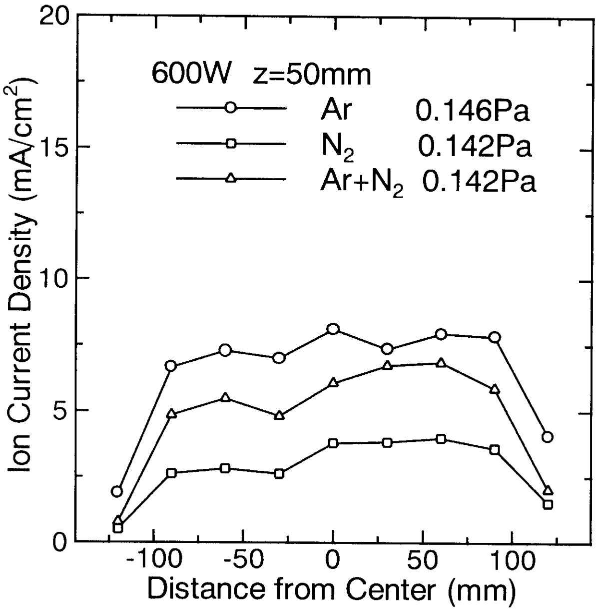

Fig. 6 Spatial distribution of plasma with various gases.

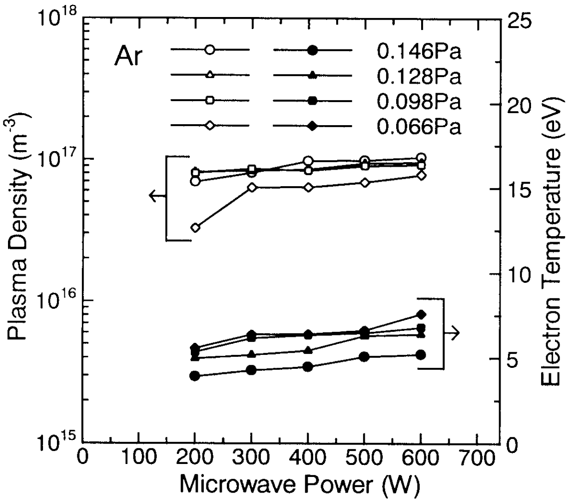

Fig.7 Plasma density and electron temperature for Ar plasma.

saturation current density with a single Langmuir probe. Although the dense plasmas are generated within 180 mm long, the profiles have peaks which coincide with the profiles of the electric field strength as shown in Fig.4. At 0.146 Pa of Ar, plasma uniformity was ±7.8 % within 180 mm in the long direction. The ion current densities increase with microwave power, and the maximum ion current density is beyond 7 mA/cm^2 at 600 W for Ar. For reactive sputter deposition of nitride materials, nitrogen was incorporated into plasma. This decreases the ion current densities, and the distribution become rough. Figure 7 shows the plasma density and electron temperature on the center of the discharge exit. At 0.15 Pa and 700 W, the plasma density for Ar was 1.04×10^{17} m^{-3} beyond the cutoff density.

Deposition characteristics of linear sputtering source

In this experiment, TiN was deposited by reactive sputter method using a Ti target and a mixture of Ar and N$_2$. Table 1 shows deposition conditions. The deposition characteristics of TiN were investigated. Deposited film thickness was measured by a stylus surface profiler. The atomic composition ratio was analyzed by X-ray photoelectron spectroscopy (XPS). Figure 8 and 9 show deposition rate and atomic composition ratio of N/Ti for various N$_2$/Ar mass flow ratios.

The deposition rate decreases with increasing N$_2$ mass flow ratio. On the other hand, the atomic composition ratio of N/Ti increases with N$_2$/Ar mass flow ratio up to 1.5 and decreases above. The maximum atomic composition ratio of N/Ti = 0.5 was achieved at mass flow ratio of N$_2$/Ar=1.5 and deposition rate of 14.0 nm/min.

Figure 10 shows the thickness profile of the deposited film in the long direction. The thickness uniformity of the film was ±11.3 % within 160 mm in the long direction. The thickness profile reflects the plasma profile, as shown in Fig.6.

Table 1 Deposition condition.

Target	Ti
Working gas	N$_2$/Ar=0.5~2.0
Pressure	0.132~0.141Pa
Microwave power	600~700W
Target voltage	200V
Substrate	Glass

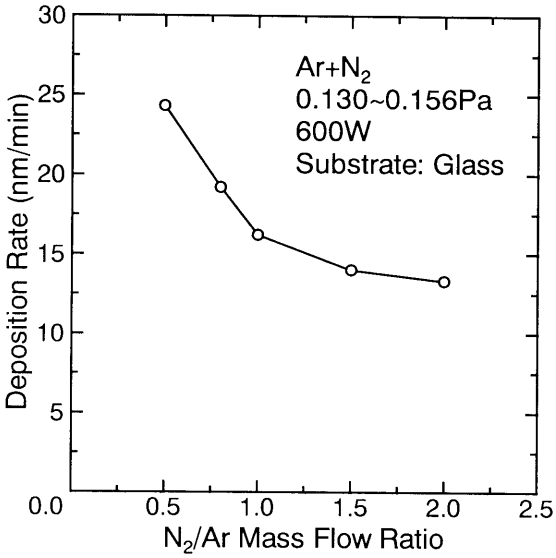

Fig.8 Deposition rate dependence on N_2/Ar mass flow ratio.

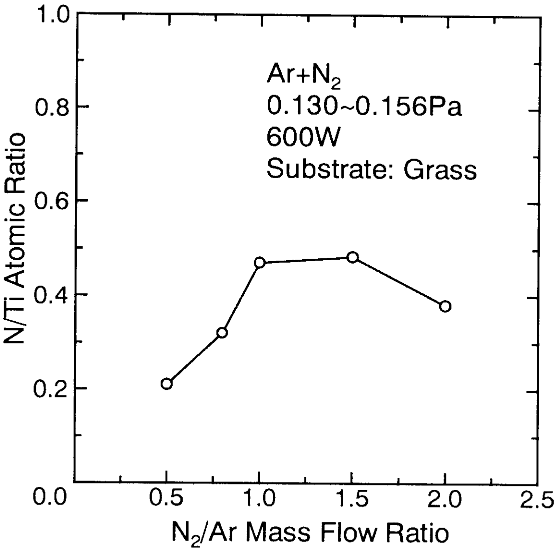

Fig.9 Atomic composition ratio dependence on N_2/Ar mass flow ratio.

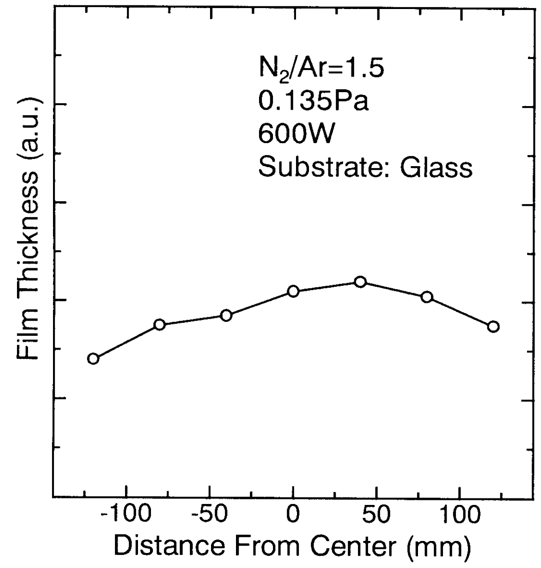

Fig. 10 Spatial distribution of deposited film thickness.

Above the deposition condition, we could not deposit stoichiometric TiN films without substrate heating. With increasing microwave power up to 700W, a stoichiometric TiN film with atomic composition ratio of N/Ti=1.1 was deposited. It is considered that activated N atom increases with microwave power. Hence, the flux of supplied Ti and activated N to the substrate was balance above the deposition experiments. This sputtering source can be deposited stoichiometric films with high deposition rate without substrate heating.

Summary

The linear sputtering source using ECR discharge was developed for reactive sputter deposition. The spatial plasma uniformity was ±7.8 % within 180 mm. The sputtering source successfully deposited TiN film with thickness uniformity of ± 11.3 % within 160 mm. A stoichiometric TiN film deposited at 700 W of microwave power and mass flow ratio of N_2/Ar=1.5.

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