Film Structure Modification in Conventional and Pulsed Dc Magnetron Sputtering

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To modify film structure further in sputter film deposition, the increase in fraction and energy of ions in the flux arriving to substrate is needed. The addition of inductively-coupled-plasma (ICP) to cathode discharge is one of the methods to increase fraction and energy of ions in conventional dc and pulsed dc magnetron sputtering. In this paper film structure modification in dc, pulsed, and ICP assisted pulsed Ti and TiN sputtering has been reviewed.

EXPERIMENTAL METHOD

The high vacuum chamber with a magnetron cathode (55 mm diam. Ti(99.99% purity)) was used in the experiment. A schematic of the apparatus is shown in Fig.1. A cupper one-turn rf antenna with a diameter of 60 mm was equipped about 20 mm above the cathode(not shown in the figure). The power supply used in this experiment was ENI TYPE PRG-50 pulsed power supply. The working gas was Ar or a mixture of Ar and N_2 (for TiN reactive sputtering). The cathode was operated at current regulation mode with a pulse frequency of 50 kHz. A PPM-421 plasma monitor (Balzers) was used to analyze a mass/charge ratio and energy of particles arriving to the substrate. The distance between the cathode surface and the orifice of the plasma monitor is 200 mm. The plasma monitor was operated in the ion collection mode (only ions can pass the energy filter). Substrate used for film deposition was glass.

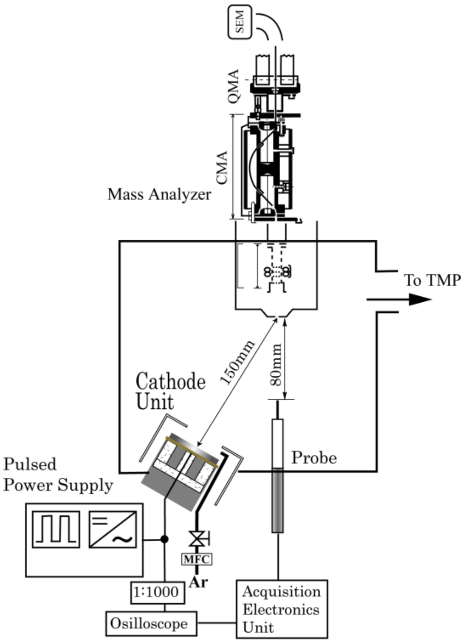

Fig.1 A schematic of the apparatus used in the experiment

ION SPECTRA AND PLASMA ANALYSIS

Energy spectra of Ar^+ and Ti^+ ions in inductively coupled plasma assisted dc and pulsed dc magnetron sputtering is shown in Fig.2. In Ar^+ ion spectra, a sharp hair-pin shape spectrum with a peak energy of about 1eV was obtained for dc sputtering. In Ti^+ spectra, a hair-pin peak with a high energy tail was observed in dc sputtering. For pulsed sputtering, the second peak appears in an energy range in about 40-50 eV in addition to the principal peak at about 1-3 eV in both Ar^+ and Ti^+ spectra. With increasing the ICP-assisting coil power, both peaks in low and high energies in the both of ions spread to the high energy region and divide into doublet.

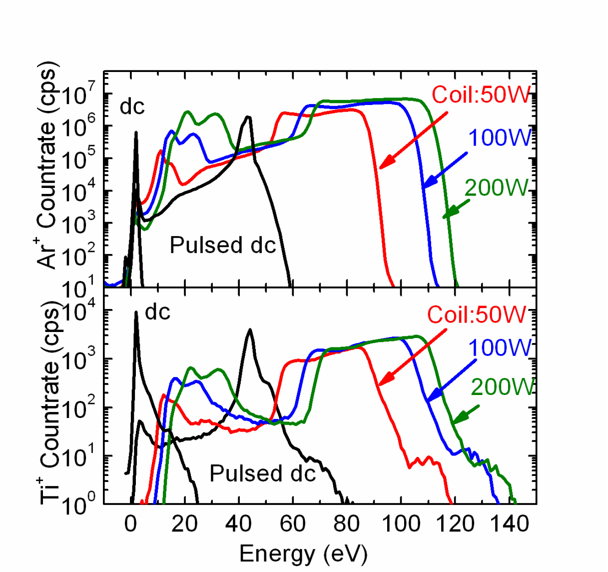

Fig.2 Energy spectra of Ar^+ and Ti^+ ions in inductively coupled plasma assisted pulsed dc magnetron sputtering

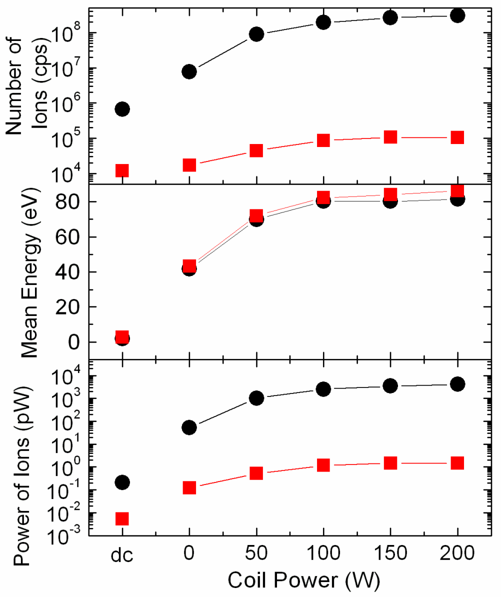

Fig.3 The number of Ar$^+$ and Ti$^+$ ions, power of Ar$^+$ and Ti$^+$ ion, and mean energy of Ar$^+$ (●) and Ti$^+$ ion (■) as a function of ICP-assisting coil power in ICP assisted pulsed Ti sputtering

The number of Ar$^+$ and Ti$^+$ ions, power of Ar$^+$ and Ti$^+$ ion, and mean energy of Ar$^+$ and Ti$^+$ ion as a function of ICP-assisting coil power in ICP assisted pulsed Ti sputtering. The numbers of Ar$^+$ and Ti$^+$ ions arriving to the substrate increase in pulsed sputtering compared to those in conventional dc magnetron sputtering. By the addition of ICP they drastically increase with increasing ICP power. In particular, the numbers of Ar$^+$ and Ti$^+$ ions increase by one order of magnitude in ICP-assisted pulsed sputtering compared to that in conventional dc sputtering. The mean energy of Ar$^+$ and Ti$^+$ ions also increases to about 80-85 eV in ICP assisted pulsed sputtering. As a result of the increase in the quantity and mean energy of the arriving ions, the power transferred to the substrate increases by about two orders of magnitude both in Ar$^+$ and Ti$^+$ ions.

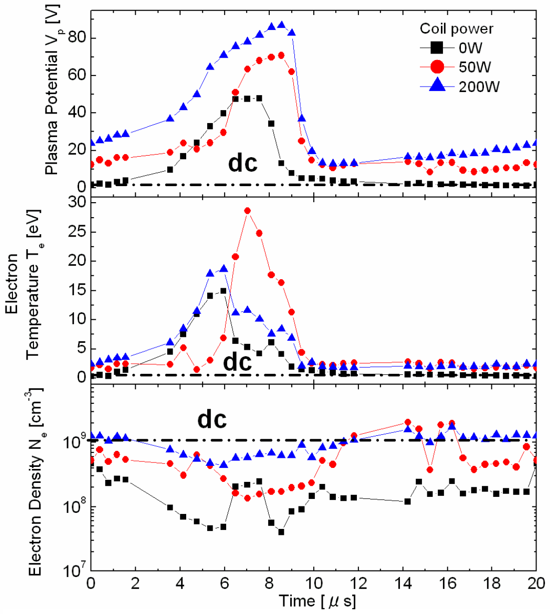

Fig.4 Plasma potential, electron temperature, and electron densities, as a function of time in ICP assisted pulsed Ti sputtering

Plasma potential, electron temperature, and electron densities, as a function of time in ICP assisted pulsed Ti sputtering are shown in Fig.4. Time resolved plasma analysis revealed that, in the phase of negative bias, plasma potential was about 2-3 V, that electron temperature is about 1 eV, and that electron density is 2×10^8 cm^{-3} in pulsed sputtering. The plasma potential and electron temperature in the negative bias phase are almost the same as those obtained for dc discharge. In positive bias phase, plasma potential increases to about 40 V and electron density decreased to less than 1×10^8 cm^{-3} without ICP assistance. By ICP assistance, electron density increases to the almost the same value obtained in the positive phase and plasma potential increases to more than 100V in the positive bias phase. These changes in plasma conditions well agree to the changes investigated in ion spectra measurements.

FILM STRUCTURE MODIFICATION

Cross sectional SEM images of Ti films deposited by dc, pulsed, and ICP-assisted pulsed sputtering are shown in Fig.5. A Ti film deposited by dc sputtering or pulsed sputtering possesses a columnar structure with a large columnar diameter. A Ti film deposited by ICP-assisted pulsed sputtering with an ICP-assisting coil power of 100 W or 200W shows smaller and denser columnar structure. Further, the surface of

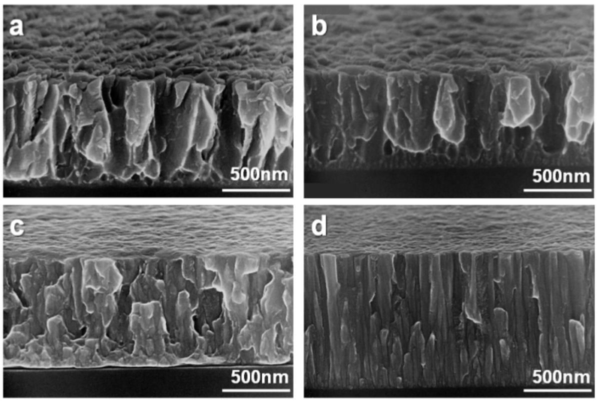

Fig.5 Cross sectional SEM images of Ti films deposited by (a) dc, (b) pulsed, and ICP assisted pulsed sputtering with ICP power of (c) 100W and (d) 200W

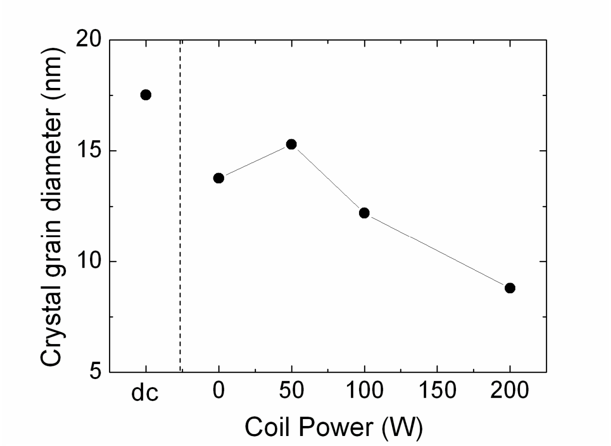

Fig.6 Diameter of crystal grain obtained from the full width at half maximum of the X-ray diffraction peak of (101) of Ti films deposited by dc, pulsed, and ICP assisted pulsed sputtering

the film deposited by ICP assisted pulsed sputtering is much smoother than that of the film deposited by dc sputtering.

In Fig.6, crystal grain diameter obtained from the full width at half maximum of the X-ray diffraction peak of (101) of Ti films deposited by dc, pulsed and ICP assisted pulsed sputtering is shown. The diameter decreases with increasing ICP power in ICP assisted pulsed sputtering.

In Fig.7, average surface roughness of Ti films deposited by dc, pulsed and ICP assisted pulsed sputtering is shown. The roughness decreases with increasing ICP power in ICP assisted pulsed sputtering.

Electrical resistivity of Ti films decreased with an addition of ICP assistance and with increasing the ICP power. Normal reflectance increased with increasing ICP power, showing film surface becoming smoother.

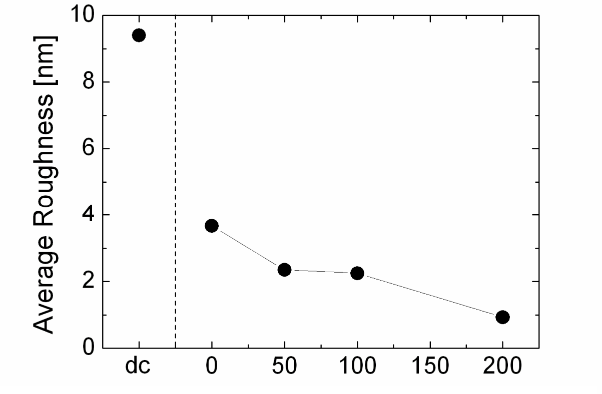

Fig.7 Average surface roughness of Ti films deposited by dc, pulsed, and ICP assisted pulsed sputtering

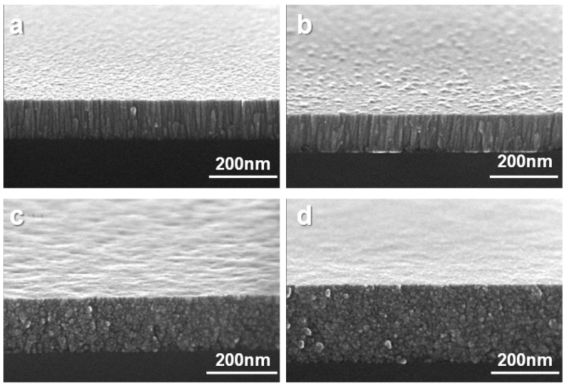

Fig.8 Cross sectional SEM images of TiN films deposited by (a) dc, (b) pulsed, and ICP assisted pulsed Ti-N_2 reactive sputtering with ICP power of (c) 100W and (d) 200W

In Fig.8, Cross sectional SEM images of TiN films deposited by dc, pulsed, and ICP-assisted pulsed sputtering are shown. A TiN film deposited by dc sputtering or pulsed sputtering possesses a fine columnar structure. A TiN film deposited by ICP-assisted pulsed sputtering with an ICP-assisting coil power of 100 W or 200W shows fine granular structure.

The tendency shown in the results of plasma analysis and mass analysis in Ti-N_2 reactive sputtering is almost same to that observed for Ti sputtering.

The results obtained in crystal grain diameter, surface roughness, and electrical properties well explain the tendency of film structure modification in pulsed and ICP assisted pulsed sputtering, *i.e;* with an addition of ICP power, the number and the energy of particles arriving to the substrate increase drastically; as a results of the increase in the energy transferred to the substrate during film growth films become denser and smoother. The ICP assistance is clearly one of the methods modify the film structure in sputtering. However the size and usage of ICP antenna limits the range of its applications.

CONCLUSIONS

It was shown that films structure was modified by ICP assistance to conventional dc and pulsed dc magnetron sputtering. The modification resulted from the increases in fraction and energy of ions in the flux arriving to the substrate. The ICP assistance widens condition windows and enhances film structure controllability in magnetron sputtering.