Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 129-131 A-3-2

Sputtering of Aluminum Film Using Microwave Plasma with High Magnetic Field

S.Takehiro,N.Yamanaka,A.Narai,H.Shindo,S.Shingubara,and Y.Horiike
Department of Electrical Engineering,Hiroshima University
1-4,Kagamiyama,Higashi-Hiroshima,Japan 724

The microwave plasma with twice higher magnetic field (2B mode) than ECR was firstly applied to the sputtering of aluminum film. The tendency to align (111) orientation was observed with decreasing temperature and increasing substrate negative bias on Si (100). The intensive (111) orientation, which is promising for reliability improvement against both electro and stress induced migration, was obtained at -40 C. The perfect filling of the submicron space was achieved at 200C, which is much lower than conventional methods. These properties are ascribable to ion irradiation effect, since ion flux is significantly large for the 2B mode plasma.

1.INTRODUCTION

An aluminum metallization has become one of key technologies which determines the performances of ULSI. Lots of efforts have been devoted for reliability improvement against electromigration and stress induced migration, and contact and via hole filling technologies. In this situation, a new film deposition technology superior to the conventional magnetron sputtering is intensively required. Recently, we found a prominently high microwave plasma ionization under a twice higher magnetic field (2B) than that of ECR (electron cyclotron resonance) [1] condition (1B). 2B mode plasma occurs due to coupling of fast electrons with a microwave whose frequency shifts to higher by Doppler effect for electrons, then resonance condition for magnetic field becomes around 2B.

In this work, we have applied 2B mode plasma with Ar^+ ions for a sputtering of aluminum at very low Ar pressure of $5x10^{-4}$ Torr, aiming at reduction of gaseous contamination in a film. Evaluation of film characteristics such as grain orientations, surface roughness, and step coverage have also been investigated.

2.EXPERIMENTAL

The microwave power of 2.45 GHz was introduced into the sputtering chamber made by stainless steel through the one end as shown in Fig.1. A microwave plasma was produced by applying a divergent magnetic field onto a water cooled cylindrical pure aluminum target with inner diameter 96 mm. For the sputtering of Al, Ar pressure of $5x10^{-4}$ Torr, microwave power of 600W, and the target bias of -600 V were used. Substrate temperature was changed between 300 C and -150 C, and the substrate bias was changed between -120 V and 50 V.

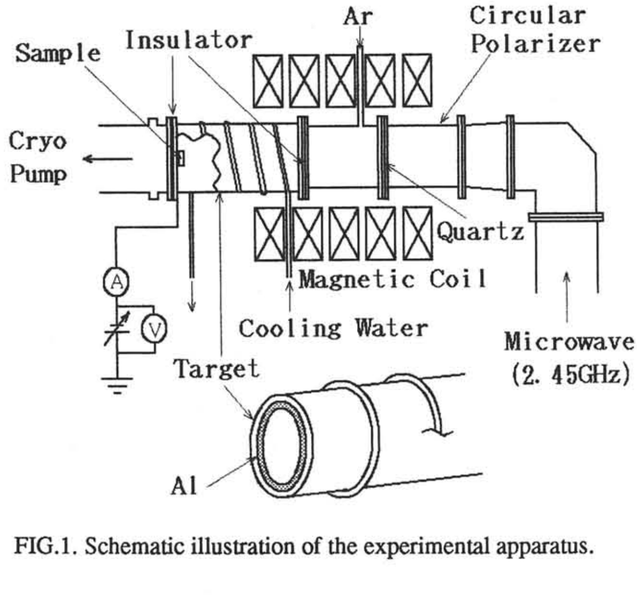

FIG.1. Schematic illustration of the experimental apparatus.

3.RESULTS AND DISCUSSIONS

The deposition rate of Al as a function of magnetic coil current is shown in Fig.2. Two peaks in deposition rate are clearly observed; the one is ascribed to ECR (1B), and the other at 200 A is considered to be due to 2B mode plasma. Axial distribution of ion current density for 1B and 2B mode are shown in Fig.3. It is apparent that spreading of ion flux from the edge of magnetic coil is much enhanced in 2B mode. Consequently, ion current density of 2B mode is much larger than 1B at the substrate.

The substrate temperature dependence of grain orientation for 2B mode was measured by X-ray diffractmetry using Si (100) substrate. X-ray peak intensity ratio for Al (111) to Al (200) as a function of substrate temperature is shown in Fig.4. An intensive tendency to orient (111) with decreasing temperature was observed. A perfect (111) orientation without any other diffraction peak was achieved at -40 C, while both (111) and (100) are formed at 200 C.

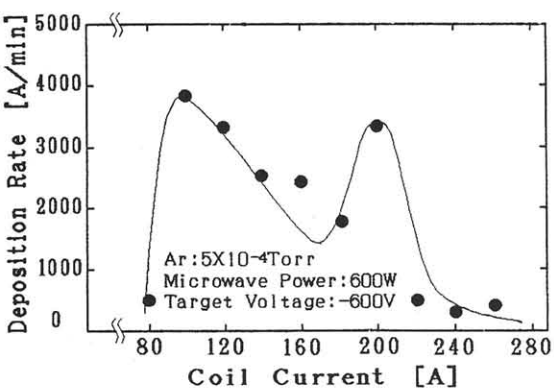

Fig.2. Deposition rate of Al as a function of the magnetic coil current.

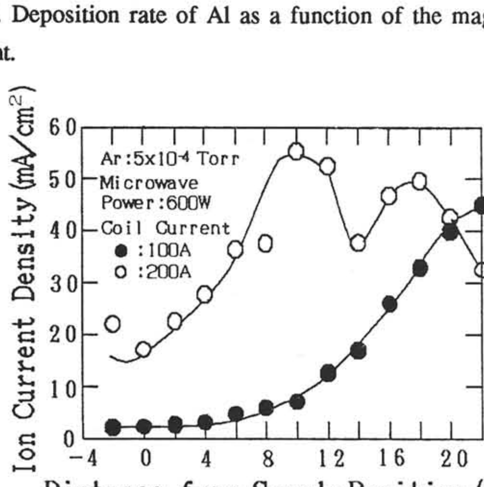

Fig.3. Axial distribution of the ion current density for the coil current 100 A and 200 A. The aluminum target is situated between 6 cm and 26 cm from the substrate.

In order to obtain better (111) orientation, the effect of substrate bias was examined at substrate temperature -40 C. Figure 5 shows a full width at half maximum (FWHM) of Al (111) rocking curve as a function of substrate bias. With increasing negative bias, the FWHM decreased remarkably.

Figure 6 shows step coverage characteristics of 2B mode at various substrate temperature. A planar perfect filling of submicron space was attained even at 200 C (Fig.6-a), which is much lower than conventional DC magnetron sputtering [2]. Step coverage became poor as temperature decreased (Fig.6-b), and an interesting surface morphology which reflected underneath step pattern was observed at -40 C (Fig.6-c). This indicates that the most of incident aluminum particles are perpendicular to the substrate.

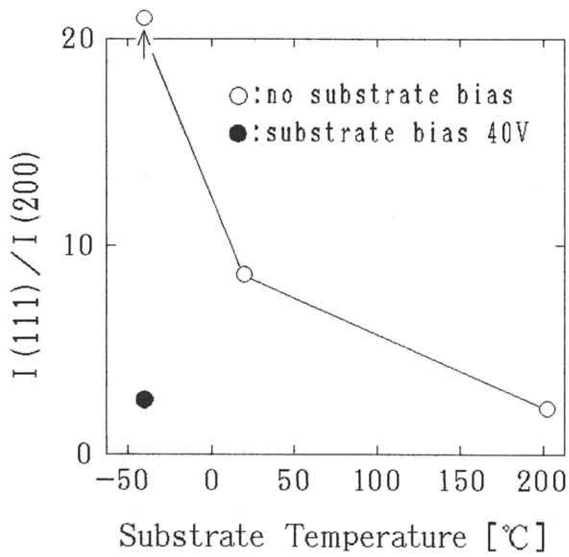

Fig.4. Temperature dependence of X-ray peak intensity ratio of Al (111) to Al (200). The coil current is 200 A.

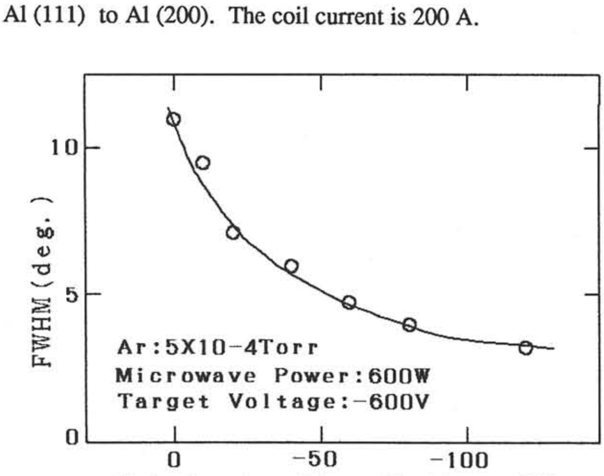

Fig.5. Substrate bias voltage dependence of FWHM. The substrate temperature is -40 C, and the coil current is 200 A.

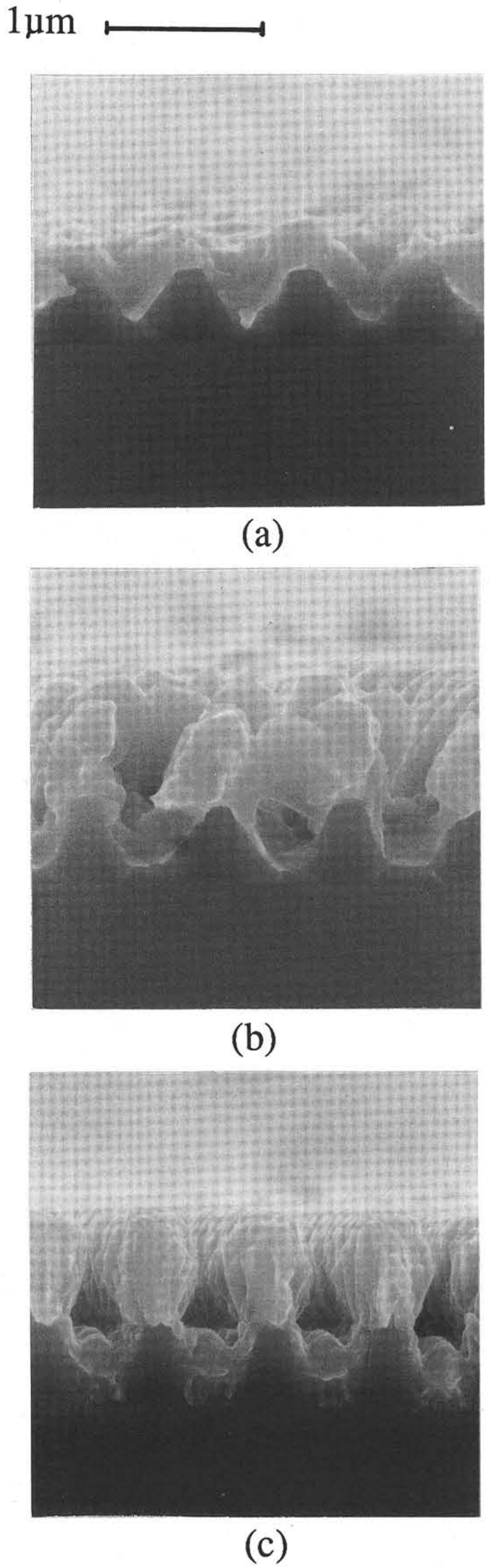

Fig.6.SEM observations of step coverage for submicron line and space at no substrate voltage. Substrate temperature is (a) 200 C, (b) 100 C, (c) -40C.

Considering that the ion flux of 2B mode plasma at substrate was large, the negative bias effect on narrowing FWHM of Al (111) rocking curve is ascribed to the ion irradiation effect [3]. The migration of surface Al atoms knocked by ions may be enhanced by increasing incident ion energy, which results in the highly aligned crystal structure. This effect also assisted the lowering of planalization temperature.

The mechanism for the tendency to align (111) orientation with decreasing temperature has not yet been understood. Nevertheless, it can be said that the system under consideration is not simply governed by surface free energy, and unclarified factors such as strain energy and defect density at an interface or others do relate this phenomenon.

4.CONCLUSIONS

The microwave plasma sputtering using twice higher magnetic field than ECR condition was firstly applied to aluminum deposition at low Ar pressure of $5x10^{-4}$ Torr. The intensive (111) orientation of Al was observed with decreasing substrate temperature to -40 C on Si (100) substrate. The perfect filling of the submicron space was achieved at 200 C at no bias, which was much lower than conventional methods. These properties are ascribed to the ion irradiation effect, since Ar and Aluminum ion densities are very high in 2B mode plasma.

5.REFERENCES

1)H.Shindo,T.Hashimoto,F.Amasaki, and Y.Horiike Jpn.J.Appl.Phys. 29(1990) 2641.

2)M.Inoue,K.Hashizume,and H.Tsuchikawa J.Vac.Sci.Tech. A6(1988) 1636.

3)L.Hultman,U.Helmersson,S.A.Barnett,J.E.Sundgrem , and J.E.Greene J.Appl.Phys. 61(1987) 552.