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Effects of Hydrogen and Bias on Single-Crystal Al Growth on Vicinal Si by DC Magnetron Sputtering

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It has been shown that the crystallinity of single-crystal Al(110) film grown on vicinal Si(100) substrate is improved by adding small amount of hydrogen into the sputtering gas (Ar) and applying the positive substrate bias voltage. By utilizing these effects and the grazing incidence growth, the growth temperature can be lowered to ≤200°C, resulting in the better surface morphology. The excess amount of hydrogen and negative substrate bias cause the degradation of the film quality. The growth model involving the roles of hydrogen and substrate bias has also been proposed.

1. Introduction

The metal interconnection is one of the important issues to determine the reliability of ULSI's. Besides the alternate use of Cu[1)] and Ag[2)], single-crystallization of Al interconnects is one of the solution to improve the reliability. Recently a kind of graphoepitaxy of Al on SiO_2 has been succeeded[3)]. However the growth temperature is still high (500°C) and it might be difficult to obtain a wide-area single crystal by this technique. We have been studying single crystallization of Al by the sputtering method and reported on the electromigration characteristics of the film grown on SiO_2 by lateral epitaxial growth[4,5)]. The main problem is that the lateral length of epitaxial growth is relatively short (≤10 μm for 600°C annealing). This short lateral growth length might be attributed to the growth of polycrystal Al with large grain on SiO_2 during the deposition. To enlarge the lateral-epitaxial growth length, lowering of the growth temperature might be effective because the grain size of the polycrystal Al film on SiO_2 becomes small at low growth temperatures and then the energy to convert the polycrystal film to single crystal becomes small. The surface morphology will be also improved by the low temperature growth.

In order to reduce the growth temperature, we have investigated the effect of hydrogen adding into the sputtering gas and of the substrate bias on the film quality together with already developed 2 step growth[6)] in which the first thin film growth was carried out at grazing condition followed by normal incidence growth.

2. Experimental

Al film (1μm thick) was deposited on hydrogen terminated p-Si(100) 4° off toward [011] direction in an ultrahigh vacuum ($5x10^{-10}$ Torr) dc magnetron sputtering system(Fig. 1). The pressure of the sputtering gas (mixture of Ar and H_2[purified by paradium diffuser : dew point ≤-76°C]) was maintained at $9x10^{-4}$ Torr. The hydrogen content and the substrate bias were varied from 0 to 5 % and from -12 to +35 V, respectively. The two step growth was employed to obtain a high quality film[4)] in which the first thin (0.1μm) film was deposited at 45° incidence from the upstairs direction with respect to the stairway like atomic steps of the vicinal Si surface (Fig. 2), followed by normal deposition (0.9μm in thickness). The X-ray diffractometer with a detectable minimum full width at half-maximum (FWHM) of ~0.18° was used for the evaluation of the film quality. The surface roughness of the film was monitored by the reflectivity of He-Ne laser light.

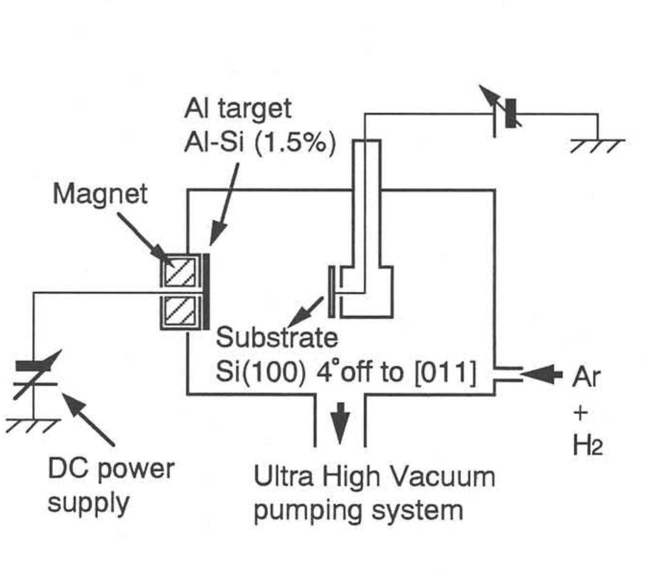

Fig. 1 Schematic diagram of UHV dc magnetron sputtering machine, in which hydrogen gas can be admitted and substrate bias can be applied. The ultimate pressure is $5x10^{-10}$ Torr utilizing 1500l/s cryo pump.

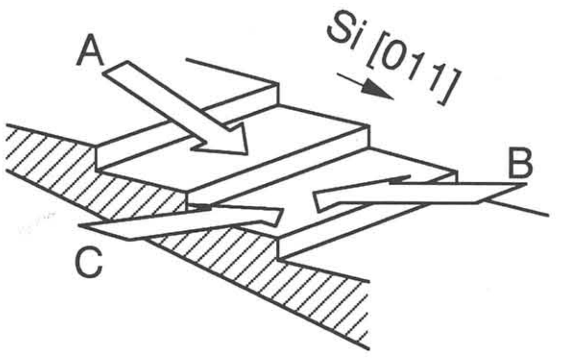

Fig. 2 Three different Al incidence configurations with respect to the ideal atomic step of the misoriented (100)Si surface tilted toward the [011] direction.

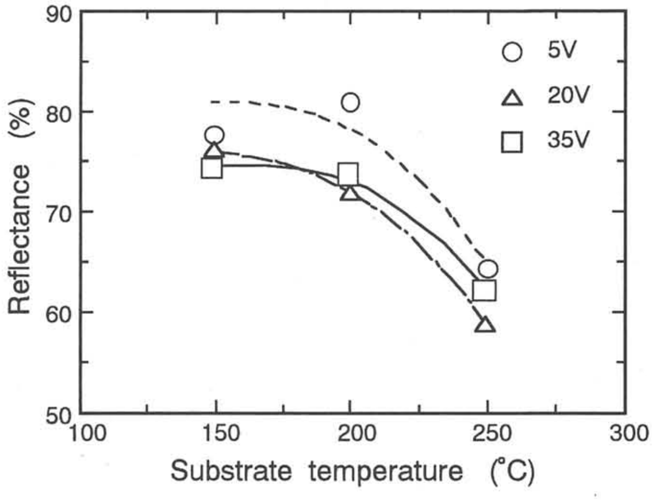

Fig. 4 Substrate temperature dependence of the optical (He-Ne laser) reflectance of Al.

3. Result and Discussion

3.1 Effect of Substrate Bias

Figure 3 shows the bias dependence of the FWHM of Al(220) diffraction peak for the obtained single-crystal Al(110) film. The FWHM decreases with increasing the applied positive bias voltage for the samples grown at 250 and 200°C, while the bias effect becomes small at a lower temperature (150°C). It should be noted that a relatively high quality film can be grown even at 200°C by applying positive bias . The optical reflectance of Al surface is increased with decreasing the growth temperature irrespective of the applied bias (Fig. 4), which indicates that the surface roughness is mainly affected by the growth temperature. Fig. 5 shows the relation between substrate current and applied bias voltage. Since a relatively high current (1.1A at +35 V) flows at positive bias, the improvement of the crystallinity could be attributed to the enhancement of the surface migration of Al atoms excited by the electron shower (~$3x10^{17}$electrons/cm^2.s at +35 V).

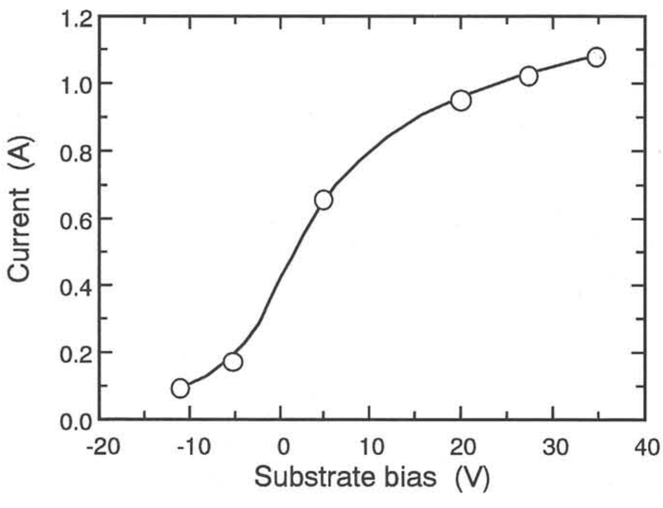

Fig. 5 I-V characteristics of Ar plasma measured at substrate electrode. Target voltage is -500V, Ar pressure is $9x10^{-4}$ Torr. Admission of hydrogen gas does not significantly affect the I-V curve.

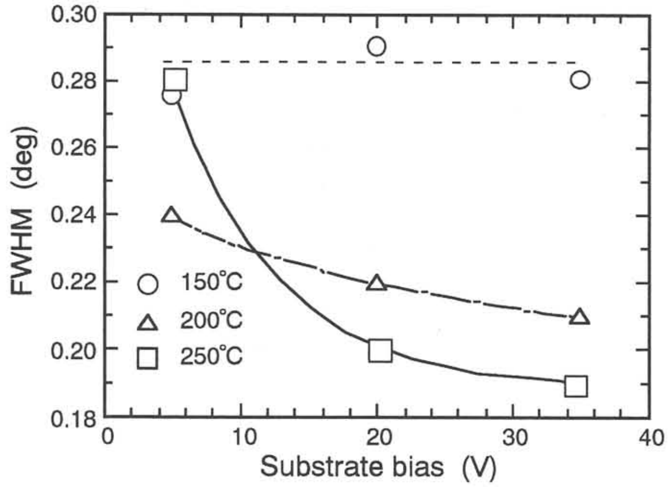

Fig. 3 Substrate bias dependence of FWHM of Al(220) of X-ray diffraction peak.

3.2 Effect of Hydrogen

In Fig. 6 the hydrogen adding effect is shown for the sample grown at 250°C. The effect is remarkable in the negative bias region, which suggests that the hydrogen passivates the surface damage induced by the accelerated Ar^+ ions. It should be noted that at a small hydrogen content (H_2/Ar=0.5%) the FWHM is decreased, whereas the higher hydrogen content (5%) results in the larger FWHM. In Fig. 7 the resistivity and the FWHM is plotted as a function of hydrogen content. The resistivity increases at small hydrogen content region and then decreases at higher content region, being closely related to the FWHM change. Besides the contamination (C, O) elimination effect, a new model is proposed for the hydrogen effect in Fig. 8. For a small amount of hydrogen Al surface is terminated by hydrogen, which enhances

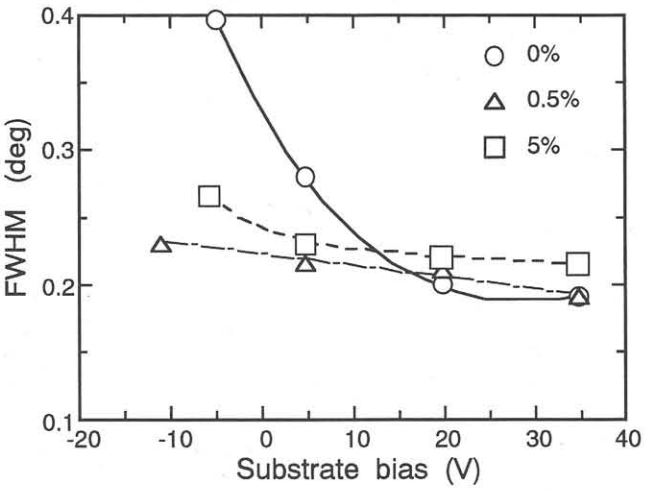

Fig. 6 Substrate bias dependence of FWHM of Al(220) as hydrogen was added into the sputtering gas(Ar) at substrate temperature 250°C.

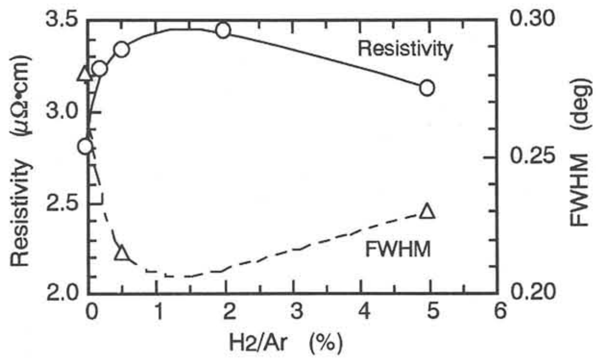

Fig. 7 Hydrogen content dependence of the resistivity and FWHM of Al(220) peak. Thge resistivity was measured for the polycrystal film deposited on SiO2 at zero bias at 400°C, and the FWHM was measured for the single crystal Al(110) grown at a bias of +5V at 250°C.

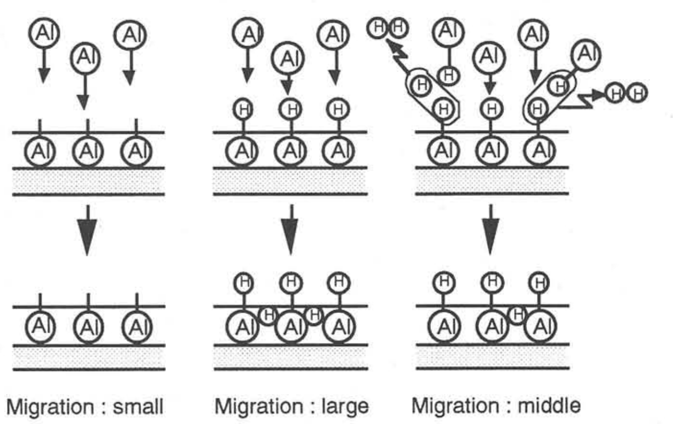

Fig. 8 Model for hydrogen effect in which Al migration is enhanced by the hydrogen termination of Al surface.

the Al migration, resulting in the high quality film. However, the resistivity is increased due to the incorporation of hydrogen. For higher hydrogen content, the hydrogen pulling-out reaction, H+Al-H→Al+H_2 or Al-H(imp.)+Al-H→Al-Al+H_2, where Al-H(imp.) indicates the impinging Al already terminated by hydrogen, will take place due to the very large binding energy of H-H bond (4.53 eV), which may also reduces the hydrogen incorporation in the film. In this case the Al surface migration might be suppressed. This model well explains the experimental data in Figs. 6 and 7.

4. Conclusion

In combining with hydrogen adding, positive substrate bias and the two step growth, the high quality Al film with better surface morphology was grown at low temperatures (≤200 °C). The growth model involving hydrogen was also proposed.

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6) S. Yokoyama et al.: Jpn. J. Appl. Phys. 32(1993)L283.