Extended Abstracts of the 1992 International Conference on Solid State Devices and Materials, Tsukuba, 1992, pp. 176-178 **PA4-1**

Lateral Epitaxial Growth of Sputtered Al(110) over SiO_2 and Its Electromigration Characteristics

S. Yokoyama, H. Ichikawa, S. Shingubara* and M. Koyanagi
Research Center for Integrated Systems, Hiroshima University
*Faculty of Engineering, Hiroshima University
Kagamiyama 1-4-2, Higashi-Hiroshima 724, Japan

Solid phase lateral epitaxy of Al(110) over SiO_2 was succeeded by the annealing of sputtered Al on misoriented Si(100) (4° off toward [011] direction) covered with patterned SiO_2. The orientation dependence of the lateral solid phase epitaxy was examined and its isotropic nature was revealed. Electromigration resistance of Al(110) single crystal was first reported. The EM life time of single crystal Al(110) is more than 100 times longer than the conventional polycrystal Al, however it strongly depends on the current direction.

1. Introduction

With scaling down of device feature size, the electromigration in the metal interconnection becomes serious problem. For solving this problem, new aluminum alloys (Al-Sc[1]), Al-Si-Pd-Nb[2])), multilayered structure (Al/TiN)[3]), new material such as Cu[4]), and single crystal Al[5,6]) are now under investigation. Shingubara et al.[5]) reported the electromigration in single crystal Al(111) grown by gas-temperature-controlled CVD, and the superior electromigration resistance was demonstrated. However, for the single crystal Al(110), the electromigration characteristics has not yet been reported. This paper describes the lateral epitaxial growth of Al(110) on SiO_2 and its electromigration characteristics.

2. Lateral Epitaxy of Single Crystal Al(110) over SiO_2

Al film (2μm thick) was deposited by DC magnetron sputtering in UHV system on vicinal Si(100) (4° off toward [011] direction) covered with a patterned SiO_2 (Fig. 1). The patterned Si wafer was set in the load-lock chamber after RCA cleaning followed by dilute HF (0.5 wt% in H_2O) dipping and final deionized water rinsing for 1 min. By this treatment the hydrogen-terminated Si surface is obtained. It has been reported that a single crystal Al(110) can be grown on Si substrate by this technique without any high-temperature thermal surface cleaning[7]). The range of the substrate temperature and the deposition rate are 50∿280°C and 80nm/min, respectively, and the other detailed conditions are already reported[7]). For

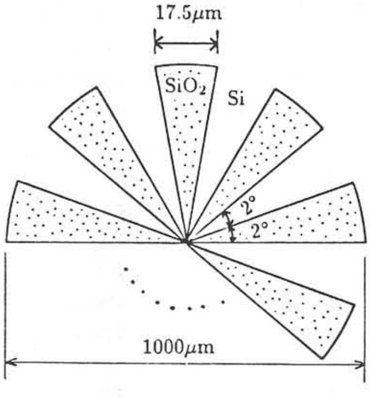

Fig. 1 SiO_2 pattern on Si.

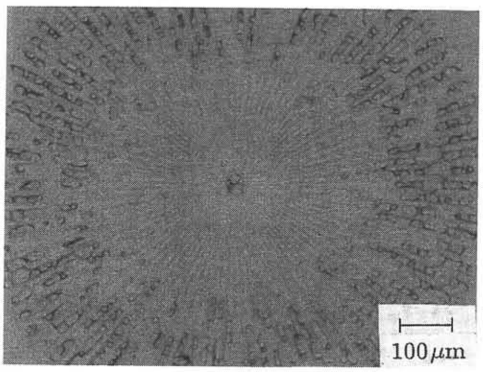

Fig. 2 Optical micrograph of Al on patterned substrate grown at 280°C followed by annealing at 600°C for 30 min.

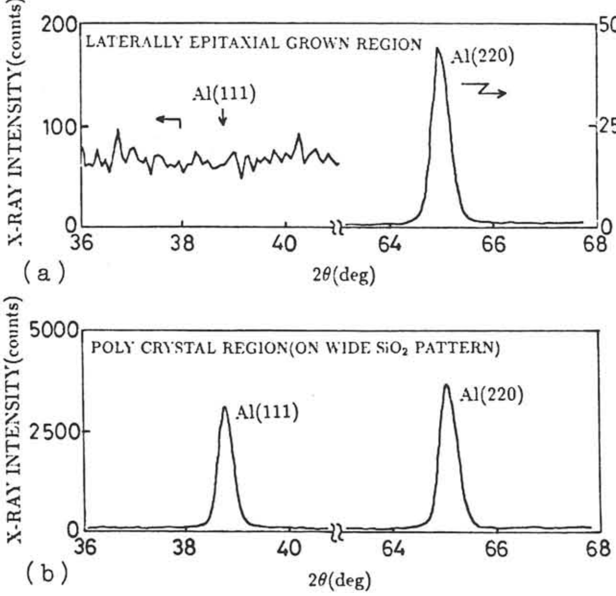

Fig. 3 Collimated (∿Φ100μm) x-ray diffraction patterns for (a) smooth and (b) rough regions.

achieving the lateral solid phase epitaxy (SPE) over SiO_2, the annealing at 300°C∿600°C for 30min was carried out after the deposition of Al in the same vacuum chamber at a pressure of 10^{-9} Torr order. Figure 2 shows the optical micrograph of the grown sample. Near the fringe of the circular SiO_2 pattern, the grains (a few μm) are clearly observed. On the other hand, a relatively smooth surface is obtained within 250μm from the center of the pattern. Figure 3 shows the collimated (∿Φ100μm) x-ray diffraction patterns at (a) the smooth region and at (b) the grain region, respectively. At the smooth region

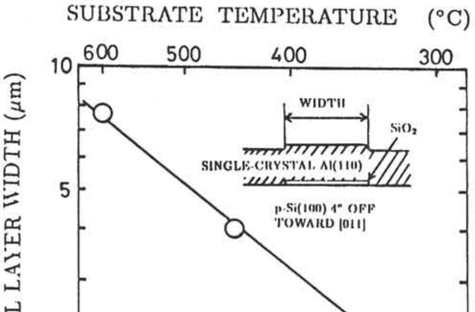

Fig. 4 Temperature dependence of laterel epitaxial-layer width.

Al(220) diffraction alone is observed, while at the grain region both Al(111) and Al(220) peaks are detected. From these results it is concluded that lateral SPE of Al(110) takes place over SiO_2 within a range of 10μm and there is no orientation dependence of the lateral SPE. Figure 4 shows the temperature dependence of the lateral epitaxial-layer width. From this figure the activation energy of ∿0.23eV is obtained, which is much smaller than that in the SPE of GaAs (∿1.6eV)[8] and Si (∿2.6eV)[9] both through amorphous phase. On the other hand, in the SPE of GaAs through polycrystal phase, the activation energy is 0.6eV.[8] In the SPE through polycrystal phase, the temperature dependence seems to be softened for Al and GaAs.

3. Electromigration in Single Crystal Al(110) on SiO_2

Figure 5 represents a structure of the electromigration (EM) test sample. The Al (initially 2μm thick) was thinned by the wet chemical etching to ∿0.6μm in H_3PO_4:CH_3COOH:HNO_3:H_2O=75:15:5:5. After reactive ion etching (RIE) of Al, phosphosilicate glass (PSG) film (140nm thick) was deposited by atmospheric pressure CVD at 400°C. The width and the length of the measured Al wire are typically 2μm and 20μm, respectively. The EM test was carried out by using the 4 probe method with a current density of $2x10^7$ A/cm^2 at ∿200°C in the SEM chamber.

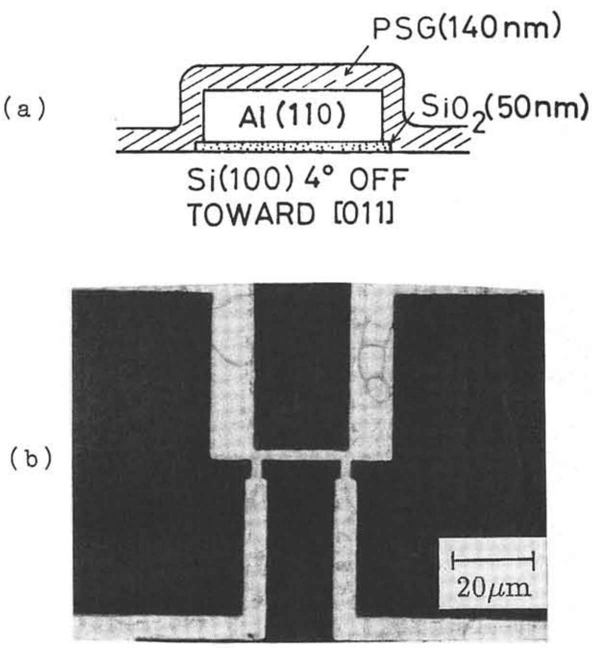

Fig. 5 Sample structure for the EM test, a) cross section, (b) plan view. The EM test samples were grown at 280°C and annealed at 450°C for 30 min.

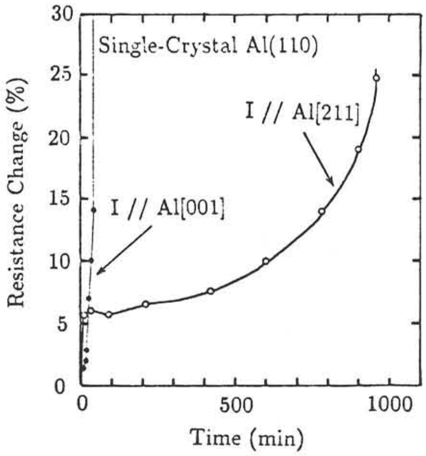

Fig. 6 Resistance change vs elapsed time.

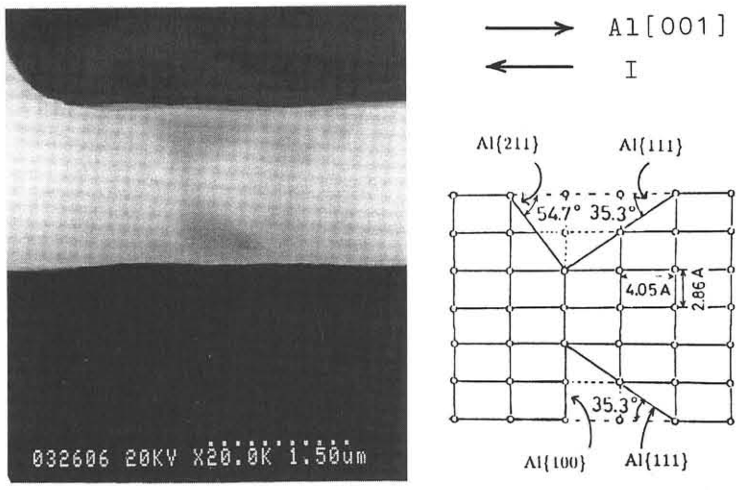

Fig. 7 SEM photograph of EM test sample (I//Al[001]).

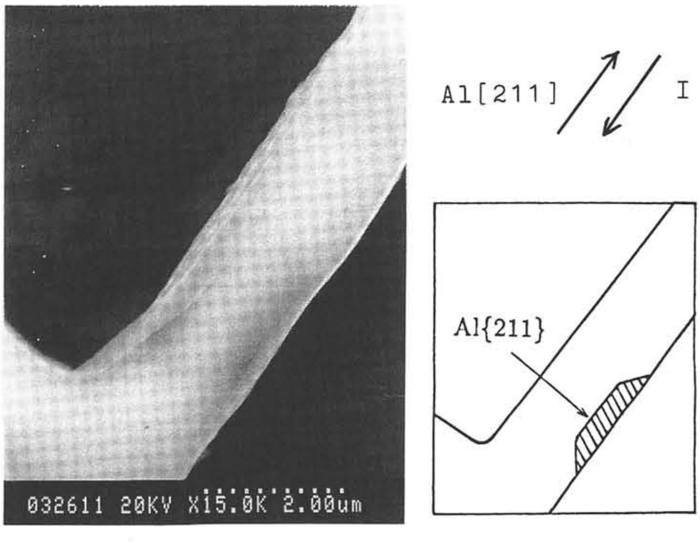

Fig. 8 SEM photograph of EM test sample (I//Al[211]).

The Joule heating alone was employed for elevating the temperature, which was deduced from the resistivity using the temperature coefficient of resistance of pure Al ($4.2 \times 10^{-3}/°C$). Resistance changes in single crystal Al(110) are shown in Fig. 6. For the current pararell to Al[001] (I//Al[001]), EM life time is about 30 min. On the other hand, when I//Al[211] the life time is more than 30 times longer than this. At the same EM test condition, the life time of the conventional polycrystalline Al is a few seconds. From Figures 7 and 8, it is found that Al{111} and Al{211} crystal planes tend to easily appear in the single crystal Al(110). The extremely long life time, when the current is pararell to Al[211], is due to the fact that the EM induced voids lie along the Al wire, while for I//Al[001] the voids lie across the Al wire, resulting in the shorter life time.

4. Conclusions

(1) Solid phase lateral epitaxy of Al(110) was succeeded[10]. The orientation dependence of the lateral SPE was, for the first time, examined and the isotropic nature was revealed.

(2) Electromigration resistance of Al(110) single crystal was first reported. The EM life time of single crystal Al(110) is more than 100 times longer than the conventional polycrystal Al, however it strongly depends on the current direction.

Acknowledgments

The authors are greatly indebted to Profs. Y. Horiike and M. Hirose for their encouragement for this research.

References

1) S. Ogawa and H. Nishimura: IEDM Tech. Dig. p.277, 1991.
2) J. Onuki et al.: ibid. p.43, 1990.
3) T. Kikkawa et al.: ibid. p.281, 1991.
4) M. Otsuki et al. Ext. Abst. '91 Int. Conf. on Solid State Devices and Mat. p.186.
5) S. Shingubara et al. Appl. Phys. Lett. 58, 42(1991).
6) K. Masu et al.: Jpn. J. Appl. Phys. 30(1991)L56.
7) S. Yokoyama and K. Okamoto, Jpn. J. Appl. Phys. 30(1991)3685.
8) S. Yokoyama et al.: J. Appl. Phys. 62(1987)1810.
9) J.A. Roth et al.: Proc. of MRS Meeting, 1981 "Laser and Electron-Beam Interactions with Solids", p.169.
10) Lateral SPE of Al(110) was first reported by K. Kusuyama et al. in Ext. Abst. (52nd Autum Meeting, '91) The Japan Society of Appl. Phys. No.2. p. 720.