Extended Abstracts of the 1991 International Conference on Solid State Devices and Materials, Yokohama, 1991, pp. 757-758 **LD-8-9**

Single Crystal Growth of Al(110) on Si(100) by Ultra-High-Vacuum Sputtering System

S. Yokoyama and K. Okamoto*
Research Center for Integrated Systems, Hiroshima University
*Faculty of Engineering, Hiroshima University
Kagamiyama 1-4-2, Higashi-Hiroshima 724, Japan

Introduction

Single crystal Al is required against electro- and stress-migration. Epitaxial Al films on Si have so far been grown by gas-temperature-controlled CVD[1], ion-cluster-beam[2], MOCVD[3] or sputtering[4] methods. However, Al(110) films on Si(100) were not single crystal so far, but consisted of two domains perpendicular with each other[1,2]. The authors have, for the first time, succeeded in making a single crystal Al(110) film on Si(100) by using a misoriented substrate in UHV sputtering system.

Experimental

A UHV dc magnetron sputtering machine with an ultimate pressure of 9.5×10^{-10} Torr has been used. After RCA cleaning (H_2O:H_2O_2:NH_4OH=5:1:0.05, 90°C, 10 min) followed by diluted HF (0.5 wt% in H_2O) dipping, the Si wafers were quickly set in the load-lock chamber without pure water rinsing. The sputtering deposition was carried out under an Ar (5-N) pressure of 1×10^{-3} Torr and at substrate temperatures ranging from 100 to 350°C, without any high-temperature or plasma surface pretreatment. The sputtering target is a 5-N Al with 1.5 wt% Si. The three kinds of wafers, (100) oriented just$\pm$0.4 deg, 4 deg. off toward [001], and 4 deg. off toward [011], were investigated. A relatively small deposition rate (~30 nm/min, cf. conventionally=80 nm/min) was employed to support the epitaxial growth. The deposited film thickness was ranging from 0.2 to 1.0 μm.

Results and Discussion

X-ray diffraction measurements show that the Al(220) peak at 2θ=65.1° was dominant and other reflections such as (111) or (200) were less than 0.5% of (220) reflection. Table 1 represents the FWHM of the Al(220) rocking curve of the films (1 μm thick) deposited on the three kinds of Si substrates at 250°C. The minimum value of 0.26° was obtained for the [011] off substrate. Figure 1 shows SEM photographs of these samples. Double domain structure is clearly observed for the just and [001] off substrates. On the other hand, one domain becomes dominant and another domain area is shrinked for the [011] off substrate. The growth model is shown in Fig. 2. The unit lattices of Si(100) and Al(110) are 0.384x0.384 (nm^2) square and 0.286x0.405 (nm^2) rectangle, respectively. The mismatch between 0.384nmx3 (Si) and 0.286nmx4 (Al) is relatively small (~0.7%). Consequently, the Al(110) films oriented in two different directions (Al[011]⊥or //Si[011]) can grow on Si(100)[1,2]. For the just orientation substrate, the two directions are equivalent. However, when the atomic steps exist, this symmetry may be broken. The one direction of the Al(110) must preferably orient to satisfy the above lattice matching condition along the step-edge line for minimizing the surface free energy. Consequently, it could be possible to grow single crystal Al(110) when the step edges are aligned to one direction. The ideal step structures on the three kinds of Si substrates are shown in Fig. 2. The [011] off substrate alone satisfies the above condition for obtaining the single crystal Al(110). This model explains the experimental results well. However, the real Si surface is much different from the ideal one, existing some roughness and at random micro-steps. In order to get better surface close to the ideal structure, the Si(100) 4° off toward [011] substrates were thermally oxidized at 1000°C (~60 nm thick) and then the oxide were etched off by the diluted HF solution, since the surface thus treated is known to be flatter than the normally treated surface[5]. Figure 3 shows the FWHM of the Al(220) rocking curve for the substrate treated by this manner (○) as a function of the growth temperature. The FWHM is drastically decreases at higher temperatures than 100°C. The FWHM of the sample without oxidation and etching (△) falls slightly larger point than this curve. It is noticed that at a substrate temperature of 350°C, single crystal Al(110) film was obtained. The SEM photograph of this film is shown in Fig. 4. Although the surface is slightly rugged, double domains are not observed. Figures 5(a) and 5(b) show the RHEED patterns of this film. The clear single spot pattern is observed. The space between the spots are differnet in Fig. 5(a) and 5(b), being consistent with the rectangular shape of the Al(110) lattice unit, while the clear double spot pattern is observed in Fig. 5(c). These results clearly show that the film is single crystal, and the orientation direction is consistent with the growth model shown in Fig. 2(a).

Conclusion

The authors succeeded, for the first time, in the formation of a single crystal Al(110) film on Si(100) substrate by using off-angle substrate and UHV sputtering system at 350°C without any additional high temperature treatment. The growth mechanism of Al(110) single crystal on vicinal Si(100) was discussed based on our new model.

Acknowledgments

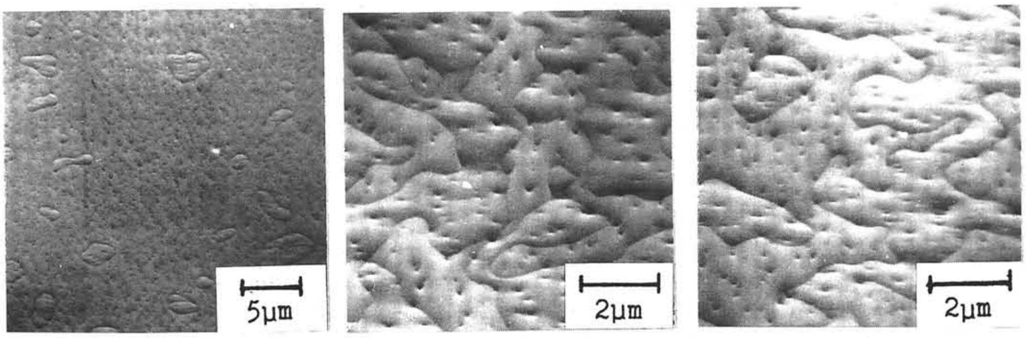
The authors are indebted to Profs S. Singubara, M. Koyanagi, Y. Horiike and M. Hirose for their valuable discussions.

References

1)T. Kobayashi, A. Sekiguchi, N. Hosokawa and T. Asamaki, Jpn. J. Appl. Phys. 27 L1775 (1988).
2)I. Yamada and T. Takagi. IEEE Trans. on Electron Devices, ED-34 1018 (1987).
3)K. Masu K. Tsubouchi, Y. Hiura, T. Matano and N. Mikoshiba, Jpn. J. Appl. Phys. 30 L56 (1991).
4)H. Kuwabara, T. Ohmi, S. Saito and T. Shibata, IEICE Technical Report 88 p.23 (1988).
5)Y. Hokari, Proc. of 1989 VLSI Technology Symposium, p. 265 (1989).

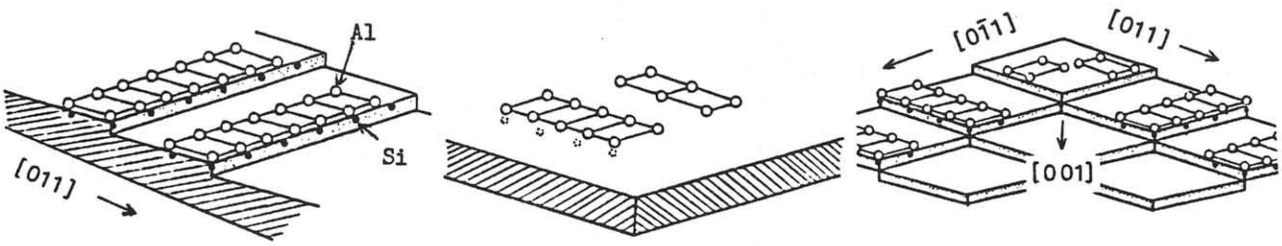
	[011] 4°off	Just	[001] 4°off
FWHM	0.26°	0.35°	0.52°

Table 1 FWHM of Al(220) rocking curve for various substrates.



(a) (b) (c)

Fig. 1 SEM photographs of Al (1µ thick) deposited on Si(100) (a) 4° off toward [011], (b) just±0.4° and (c) 4° off toward [001] at 250°C.



(a) off toward [011] (b) just (c) off toward [001]

Fig. 2 The growth model of Al(110) on Si(100) with different off direction.

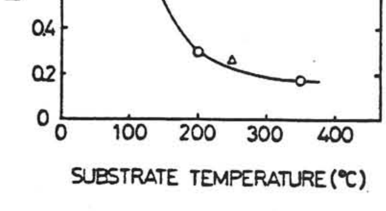


Fig. 3 FWHM of Al(220) rocking curve as a function of growth temperature. Substrate is Si(100) 4° off toward [011], thermally oxidized and the oxide is removed to get flat surface (○). △ is for the normally treated substrate.

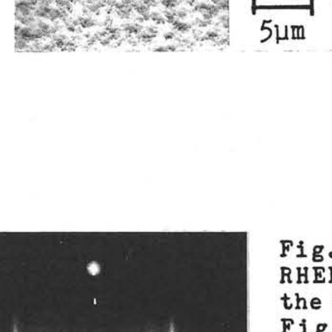
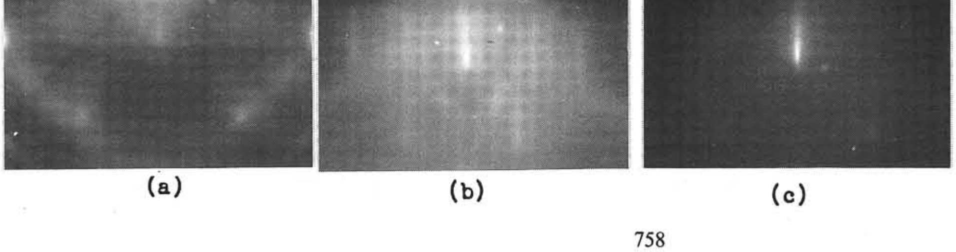


Fig. 4 SEM photograph of Al(1µm thick) on Si(100) 4° off toward [011] with thermal oxidation and removal of the oxide.



(a) (b) (c)

Fig. 5 (a) and (b) RHEED patterns of the sample shown in Fig. 4 at 60 kV along (a) [011] and (b) [0$\bar{1}$1] Si azimuths. (c) is for the double domain Al(1um thick) on just Si(100) grown at 250°C, [011] azimuth.