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High Electron Mobility Silicon Films Grown on Sapphire at High Growth Rate

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Electron mobility and other electrical properties of silicon films on sapphire strongly depend upon the film growth rate.(1) Effects of the growth rate on the film properties were examined and high electron mobility films obtained by using rapid growth. This paper presents the film characterization and discusses the reasons for mobility enhancement.

1. Film preparation: The (100) plane silicon layer was deposited on $(1\bar{1}02)$sapphire at a temperature of 970°C. Film thickness was 1.0~1.3μm. Pure silane was used as the source gas in a purified hydrogen atmosphere. Phosphine was used as the dopant source to achieve $9x10^{15}$~ $5x10^{16}/cm^3$ donor level. Epitaxial growth was carried out in bell-jar type reactor having SiC coated susceptor.

2. Results:

2-1 Electron mobility; The electron mobilities measured by the Van der Pauw method as a function of growth rate and silane content in H_2, are shown in Fig.1 . High mobility, 550 $cm^2/V.sec$, could be obtained in 10~20 μm/min films. Temperature dependences of the mobilities for high growth rate and low growth rate films are typically represented in Fig.2 . It is noticed that the lower the temperature,the more marked the mobility differences. In this work an attempt was made to explane the behaviors of the mobilities by applying the relation of the reciprocal sum of three kinds of mobility;(2) the bulk silicon mobility, the dislocation scattering mobility and the space charge scattering mobility. Dislocation density Nd and space charge scattering factor Ns were determined to fit the curves in Fig.2, by applying a numerical calculations. Nd and Ns values as a function of growth rate are shown in Fig.3 .

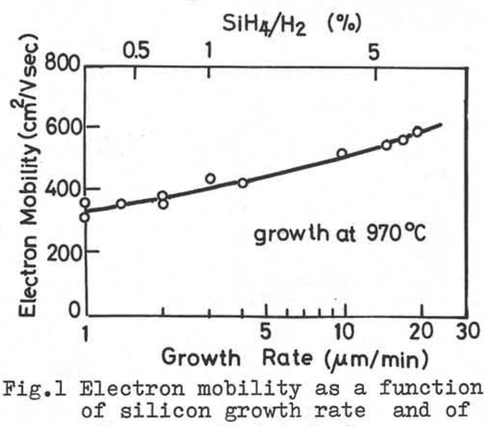

Fig.1 Electron mobility as a function of silicon growth rate and of silane content in hydrogen.

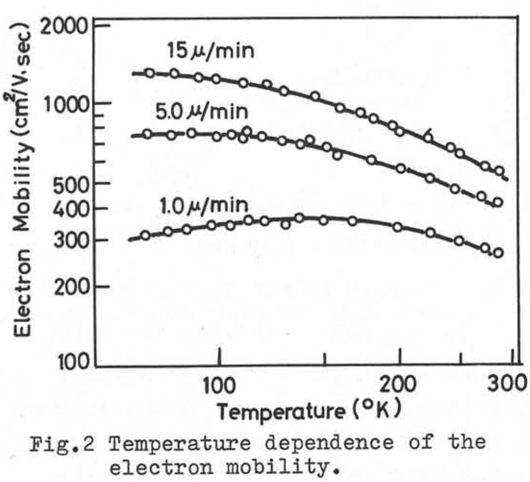

Fig.2 Temperature dependence of the electron mobility.

2-2 Defects; Figure 4 shows the dislocation etch pits and stacking faults revealed by the reagent (fluoric acid 1.8%, potassium iodide 1.3%, iodide 0.7%, methyl alchohol 34%, aqua 62% in molar), which has developed by the authors.[3] This reagents characterization expose defects more clearly than the conventional etchants for silicon. Defects densities as a function of growth rate are plotted in Fig.3. The effect of the rapid growth on the stacking faults is far more distinct than the dislocation density. Especially, at the region of growth rate, 10~20 μm/min, stacking fault density decreases as a factor of 10.

2-3 Aluminum concentration profile; Ion mass-spectrometric analyzer profiles of the aluminum concentration in the boundary region are shown in Fig. 5 for three films grown at 1.0, 9.9 and 20 μm/min. In a silicon region 200Å from the interface, aluminum abruptly decreases for high growth rate films are apparently observed. However, in the 200 ~ 1500Å region, aluminum increases for the films. Auto-doping levels of aluminum are $4\times10^{18}/cm^3$ for each film at 2000Å from the substrate. The concentration smoothly decreases from the 2500Å point to the film surface. Therefore, the rapid growth does not reduce the auto-doping level, excepting for the interface region.

3. Conclusion: Electron mobility enhancements by rapid growth are strongly associating with the decreases of ⟨110⟩ stacking faults in the silicon layer. Dominant mechanism in limiting the mobilities at high growth rate is space charge scattering caused by the stacking faults. Dislocations represented by the etch pits in Fig.4 are not dominant defects in limiting the mobilities. Since the greater part of the auto-doped aluminum is electrically inactive, aluminum does not solely suppress the mobility enhancements.

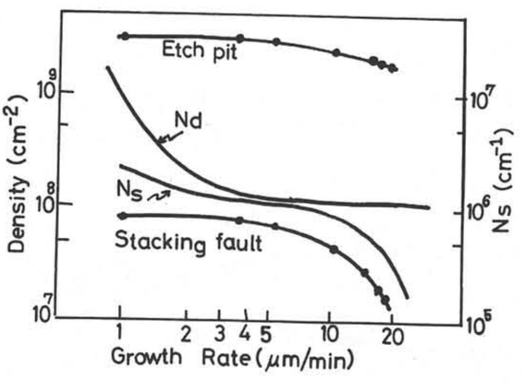

Fig.3 Calculated Nd and Ns, observed dislocation etch pit and stacking fault density versus growth rate.

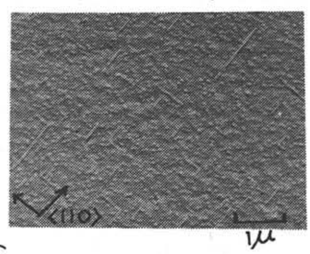

Fig.4 Etch pit and stacking fault on the film surface.

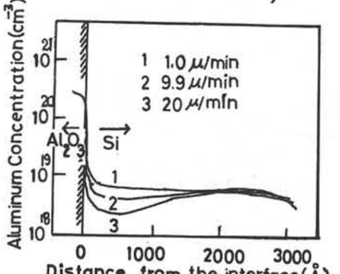

Fig.5 IMA profile of aluminum in the film.

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