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Self-cleaning by Silicon Beam in Molecular Beam Epitaxy

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In molecular beam epitaxy (MBE), crystal defects are induced by contaminants, mainly oxygen, carbon and nitrogen complexes on the surfaces of silicon substrates. These contaminants are mainly formed on the surfaces in atmospheric surroundings before inserting silicon substrates into a vacuum chamber and also formed by residual gases in the chamber. Thus in-situ cleaning and residual contaminant control in the chamber are essential in the crystal defect control of MBE crystal growth.

In Si-MBE, surface cleaning techniques such as high temperature annealing of silicon surface[1] and pre-heat (PH) cleaning capped with amorphous silicon (a-Si)[2] have been reported. In this paper we have introduced the surface self-cleaning effect induced by the continuous impinging of silicon molecular beams. This effect is based on the facts that silicon-dioxide are etched away at lower temperatures by silicon[3] beams and the surface of natural oxide (SiOx) is far less active than that of bare fresh silicon.

Wafers, 3"φ CZ P(111) Si, were rinsed and finally covered by clean SiOx after the NH_4OH-H_2O_2 cleaning process. SiOx films were removed by PH cleaning processes and epitaxial films of 1μm thick were grown. Cleaning effects were evaluated by etch pit densities (EPD) after Sirtl etching for 20 seconds and opticalmicroscopic observation at ×500 and ×1250. We have also evaluated EPD increases due to contaminants coming from residual gases during epitaxial growth.

Figure 1 shows the EPD's of epitaxial films prepared by the various PH (2 min) cleaning processes as follow. A: Simple 850°C PH, B: 850°C PH capped with the 5Å a-Si layer, C: 800°C PH capped with the 5Å Si layer formed in a second at 800°C, D: 800°C PH impinged by Si molecular beams at 0.6Å/S. The figure clearly shows that the process D had very strong self-cleaning effect of silicon surfaces.

Figure 2 shows the relation between Si beam intensity and EPD at various PH temperatures. The epitaxial growth temperature was equal to the PH temperature. The total amount of Si beams during PH was equivalent to 30Å∿ 100Å thick. The figure shows that the cleaning effect becomes higher as the PH temperature is higher and also as the Si beam intensity is lower. These results show the almost same SiOx etching behaviors with the results of Tabe[3] as shown in Fig.3.

Figure 4 shows the relation between EPD and the epitaxial growth temperture when two minute interruption was introduced during epitaxial growth. In the experiment, the optimized PH process D was applied to minimize EPD and the epitaxial growth condition was kept the same before and after the interruption. The figure shows that EPD increased as the growth tempertures decreased. This indicated that at the lower temperatures, the even lower Si beam intensity can not realize the low EPD due to the increased sticking coefficient of the contaminants in the residual gases. This is one of the causes of high EPD at 650°C PH in Fig.2.

In conclusion, self cleaning by the Si beam at PH is very effective to reduce EPD. This is due to that the surface of natural oxide is inactive and that the contaminants are effectively eliminated in the process of natural oxide removal during the self cleaning process. It is also shown that the optimum conditions to minimize EPD exist between Si beam intensities and the PH temperatures, or the contamination due to the residual gases during the cleaning process.

References
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3) M. Tabe; Jap. J. Appl. Phys. 21 (1982), 534.

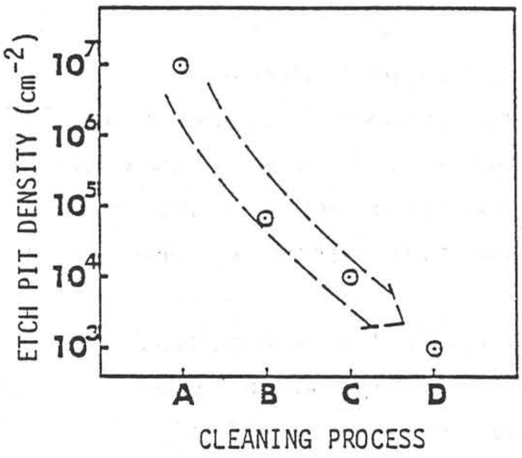

Fig. 1. The relation between EPD and the surface cleaning process.

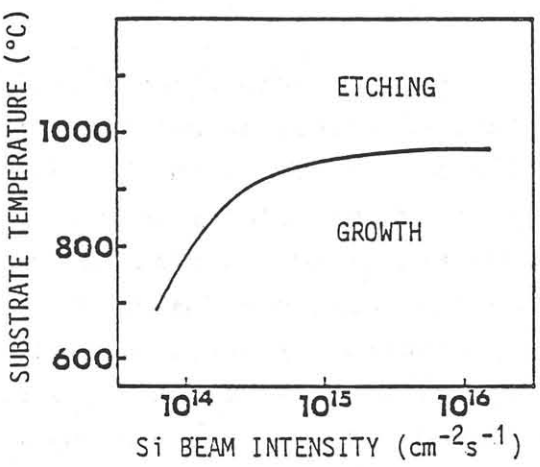

Fig. 3. Critical temperature as a function of Si beam intensity.$^{3)}$

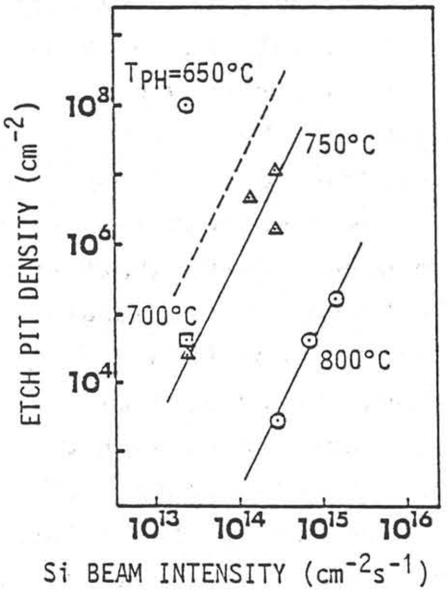

Fig. 2. Self-cleaning effect at various PH temperatures.

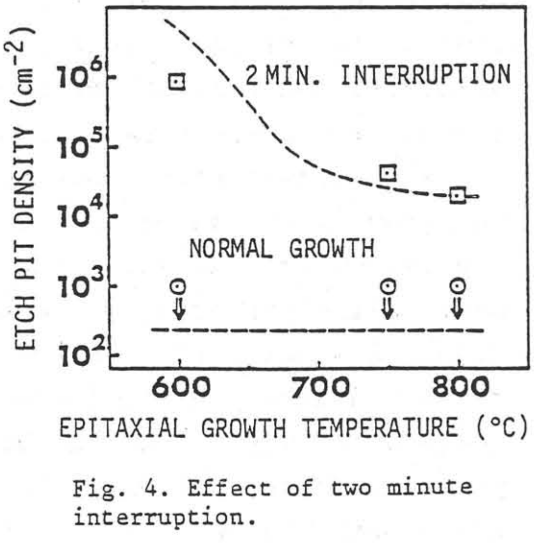

Fig. 4. Effect of two minute interruption.