Defect Reduction of Ge on Si by Selective Epitaxy and Hydrogen Annealing

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We demonstrate a promising approach for the monolithic integration of Ge-based nanoelectronics and nanophotonics with Silicon: the selective deposition of Ge on Si by Multiple Hydrogen Annealing for Heteroepitaxy (MHAH). Very high quality Ge layers can be selectively integrated on Si CMOS platform with this technique. We confirm the reduction of dislocation density in Ge layers using transmission electron microscope (TEM) analysis and Schottky diode electrical behavior. In addition, the analysis of the growth directions and the geometrical shape of the resulting films based on the growth conditions provide further insight to the selective Ge growth mechanism

At 400°C, the growth in the <100> direction is dominant while <311> directional facets are observed giving the film a characteristic trapezoidal shape. This is primarily due to the relatively slow growth rate along the <311> direction at these conditions, and it can be explained by surface migration (Fig 1(a)). As the deposition time is increased, the layer forms into a pyramid-like structure. Once the full pyramid is formed, the film thickness does not increase significantly with further growth time. This can explain the difference in the film thicknesses grown in varying dimensions of SiO_2 windows. However, in Figure 1(b), a different shape is observed when films are grown at 600°C due to high growth rates in both the <311> direction (94 nm/min) and the <100> direction (480 nm/min). This shape is attributed to restricted surface migration by an excessive number of nucleation centers[1].

We analyzed the threading dislocations in the grown films. In Figure 2, it is clearly shown that most of dislocations are at the Ge/Si interface and the surface of the film has low defect density due to the hydrogen annealing[2]. The threading dislocations A, B, and C show that they change direction and terminate at the surface normal to the facet that occurred due to the selective growth. Therefore the density of dislocations is reduced due to combined mechanism of hydrogen annealing and the selective growth.

The current-voltage characteristic of the Schottky diode is also an indication of material quality[3]. Figure 3(b) shows the metal semiconductor(MS) (Ti-Ge) Schottky diode I-V characteristics with 400 °C and 500 °C multi-step growth on a10μm x10μm selective area followed by hydrogen annealing. The I-V characteristic of the Ti-Ge junction shows a Schottky diode behavior with decent rectification which is another indication of the low defect density of the selective MHAH-Ge substrate. At -1V, a diode leakage current 10.15nA is observed.

In conclusion, high quality Ge can be selectively grown on Si by MHAH with a SiO_2 masking pattern. Two different growth mechanisms were observed at 400°C and 600°C resulting from relative growth rates in <311> and <100> directions. The hydrogen annealing and the selective growth can be used to reduce the dislocation density and the surface roughness.

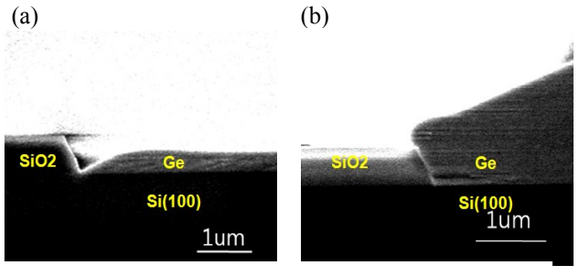

Fig 1. Cross-sectional SEM images in growth temperatures of (a) 400 °C and (b) 600 °C

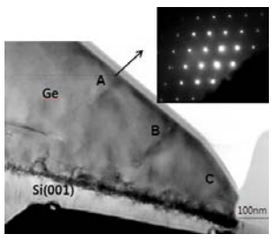

Fig 2. XTEM image and SAED pattern in SiO_2 windows of 10um width with 400 °C and 500 °C growth followed by 825 °C Hydrogen Annealing showing the dislocations under the influence of faceting

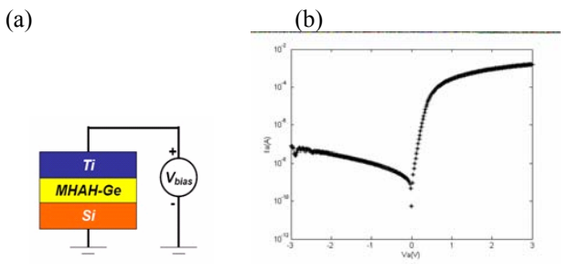

Fig 3. (a) Schematic diagram of Cross-section for I-V measurement (b) I-V characteristics of MS diode(Ti-Ge)

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