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Low temperature growth of homoepitaxial film on Si substrate cleaned *in-situ* by ECR hydrogen plasma

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As device dimensions are reduced into the sub-micron region in pursuit of higher integration density and better circuit performance, low temperature processing, including low temperature cleaning and low temperature epitaxial growth, is becoming important. In order to achieve high-quality epitaxy with low temperature processing, the technique of *in-situ* plasma cleaning has been developed [1, 2]. Although there have been some reports on silicon homoepitaxial growth using low temperatures [3–5], there are few reports of systematic studies on the effect of the growing temperature on the structural quality of epitaxial film. In this study, we have performed low temperature *in-situ* cleaning in order to reduce the interfacial contaminants and we have investigated the feasibility of low temperature growth of the silicon epitaxial layer.

Substrates were 100 mm in diameter, czochralski-grown, p-type (100) silicon with 0.5–20 Ω-cm resistivity. The wafers were RCA cleaned and HF dipped for 20–30 s in 10:1 aqueous solutions and rinsed in DI (deionized) water and then dried using a spin-dryer. All the processes were performed inside a class 100 cleanroom and it took only 10 s to load the wafer into the load lock chamber of the CVD reactor after the wafer was dried. After the wafers were transferred and loaded onto the heater stage, the main chamber was pumped down and ultimately a vacuum of $1–2 \times 10^{-8}$ Torr was attained.

In-situ predepositon wafer cleaning was done using ECR hydrogen plasma. ECR hydrogen plasma is able to deliver a higher density of low energy and light hydrogen ions to the wafer, resulting in highly efficient cleaning without substrate damage [2]. The ECR chamber was at the side of the CVD chamber. The ECR was operated in the 2.45 GHz S-band microwave frequency. Depositions were achieved by flowing 10 standard cubic centimeters per min (sccm) SiH_4 without carrier gases, immediately after the plasma was extinguished. We applied *in-situ* cleaning conditions with a microwave power of 300 W, DC bias of 10 V, pressure of 1 mTorr, and we varied the cleaning temperature in the range of 550 °C–660 °C. Subsequently we deposited the silicon epitaxial layer at the same temperature as used for *in-situ* cleaning for 100 min.

The thicknesses of the grown silicon epitaxial layers were measured as 100–320 Å, 1300 Å, and 1900 Å, at temperatures of 550 °C, 600 °C, and 660 °C, respectively. This indicates that the growth rate of the Si epitaxial layer increases with increasing growth temperature. Also the film thickness in the center of the wafer (320 Å) was much greater than that at the edge of the wafer (100 Å) when the growth temperature was 550 °C. Since the thickness of the epilayer-substrate interface is related to the degree of defectiveness, we measured the interfacial thickness from the XTEM images, revealing that the interfacial thicknesses at temperature of 550 °C, 600 °C, and 660 °C, respectively, were 30–50 Å, 22 Å, and 7–15 Å.

Fig. 1 shows the XTEM images of the epitaxial layer and the epi/substrate interface at temperatures of 550 °C and 660 °C. It is noteworthy that a defect-free epitaxial layer is deposited at a temperature of 550 °C. Fig. 2 shows the interfacial oxygen and carbon concentration at temperatures of 550 °C and 660 °C, based on SIMS data, revealing that considerable amounts of oxygen at the epilayer/substrate interface are eliminated by the *in-situ* surface cleaning. Regarding the interfacial carbon concentration, the integrated doses were about 1.7×10^{13} cm^{-2} and about 1.7×10^{14} cm^{-2}, respectively, at temperatures of 550 °C and 660 °C. Regarding the interfacial oxygen concentration, the integrated doses were about 1.5×10^{15} cm^{-2} and about 1.0×10^{14} cm^{-2}, respectively, at temperatures of 550 °C and 660 °C. We have thus revealed that the interfacial carbon and oxygen concentration increase and decrease, respectively, with increasing *in-situ* cleaning and growing temperature. Since the interfacial oxygen is responsible for defects in the epitaxial layer and the epi/substrate interface [2], the SIMS data agree with the XTEM image, indicating the dependence of interfacial thickness on the oxygen concentration. Further systematic study is necessary to reveal the effect of carbon on the generation of defects.

In summary, we have demonstrated the growth of defect-free epitaxial layer at a low temperature, 550 °C. We have applied low temperature *in-situ*

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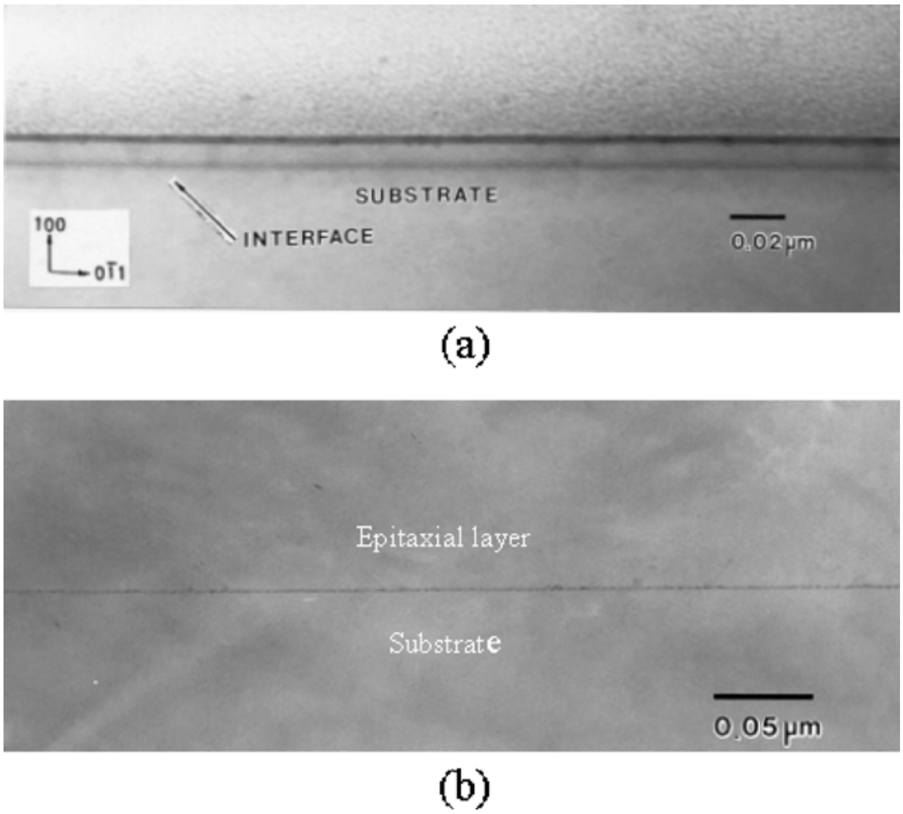

Figure 1 XTEM image of silicon epilayer and the interface, *in-situ* cleaned with a microwave power of 300 W, DC bias of 10 V, pressure of 1 mTorr. The *in-situ* cleaning and deposition temperature is set to (a) 550 °C and (b) 660 °C. A high-quality epitaxial layer is produced by applying *in-situ* plasma cleaning.

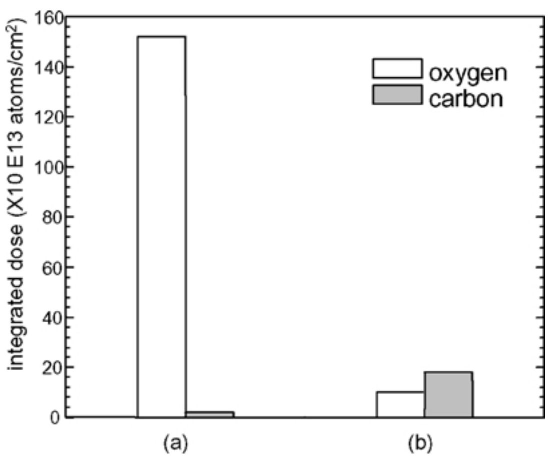

Figure 2 Column bar graph showing the effect of *in-situ* cleaning and growing temperature on the interfacial oxygen and carbon concentration. The *in-situ* cleaning and deposition temperature is set to (a) 550 °C and (b) 660 °C.

cleaning using ECR hydrogen plasma in order to reduce the surface contaminants. The epilayer/substrate interface at 550 °C had a higher oxygen concentration than that at 660 °C. XTEM images reveal that the epi/substrate interface at 550 °C is thicker than that at 660 °C.

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