Growth of high-quality SiGe films with a buffer layer containing Ge quantum dots

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Thin strain-relaxed SiGe buffer layers are of particular importance for high-speed sub-100-nm CMOS devices. To achieve this objective, several methods, such as those using a low-temperature Si, ion-implanted Si or compliant substrates, have been employed [1]. In this work, we demonstrate a simple and efficient method to grow high-quality relaxed SiGe films with the use of a buffer layer containing Ge quantum dots (QDs).

All structures investigated in this work were grown at 600 °C in a UHV/CVD system. Pure SiH₄ and 5% GeH₄ diluted in He were used as precursors. Pure SiH₄ and 5% GeH₄ diluted in He were used as precursors. A 60-nm-thick Si buffer was first grown. After depositing the Si buffer, a 13.1 eq-ML Ge layer was then deposited to form the self-assembled Ge QDs. Finally, a 500-nm-thick Si₀.₈Ge₀.₂ film followed by a 20-nm-thick strained-Si layer were grown on the 1-, 5- and 10- and 20-period Ge QDs/Si bilayers with a 20 nm Si spacer.

Figure 1(a) shows the XTEM image of the Si₀.₈Ge₀.₂ film grown on the 10-period Ge QDs/Si bilayers. It is evident that the dislocations are mainly confined in the Ge QDs multilayers, leaving the top SiGe layer free of threading dislocations. The Ge QDs in the buffer layers play a crucial role in decreasing the threading dislocation density and avoiding pile-ups of the dislocations, as shown in Fig. 1(b) and (c). Figure 2 shows an as-etched sample with 10-period Ge QDs/Si bilayers. The threading dislocation density was measured to be $2.0 \times 10^5$ cm⁻². The root mean square roughness was measured to be about 3.4 nm. Figure 3 shows the Raman spectrum of a sample with the 10-period Ge QDs/Si bilayers. Utilizing the Si-Si and Si-Ge peaks, the Ge composition in the uniform layer and residual strain were obtained to be 20% and 11%, respectively. It is worthwhile to point out that the strain relaxation of the SiGe epilayers was enhanced markedly with the increase of periods of Ge QDs layers up to 10 periods, as shown in the inset of Fig. 3.

Long-channel strained-Si n-MOSFETs with various relaxed Si₀.₈Ge₀.₂ substrates were fabricated to extract the effective electron mobility $\mu_{\text{eff}}$ in the strained-Si channel. Figure 4 shows the schematic diagram of surface-channel strained-Si n-MOSFETs on relaxed Si₀.₈Ge₀.₂ with the multiple QDs layers. As shown in Fig. 5, the peak electron mobility for the device using multiple QDs buffer layers was found to be 90% higher than that of Si control device, and slightly higher than that of device with a graded buffer layer. In addition, these strained-Si devices also show the similar enhancement of the output current in the I-V characteristics.

In conclusion, a simple method to grow the high-quality, thin, strain-relaxed SiGe films with a buffer layer containing Ge QDs by UHV/CVD is developed. The Si₀.₈Ge₀.₂ films grown on the 10-period Ge dots/Si bilayers were demonstrated to have a threading dislocation density of $2.0 \times 10^5$ cm⁻² with a residual strain of only 11%. The work demonstrates a useful way to fabricate high-speed strained-Si or integration with III-V devices.

References
Fig. 1 XTEM images of (a) Si$_{0.8}$Ge$_{0.2}$ film grown on the 10-period Ge QDs/Si bilayers, (b) and (c) magnified view of a selected region of the buffer layer, where M indicates the misfit dislocations.

Fig. 2 Normaski image of an as-etched sample with 10-period Ge QDs/Si bilayers. The inset shows the AFM image of an as-grown sample surface.

Fig. 3 Raman spectrum of a sample with 10-period Ge QDs/Si bilayers. Inset is a plot showing the variation of relaxation with the period of the QDs/Si bilayers.

FIG. 4 Schematic presentation of strained-Si n-MOSFETs on relaxed Si$_{0.8}$Ge$_{0.2}$ with the multiple Ge QDs buffer layer. (gate length = 100 µm, gate oxide = 30 nm)

Fig. 5 Effective electron mobility $\mu_{\text{eff}}$ of strained-Si n-MOSFETs with various buffer layers and Si control device as a function of effective electric field $E_{\text{eff}}$ (L= 100 µm, W=200 µm).