Extended Abstracts of the 22nd (1990 International) Conference on Solid State Devices and Materials, Sendai, 1990, pp. 1151-1152

LN-D-1

Suppression of Interfacial Mixing in Si/Ge Superlattices by Sb Deposition

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Atomic mixing at Si/Ge interfaces in strained layer superlattices (SLS's) is investigated by means of SIMS and XPS. The interfacial mixing is attributed to surface segregation of Ge atoms on which Si layer is commensurately grown during MBE. It is demonstrated that the surface segregation is remarkably suppressed by depositing submonolayer Sb atoms on Ge layers before Si overgrowth and that Ge layers are revealed to be confined to within 0.8 nm.

Recently, atomic mixing has been reported at the Si/Ge interfaces in SLS's formed by molecular beam epitaxy (MBE)[1]. Although the origin of the mixing has been attributed to surface segregation, interdiffusion or Ge island formation during MBE growth, it has not been clarified which process dominates. It is of primary importance to understand the mechanism of the interfacial mixing to fabricate SLS's with interfacial integrity. Reduction in the atomic mixing of Ge with overlying Si layers have been demonstrated by depositing surface segregants, As[2] and Ga[3], on top of the Ge layer. Arsenic is, however, not favorable to Si-MBE because of the lack of flux controllability. Therefore, it seems sensible to investigate whether mixing suppression is effected by Sb deposition, since Sb is the most useful n-type dopant in Si-MBE.

We investigated the interfacial mixing of Si/Ge SLS's commensurately grown by MBE, with the aid of secondary ion mass spectrometry (SIMS) and X-ray photoemission spectroscopy (XPS).

Ge atoms were depth-profiled in Si/Ge SLS's grown at 500°C (Fig. 1). The SLS's consist of 8 periods, each of which contains 3 ML Ge and a 30 nm thick Si layer. 0.75 ML Sb atoms were deposited only on the surface of the 5th Ge layer. It can be seen in Fig. 1 that the profile exhibits a sudden change at the 5th Ge layer and that the profile of the following Ge layers becomes significantly sharpened. More quantitatively, the change in the profile is characterized by leading slopes. 0.59 dec/nm and 0.23 dec/nm are obtained for Ge atoms covered with and without Sb respectively. The difference in the profile of Ge layers clearly demonstrates that Sb atoms persistent on the growing surface suppress the mixing of Ge with overlying Si atoms.

XPS measurements were conducted on samples consisting of a single 4 ML thick Ge layer on Si followed by a Si overlayer with varying thickness grown at 500°C. Fig. 2 shows normalized photoelectron intensities from Ge covered with and without Sb (0.75 ML). Unaltered intensities from Sb regardless of the overlayer thickness indicate strong segregation of Sb. It is noteworthy that Ge atoms are traceable even after 10 nm thick Si overlayers are grown, when Sb is not deposited. In contrast, when Sb is deposited on the Ge layer, the intensiy of Ge attenuates rapidly after Si overgrowth. Intensities of Ge can be calculated by taking Ge distributions into account. The excellent agreement between experimental and calculated intensities indicates that the interfacial mixing in Si/Ge SLS's is predominated by the surface segregation of Ge during Si overgrowth. It is also shown that the surface segregation of Ge is effectively suppressed by deposition of Sb atoms and that Ge atoms are located within the region narrower than the electron escape depth, 0.8 nm.

In conclusion, it was found that the Si/Ge interfacial mixing in SLS's is dominated by surface segregation of Ge atoms during MBE growth. The suppression of the surface segregation of Ge was successfully demonstrated by submonolayer Sb deposition. Ge atoms were revealed to be confined in a region narrower than 0.8 nm simply by depositing Sb on Ge surfaces.

The authors acknowledge S.Ohtake for technical support.

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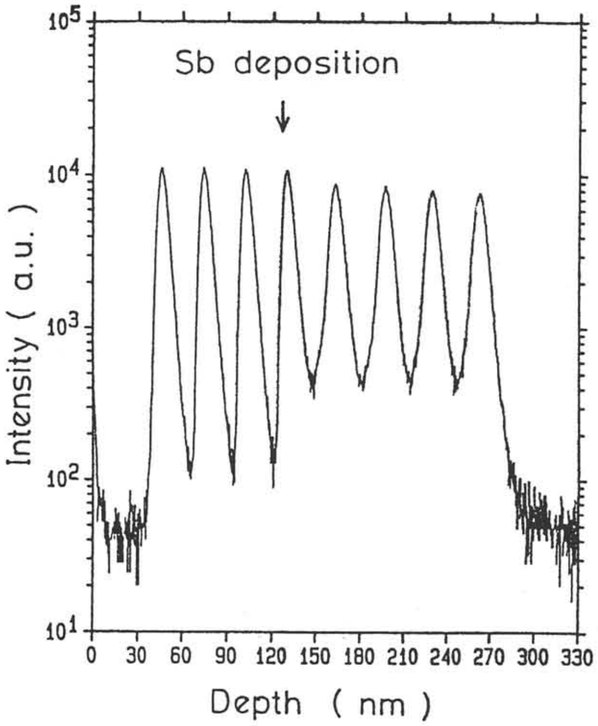

Fig. 1 SIMS profiles of Ge in Si/Ge SLS's. 0.75 ML Sb atoms are deposited on top of the 5th Ge layer (arrow) before Si overgrowth.

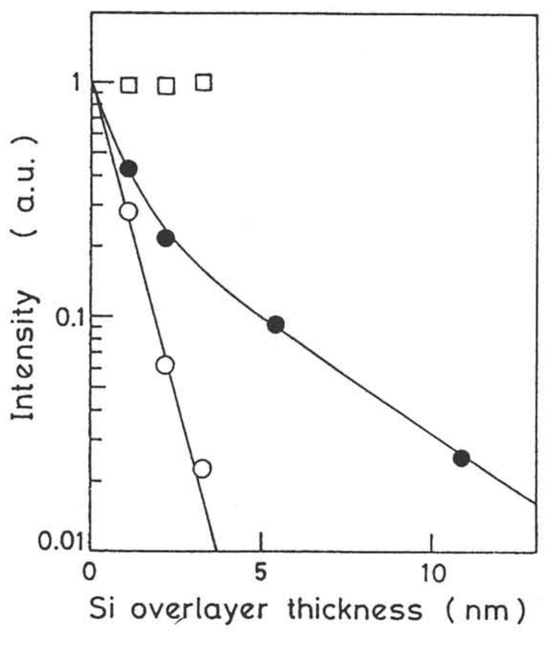

Fig. 2 XPS intensity of Ge and Sb against Si overlayer thickness. Filled (●) and open (○) circles represent the intensities of Ge covered with and without Sb before Si overlayer growth respectively. The intensity of Sb is shown with squares.