Direct growth of InAs/GaSb type II superlattice photodiodes on silicon substrates

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Abstract

In this poster, p-i-n InAs/GaSb* type II superlattice photodiodes were directly grown on Si* substrates. The superlattice structures were grown monolithically on miscut Si substrates via a 10nm AlSb* nucleation layer. Interfacial misfit array technique was used to accommodate the large lattice mismatch between III-Sb epi-layers and Si. Atomic force microscopy and X-ray diffraction measurements revealed degraded material quality of type II superlattices grown on Si, compared with the sample grown on GaAs. Photoluminescence characterization indicates comparable optical properties with about 39% deduction of peak intensity. Dark current measurements were also used to study the electrical properties of the samples.

Method

All epi-layers were directly grown on a Si(100) substrate by molecular beam epitaxy (MBE). Firstly, the Si substrate was heated in ultra-high vacuum at 900° C for 30 minutes to fully remove surface native oxide. After this, the substrate was cooled down to 400° C and a 10nm AlSb nucleation layer was deposited by the migration enhanced epitaxy. Then, the growth temperature was raised to about 500° C and a buffer was grown, which consisted of two superlattices each followed by 500nm GaSb. The superlattices, 100nm in thickness, were made from alternating GaSb and AlSb layers. The growth of the superlattices was performed at a lower substrate temperature. Each period consisted of 10ML (monolayer) GaSb and 10ML InAs. The lattice constant of InAs is 0.75% smaller than that of GaSb and a thin InSb layer within 1ML was inserted between the InAs and GaSb layers for strain balance[1]. The T2SL photodiodes had a standard p-i-n structure with 500nm p-region, 2µm intrinsic region, and 500nm n-region. Finishing with a heavily doped 50nm GaSb top contact layer. A reference sample with the exact same T2SL photodiode structure was grown on a GaAs(100) substrate with 1µm GaSb deposited on the GaAs surface after 200nm GaAs buffer instead of the AlSb nucleation layer.

** Si (Silicon), In (Indium), As (Arsenic), Ga (Gallium), Sb (Antimony), Al (Aluminum)*

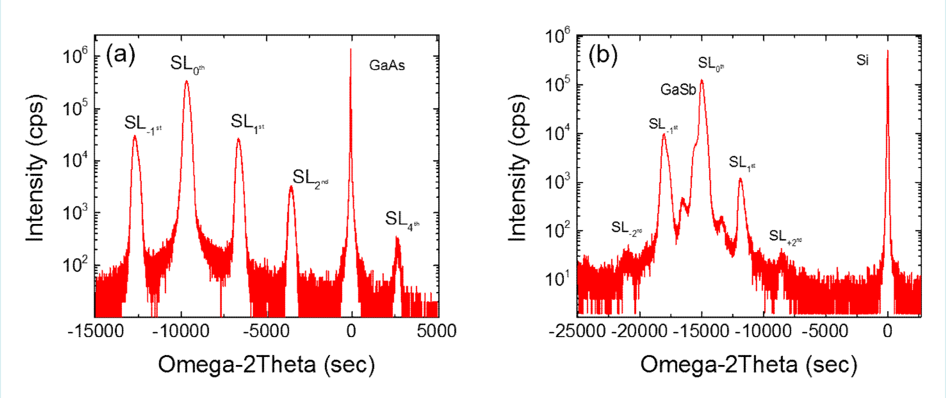

Figure 2: High resolution omega-2theta scans of the T2SLs grown on (a) GaAs substrate and (b) Si substrate

Results and Discussion

Figure 1(a)(b) depicts the surface morphology using the atomic force microscopy (AFM). ***1(a)*** Si has a rough surface with irregular undulation, with root mean square (RMS) roughness of 1.7nm for a 1 × 1µm² area and 12.0nm for a 5 × 5µm² area. ***1(b)*** GaAs has a very smooth surface with clear atomic terraces, with RMS roughness of 0.5nm for a 1 × 1µm2 area and 0.9nm for a 5 × 5µm² area.

Figure 1(c)(d) depicts the cross-sectional bright-field TEM images at the interface of the III-Sb buffer grown.

Figure 2 depicts the X-ray diffraction (XRD) patterns for the two samples. The zeroth order superlattice peaks overlapped with the GaSb buffer, indicating nearly lattice matched superlattice layers with respect to the GaSb buffer. The full width at half maximum (FWHM) of the zeroth peak is: on GaAs 300.2 arcsec and on Si 331.9 arcsec.

Figure 3 depicts the optical properties of both samples using a Mid-IR photoluminescence (PL) spectrometer. These were placed in a closed-cycled liquid helium cryostat under vacuum at 10K, excited by a 532nm laser with power from 100 to 600mW, and measured by a lock-in amplifier. The PL intensity on Si is 44% less than GaAs within the entire power range.

Figure 4 depicts dark current density voltage (JV) characteristics obtained by device fabrication using standard photolithography, wet chemical etching, and metallisation without passivation. The higher quality of the GaAs gives a lower dark current density, both devices showed comparable levels within one order of difference in magnitude and significant leakage currents.

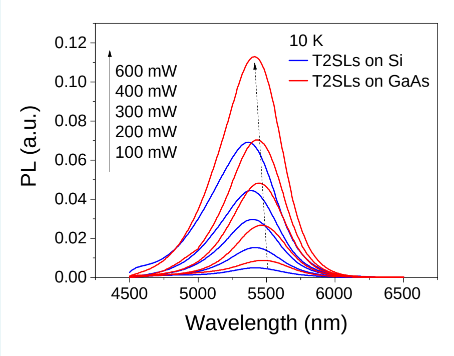

Figure 3: Power dependent PL spectra at 10K

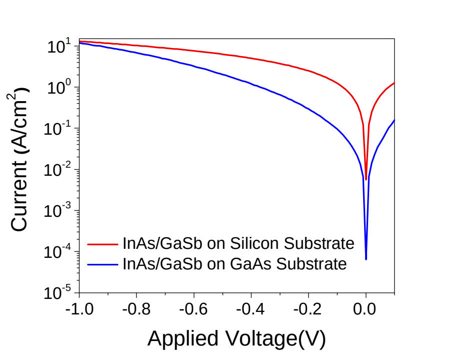

Figure 4: Current density voltage characteristics at 10K

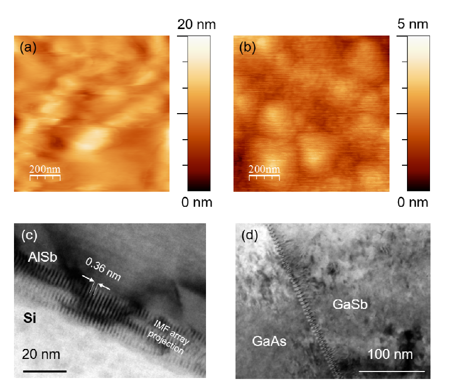

Figure 1: T2SL photodiode in Si (a, c) and GaAs (b, d). AFM images (a, b) and TEM images (c, d)

Conclusion

Direct growth of InAs/GaSb T2SL photodiodes have been carried out on Si substrate for the first time by MBE. Compared with the reference sample on GaAs, similar structural and optical properties have been achieved for the T2SL photodiode on Si by AlSb/GaSb buffer layers. The measured XRD FWHM is only slightly reduced indicating similar dislocation density. PL studies also show the optical emission of the T2SL on Si is only reduced less than half. A large leakage current has been measured for both samples. Therefore, the growth and fabrication of T2SL may require further optimization, like the use of passivation coating.

References

[1] J. Chen et al, "Growth and fabrication of InAs/GaSb type II superlattice mid-wavelength infrared photodetectors," Nanoscale Research Letters, vol. 6, (1), pp. 635, 2011.

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