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Atomic Scale Analysis of Chemical Intermixing in MBE-grown GaSb/InAs Superlattices Based on Z-contrast Imaging

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Type-II superlattices (T2SLs) consisted of GaSb and InAs have great potential for applications in laser and photodetectors operating in mid-wavelength to long-wavelength infrared (IR) regime [1]. In comparison to the conventional HgCdTe (HCT) based detectors, T2SLs offer several advantages such as band-gap tunability, reduced tunnelling current, and compatibility with III-V semiconductor production [2]. Additionally, theory predicts a longer Auger lifetime in T2SLs and significant detector performance advantage compared to HCT detectors with the same energy gap [3]. Until recently, the detector performance of fabricated T2SLs, however, was inferior compared to HCT detectors and does not meet the theoretical prediction [4]. Interfacial intermixing and roughness are among the factors suggested that could contribute to the degraded IR detector performance. The state-of-the-art MBE enables the growth of strain balanced GaSb/InAs T2SLs without forming misfit dislocations. The chemical intermixing at the interfaces is, however, unavoidable due to the growth kinetics [5]. Investigation of interfaces in GaSb/InAs T2SLs is essential to obtain chemical information across the interfaces and further optimize growth conditions. Scanning transmission electron microscopy (STEM) and template matching image processing technique are employed for this study.

We have developed the image processing technique based on template matching for quantitative interface analysis. Firstly, the template images are created from a Z-contrast image obtained with a STEM using a high angle annular dark field (HAADF) detector. Imaged along the [110] zone axis, the cation-anion pairs of zinc-blend structures like GaSb and InAs appears as so-called dumbbell structures. These dumbbell structures for GaSb and InAs are distinguishable in a Z-contrast image because of large difference in atomic numbers. The templates for GaSb and InAs are created by spatially averaging over many repeated patterns in each layer to reduce the noise in an as-recorded Z-contrast image. The Z-contrast image is, then, matched with two templates. The amplitude values, which contain quantitative contribution of each template to the recorded Z-contrast image, are extracted by linear decomposition. Fig. 1(a) presents a high magnification Z-contrast image of T2SL recorded with the electron energy of 300 kV. A T2SL was grown on GaSb substrate. The thicknesses of GaSb and InAs are 2.2 nm and 4.4 nm, respectively to target a specific IR wavelength. The GaSb and InAs templates, obtained by spatial averaging, are displayed in Fig. 1(b) and (c) with reduced noise level. Using amplitude values obtained with template matching technique, the chemical distribution of GaSb and InAs is quantitatively displayed as amplitude maps in Fig. 2 (a) and (b). At interface regions, both GaSb and InAs peaks are detected, which suggests chemical intermixing of GaSb and InAs. The line profile along growth direction as shown in Fig. 2 (c) indicates that InAs-on-GaSb interfaces are more extended than GaSb-on-InAs interfaces. Also, the amplitude value of GaSb in T2SL is less than that of GaSb substrate. This result presents the GaSb in T2SL is chemically mixed with InAs components.

Using template matching technique with atomic resolution Z-contrast images, we have demonstrated atomic scale analysis of chemical intermixing in MBE-grown GaSb/InAs T2SLs. The comparison between GaSb/InAs T2SLs with different growth schemes will be also discussed.

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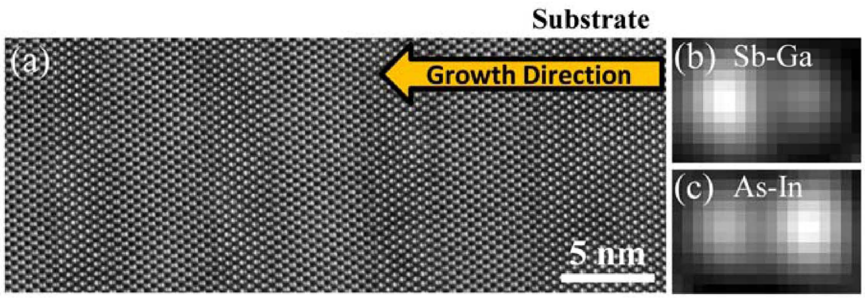

Figure 1. (a) Z-contrast image obtained with the electron energy of 300 kV. (b) GaSb and (c) InAs templates.

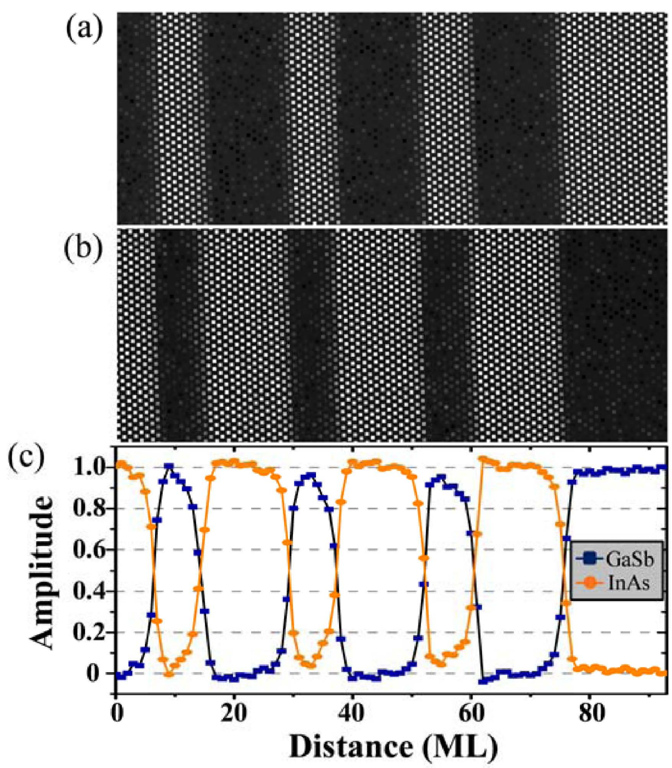

Figure 2. (a) GaSb and (b) InAs amplitude maps. (c) Line profiles of GaSb and InAs obtained from amplitude maps.

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