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Low dislocation density MBE process for CdTe-on-GaSb as an alternative substrate for HgCdTe growth

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ABSTRACT

This work demonstrates a low dislocation density molecular beam epitaxial process (average etch pit density ~$1.4 \times 10^5\,cm^{-2}$) for the growth of CdTe buffer layers on GaSb (211)B alternative substrates for subsequent growth of HgCdTe infrared materials. This dislocation density is much lower than that for CdTe layers grown on other alternative substrates (mid-10^6 to low-$10^7\,cm^{-2}$ range for Si, Ge and GaAs), is well below the critical level required for fabricating high performance long-wave infrared HgCdTe detectors ($5 \times 10^5\,cm^{-2}$), and is close to that achieved on lattice-matched CdZnTe substrates (mid-10^4 to low-$10^5\,cm^{-2}$ range). The low dislocation density is achieved by inserting a ZnTe/CdTe-based transitional buffer layer between the GaSb substrate and the CdTe buffer layer. The main purpose of this transitional buffer layer is to better accommodate the 6.1% lattice mismatch between the GaSb substrate and the CdTe epitaxial layer, which is evidenced by X-ray diffraction reciprocal space mapping. Additional benefits of this transitional buffer layer include possible blocking/filtering of misfit dislocation propagation, as well as gettering of defects and impurities. More importantly, an even lower dislocation density can be expected by increasing the thickness of the CdTe epitaxial layer and implementing a thermal annealing cycle for more efficient gettering. The results of this study indicate the great potential of GaSb as an alternative substrate for growing next generation HgCdTe infrared materials to meet the focal plane array requirements of higher device yield, lower cost and larger array format size.

1. Introduction

Over the past several decades, HgCdTe infrared detectors have dominated the high performance end of infrared imaging arrays and systems due to their unsurpassed device performance, including high quantum efficiency, high detectivity, and fast response time [1–4]. The further development of HgCdTe infrared technology requires new features that will enable lower cost and larger format arrays, which presents significant challenges due to substrate limitations [4]. Current high performance infrared technology is based on HgCdTe grown on lattice matched $Cd_{0.96}Zn_{0.04}Te$ substrates which, however, suffer severe limitations, including high cost (~US$300/cm^2), small wafer size (maximum size available commercially of 6 cm × 6 cm), relatively low crystal quality (etch pit density of mid-10^4 to low-$10^5\,cm^{-2}$), and limited wafer suppliers (only one commercial vendor world-wide) [4–6]. These substrate limitations represent the main disadvantage of HgCdTe infrared technology, and result in low device yield, high cost, and limitations to array format size [4]. Consequently, significant effort has been devoted to developing alternative substrates to replace CdZnTe, including Si, Ge and GaAs [7–9]. In principle, these alternative substrates all have the potential to drive down costs, improve device yield, and increase the format size of HgCdTe imaging focal plane arrays (FPAs) due to their far superior crystal quality and ready availability of larger wafer sizes in comparison to lattice-matched CdZnTe. However, due to the large lattice mismatch between HgCdTe and these alternative substrates (19%, 14.3% and 14.4% lattice mismatch for Si, Ge and GaAs, respectively), a high density of misfit dislocations are generated within the substrate/buffer heterostructure interface, which then propagate into the HgCdTe layer during growth even though a thick CdTe buffer layer is commonly used to block and filter the dislocations. This leads to dislocation densities in the mid-10^6 to low $10^7\,cm^{-2}$ range as determined by etch pit density (EPD) measurements for both CdTe buffer layers and HgCdTe layers grown on Si, Ge and GaAs [7,9–11], which are around two orders of magnitude higher than that of HgCdTe layers grown on lattice matched CdZnTe [7]. Although such high dislocation densities can be tolerated by mid-wave infrared (MWIR) HgCdTe detectors, they significantly degrade the performance of long-wave infrared (LWIR) HgCdTe detectors, which are more sensitive to isolated defects due to their narrower bandgap. In order to achieve high performance LWIR HgCdTe arrays, the EPD needs to be

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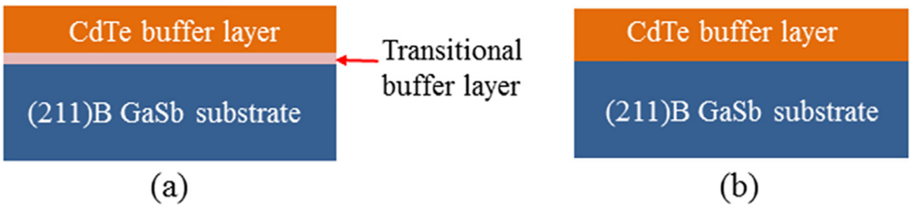

Fig. 1. Schematic sample structure for CdTe layers grown on GaSb substrates: (a) Structure A, and (b) Structure B.

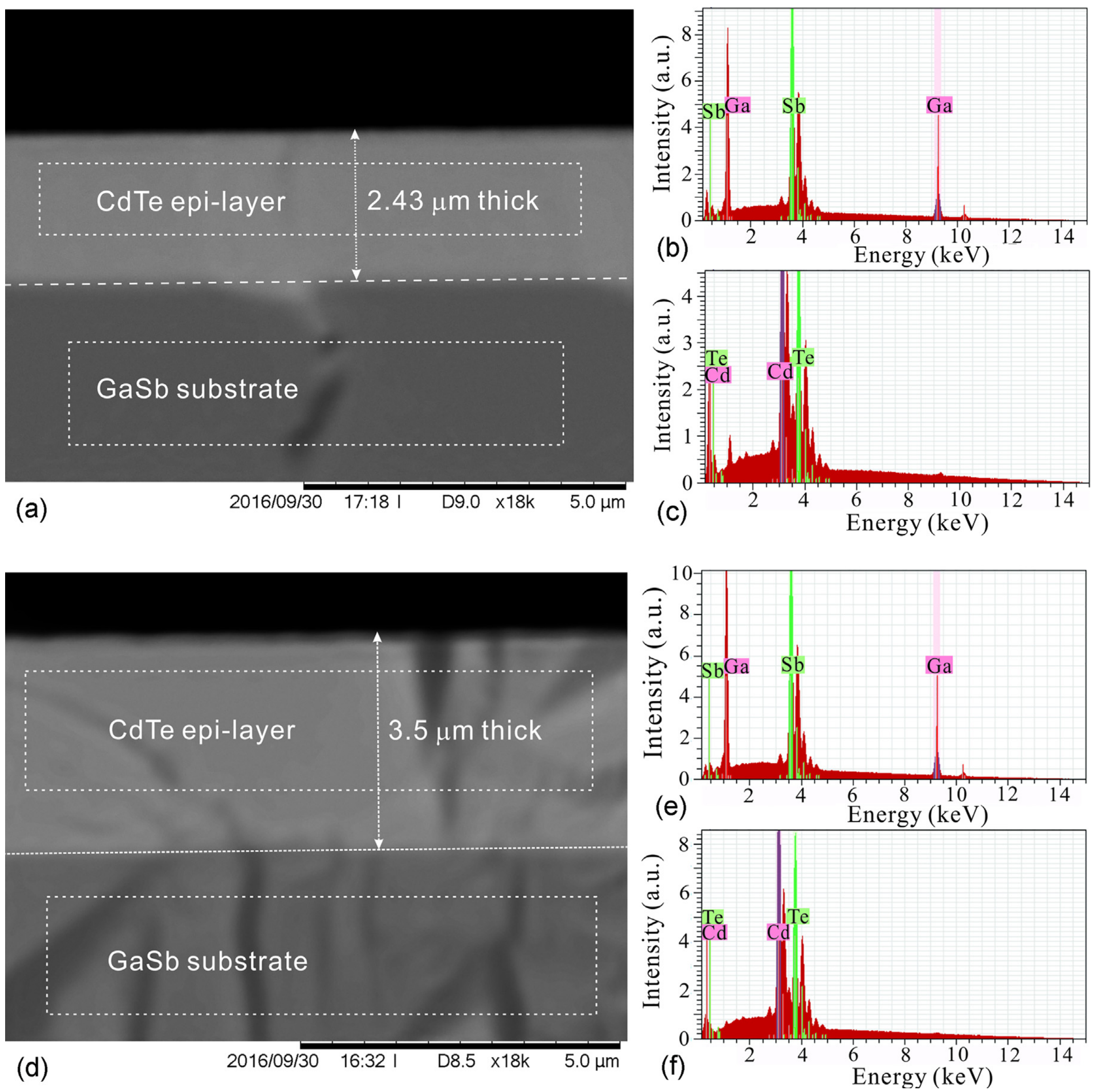

Fig. 2. Cross-sectional SEM images and EDX spectra of selected areas of representative Sample A ((a), (b) and (c)) and Sample B ((d), (e) and (f)). Note that the EDX spectra (b) and (e) are collected from the areas labeled with the white dashed rectangles in the upper part of the cross-sectional SEM images (a) and (d), whereas the EDX spectra (c) and (f) are collected from the areas labeled with the white dashed rectangles in the lower part of the cross-sectional SEM images (a) and (d).

less than $5 \times 10^5\,cm^{-2}$ [12], which renders Si, Ge and GaAs substrates unsuitable for growing LWIR HgCdTe epitaxial materials.

Because of the much smaller lattice mismatch (6.1%) between GaSb and HgCdTe compared with Si, Ge and GaAs, GaSb has recently been proposed as a new and better alternative substrate for growing high quality HgCdTe, especially LWIR materials [4–6]. Indeed, significant progress has already been made in the area of GaSb alternative substrates for growing HgCdTe, and EPDs in the range of low-10^6 to low-$10^7\,cm^{-2}$ have been demonstrated in preliminary experiments for both CdTe buffer layers and HgCdTe layers grown on GaSb, which is comparable to layers grown on well-established GaAs [4–6]. However, these dislocation density values are still much higher than that required for fabricating high performance LWIR HgCdTe FPAs, and significant effort will be needed to reduce these values to below the critical level of $5 \times 10^5\,cm^{-2}$. In this work, a very low dislocation density (average value $\sim 1.4 \times 10^5\,cm^{-2}$) is demonstrated for CdTe buffer layers grown on GaSb substrates via a unique “transitional buffer layer” technology, which is well below the critical level of $5 \times 10^5\,cm^{-2}$, and even comparable to that obtained for HgCdTe grown on commercial CdZnTe substrates. This result clearly indicates the feasibility of growing high