Dislocation dynamics as a function of MBE growth conditions in metamorphic InAsSb

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Long wavelength IR III-V based devices have long been of interest for potential applications such as chemical sensing and large format IR imaging. Within the III-V family, extending to the longest wavelength requires the use of $InAs_{1-x}Sb_x$ ($x \leq 0.6$) which offers the lowest bandgap energy (E_g) ranging from 0.05-0.35 eV [1]. However, the lack of conventional substrate at the desired lattice constant has restricted progress on the growth and study of this material system. To overcome this limitation, we employ a metamorphic step-graded $InAs_{1-x}Sb_x$ buffer on GaSb, enabling the study of low-E_g $InAs_{1-x}Sb_x$ as a function of growth conditions. Using this method, we previously presented the effect of substrate temperature (T_{sub}) and V/III on Sb incorporation of the lowest-E_g cap layer [2]. Here, we investigate the effect of V/III on Sb incorporation as a function of x and use x-ray reciprocal space mapping (RSM) to examine the effect of growth conditions on strain and dislocation dynamics.

We grew several $InAs_{1-x}Sb_x$ step-graded structures in which the Sb/(As+Sb) flux ratio was varied from 0.05 to 0.50 in 0.05 increments, under various T_{sub} and V/III, and identified the Sb composition in each layer using RSM along [110] with (004) and (115) reflections. This allows comparison of Sb-content as a function of Sb/(As+Sb) for various V/III, given in Fig. 1. These results suggest that V/III has little effect on Sb incorporation, in direct conflict with our previous photoluminescence (PL) results [2]. To understand the discrepancy between PL and RSM, we measured (004) RSM of the same three samples with the x-ray beam incident along [$1\bar{1}0$], revealing extremely different strain relaxation compared to the [110] case. Asymmetric strain relaxation has been observed in other III-V graded buffer systems and has been explained by different dislocation formation energies and glide velocities along each direction resulting from the core structure of the dislocation being terminated with either a group-III or a group-V element [3]. To develop an understanding of this mechanism within $InAs_{1-x}Sb_x$ graded buffers, we will employ the x-ray analysis of Ayers [4] to quantify the threading dislocation density (TDD) in these films along both [110] and [$1\bar{1}0$], thus enabling a comparison of TDD as a function of growth conditions, thickness, and propagation direction. AFM and TEM will further support these results. Taken together, we will develop a picture of dislocation dynamics during the growth of metamorphic $InAs_{1-x}Sb_x$.

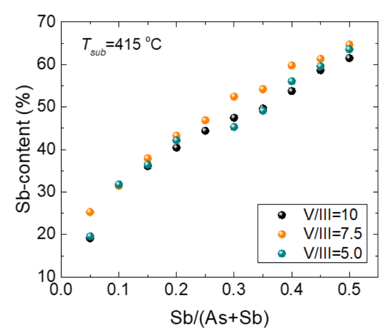

Fig. 1: Sb-content vs. Sb/(As+Sb) for samples grown at T_{sub}=415 °C with various V/III.

[1] Lin et al. *J. Electron. Mater.* **42**, 918 (2013).
[2] Tomasulo et al. *J. Vac. Sci. and Technol. B* **36**, 02D108 (2018).
[3] France et al. *J. Appl. Phys.* **107**, 103530 (2010); Gelczuk et al., *J. Cryst. Growth* **310**, 3014 (2008).
[4] Ayers, *J. Cryst. Growth* **135**, 71 (1994).

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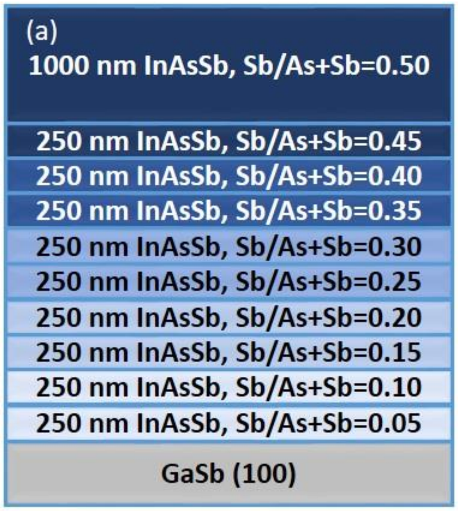

(b)

V/III/ T_{sub}	400 (°C)	415 (°C)	430 (°C)
5.0	x	x	x
7.5		x	
10.0	x	x	x

Fig. 1: (a) Cross-sectional schematic of samples and (b) growth conditions (substrate temperature, T_{sub}, measured via pyro and V/III beam equivalent pressures) explored here.

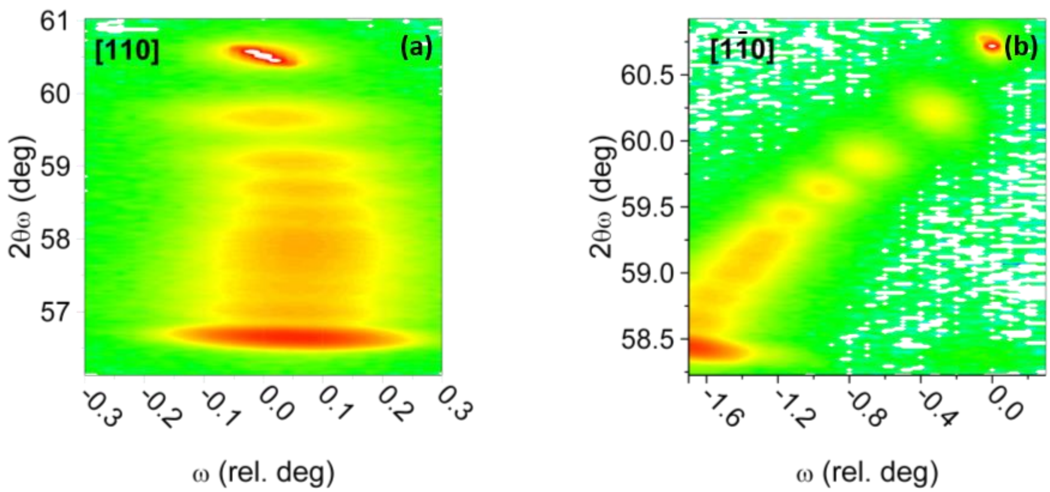

Fig. 2: (004) x-ray reciprocal space maps of the same InAsSb sample (T_{sub}=415 C, V/III=10) taken with the incident x-ray beam along (a) [110] and (b) [$1\bar{1}0$] suggesting significant directionality in the relaxation of metamorphic InAsSb.