Metamorphic antimonides for infrared photonics

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BIOGRAPHY

Gregory Belenky IEEE Fellow received the D.Sc. degree in physics and mathematics from the Institute of Physics, Baku.

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TECHNICAL ABSTRACT

The III-V based interband type devices for infrared photonics operating within the spectral region of $\lambda > 2$ µm can be grown today only on commercially available InAs, GaSb and InSb substrates. Due to a large difference between lattice parameters of InAs GaSb and InSb, the requirement of pseudomorphic growth limits the device design capabilities.

For example, in the case of GaSb based Type I lasers, the content of As in GaInAsSb quantum wells (QWs) must first be high enough to satisfy the conditions of pseudomorphic growth but high As content in QWs severely affects the device performance [1].

Another well-known example is the GaSb based superlattices, as their fabrication requires multiple interfaces between thin layers of semiconductors. The thicknesses of the individual layers lead to low (or zero) hole mobility along the structure due to the tunneling based nature of the carrier transport in superlattices [2] and may further reduce the carrier recombination process in structures with poorly designed interfaces.

In this work we will show that using linearly compositionally graded buffer layers on GaSb [2,3] allows the growth of unstrained and unrelaxed thick (up to 5 µm) layers with lattice parameters larger (0.9%, 1.4% and 2.1%) than that of the substrate.

All structures discussed in this paper have two types of buffers (GaInSb or AlGaInSb) and were grown by solid source molecular beam epitaxy. The topmost portion of the buffer remained dislocation free (See Fig.1) but pseudomorphicly strained with respect to the underlying relaxed section [3]. The in-plane lattice parameter of the topmost portion of the buffer was grown to be equal to the lattice of the unstrained top structures: lasers heterostructures or absorber layers with narrow bandgap. TEM results do not show any noticeable difference in the dislocation morphology of these two buffer layers or in the laser or absorber layer structures grown on top of them, both appear to be equally efficient in accommodating the misfit strain.

Figure 1 shows {110} cross-sectional TEM images of representative structures grown on GaSb substrates and containing 2-µm-thick GaInSb and AlGaInSb linearly compositionally graded buffer layers. The misfit dislocations are confined within approximately the bottom 1.5 µm portion of the buffer while the top 500 nm portion remains dislocation free. No dislocations were observed in the top portion of the buffer over the field of view observable by TEM. The HRXRD reciprocal space maps (RSM) obtained for the symmetric (004) and asymmetric (335) reflections were used to determine the degree of relaxation and the value of in-plane lattice parameter of the topmost part of the graded buffer.

We used the buffer with topmost $Ga_{0.84}In_{0.16}Sb$ composition (lattice constant of about 0.9% larger than that of GaSb) to fabricate diode lasers emitting near 2.2 µm at 20 C [4]. The whole laser heterostructure was grown without the use of arsenic. The devices demonstrate the CW threshold current densities below 150 A/cm^2 and CW output power of more than 1.4 W (Figure 2a).

Two types of buffers GaInSb and AlGaInSb were used to fabricate lasers operating at 3 µm. In this case the lattice constant of the AlInSb/AlGaInAsSb/GAInAsSb laser heterostructures was about 1.4% larger than that of GaSb. Output powers of 200 mW and 170 mW CW were obtained at room temperature from the lasers grown on GaInSb and AlGaInSb buffers (Figure 2b).

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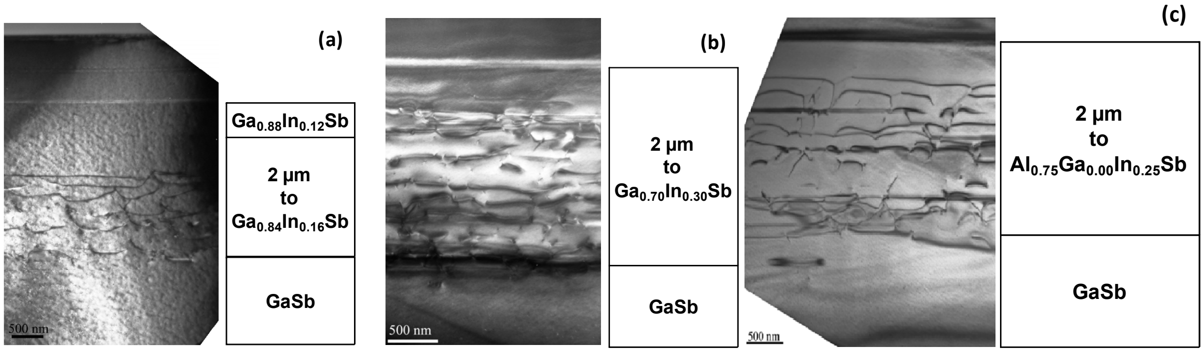
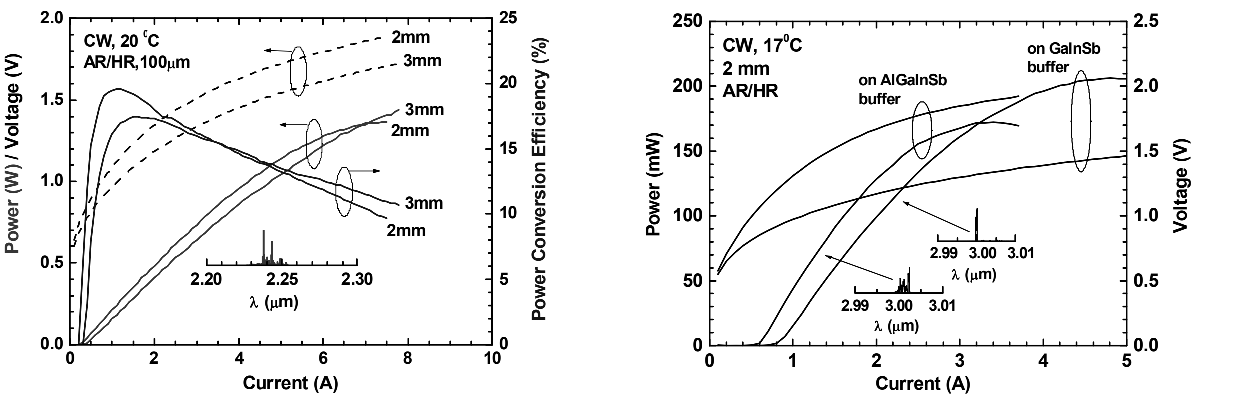


Figure 1. Cross-section TEM images of samples with 2 μm thick lineraly graded composition buffers grown onto GaSb substrates: (a) GaInSb with top In content of 16% - mismatch accomodated 0.9%; (b) GaInSb with top In content of 30% - mismatch accomodated 1.4%; (c) AlGaInSb with top Al, Ga and In contents of 75, 0 and 25% respectively - - mismatch accomodated 1.4%.



(a) (b)

Figure 2. CW power-curent-voltage characteristics of 100-μm-wide, 2-mm-long AR/HR coated diode lasers emitting near (a) 2.2 μm and (b) 3 μm and grown on metamorphic buffers.

Unrelaxed $InAs_{1-x}Sb_x$ layers with lattice constants up to 2.1 % larger than that of GaSb substrate were grown on Ga(Al)InSb buffers. The in-plane lattice constant of the top buffer layer was grown to be equal to the lattice constant of unrelaxed and unstrained InAs1-xSbx with a given X and the thickness up to 1.5 microns. At T = 77 K the PL intensity peaks were found at 5.4, 7.6 and 10 μm for the Sb content of 20, 30 and 44 %, respectively. We use the modulation response technique [5] to measure the minority carrier life time τ. At 77K the τ = 310 ns was obtained for the 1-μm thick InAs $_{0.8}$Sb $_{0.2}$ Sb layer grown on an AlGaInSb buffer.

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Keywords: GaSb, InAsSb, metamorphic, narrow bandgap, infrared, diode lasers

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