# Dilute-Nitride Active Regions on GaSb for Mid-Infrared Semiconductor Diode Lasers

**Hari P. Nair, Adam M. Crook, and Seth R. Bank**
*Microelectronics Research Center, The University of Texas at Austin, Austin, Texas 78758*
*hnair@mail.utexas.edu*

**Abstract:** We present the first room-temperature photoluminescence from GaSb-based dilute-nitrides, enabled by minimizing the incorporation of non-radiative defects. This material system could provide a pathway for covering the 3-5 μm regime with diode lasers.
**ICIS codes:** (160.4670) Optical materials; (250.5230) Photoluminescence; (250.5960) Semiconductor lasers

## 1. Introduction

Coherent mid-infrared (mid-IR) light sources are attractive for a variety of applications including trace gas sensing, free-space optical communications, and infrared countermeasures. GaSb-based type-I quantum well (QW) diode lasers are excellent candidates for coherent sources operating at mid-IR wavelengths due to their relatively simple design, growth, and fabrication. Recently, GaSb-based diode lasers with InGaAsSb/AlInGaAsSb active regions have demonstrated lasing up to 3.6 μm [1], though with only modest output powers that degrades rapidly with temperature. This marked degradation in performance, as compared with shorter wavelength devices, is likely due to the increase in the QW arsenic mole fraction, which reduces the split-off energy between the heavy hole band and the split-off band, likely exacerbating the CHHS Auger recombination process. Additionally, increasing the arsenic content decreases the valence band offset, increasing hole leakage.

An alternative is to employ dilute-nitride active regions, where the emission wavelength can be extended without increasing the arsenic content in the QW [2]. Incorporating dilute quantities of nitrogen into a host III-V matrix leads to a rapid reduction in bandgap due to band anticrossing between the host conduction band and the localized level introduced by nitrogen. This bandgap reduction is entirely due to the lowering of the conduction band minimum leaving the valence band virtually unperturbed. While GaSb-based dilute-nitrides have many beneficial properties for mid-IR diode laser applications, the optical quality has proven to be a significant challenge. Photoluminescence has been observed only at low temperatures [2,4,5] or using ultra-fast up-conversion techniques [6], due to the very short carrier lifetimes of only a few picoseconds. Here, we demonstrate the first room-temperature photoluminescence (PL) from GaSb-based dilute-nitride QWs, enabled by careful control of the growth conditions to mitigate formation of non-radiative centers.

## 2. Optical quality challenges

Analogous to the GaAs-based dilute-nitrides, we believe that the poor optical quality is due to the incorporation of nitrogen into non-substitutional lattice sites likely in the form of N-N and Sb-N split interstitials [7]. To mitigate these undesirable species, we carried out systematic studies of nitrogen incorporation into GaSb using high resolution X-ray diffraction, secondary ion mass spectrometry and nuclear reaction analysis Rutherford backscattering. The samples were grown on a Varian Gen. II solid-source molecular beam epitaxy (MBE) system equipped with a Veeco Mark-IV valved-cracker for antimony, Veeco SUMO effusion cells for gallium and indium, and a SVTA rf plasma source for nitrogen. We found that relatively high growth rates ( >1 μm/hr ) and low substrate temperatures ( < 340 °C) significantly suppress the incorporation of non-substitutional nitrogen through surface kinetics. To test the optical quality, we grew GaInSb(N) QWs under these optimized growth conditions. The sample structure is shown in Fig. 1. An identical nitrogen free sample was also grown. The samples were characterized using room temperature photoluminescence (PL). As shown in Fig. 2, the PL peak from the dilute-nitride sample was redshifted relative to the nitrogen free sample, indicative of bandgap reduction due to nitrogen incorporation. Although the PL signal was ~10x weaker than that from the nitrogen-free control sample, it is still visible at room temperature demonstrating the significant improvement in optical quality achieved through optimized growth conditions.

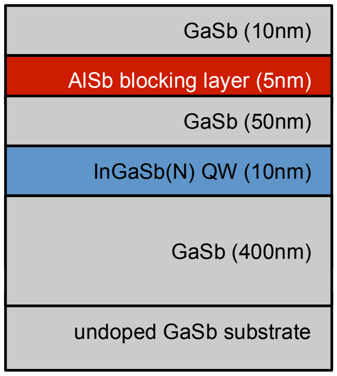


Fig. 1: Sample structure used for photoluminescence study. The AlSb carrier blocking layer prevents recombination of photogenerated carriers at the surface.

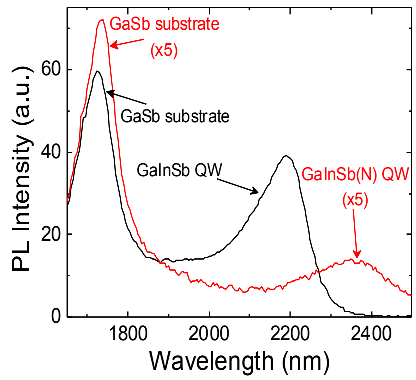


Fig. 2. Room temperature photoluminescence spectrum from GaInSb(N) QW with GaSb barriers demonstrating bandgap reduction due to nitrogen incorporation.

Post-growth thermal annealing is known to improve the optical quality of GaAs-based dilute-nitrides [8] and preliminary annealing studies indicate that the optical quality of GaSb-based dilute-nitrides can be similarly improved. As shown in Fig. 3, the PL peak increased in intensity and blueshifted with increasing annealing temperature. The blueshift is likely due to a rearrangement in local bonding conditions of the nitrogen atoms.

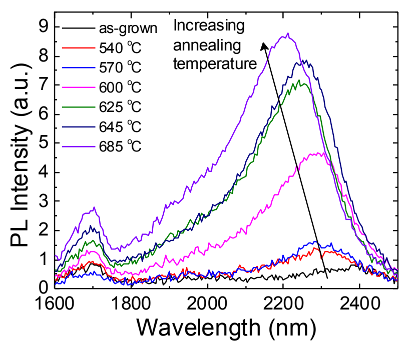


Figure 3: PL spectra from post-growth thermal annealed samples indicating significant improvement in optical quality upon annealing.

## 3. Conclusions

We demonstrate that the low optical-quality associated with GaSb-based dilute-nitrides is likely not an intrinsic issue and can be overcome with careful optimization of the growth conditions. With further improvement, this material system has the potential to extend the emission of GaSb based type-I diode lasers throughout the mid-IR.

## 4. References


[1] K. Vizbaras and M.-C. Amann, “3.6 μm GaSb-based type-I lasers with quinternary barriers, operating at room temperature,” *Electronics Letters*, vol. 47, no. 17, p. 980, 2011.

[2] W. Li, J. B. Héroux, and W. I. Wang, “InGaAsSbN: A dilute nitride compound for midinfrared optoelectronic devices,” *Journal of Applied Physics*, vol. 94, no. 7, p. 4248, 2003.

[3] L. Shterengas, G. Belenky, M. V. Kisin, and D. Donetsky, “High power 2.4 μm heavily strained type-I quantum well GaSb-based diode lasers with more than 1; W of continuous wave output power and a maximum power-conversion efficiency of 17.5%,” *Applied physics letters*, vol. 90, no. 1, pp. 011119–011119, 2007.

[4] S. Iyer, L. Wu, J. Li, S. Potoczny, K. Matney, and P. R. C. Kent, “Effects of N incorporation on the structural and photoluminescence characteristics of GaSbN/GaSb single quantum wells,” *Journal of Applied Physics*, vol. 101, no. 11, pp. 113508-5, Jun. 2007.

[5] S. Bharatan, S. Iyer, J. Li, T. A. Rawdanowicz, and L. Reynolds, “Study of molecular beam epitaxially grown InGaAsSbN/GaSb single quantum wells,” *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures*, vol. 29, no. 3, p. 03C112, 2011.

[6] D. Wang et al., “Band edge optical transitions in dilute-nitride GaNSb,” *Journal of Applied Physics*, vol. 105, no. 1, p. 014904, 2009.

[7] H. T. Pham, S. F. Yoon, K. H. Tan, and D. Boning, “Effects of nitrogen incorporation in $InSb_{1-x}N_x$ grown using radio frequency plasma-assisted molecular beam epitaxy,” *Applied Physics Letters*, vol. 90, no. 9, p. 092115, 2007.

[8] H. P. Xin, K. L. Kavanagh, M. Kondow, and C. W. Tu, “Effects of rapid thermal annealing on GaInNAs/GaAs multiple quantum wells,” *Journal of Crystal Growth*, vol. 201-202, pp. 419-422, May 1999.