Enhancing the Luminescence Efficiency of GaSb-Based Dilute-Nitrides by Rapid Thermal Annealing

Nathaniel Wendt

Computer Engineering, Gonzaga University

NNIN REU Site: Microelectronics Research Center, The University of Texas at Austin, Austin, TX
NNIN REU Principal Investigator: Seth Bank, Electrical and Computer Engineering, The University of Texas at Austin
NNIN REU Mentor: Hari Nair, Electrical and Computer Engineering, The University of Texas at Austin
Contact: nwendt@zagmail.gonzaga.edu, sbank@ece.utexas.edu, hnair@austin.utexas.edu

Abstract:

It has been shown that gallium antimonide (GaSb)-based dilute-nitrides display improved photoluminescence (PL) with *in situ* annealing in the molecular beam epitaxy (MBE) growth chamber under a Sb ambient. This improvement in luminescence efficiency translates into improved performance of optoelectronic devices, such as lasers, where this will lead to a reduction in threshold current densities. However, similar improvement in luminescence efficiency was not observed during *ex situ* annealing in a rapid thermal annealing (RTA) furnace. The ability to recreate similar annealing performance in the RTA would allow for increasingly efficient annealing. Upon further study, we determined that the degradation in PL resulted from over-annealing of the sample. Attributing this issue to the silicon (Si) carrier wafer, which has a higher band gap than the GaSb sample, infrared radiation was heating the sample more than indicated by the carrier wafer pyrometer measurement.

We mitigated this issue by integrating a low bandgap indium arsenide (InAs) layer into the carrier wafer and were able to ensure that our sample was below the temperature indicated by the pyrometer. This optimization allowed us to pinpoint the optimal annealing temperature more accurately and achieve PL performance similar to that of *in situ* annealing.

Introduction:

Semiconductor lasers operating in the mid-infrared are highly sought after for their applications with infrared countermeasures, gas sensing, and free space optical communication. GaSb-based dilute-nitrides are an attractive solution for these applications, but require optical quality enhancement. Similar materials, namely gallium arsenide (GaAs)-based dilute-nitrides, have shown significant improvement in optical quality by annealing [1]. Furthermore, it has been shown that *in situ* annealing in the molecular beam epitaxy (MBE) growth chamber has improved optical quality of GaSb-based dilute-nitrides materials. While this method has proved effective, the process is time intensive. This project aimed to dramatically improve the time efficiency of annealing by employing a rapid thermal annealing (RTA) furnace.

Since the pyrometer in the RTA measures the temperature of the carrier wafer, the material of this carrier wafer significantly affects the annealing process. Also, the lamps in the RTA emit photons over a wide energy spectrum. Si, with a bandgap of 1.12 eV at 300 K, is less responsive to temperature than the GaSb-based sample at approximately 0.73 eV at 300 K. Photon energies between these two bandgaps (0.73 eV to 1.12 eV) are absorbed by the sample and not the carrier, leading to overannealing. Overannealing has been shown to considerably degrade the optical quality of GaAs-based dilute-nitrides [2]. This underscores the need for a carrier wafer of equal or lower bandgap than the sample so that the carrier wafer is at the same temperature as the sample.

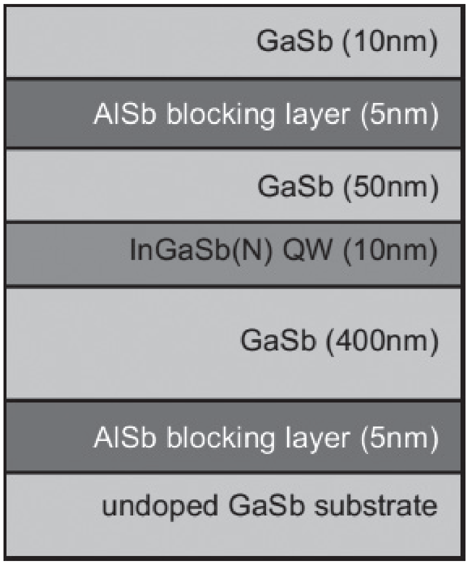

Figure 1: Sample structure used for annealing studies.

Experimental Procedure:

Figure 1 shows the sample structure that was used for the annealing studies. Annealing was carried out at varying temperatures for one minute in a AW 610 RTA furnace under a nitrogen ambient. We used two different carrier wafers for the annealing studies: InAs (bandgap 0.354 eV) and Si (bandgap 1.12 eV). A Si proximity cap was utilized to prevent Sb loss from the sample surface. Optical quality was characterized by use of the photoluminescence (PL) lab with a diode pumped solid-state laser (DPSS) operating at 532 nm. The PL spectrum was obtained using a grating monochromator and an InSb photodetector cooled to 77 K. All PL scans were scaled to a standard sample for comparison.

Results and Conclusions:

Figure 2 shows the increased responsiveness of the InAs carrier wafer from constant lamp intensity in the RTA than GaSb and Si. This indicates that when annealing with a Si carrier wafer, the sample temperature may be significantly higher than the temperature indicated by the RTA pyrometer leading to overannealing.

We were able to reproduce optical quality enhancement within 17% of *in situ* annealing with the InAs carrier wafer. Figure 3 illustrates this considerable improvement over the Si carrier wafer that was within 33% of *in situ* annealing. We believe that this improvement was due to the lower bandgap of the InAs carrier wafer. By ensuring that the sample temperature was equal to or lower than the carrier wafer, we were able to achieve better temperature feedback, and thus, avoid overannealing.

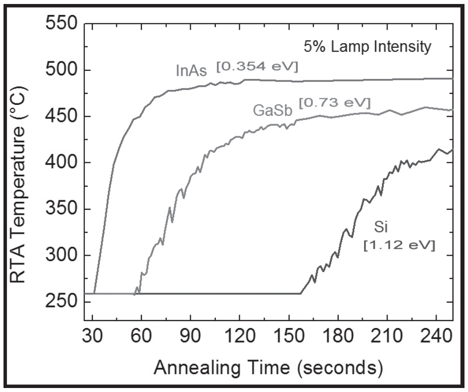

Figure 2: Various carrier wafer responses to constant RTA lamp intensity. With decreasing bandgap the response of the carrier wafer improves.

Future Work:

These studies should be continued by more precisely optimizing the annealing temperatures to more closely replicate or improve upon *in situ* annealing. Additional study would investigate various sample structure variations and their effects on annealing effectiveness.

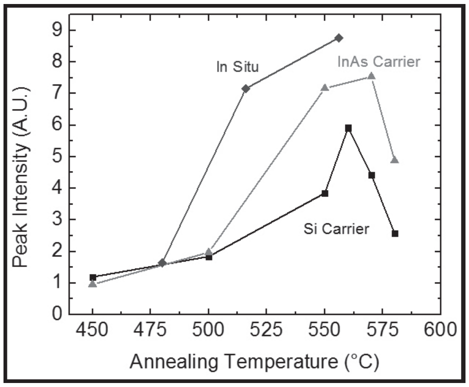

Figure 3: Si and InAs carrier wafer annealing as compared to in situ.

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