Material Characterization for Optimizing Passivation of Type-II InAs/GaSb Superlattice Infrared Photodetectors

Nicole Escudé, Physical Science - Chemistry, Biola University
NNIN REU Site: Nanoscience @ UNM, University of New Mexico

NNIN REU Principal Investigator: Sanjay Krishna, Electrical Engineering, University of New Mexico
NNIN REU Mentor: Elena Plis, Electrical Engineering, University of New Mexico
Contact: Nicole.c.escude@biola.edu, skrishna@chtm.unm.edu

Abstract:

High-temperature superlattice (SL) infrared (IR) photo-detectors have applications in thermal imaging. However, surface states on the superlattice trap charge carriers and greatly decrease detector performance. Passivating the photodetectors by sulfidization has been shown to reduce surface states, thus improving device performance. Towards optimizing a passivation method for III-V SLs, material characterization was performed on one unpassivated detector. Its performance was determined based on the analysis of basic detector figures of merit extracted from spectral response, dark-current, and total current measurements. Combining this data with further data could be used to: (1) compare the efficacy of aqueous and non-aqueous sulfur-based passivation solutions, and (2) find the most effective recipe and application time for a chosen solution on type-II, III-V SL photodetectors.

Introduction:

When layers of p- and n–type material are grown below and above the SL region of a strained-layer superlattice (SLS), a photovoltaic diode that responds to IR radiation is produced [1]. Research on SLSs of two alternating III-V semiconductor binaries for use in IR detectors and lasers continues.

Uncooled IR detectors have many potential applications in thermal imaging, including optical remote sensing, night-vision, fire control, etc. Type-II broken band gap III-V SLS IR photodetectors have several advantages over competing IR detectors, including an easily tailored bandgap, better spatial uniformity, and high operation temperatures [2].

Research in SLS IR detector fabrication must address the problem of surface states (localized electronic states within the forbidden energy region between the semiconductor valence and conduction bands [3]). Surface states trap charge carriers, increasing detector dark-current and decreasing photocurrent. Performing surface passivation can improve detector performance, and sulfidization facilitates both chemical and electronic passivation by protecting the surface from oxidizing and decreasing surface state density.

Outlined here is an experimental/analytical procedure by which the effectiveness of aqueous and non-aqueous sulfur-based passivation solutions can be compared, and an optimized passivation scheme for type-II InAs/GaSb SL photodetectors reached.

Experimentation:

The sample chip, L5-68-diced, held two InAs/GaSb-based, individually diced unpassivated SL photodetectors. The photodetector structure is shown in Figure 1, with n-contact Ti/Au 500Å/3000Å, p-contact Ti/Pt/Au 500Å/500Å/3000Å, and aperture diameter 200 µm.

The sample was loaded into the cryostat sample chamber of a Janis closed cycle refrigerator system. Checking the connections on the device contacts using a Semiconductor Parameter Analyzer (set up to plot current flowing through the device over a range of applied biases) revealed that only

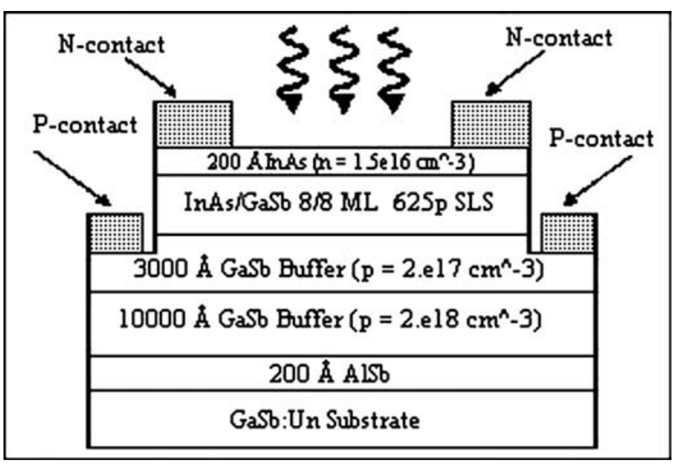

Figure 1: L5-68-Diced sample detector composition.

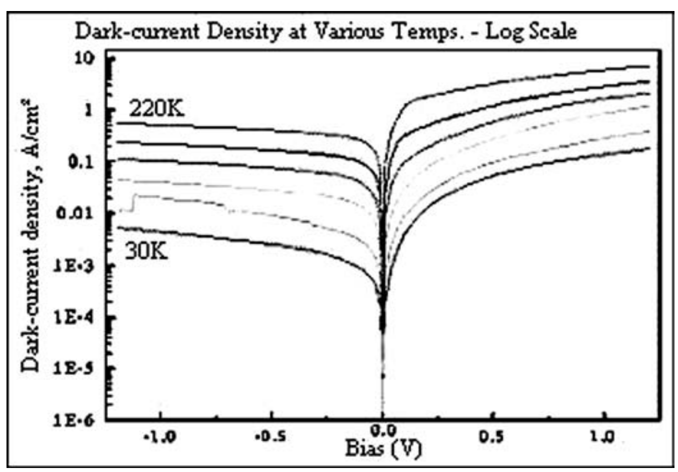

Figure 2: Dark-current density.

one of the detectors was functioning. Thus, the inoperative detector was disregarded for all remaining measurements.

For spectral response measurements, the sample chamber was sealed and cooled to 90.000 Kelvin (K). Measurements (with the background spectrum subtracted) were taken using Thermo Electron Corporation's OMNIC software. Sample temperature was increased gradually from 90K until a nontrivial detector response was no longer observable. At each temperature, measurements were taken for $^{-}0.6000$V and $^{+}0.6000$V applied bias.

The software was then set up to measure current through the detector. Total current was measured with the blackbody light source incident to the detector, and dark-current with all light blocked from the detector. Temperature was varied from 30 to 300K, and at each temperature voltage bias was varied in 0.01V increments from 1.2V to $^{-}1.2$V.

Results:

Detector spectral response was best at lower temperatures, since that is where thermal carrier generation was minimal and measured current intensity was high. Still, a nontrivial response was detected for up to 280K.

Dark-current density (measured dark-current divided by the device's active optical area) is displayed in Figure 2. At 90K and $^{-}1.0$V of bias, dark-current density for this device was found to be approximately 10^{-2} A/cm^2, indicating high (but typical) leakage current.

Subtracting dark-current data from measured total current yields photocurrent values. However, at lower temperatures these values were unreasonable, and it was concluded that the total current measurements were erroneous. Plans were made to re-measure total current, but all further use of the cryostat system was prevented, as compressor maintenance was required. Detector figures of merit that depend on photocurrent (background limited infrared photon temperature and specific detectivity) are therefore unreliable, and thus not presented.

Detector responsivity, shown in Figure 3, is the current output produced in response to one watt of input optical radiation from the blackbody source [4].

The dynamic impedance-area product (R_oA) at zero bias is shown in Figure 4 for temperatures from 30-240K. At 50K, a poor data point was obtained and corrected for.

Conclusions:

These procedures and characterizations outline a good starting point for further experimentation and investigation into the benefits of passivation, and discovering which passivation methods are most effective. Accordingly, the intended next step in this experiment was to passivate the sample, recalculate all figures of merit, and compare the results of the passivated detector with results obtained prior to passivation. Multiple detectors, passivated and unpassivated, could then be tested and compared in a similar fashion. Also, various types of passivation could be evaluated. Here, the intended focus was on liquid sulfidization, contrasting aqueous and non-aqueous passivating solutions. After discovering which of these two sulfidization methods most improved type-II InAs/GaSb photodetector performance, solution concentration and application time could be fine-tuned.

Moreover, information obtained from such experiments might be applied to other SLS structures. For InAs/(GaIn)Sb photodetectors, will the same passivation scheme work? If not, what changes must be made, and why? These and other related questions could be explored.

Acknowledgements:

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References:

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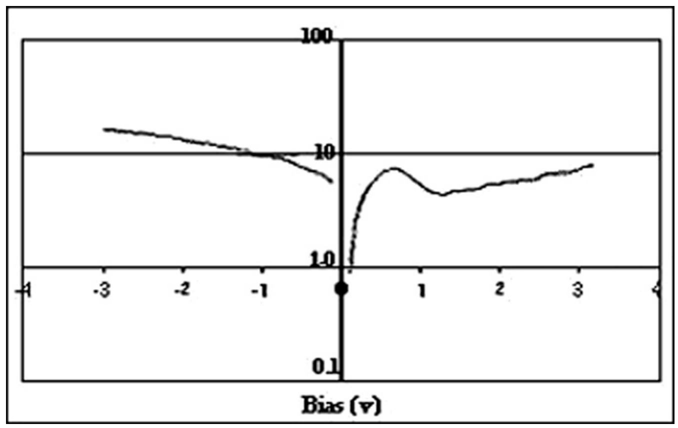

Figure 3, above: Responsivity.

Figure 4, below: R_oA-product, zero bias.