Optical Characterization of AlInAsSb Digital Alloy Films

Harold Fu
Chemical Engineering, Cornell University

NNIN REU Site: Microelectronics Research Center, The University of Texas, Austin, TX
NNIN REU Principal Investigator: Seth R. Bank, Electrical and Computer Engineering, The University of Texas at Austin
NNIN REU Mentor: Scott D. Sifferman, Electrical and Computer Engineering, The University of Texas at Austin
Contact: hjf42@cornell.edu, sbank@ece.utexas.edu, scott.d.sifferman@utexas.edu

Abstract:

Aluminum indium arsenide antimonide (AlInAsSb) is a promising material because its band gap can be widely tuned while maintaining lattice matching to a substrate by varying the constituent element compositions. These characteristics allow for applications as photodetectors in the near- to mid-infrared region. These materials were grown on a gallium antimonide (GaSb) substrate via molecular beam epitaxy using a digital alloying technique. This report focuses on the optical characteristics of these digital alloys. Emission spectra were measured using photoluminescence spectroscopy at both 77K and 300K to determine bandgaps. Transmittance and reflectance data were measured using Fourier transform infrared spectroscopy. Due to the absorbance of the GaSb substrate, absorption features of wide-bandgap AlInAsSb alloys are obscured. To mitigate this, the spectra were also taken after thinning the substrate to ~150 µm. Absorption characteristics were extracted from the measurements using transfer matrix methods and numerical fitting. From these data, optical parameters of the films such as absorption coefficients and refractive indices were obtained.

Introduction:

AlInAsSb shows promising application as a photodetector material throughout the near- to mid-infrared. The band gap of AlInAsSb can be widely tuned by adjusting the constituent element concentrations, while maintaining lattice matching to the substrate. Unfortunately, the fabrication of arbitrary alloys of AlInAsSb is hampered by a large miscibility gap. Using molecular beam epitaxy and a growth technique called digital alloying, AlInAsSb can be grown by alternating layers of III-V binary alloys of the constituent elements. The grown films would thus reproduce the macroscopic optical properties of the bulk alloy.

AlInAsSb films, 300 nm thick, were lattice matched to 500 µm GaSb substrates. Since GaSb has a smaller bandgap than many of the wider bandgap films with higher Al percentages, the absorption within the thick substrate would be much greater than that of the thin film. GaSb would thus obscure the absorption features of these digital alloys. Therefore, substrate thinning was needed to reduce the GaSb absorption.

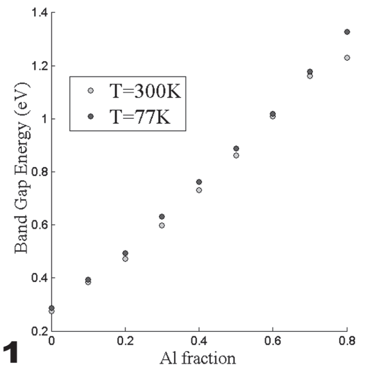
Here, we report on the emission and absorption characteristics of these digital alloys. Using various spectroscopic techniques and numerical modeling, we obtained AlInAsSb band gap energies, absorption coefficients, and indices of refraction.

Experimental Procedure:

Photoluminescence spectroscopy was conducted on a GaSb control and 0-80% Al containing digital alloy samples at 300K and 77K. A 532 nm laser was used to excite the samples, and an InSb detector gathered emission data [1]. Substrate thinning was performed on each sample to thin GaSb substrates from 500 µm to 150 µm. Using a KBr beamsplitter and SiC globar source, Fourier transform infrared spectroscopy (FTIR) was used to gather reflectance and transmittance data before and after thinning. The transmittance data was used in a numerical model to calculate absorption spectra [2]. Using obtained absorption coefficients, the refractive index was calculated from Kramers-Kronig relations.

Results and Conclusions:

Emission spectra from photoluminescence measurements at 300K and 77K indicate a monotonic increase of band gap energy with increasing Al fractions, as illustrated in Figure 1. At 77K, the emission spectra were narrowed and more intense than 300K due to reduced thermal broadening [1]. In FTIR reflectance measurements shown in Figure 2, there was decreased reflectance with increasing Al fraction. After substrate thinning, there was little change in the spectra, making it unsuitable for differential calculations of absorption spectra. The transmittance spectra in Figure 3 indicated lowered transmittance in the 2-3 µm region, which was attributed to surface scattering effects of light



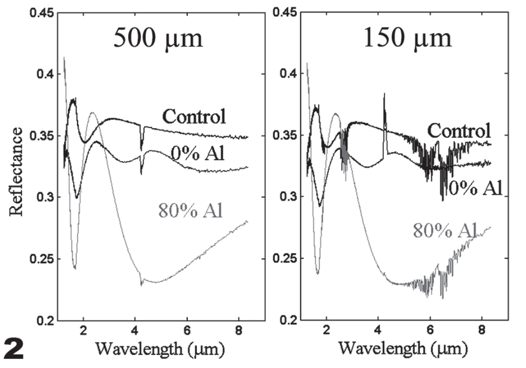
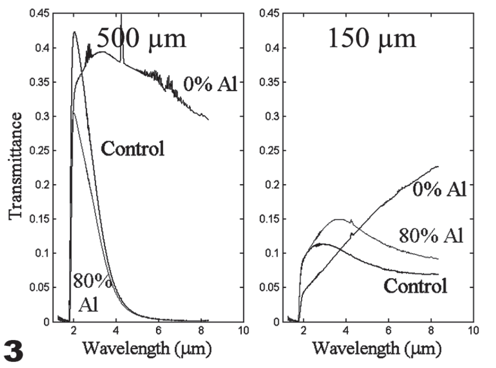
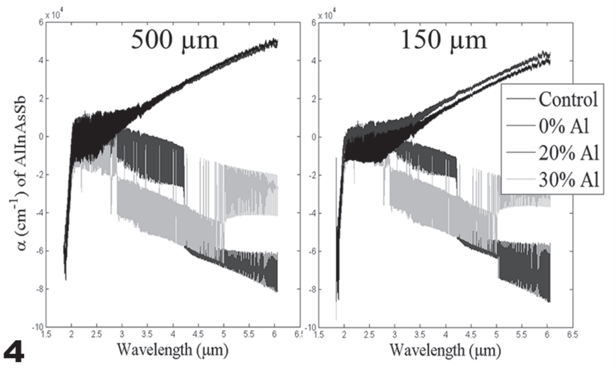


***Figure 1, far left:** Comparison of AlInAsSb band gap energy. **Figure 2, left:** Reflectance measurements before and after substrate thinning. **Figure 3, below left:** Transmittance measurements before and after substrate thinning. **Figure 4, below right:** Calculated absorption coefficients (α) before and after substrate thinning.*





on the roughened GaSb after thinning. Diminished transmittance for various samples like the control and 80% Al at higher wavelengths were attributed to higher doping levels in the GaSb substrate, which contribute to increased free carrier absorption.

Using a transfer matrix model, we first solved for the absorption spectra of GaSb, in which the physical characteristics obtained served as a proof of concept for the model [3]. The transmission coefficient of polished and roughened GaSb surfaces were then found to account for surface scattering. Differential calculations using transmittance data before and after thinning were used to find substrate absorption within the digital alloy samples, which can be used to find the absorption spectra of AlInAsSb.

As shown in Figure 4, nonphysical absorption coefficients of AlInAsSb were obtained because the GaSb substrate were strongly absorbing despite thinning. Furthermore, samples with stronger free carrier absorption further masked the optical characteristics of AlInAsSb. Extreme oscillations in the spectra were attributed to the etalon effect. The band gap for the 0% Al sample was observed at 0.294 eV (4.22 µm), which closely matches the respective band gap at 0.287 eV found in photoluminescence spectroscopy at 77K. Due to nonphysical nature of the absorption spectra, the calculated indices of refraction also do not provide realistic results.

While photoluminescence measurements do provide promising results towards the ability to tune the band gap of AlInAsSb, the nonphysical absorption coefficients illustrate the difficulty of separating AlInAsSb absorption from that of the substrate.

Future Work:

The numerical model may be refined to account for individual binary layers in the digital alloy. Experimentally, AlInAsSb may regrown with an etch stop layer used for membrane liftoff onto a substrate transparent in the IR region. This would allow direct measurement of AlInAsSb without obscuration from absorption in GaSb.

Acknowledgements:

I want to thank Scott Sifferman, Dr. Seth Bank, and the rest of the LASE group for their incredible guidance. I also want to thank the National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program and the National Science Foundation for their support under Grant No. ECCS-0335765.

References:

[1] Gfroerer, T.H.; Encyclopedia of Analytical Chemistry, R.A. Meyers, 9209-9231 (2000).

[2] Katsidis, C.C., Siapkas D.I.; Applied Optics, 41 (19), 3978-3987(2002).

[3] Adachi, S; Journal of Applied Physics, 66, 6030 (1989).