Quantum Well Intermixing on a Hybrid Silicon or Silicon Dioxide Bonded AlGaAs/GaAs/InGaAs Platform

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Abstract:

Quantum well intermixing (QWI) allows one to controllably alter the bandgap in a quantum well heterostructure for use in photonic integrated circuits. QWI has been successfully implemented on various platforms to create higher bandwidth photodetectors, modulators, and tunable lasers. The success of QWI can be measured by the shift in wavelength of a sample's photoluminescence (PL). The focus of this project was to develop a successful QWI process for a hybrid silicon or silicon oxide (Si, SiO_2)-bonded gallium arsenide/indium gallium arsenide (GaAs/InGaAs) laser platform. This low loss Si or $SiO_x(N_y)$ waveguide enables the world's longest integrated semiconductor lasers to displace currently used fiber lasers and solid state lasers in terrain mapping LIDAR systems. The first part of this project was to develop a way to measure the sample's PL. The second part of this project was to induce the greatest wavelength shift through impurity free vacancy diffusion (IFVD).

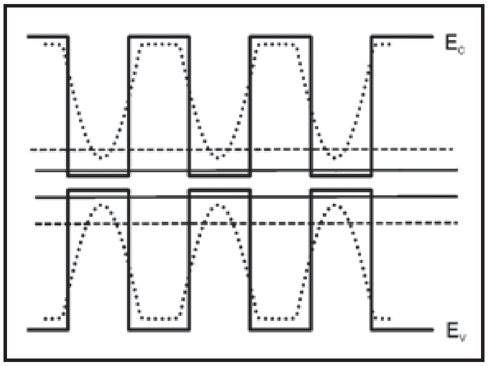

Figure 1: Energy band diagram of quantum wells before and after QWI.

Introduction:

In bulk semiconductor material, electrons and holes have a continuum of available states; however, at the nanoscale of quantum wells, these states become discretized in one dimension. This is a fundamental aspect of a quantum well laser. In this material system, QWI works by creating vacancies in the barriers and the wells. The vacancies then allow for indium from the InGaAs quantum wells to diffuse into the barriers, in exchange, gallium from the GaAs barriers diffuses into the wells. The subsequent disruption in band structure causes a change in wavelength of the sample's PL. The solid lines in Figure 1 indicate the bands of the wells before the intermixing process, and the dotted lines represent the wells after the intermixing process. The solid and dashed lines correspond to the respective discrete states that the carriers can occupy.

QWI can be implemented through three different mechanisms: impurity induced disordering (IID), impurity free vacancy disordering (IFVD), and ion implant enhanced interdiffusion (IIEI). Only the latter two were employed in this study.

IFVD was implemented by depositing a layer of SiO_2 on top of the sample using plasma-enhanced chemical vapor deposition (PECVD). The vacancies in porous SiO_2 then diffused downwards upon a rapid thermal anneal (RTA). IIEI worked by bombarding the sample with an ion, which then physically disrupted the structure, also creating vacancies.

Experimental Procedure:

First in the IIEI experiment, a sample was implanted with P^+. To prevent outward diffusion the sample was capped with Si_xN_y. It then underwent a RTA for 30 seconds at 900°C.

In the IFVD experiment, another sample had SiO_2 deposited via PECVD. It was then capped with Si_xN_y to prevent any bonding with the carrier wafer and any outdiffusion of material during the RTA. This sample underwent a RTA process at 850°C for 3 minutes.

Figure 2 shows a diagram of the PL setup. A pump laser diode (780 nm) operating at 1.5 mW was already properly aligned. The laser diode was collimated and then focused onto our samples. The sample's PL was focused onto a multimode fiber which was fed into an Ando AQ6315 Optical Spectrum Analyzer controlled via Labview.

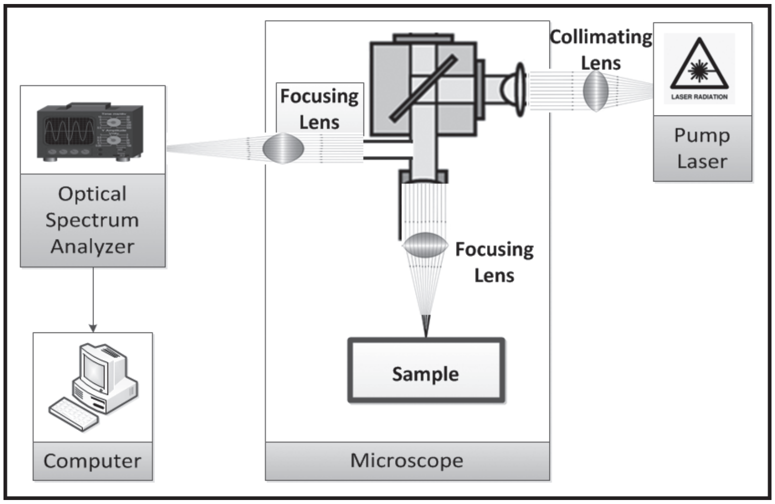

Figure 2: Diagram of PL setup.

Two other lasers, 658 nm at 60 mW and 780 nm at 100 mW, were also added to the system. They are in the process of being optimally aligned.

Results:

The sample that underwent IIEI was visibly damaged by the RTA process—opaque crystalline growths covered the phosphorous implanted regions at the surface of the SiN. Areas masked by the clips securing the sample while implanted were unaffected. Thus, no PL measurements were taken of this sample. Figure 3 shows a cross-sectional SEM of the sample with noticeable cracking and damage at the surface. Figure 4 shows the PL of the unmodified sample and the PL of the IFVD induced sample.

Conclusions:

EDAX was performed on the damaged P^+ implanted sample to see the chemical composition of the distinct regions. The damage is believed to be due to an out diffusion of aluminum. It was found that this procedure of IIEI was not a feasible method for our material system [1].

The plots in Figure 4 show peaks around 870 nm. This corresponds to the bandgap of a GaAs layer closer to the surface of our device. It is believed that this top layer absorbed all the light and gave off this signal. An etch was performed to remove this layer and it was found that an H_2O: H_2SO_4: H_2O_2, 1:5:1, wet etch for at least 120 seconds would etch through 100 nm of GaAs. As seen in Figure 4, the GaAs peak is markedly diminished compared to the unmodified sample. However, no peak was observed at 1030 nm.

Future Work:

Two higher powered lasers are currently being added into the setup. It is believed that sufficient light from the current 1.5 mW pump lasers is not reaching the sample. Additionally, a larger core (1 mm) multimode fiber could potentially capture a larger signal than the current 65 μm core.

After testing whether depositing SiO_2 induces any wavelength shift, selectively intermixing certain regions will be attempted. It has been proven in a similar material system that SiNx suppresses any wavelength shift [2].

Acknowledgements:

I would like to thank the NSF, the NNIN REU Program, UC Santa Barbara, my P.I. Dr. John Bowers, my mentor Jock Bovington, John Parker, Members of the Bowers Group, the Blumenthal Group, and the Coldren Group, the staff at the Nanofab, the other NNIN REU interns, and a special thanks to Angela Berenstein.

References:

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[2] Wang, Chad S., "Short-Cavity DBR Lasers Integrated with High-Speed Electroabsorption Modulators using Quantum Well Intermixing", Electrical and Computer Engineering Department UCSB, 38-61, (2007).

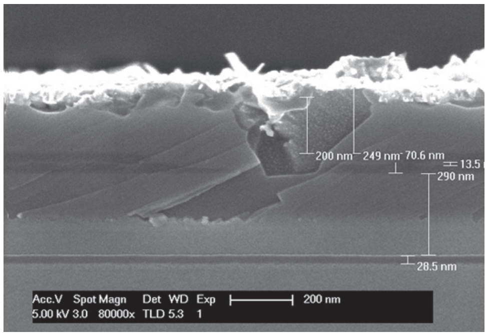

Figure 3: SEM of sample.

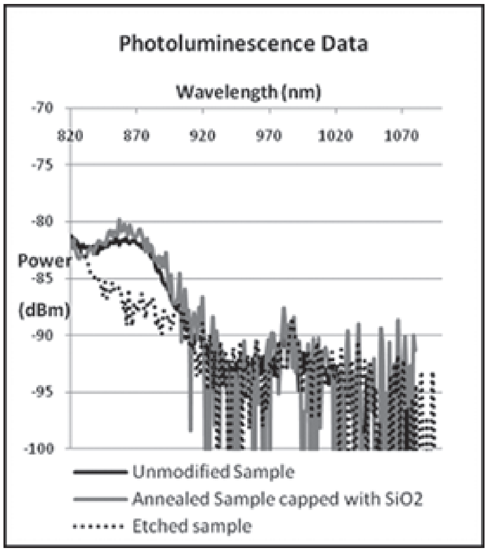

Figure 4: PL data of samples.