Effect of Hydroxide Surface Treatments on Photoluminescence of InP/InGaAs Heterostructures

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Abstract/Introduction

It has been previously shown that the surface recombination velocity of exposed indium gallium arsenide (InGaAs) quantum wells can be significantly reduced by permanently placing the heterostructure in a hydroxide solution or by forming a hydroxide crystalline layer [1]. The focus of this experiment is to use temporary hydroxide treatments, which do not form a crystal layer, to improve surface quality. A step was etched into an indium phosphorus (InP)/InGaAs heterostructure to expose a quantum well. Next, half of the sample (perpendicular to the step) was covered with photoresist and the whole sample was treated with buffered oxide etch and various concentrations of sodium hydroxide (NaOH) solution. After stripping the resist, the covered side was compared to the treated side to measure the difference in photoluminescence. The measurements show that the surface treatments did not reliably improve surface quality. Specifically, with a 90% confidence level, it was determined that a 1 mM NaOH, 30 minute treatment had no effect.

The ultimate goal of this research was to improve a device being developed for nanomechanical tuning of electron states.

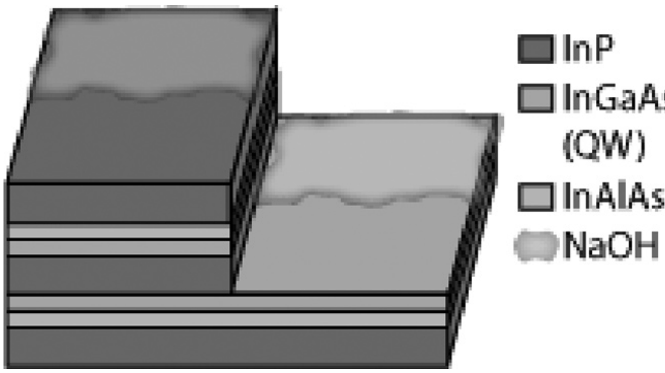

Figure 1: Four regions of the sample used in the experiment (With InP Cap/Exposed InGaAs Well, Treated or Not Treated).

Theory

InP/InGaAs Heterostructures. A quantum well is formed in a semiconductor when a thin semiconductor with a lower band gap (ex: InGaAs) is sandwiched between two thicker layers of a different semiconductor (ex: InP) with a higher band gap. Electrons within the middle layer are confined to the 2-dimensional plane of the well.

Surface Recombination. When the layer above the quantum well is etched away, the well is “exposed.” The incomplete bonds at the surface create trap states. Trap states are energy levels between the conduction band and the valence band at which electron-hole pairs recombine non-radiatively. Chemical bond passivation is used to slow trapping and recombination.

Photoluminescence (PL). When photons are absorbed by a semi-conductor, electrons within the compound are excited to higher energy states. When these electrons recombine to their original state through radiative recombination, photons are emitted. The amplitude and wavelength of the emitted light can be measured to further characterize the semi-conductor which produced the PL. Because PL intensity decreases when many electron-hole pairs recombine non-radiatively at the surface, a low PL indicates a large amount of surface recombination.

Experimental Procedure

To measure the effect of the hydroxide treatment on exposed quantum wells, steps were etched into the InP/InGaAs heterostructures, exposing the quantum wells. A standard photolithography process using 1818 photoresist was used to cover half the sample with photoresist. Next, the sample was etched in a solution of HCl: H_3PO_4:CH_3COOH (1:1:2) for 120 seconds, a solution of H_2SO_4:H_2O_2:H_2O (1:8:500) for 120 seconds, and, again, a solution of HCl:H_3PO_4:CH_3COOH (1:1:2) for 90 seconds.

Because it was expected that the surface treatment only affected the exposed quantum well, the treated and untreated regions of the capped quantum well were used to check the experimental procedure. A great difference in PL of the capped regions would indicate a systemic error in the experiment.

After etching, photoresist was painted onto half of the sample (perpendicular to the step). (A standard photolithography process was not used because the developer may chemically passivate the exposed quantum well bonds.) Then, an eye-dropper was used to form a bubble of NaOH solution on the sample. After various times of treatment, the sample was rinsed with deionized (DI) water and a solvent rinse.

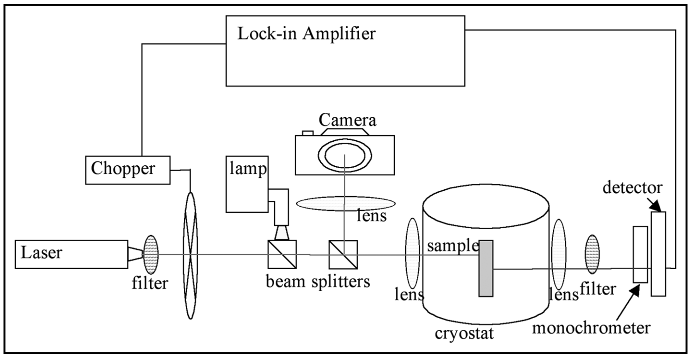

Figure 2: Apparatus for measuring photoluminescence.

The PL of four points on each of the four resulting regions was measured using the apparatus shown in Figure 2 from a frequency of 800 nm to 1750 nm, at room temperature.

Results and Conclusions

The average maximum PL of the untreated side is 1.56 pA (standard deviation = 1.26) while the average maximum PL of the treated side is 1.43 pA (standard deviation = 1.43). The means are statistically similar, with a confidence level of 90%. Treatments from 1 mM to 10 M and treatment times from 1-30 minutes were tested. A student t-test was used to analyze the data because previous experiments showed that the variation across the sample after etching, but before surface treatment, was about 100%. Therefore, only an improvement of above 100% could be attributed to the surface treatment, and not sample variation. Other experimental data indicates that the photoresist itself did not effect the PL of the samples.

Future Work

While it can be concluded that a 1 mM NaOH solution treatment for 30 minutes did not significantly improve the PL of the heterostructure, other concentrations and treatment times may have an effect. However, when the concentration was increased to 1M, the photoresist was etched away on the sample and so the control side was not preserved. A different photoresist may prevent this phenomenon.

It was also observed that longer or stronger treatments triggered a chemical reaction that resulted in a dark-colored film on the surface of the heterostructures. It would be worthwhile to experiment with other hydroxide solutions, such as potassium hydroxide (KOH), to determine if the formation of the film could be prevented. It would also be interesting to repeat this experiment, but allow a crystal layer to form, just to see if the previous results of Yablonovitch could be duplicated with this experimental apparatus.

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References

[1] E. Yablonovitch, H.M. Cox, T.J. Gmitter. "Nearly ideal electronic surfaces on naked InGaAs quantum wells", Appl. Phys. Lett., March 21, 1988, Volume 52, Issue 12, pp. 1002-1004.

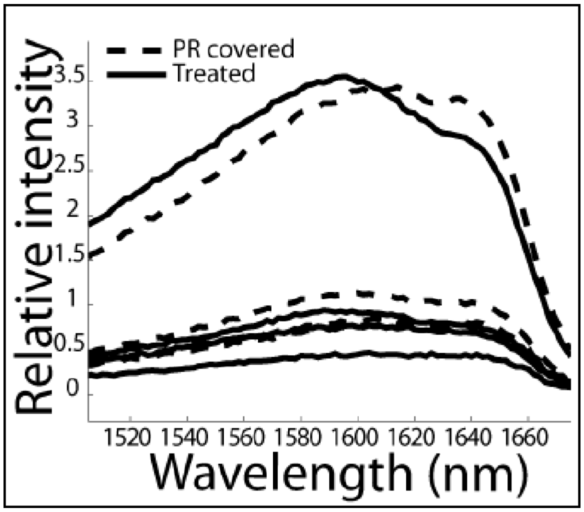

Figure 3: PL of exposed quantum well treated in 1 mM NaOH solution for 30 minutes.