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Optimization of Surface Preparation and Surface Passivation for GaSb Infrared Photodetectors

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GaSb can be used as an efficient mid-wavelength infrared photodetector, so its improvement is an important field of study. The passivation of GaSb is not as effective as passivation of other semiconductors. We report on the use of surface treatments of Buffered Oxide Etch (BOE) and ammonium sulfide, and their effect on the quality of ZnS passivation. These treatments are compared using Capacitance-Voltage measurement of metal-insulator-semiconductors structures made from the treated GaSb.

Introduction

Midwavelength infrared (MWIR) photodetectors have played an important role in technology over the past few decades. They are being used in many different fields, such as medicine, law enforcement, astronomy, and industrial processes. They have been useful in pollutant detection and thermal imaging. Mercury Cadmium Teluride has been used for more than two decades as the material for infrared detection.[1–5] However, Indium Arsenide and Gallium Antimonide based superlattices have been shown to be a promising material for MWIR photodetector.[6,7] There is ongoing research to improve these photodetectors' efficiency and usability.

Passivation of a semiconductor is used to reduce the surface charges and foreign material on the semiconductor. Passivation is necessary because a semiconductor is made of crystal lattice structure, and the atoms on the surface of the crystal have unsatisfied bonds. These bonds are either filled by unwanted material near the semiconductor, or they are left as dangling bonds, both of which reduce the quality of the semiconductor. Passivation is the attachment of a selected material to the surface of a semiconductor, to reduce the dangling bonds. The material is chosen to bond to the semiconductor, the passivants, is similar in structure to semiconductor. Surface treatment of the semiconductor happens before the passivation, and is intended to remove any unwanted materials that may have bonded to the surface of the semiconductor. Surface treatments also are used to smooth out the surface of the semiconductor.

There have been many previous attempts at GaSb passivation with aqueous solutions of sodium and ammonium sulfide.[8–10] Less common methods of passivation using wet and dry methods have also been studied for GaSb passivation.[11–13] These processes have still yielded detrimental levels of oxide growth on the surface of GaSb.[14] Some reports have pointed to non-aqueous passivation to lower the oxide growth,[15] and previous work by our lab shows that ZnS passivation works better than SiO_2 and SiN_x, as shown in Figure 1.

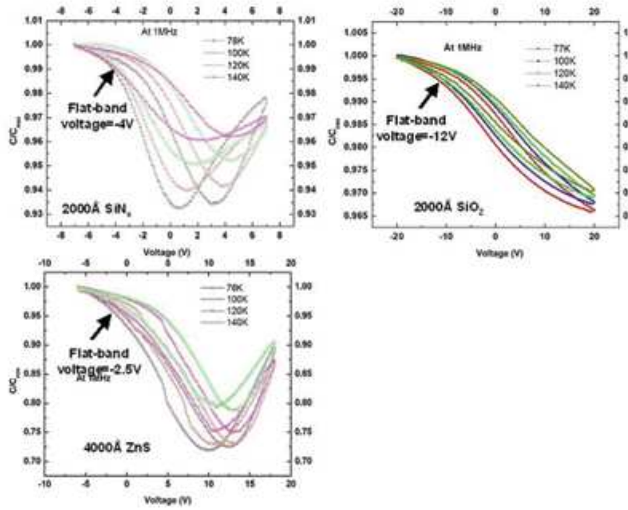

FIG. 1: C-V characteristics of different passivants measured at different temperatures and 1 MHz.

Methods

Metal-insulator-semiconductor structures were made to test the quality of the passivation and surface treatments. Three chips (chips A,B, and C) of GaSb were each cleaned by soaking in acetone, methanol, trichloroethylene (TCE), and DI water. The chips were in each solution for 5 minutes at 60°C, except for the DI water which was 5 minutes at room temperature. All of the chips were then etched by a 2:1:20 H_2O_2:H_3PO_4:DI water mix. They sat in the mix for 5 minutes at room temperature. Chip A was soaked in a Buffered Oxide Etch (BOE) for 5 minutes at room temperature. Chip B was soaked in $(NH_4)_2S$ at room temperature for 10 minutes. No treatment beyond the 2:1:20 H_2O_2:H_3PO_4:DI water mix was applied to Chip C. After the final surface treatment, each chip was quickly passivated. 4400 ÅZnS was used as the passivation layer. The passivation layer was deposited with the help of electron-beam deposition with a deposition rate of 0.6-0.7 Å/s below 500 Åand ∼1-1.2 Å/s till the end. A slower initial deposition rate was maintained to help the passivant molecule find the minimum energy position on the semiconductor surface. Gold dots of 1 mm diameter and 1500 Åthickness were deposited on top of the passivants using Varian, a metal deposition machine where a high-energy electron-beam is focused on a crucible containing the metal of choice in a vacuum chamber. The metal is evaporated and eventually gets deposited on the samples placed at an angle at the top the chamber. After the gold was deposited, a piece of the passivants was scratched off the surface of the semiconductor using a scalpel, and Indium was applied to the exposed GaSb to be used a contact.

Experimental

After each sample was prepared they were entered into the probe station. The probe station is evacuated to create a vacuum, and the temperature is lowered to 78 K. The electrodes of the probe station made contact with a gold dot, and the indium. The voltage is swept from -5 volts to 10 volts by the Model 4275A multi-frequency LCR meter, which measures the capacitance. These C-V measurements are done several times for each sample, placing the electrode at a different gold dot each time.

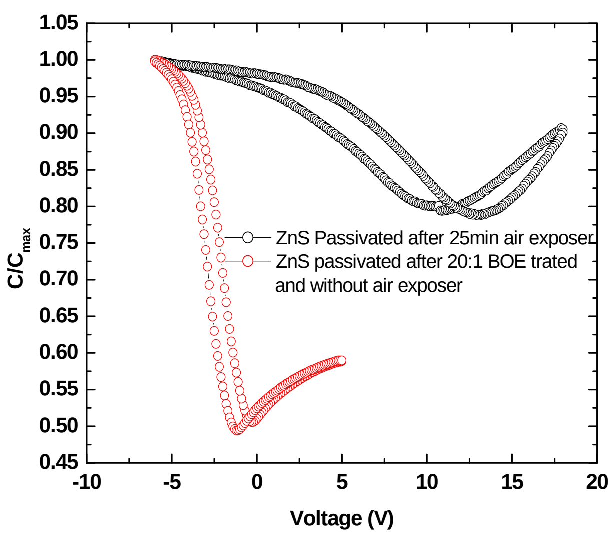

FIG. 2: Comparison of C-V characteristics of ZnS passivated sample with and without 20:1 BOE treatment measured at 78 K and 1 MHz.

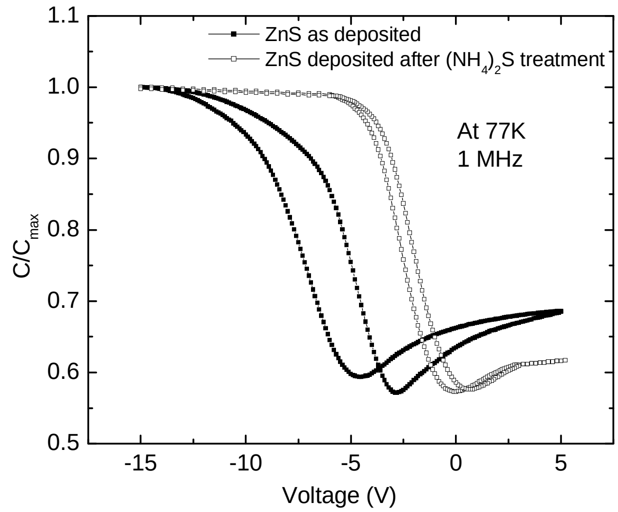

FIG. 3: Comparison of C-V characteristics of ZnS passivated sample with and without prior Ammonium Sulphide treatment measured at 78 K and 1 MHz.

Analysis

The C-V measurements from chips A and C are shown in Figure 2. The figure shows that hysteresis in chip C (with air exposure, no BOE treatment) is around 2.5 V, and the hysteresis in chip A (BOE treated) is around 1 V. The hysteresis indicates the presence of interfacial charges located at the ZnS/GaSb contact point, and the mobile charges within the ZnS. These charges causes a band bending the surface of the semiconductor material which is detrimental to the flow of charge carriers. In a photodetector, carriers are generated by absorbed photons and then they travel to the contacts due to the electric field present inside the device. As the carriers reach the contacts, current is generated and provides an way to detect or measure the incident radiation. However, the presence of surface states, as pointed out from the hysteresis, capture these carries and prevent them form reaching the contacts. This results in a lower detectivity of the detector. Also since this capturing phenomenon is random in nature, it adds to the noise of the device. So, as evident, the BOE treated sample chip A having a lower hysteresis is preferable for a good photodetector.

Figure 3 shows a comparison between chip A (ZnS as deposited) and chip B(ZnS deposited after ammonium sulphide treatment). A comparison with chip C is not presented since it is already clear that chip A performed better than chip C. For chip B, not only that the hysteresis is further lessened compared to chip A, the flatband voltage also has a significant reduction. Flatband voltage is the voltage at which the capacitance curve starts falling down as the voltage is swept from low to high in a p-type sample. Unlike hysteresis, the flatband voltage is an indicator of fixed charges inside the passivation layer. During processing or from the atmosphere, chemical agents are incorporated within the passivation layer creating charge centers within it. This makes the semiconductor material act differently at the passivation-semiconductor interface. Ideally the flat-band voltage should be zero but depending on the nature of the fixed charge, bands bend upward or downward shifting the flat-band voltage and resulting in an accumulation or a depletion or an inversion condition even at zero bias. The ammonium sulphide treated sample had a flat-band voltage of -0.5 V compared to -4.0 V of the sample without the treatment.

Conclusion

From the results, we can conclude that treating the surface of GaSb with ammonium sulphide prior to ZnS deposition largely enhances the passivation quality. It shows a significant reduction in the flat-band voltage and the hysteresis indicating fewer amounts of fixed charge and surface states, which are likely to further promote the performance of the photo-detectors.

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