Characterization of InAs/AlSb/GaSb Heterostructures When Exposed to *in situ* Plasma Cleans in an ALD Process

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Abstract:

The ability to control the carrier density in a semiconductor using a voltage applied to a metal gate electrode on top of a dielectric insulating layer is critical to many device applications. Gallium antimonide/indium arsenide/aluminum antimonide/gallium antimonide (GaSb/InAs/AlSb/GaSb) heterostructures have electronic properties that make them useful for electronic and optoelectronic application [1]. However, the gating efficiency has generally been low with hysteretic behavior. Surface contamination and surface oxides on the heterostructures are believed to be the cause of hysteric gate operation. The main goal of the project is to improve gate control of group III-V antimonide based semiconductor heterostructures. An *in situ* plasma clean using both hydrogen and nitrogen was used prior to depositing of a AlN dielectric film by atomic layer deposition (ALD). Images were taken using atomic force microscopy (AFM) before and after deposition to determine if degradation of the surface occurred, and if so, the rate of degradation; also to view the atomic layers that had been deposited. Optical and atomic force microscopy images were taken between fabrication steps, as well as after fabrication was completed. The electrical properties were also measured (mobility, resistivity, carrier density via four-point probe techniques and the Hall Effect) of the full heterostructures and lone insulating buffers before and after exposure to fabrication steps. These measurements help understand the effects of surface roughness, surface contamination, and processing induced defects on gate operation of the heterostructures.

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Introduction:

Compound semiconductors have applications in electronics and optoelectronics such as transistors, infrared detectors and infrared emitters. InAs is a compound semiconductor and GaSb/InAs/AlSb/GaSb heterostructures have electronic properties that make them useful for high speed, low power electronics and infra-red optoelectronic application [1]. However, their implementation in electronic devices has been limited because of difficulties in fabricating devices. Using InAs and AlSb layers, the InAs creates a channel where electrons become confined; this is called a quantum well. When processing the material to make these applications often a metal gate electrode must be fabricated onto the material that allows control of the electron density in the InAs channel by applying a voltage to the gate.

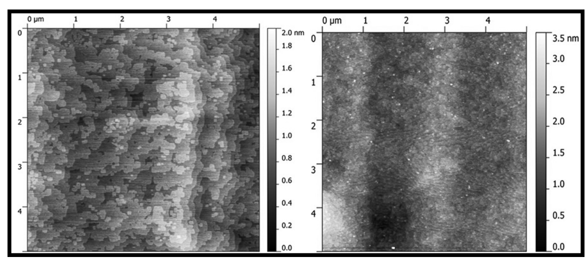

Figure 1: AFM images of the GaSb surface before and after basic photolithography process and compatible chemical clean.

Contamination of the GaSb surface occurs very readily. It can begin to oxidize as soon as the surface is exposed to air after the growth process of the material is over [2]. It can also become contaminated when performing fabrication processes on the material. Therefore, a way to clean and protect the surface without changing the material's performance is needed. The following atomic force microscopy images depict a surface immediately after growth on the right and on the left is the same sample after going through a standard photolithography process and solvent clean (see Figure 1).

Experimental Procedures:

In this experiment, two samples were tested. The first being an InAs layer 5 nm from the surface and the second being an InAs layer 55 nm from the surface. The samples were first measured for Hall mobility, sheet resistivity, and sheet carrier density by Hall measurements using four-point contacts at the corners of the samples. The samples then underwent an ALD process where in a chamber the GaSb/InAs/AlSb/GaSb heterostructure was heated to 300°C and then cleaned with hydrogen plasma and then with nitrogen plasma for a combined 10 seconds under 50W of power. Then AlN was layered in a self-limiting manor. The exposure to the nitrogen and hydrogen plasmas were repeated 1, 10, and 100 times for different ALD runs, and electronic properties were determined by Hall measurements after the combined plasma cleans and ALD process.

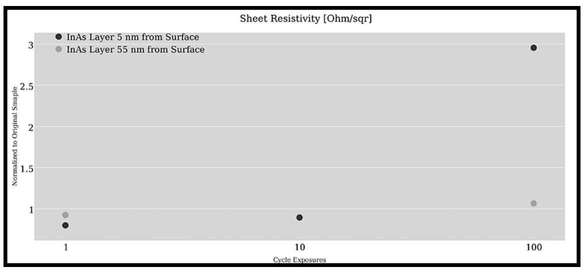

Figure 2: Plot of number of ALD cycles versus resistivity normalized to the original sample.

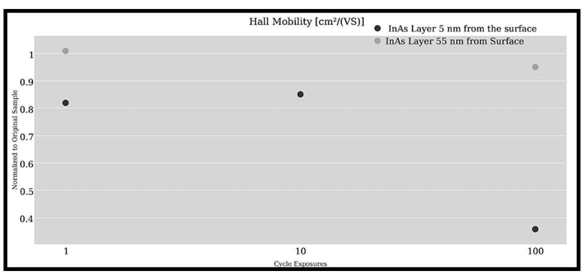

Figure 3: Plot of number of ALD cycles versus mobility normalized to the original sample.

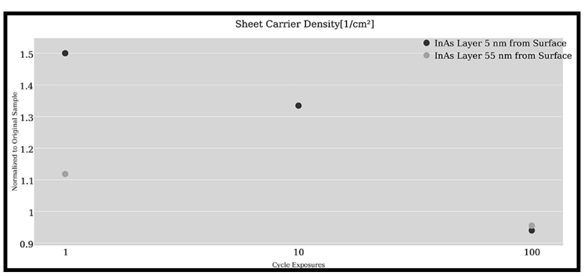

Figure 4: Plot of number of ALD cycles versus carrier density normalized to the original sample.

Results and Conclusions:

It was desired that resistivity and mobility measurements (see Figure 2 and 3) stay as close as possible to the original sample to maintain the functionality of the material. Carrier density was expected to change due to removal of surface contamination changing the surface carrier density and bulk properties changing after many cycle exposures (see Figure 4).

AlN deposition including a hydrogen and nitrogen *in situ* plasma clean was thought to be a useful agent in the passivation of GaSb/InAs/AlSb/GaSb heterostructure.

This study has shown that the electrical properties of quantum wells set back at greater distances from the structure's surface are less affected by the cleaning process while the electronic properties of quantum wells close to the structures surface were sensitive to the cleaning process.

Future Work:

This ALD process of AlN could be a possible precursor of other treatments of the GaSb surface to prevent impurities from forming on the surface during processing as well as preventing oxidation; it is desired to use the optimal amount of cycle exposures of AlN and then also test deposition of a dielectric on top of the AlN layers to possibly improve the gating process when testing the material.

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References:

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[2] Ruppalt, Laura B., Erin R. Cleveland, James G. Champlain, Sharka M. Prokes, J. Brad Boos, Doewon Park, and Brian R. Bennett. "Atomic layer deposition of Al_2O_3 on GaSb using *in situ* hydrogen plasma exposure." Applied Physics Letters 101.23 (2012): 231601. Print.