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14. ABSTRACT

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RPPR Final Report

as of 23-Aug-2021

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INVESTIGATOR(S):

Name: Gregory A Belenky Ph.D.
Email: gregory.belenky@stonybrook.edu
Phone Number: 6314311267
Principal: N

Name: Leon Shterengas
Email: leon.shterengas@stonybrook.edu
Phone Number: 6316329376
Principal: Y

Organization: **Research Foundation of SUNY at Stony Brook University**

Address: W-5510 Melville Library, Stony Brook, NY 117943362

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Final Report for Period Beginning 15-May-2020 and Ending 14-May-2021

Title: Upgrade of GEN-930 MBE System for Epitaxial Regrowth of Antimonide Photonics Materials

Begin Performance Period: 15-May-2020

End Performance Period: 14-May-2021

Report Term: 0-Other

Submitted By: Leon Shterengas

Email: leon.shterengas@stonybrook.edu

Phone: (631) 632-9376

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STEM Degrees: 1

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Major Goals: The Veeco GEN-930 solid-source MBE system was upgraded with clean cryo shrouds in main reactor, increased pumping capacity in buffer chamber where atomic hydrogen cleaning is performed, and more functional hydrogen delivery system to increase the crystalline quality and improve surface morphology of the epitaxial heterostructures. The major goal was minimization of the material contamination during growth and during critical surface preparation steps.

Accomplishments: The funds were utilized to acquire the necessary equipment, services and materials to improve the vacuum quality of the MBE system and perform necessary verification tests.

The upgraded MBE will be used to grow device heterostructures to support the following on-going research programs at Stony Brook University, namely:

1. Development of the high power GaSb-based photonic crystal surface emitting lasers – sponsored by US Army Research Office;
2. Development of novel metamorphic heterostructures for long wave infrared optoelectronics – sponsored by US Army Research Office and FLIR Inc;
3. Development of the novel electrically pumped bi-photon emitters for quantum photonic applications – sponsored by US National Science Foundation;
4. Development of the GaAs-based x-ray photodetector arrays for X-ray beam position monitoring.

The upgraded MBE system will enable new research directions, namely:

1. Development of the passively mode-locked GaSb-based cascade diode lasers for ultrafast pulse and optical frequency comb generation.
2. Development of the linear and Geiger mode avalanche photodiodes for mid-infrared region of spectrum.
3. Development of the epitaxially regrown in-situ passivated barrier photodetectors.

RPPR Final Report as of 23-Aug-2021

As of May 2021, all services and installations has been completed, system was fully baked out and tested and is being used to grow materials for aforementioned on-going research projects. The efficiency of the cryo shrouds has been improved dramatically - liquid nitrogen evaporation rate reduced by two-to-three times. The quality of the epitaxial material has been improved dramatically as evident from consistently obtained improved surface morphology and device luminescence efficiency.

Training Opportunities: Two graduate students were involved in system upgrade process and testing.

Results Dissemination: Nothing to Report

Honors and Awards: Nothing to Report

Protocol Activity Status:

Technology Transfer: Nothing to Report

Partners

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I certify that the information in the report is complete and accurate:

Signature: Leon Shterengas

Signature Date: 8/12/21 6:02PM

Upgrade of GEN-930 MBE System for Epitaxial Regrowth of Antimonide Photonics Materials.

Major Goals

The Veeco GEN-930 solid-source MBE system was upgraded with clean cryo shrouds in main reactor, increased pumping capacity in buffer chamber where atomic hydrogen cleaning is performed, and more functional hydrogen delivery system to increase the crystalline quality and improve surface morphology of the epitaxial heterostructures. The major goal was minimization of the material contamination during growth and during critical surface preparation steps.

Summary

The funds were utilized to acquire the necessary equipment, services and materials to improve the vacuum quality of the MBE system and perform necessary verification tests.

The upgraded MBE will be used to grow device heterostructures to support the following on-going research programs at Stony Brook University, namely:

1. Development of the high power GaSb-based photonic crystal surface emitting lasers – sponsored by US Army Research Office;
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The upgraded MBE system will enable new research directions, namely:

1. Development of the passively mode-locked GaSb-based cascade diode lasers for ultrafast pulse and optical frequency comb generation.
2. Development of the linear and Geiger mode avalanche photodiodes for mid-infrared region of spectrum.
3. Development of the epitaxially regrown in-situ passivated barrier photodetectors.

The key items acquired using DURIP funds included:

1. Veeco GEN-930 Cryo Shroud removal, cleaning and installation – Riber, Inc.;
2. HiPace 700 H turbo pump and oil-free backup pump – Pfeiffer Vacuum, Inc.;
3. Rebuild kits for substrate heater module – Veeco, Inc.;
4. Effusion cells update – Veeco;
5. Hydrogen gas delivery system (MFC, regulators, valves, welding) – multiple vendors;
6. Substrates and liquid nitrogen delivery for system tests – Veeco;

In addition, there were charges for shipping, acquisition of valves, vacuum adapters, gaskets, and many small items necessary for installation of the additional elements and reinstallation of the cleaned cryo shrouds.

As of May 2021, all services and installations has been completed, system was fully baked out and tested and is being used to grow materials for aforementioned on-going research projects. The efficiency of the cryo shrouds has been improved dramatically - liquid nitrogen evaporation rate reduced by two-to-three times. The quality of the epitaxial material has been improved dramatically as evident from consistently obtained improved surface morphology and device luminescence efficiency.

As an illustration of the nearly perfect MBE system operation we would like to present one of the recent experiments performed in the newly cleaned MBE reactor and utilizing the atomic hydrogen surface cleaning step in buffer chamber.

To confirm the effect of the surface oxide desorption process on the morphology of the regrowth interface we performed an independent experiment in which epitaxial GaSb was subjected to thermal and atomic hydrogen assisted oxide desorption steps and the resulting surface morphology was assessed by Atomic Force Microscopy (AFM). At the first step, we grew ~ 600 nm thick GaSb buffer on 2" GaSb 001 commercially available epi-ready wafer to smooth out any imperfections associated with chemical mechanical polishing of the GaSb material. The wafer was taken out from MBE reactor, cleaved into quarters and left to oxidize in atmosphere for two weeks. The $5 \mu\text{m} \times 5 \mu\text{m}$ AFM surface scan (Figure 1a) showed apparent atomic terraces loosely aligned to 110 direction. The profile roughness (aside from ~ 300 pm tall atomic steps – Figure 1c top plot) was dominated by measurement noise. One quarter of this wafer was subjected to atomic hydrogen oxide desorption step. The presence of oxide before the hydrogen treatment and removal of it after the treatment was over were confirmed by RHEED. Figure 6b shows the $5 \mu\text{m} \times 5 \mu\text{m}$ AFM surface scan of this sample. The ~ 110 -aligned atomic-terraces can be well resolved (Figure 1c middle plot), however, their widths seem to increase, and apparent increase of surface roughness was observed. The observation can be explained by slow etching of the GaSb surface by atomic hydrogen atmosphere without significant degradation of the surface morphology. Figure 1d shows the $5 \mu\text{m} \times 5 \mu\text{m}$ AFM surface scan measured for the quarter wafer from which the oxide was removed thermally. There are no observable atomic steps – the surface morphology degraded dramatically with roughness increased by more than an order of magnitude.

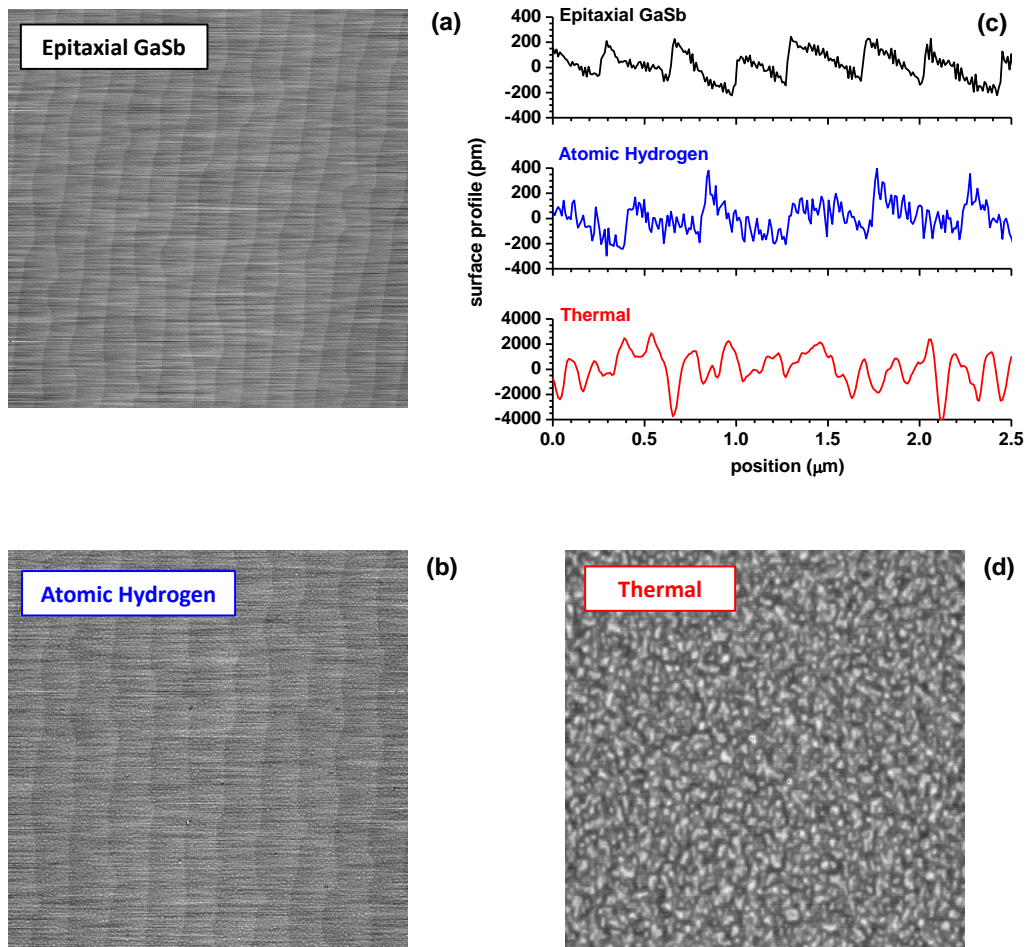


Figure 1. The $5 \mu\text{m} \times 5 \mu\text{m}$ AFM surface scan of: (a) – ~ 600 nm GaSb buffer layer; (b) – GaSb buffer layer after the atomic hydrogen assisted oxide removal step; (d) – GaSb buffer layer after the thermal oxide desorption step (the gray shade scale is 20 nm vs 5 nm for two previous scans). Panel (c) shows the surface profiles measured for all samples in the direction perpendicular to atomic terraces observed for as grown buffer and atomic hydrogen treated samples.

Our experiment demonstrates that when heterointerface morphology is an important factor, the thermal oxide desorption step must be followed by growth of the smoothing buffer layer made of the same material prior to regrowth with alloy of different composition. This experimental studies relied on the high quality epitaxial growth with low contamination and efficient atomic hydrogen cleaning capability – a functionalities enabled by this award.