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14. ABSTRACT

The optoelectronic stuctures and devices, whose study will be enabled by the acquired research instrumentation, including ultra-broadband modulators, photonic crystal lasers, and very fast optical logic circuits, are of intense interest for future Air Force needs. The objective of the research instrumentation acquisition is to enhance the institution's ability to study III-V semiconductor materials and devices. An inductively-coupled plasma reactive-ion etcher will be acquired for sophisticated, on-site fabrication of photonic and optoelectronic devices with novel III-V heterostructures.

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Advanced Plasma Etching of Complex Combinations of III-V Heterostructures

Defense University Research Instrumentation Program
AFOSR contract FA9550-07-1-0280
3/1/2007 to 6/30/08

Final Report

Submitted by Professor Erich P. Ippen, Professor Leslie A. Kolodziejski
Massachusetts Institute of Technology
September 28, 2008

With the funds provided by the DURIP award, we were able to acquire an inductively-coupled plasma reactive-ion etcher (ICP-RIE) for the fabrication of photonic and optoelectronic devices composed of novel III-V heterostructures. III-V heterostructures designed to consist of antimony-based materials, arsenide-based materials, phosphorus-based materials, as well as mixed arsenide/phosphide materials (with various layers containing indium, gallium, and aluminum) will be etched with the new etching tool.

The ICP RIE that was acquired has two very important attributes necessary for dry etching complex combinations of III-V heterostructures: (1) a *dedicated* chlorine-based gas chemistry will be used and will allow all of the aforementioned III-V materials to be etched, and (2) the sample chuck can be elevated in temperature for the desorption of residual chemical by-products that occur when etching materials containing In. The choice of purchasing an inductively-coupled plasma-RIE enables the density of the plasma and the energy of impinging reactive species (affected by the bias on the wafer or chuck) to be controlled separately. Such control of the etch process is advantageous for creating sidewalls with minimal roughness and for etching device structures that have large aspect ratios, i.e. the etch depth is large compared to the lateral feature size. The advanced devices and photonic integrated circuits that this capability will enable us to fabricate are crucial to our research efforts on integrated ultrashort-pulse lasers, devices for optical clocks and arbitrary waveform generation, and devices for all-optical signal processing for ultrahigh bit-rate networks. The new capability offered by the availability of the ICP-RIE will also greatly benefit our collaborative research endeavors on the design, fabrication and testing of novel photonic crystal structures and devices.

The purchase and installation of the ICP RIE was truly a joint effort of several faculty members. The list price of the SAMCO RIE-200iP that was purchased was $526.4K; however, negotiations with the SAMCO representatives and with agreements to share etch results between the two entities (SAMCO and MIT), the final purchase price was reduced to $330K. The DURIP award was for $260K. The balance of the funds to purchase the etch tool ($70K) was provided by the following faculty: Professors Leslie Kolodziejski, Erich Ippen, Franz Kaertner, Rajeev Ram and Qing Hu. Furthermore, installation of the tool was needed and cost additional monies exceeding $110K; the installation costs were covered by funds provided by the Research Laboratory of Electronics with Professor Jeffrey Shapiro as Director. Space was also made available in

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the Nanostructures Laboratory (NSL) that is supervised by Professors Karl Berggren and Henry Smith.

At the present time, the ICP RIE tool has been received and is installed in the NSL. Figure 1 shows the ICP RIE tool located in the NSL laboratory. Figure 2 shows part of the gas delivery system that has been built to transport the various gases to the reactor. The gases (Cl_2, BCl_3, $SiCl_4$, O_2, N_2, Ar, and CHF_3) that are needed to etch the III-V material combinations have been plumbed to the tool. Furthermore, two principal research scientists and two graduate students have been trained by the SAMCO technicians. Figure 3 (a) shows the preliminary etch results that have been obtained using GaAs substrates and Figure 3 (b) shows the preliminary etch results that have been obtained using InP substrates. These etch results are by no means optimized etch parameters; investigation of the range of etch parameters is underway. Of particular importance is the process sequence that will be implemented to etch different III-V materials from one day to another and to ensure that etch results are repeatable and provide reproducible results.

Figure 1) The SAMCO ICP-RIE system installed within the NanoStructures Laboratory (NSL).

Figure 2) The inert gas panels for the ICP RIE system. The monitor in front is for a Rapid Thermal Processor.

a) b)

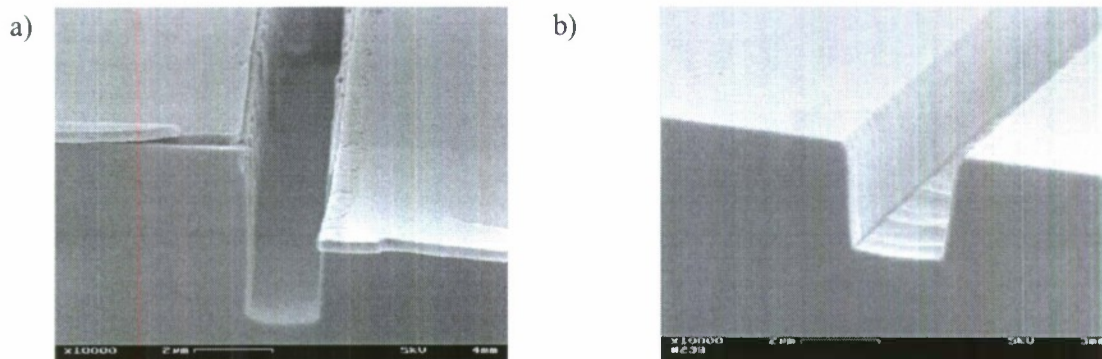

Figure 3 (a) Scanning electron micrograph (SEM) of a GaAs sample etched with the ICP RIE system. (b) A SEM image of an InP substrate etched with the ICP RIE system.

The ICP RIE tool will be dedicated to the etching of III-V compound semiconductor materials. To care for the tool, a research scientist, Dr. Gale Petrich will be monitoring the use and making sure that the tool is maintained as needed for proper functioning and so that the tool is properly maintained. In addition, Dr. Petrich will train each user in the proper operation and cleaning of the system. As an additional feature, Dr. Petrich has implemented the software tool Microsoft Access to enable collection of recipes and results of various etch processes. The users will be able to add their recipes and etch results into the program and will also be able to view all recipes and etch results obtained by other users. Hopefully, sharing of these data will allow research progress to advance more rapidly. Figure 4 shows a sample of the Microsoft Access interface that will be used by every user.

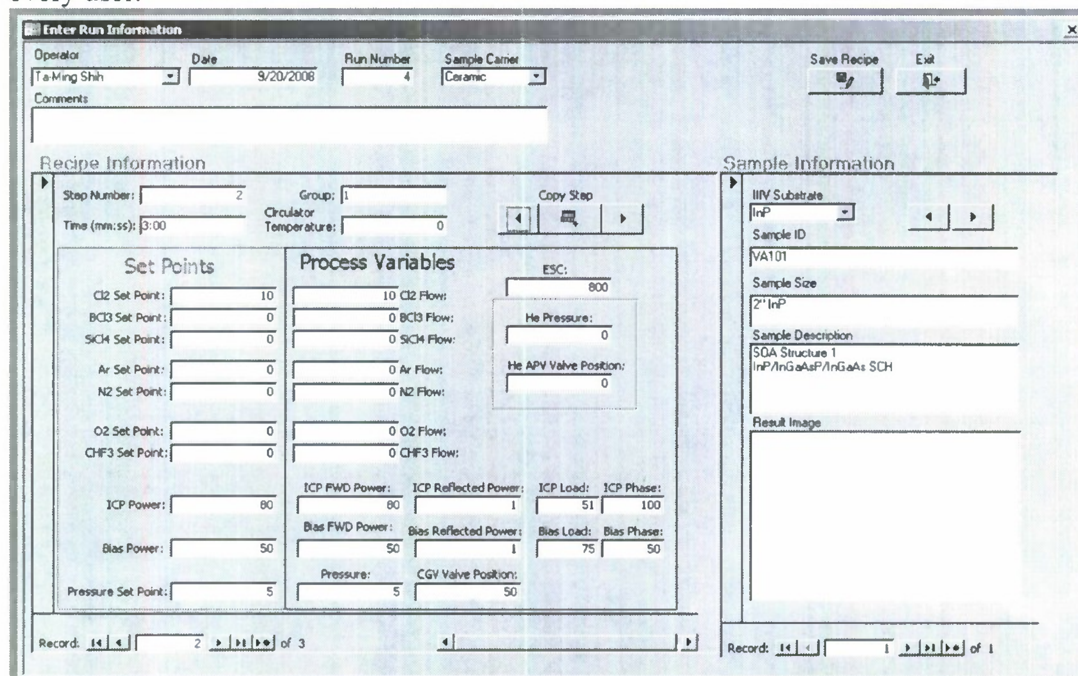

Figure 4: Example of user interface for ICP RIE as a method to record etch recipes and etch results.