ECR Etching of III-V Group Compound Materials

Author
L. Seventh Star Singh

Supervisor
Prof. Z H Zaidi
Department of Physics
Faculty of Natural
Sciences,JMI

Nowadays plasma etching is becoming very useful in the device fabrication. Plasma is mysterious beehive of energetic electrons, photons, ions, neutral particles and chemically reactive gas molecules. The challenges in the plasma processes are the optimization of a long list of process parameters, including etch rate, selectivity, damage etc. However, etch processes have some additional challenges: the complexity of the structures being patterned is increasing (multi-layer film stack etches are now common) and new devices are giving rise to a wider diversity in the types of materials that must be etched.

Some of the important techniques which are used in the removal of material by a plasma based process are: reactive ion etching (RIE), reactive ion beam etching (RIBE), magnetically enhanced reactive ion etching (MERIE), sputter etching and downstream plasma etching etc. More recently, high-density plasma sources like electron cyclotron resonance (ECR), inductively coupled plasma (ICP), helicon and decoupled plasma source (DPS) have been developed.

The dry plasma etching of GaAs and related compounds is gaining a new interest due to the need to achieve high-resolution, anisotropic etching in device applications. There are a variety of requirements such as fast etch rate, high selectivity for say GaAs over AlGaAs, or conversely equi-rate etching for these materials which are desirable in various fabrication schemes. Consequently, there has been considerable effort expended to determine the appropriate etch gas chemistries and etching conditions needed for these often diametrically opposed requirements. Dry etching of GaAs and related compounds has generally been performed using Cl2-based discharges, principally because of the volatile nature of As and Ga chlorides. Some of the gas mixtures used for GaAs include Cl, BCl_3, CCl_4, $SiCl_4$, $COCl_2$, and chlorofluorocarbons (CFC) such as CCl_2F_2. Generally, these gases have been reported to give high etch rates with reasonably smooth surface morphologies, at least for GaAs itself. The common constituent of most of these mixtures is chlorine, which is attractive because gallium chlorides are volatile at relatively low temperatures, as opposed to the stable gallium fluoride. It is common to use Cl_2-based gases for etching GaAs. Most of the Cl-containing gases also contain carbon, and often problems are encounter with the deposition of polymeric films on the GaAs surface during etching, leading to irreproducible results. Recently, excellent have been obtained with $SiCl_4/SF_6$ mixtures, however the toxicity of $SiCl_4$ is a disadvantage with this chemistry. Generally, the disadvantages with other Cl_2-based gases are their corrosiveness, toxicity, the need to use evacuated gas cabinets to store them in.

Moreover, one bigger disadvantage for us is that these Cl_2-based gases except CFCs are not available in India. But CCl_2F_2 is easily available in the Indian markets in the research grade and the disadvantages are also reduced in great extent with chlorofluorocarbons. Because, CCl_2F_2 has been used in the refrigerant industry. Therefore, we have chosen this gas as the reactive gas for our etching purposes.

As the circuit complexity increases and device dimensions decreases, it is very necessary to choose right technique in order to get a highly anisotropic result. Ternary and quaternary III-V materials are key components in many of these devices, and therefore one must also be careful in choosing the etching processes that can remove different semiconductors at the same rates. In order to achieve our aim we have chosen the ECR etching technique, the most popular technique in our knowledge.

Electron cyclotron resonance (ECR) plasmas have been utilized for the last 35 years in various fields of plasma and ion beam technologies: low-temperature plasma enhanced chemical vapor deposition, plasma stream and reactive ion beam etching, and ion implantation, The attractive feature of the ECR plasmas are the absence of heated filament, negligible wall sputtering (low plasma potentials), high degree of ionization (>10%) and decomposition working gas at low pressure (10^{-6}-10^{-3} Torr), high density plasma, compatibility with active and corrosive gases, long lifetime (hundreds of hours), and stability of operation.

We have assembled an ECR etching system in the Department of Physics, Jamia Millia Islamia. The main ECR Etching Source was obtained from M/S Roth & Rau, Germany including the substrate holder and the three MFC's were obtained from M/S Bronkhorst, Netherland, which are used to controlled the flow of the different gases through a control system E-7000 in a flow range corresponding to the actual process. For a complete ECR etching system we need a specified vacuum chamber. Therefore, the design and the drawing with the necessary specification were prepared and finally a vacuum system was fabricated indigenously with the help of M/S VEQCO. This system gives the ultimate base pressure of around 10^{-6} mbar, which is required for the optimal operation of the ECR source. This system has a pumping system having a high throughput oil diffusion pump and a mechanical rotary pump (1000 l/m). Substrate holder and rf source were properly fitted with water cooling facilities. A separate earthing was provided for this system as a precautionary measure as specified by manufacturer of rf source. Gas pipeline of high quality are used for the connections of the MFC's and cylinders. After having all the necessary facilities, finally, a complete ECR etching system was assembled.

First the system was successfully tested with an ashing experiment of photoresist. The ashing was accomplished using O_2/Ar gas mixture and the ashed sample has been examined at SSPL. The depth of the ashed sample was found to be 1.972 m m. Dry etching experiments were performed using CCl_2F_2/Ar and CCl_2F_2/Ar/O_2 discharges. We have done our etching experiments with the changes of the flow rate of reactive gases, addition of oxygen, etching time, plasma power density, rf power. Our system can also operate in the RIE mode. In this case we have used the RF biasing of the substrate holder where the magnets and ECR source are not used. Therefore, we investigated the etching experiments of GaAs with this mode and the results obtained are compared with that of the ECR etching technique.

The dependence of GaAs etch rate in these two discharges on the various plasma parameters reveals a number of features:

- Anisotropic etching can be achieved with the above discharges.
- Under our conditions the etch rate is linear with time.
- Etch rate of GaAs increases linearly with additional rf biasingapplied to the samples.
- Surface roughness increases with the increase in rf biasing.
- There seems to be some different in the etched surface with the changes of plasma power i.e. surface roughness seems to be decreases with the increase in plasma power density. This may not be due to more effective ion-enhanced sputtering of any possible polymer layer forming on the GaAs surface, but may be due to more effective removal of the more involatile etch product $GaCl_3$ at higher power densities.
- There is an initial linear increase in the etching of the GaAs with power density but the etch rate actually decreases for GaAs at the higher powers. The most straightforward explanation for such a decrease is to assume that the Cl radicals actually are desorbed from the GaAs surface by sputtering before they have a chance to react. In other words, the etching at high-power densities is adsorption limited, whereas at low powers it is desorption limited. Therefore, increasing the power density leads to an enhancement of reactant desorption through an increase in the energy of the bombarding ions crossing the plasma sheath.
- Increasing the oxygen concentration in the gas mixture does not lead to any additional oxide formation on the GaAs surface.
- Etching at higher power densities leads to increased contamination of the GaAs surface with a chlorofluorocarbon polymer layer.
- ECR conditions provide much higher etch rates than the RIE techniques for GaAs and related compounds.