Low-Temperature Plasma Etching of GaAs, AlGaAs, and AlAs

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Dry etching of compound semiconductors is becoming increasingly important as design rules shrink for electronic devices. For photonic device applications, dry or plasma etching is used for device isolation, fine-line pattern transfer, and fabrication of optical quality interfaces. As has been well established for Si and W, plasma etching at reduced temperatures can provide superior critical dimension control and obviate the need for operating at high bias voltages that produce excessively energetic ion bombardment. In this work, we explore low-temperature (−60°C to +60°C) etching of the compound semiconductors GaAs, AlGaAs, and AlAs. In addition to improving etch anisotropy, which provides critical dimension control, we find that processing at lower temperatures improves microuniformity and reduces loading effects. At high temperatures, where larger samples are observed to etch more slowly than smaller pieces (loading effect), etching rates appear limited by reactant transport to the wafer. In this regime, both microuniformity and macrouniformity are poor. As the temperature is reduced, the etching rate becomes limited by surface processes as a residue containing the semiconductor elements, etchant gases, and residual background gases forms on the surface. In this regime, the etch rate becomes independent of surface area and uniformity is improved.

KEY WORDS: Reactive ion etching; loading; uniformity; anisotropy; triode; pattern transfer.

1. INTRODUCTION

Compound semiconductors such as GaAs, AlGaAs, and AlAs are important materials used in the fabrication of fast electronic and photonic devices such as surface emitting lasers, optical resonators, photodetectors,
and heterojunction bipolar transistors. As in Si-based technology, the trend toward decreasing feature size has led to the use of dry or plasma etching for high-fidelity pattern transfer in making these devices. Besides the usual problems encountered in Si technology, etching of compound semiconductors is complicated further by the use of multi-element materials having widely varying chemical and physical properties.\(^{11}\) For example, in etching a multi-layer stack of GaAs/AlGaAs/AlAs, which might be used as a mirror for a surface-emitting laser, products with different vapor pressures are expected yet the etching must be nonselective and anisotropic; sidewalls must remain damage-free and stoichiometric to avoid excessive carrier recombination. In other cases, it may be desirable to take advantage of the different chemical properties of the layers and stop etching when the AlGaAs or AlAs layer is encountered.

One of the principal means of controlling the etching of semiconductor materials is to control the semiconductor temperature. For example, Tachi et al.\(^{12}\) have shown that side-wall etching of Si and W can be suppressed without dramatically compromising vertical etch rates by etching at temperatures as low as \(-150\, ^\circ\text{C}\), although at much higher temperatures Daele et al.\(^{13}\) found qualitatively similar improvements in the etching of GaAs and InP in a SiCl\(_4\) plasma.\(^3\) Other studies of III–V etching as a function of temperature have mostly focused on the regime above room temperature.\(^{4,5}\) Only in a few of these studies has the surface temperature been accurately monitored during the process. Similarly, only in a few studies has the wafer been properly heat sunk to the electrode platen. It is now well known that wafer temperatures can increase by more than \(100\, ^\circ\text{C}\) with respect to the electrode platen during plasma exposure. Ion bombardment and exothermic surface reactions coupled with poor thermal contact between the electrode and the sample can contribute to rapid heating.\(^{6}\)

Previous temperature-dependent etching studies have also tended to ignore loading effects. As Mogab has shown,\(^{7}\) when etching is limited by transport of reactive species to the surface, the etching rates may depend strongly on the surface area exposed to the plasma. Under such circumstances, the apparent activation energy deduced from temperature-dependent etching rates may be in serious error. Only when rates are extrapolated to zero load (zero surface area) can meaningful rate parameters be determined.

\(^{1}\) The surface temperature was not well characterized in these experiments: for the “low”-temperature etch the wafer was bonded with grease or photoresist to an electrode whose temperature was reported to be 40 \(^\circ\text{C}\); for the “high”-temperature etch, the wafer was placed on the electrode without any attempt to heat sink or measure actual wafer temperature.