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Cl_2+Ar REACTIVE-ION-BEAM ETCHING OF InGaAlAs FOR SMOOTH, LOW-DAMAGE DEFINITION OF ASYMMETRIC FABRY-PEROT OPTICAL TRANSMISSION MODULATORS

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Cl_2+Ar Reactive-Ion-Beam Etching is demonstrated for anisotropic, low-damage etching of InAlGaAs semiconductor alloys for use as optical transmission modulators at 1.32 µm wavelength.

Transmission modulators are under development for free-space bi-directional communications links for applications such as process/sensor monitoring in remote/hostile environments, satellite communications, etc. Such systems will utilize transmission modulators in conjunction with corner-cube retroreflectors to accurately return the incident probe beam to its source location. Typically, low power consumption is required for these applications, but extremely low insertion loss and high contrast ratio are not necessary. We discuss the development of a dry etching process suitable for fabrication of 1.32 µm-wavelength Fabry-Perot resonator transmission modulators. These devices consist of $In_{0.33}Ga_{0.67}As$-$In_{0.32}Al_{0.68}As$ quarter-wave mirror stacks and an $In_{0.38}Ga_{0.62}As$-$In_{0.28}Al_{0.27}Ga_{0.45}As$ strained-layer superlattice active cavity region grown on a semi-insulating GaAs substrate with an interposed step-graded InAlGaAs buffer layer. These P-free, In-containing, materials etch differently than conventional phosphides due to the altered balance of reactivity and volatility of the group III and V reactants and etch products.

The primary requirements for etching these structures are that the mesa sidewalls be nearly vertical, sidewall etch-induced damage be as low as possible (due to an exposed junction) and that the etch be stopped accurately within a single $In_{0.33}Ga_{0.67}As$ layer of the lower n-type mirror. This last requirement is due to the fact that ohmic contact to the n-side of the device is made at the top of the n-type mirror.

Cl_2-based Reactive-Ion-Beam Etching (RIBE) was chosen for the etch due to its demonstrated low etch-induced sidewall damage,[1] anisotropy, and high vertical resolution.[2] Although pure Cl_2 RIBE of InP leads to undercut sidewall profiles under smooth-etch conditions,[3] use of Cl_2+Ar mixtures yields smooth anisotropic etching of InP and InGaAsP.[4] Based on this background and the fact that our RIBE system has a base pressure below 10^{-8} mTorr, such that Al-containing materials do not oxidize significantly during the etch process, a Cl_2+Ar gas mixture was chosen for etching these relatively new $In_{0.33}Ga_{0.67}As$-$In_{0.32}Al_{0.68}As$ layers.

Etching was done at 0.45 mTorr pressure, 7:3 Cl_2:Ar mixture and 160°C substrate temperature. Ion-beam energies of 300, 400 and 500 eV were tried. The 500 eV etch gave very rough results while the 400 eV etch was more smooth but still visibly "grassy". The 300 eV etch resulted in a mirror-like surface (Fig. 1) and reasonably straight sidewalls.

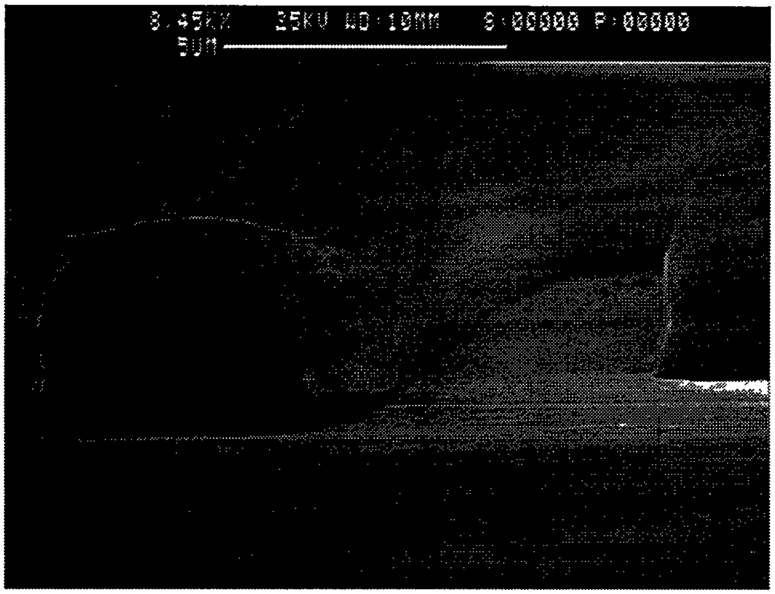

Figure 1: SEM image of 300 eV etch. Material is that of the upper mirror stack. Partially reflowed AZ4330 photoresist mask is still in place on top of the etched rib.

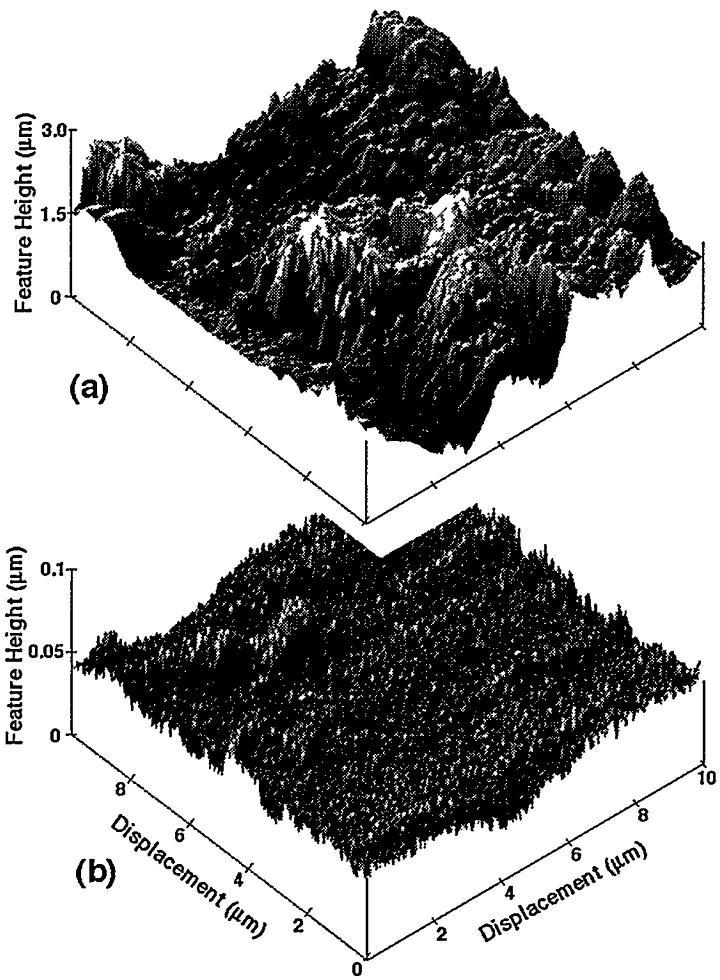

Figure 2: Scanning probe microscope etch topography. (a) 500 eV beam energy etch with 372 nm rms roughness. (b) 300 eV etch with 5.4 nm rms roughness.

The progression towards smoother etching as the beam energy is lowered from 500 eV to 300 eV is consistent with the establishment of an etch-rate-limiting In-rich surface at the lower energies. As the beam energy is raised above 300 eV the In-rich surface is partially sputtered away, exposing stoichiometric material with a much higher etch rate. This leads

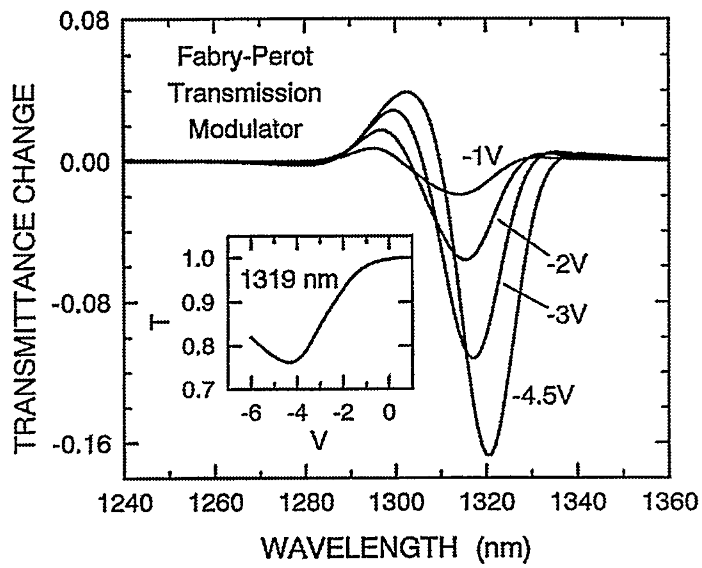

Figure 3: Wavelength and voltage response of transmittance through Fabry-Perot modulator.

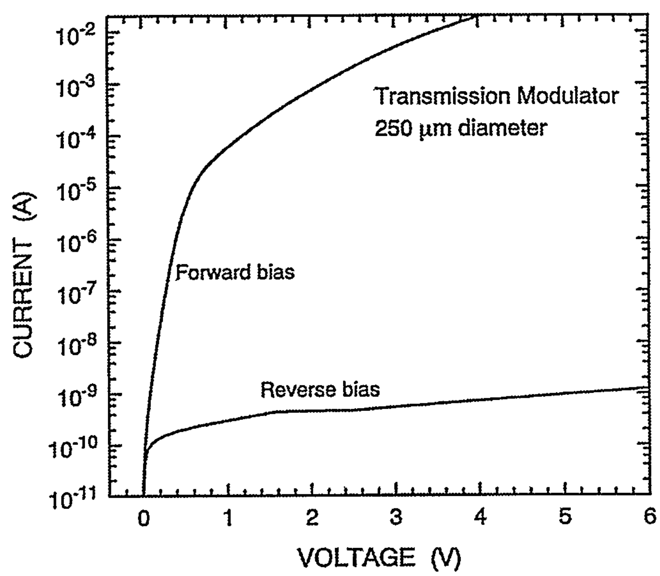

Figure 4: Current versus applied voltage curves of Fabry-Perot modulator etched at 300 eV beam energy. Very low reverse leakage is characteristic of a low-damage etch process.

to the formation of "grass" where the base of the grass etches at the stoichiometric rate while the top of the grass is micromasked by the In-rich material and etches at a lower rate (Fig. 2).

The 300 eV beam energy was chosen for the actual device etch since one requirement of the etch process was to achieve very high etch depth accuracy, so as to stop the etch within the upper 20% of the desired ~100 nm-thick quarter-wave layer. This low energy combines a smooth etch surface with an etch rate low enough (44 nm/min.) that *in-situ* reflectance measurements could be used to detect endpoint and the etch easily stopped within the available 30 sec time window. Finished devices exhibited a 24% contrast ratio at 4.5 V bias (Fig. 3). An 80% device yield of diodes with reverse leakage less than 1 nA at 6 V reverse bias was achieved for 1-mm diameter devices (Fig. 4).

In conclusion, Cl_2+Ar RIBE has been successfully used to etch novel InGaAlAs modulators. The resulting etch is very smooth, anisotropic and has low etch-induced damage. Use of this simple chemistry eliminates the difficulties with polymer formation experienced with hydrocarbon-based etches often used with In-containing materials.

ACKNOWLEDGMENT

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