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Plasma-etched and sputtered GaAs(100) surfaces investigated by ellipsometry and Raman spectroscopy

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Abstract. GaAs (100) surfaces were prepared by reactive ion etching using different etches and a series of plasma powers. In order to study the surface quality ellipsometry and Raman scattering were applied. This combination allows damage at the surface and the presence of surface films to be detected. For this purpose the imaginary part of the dielectric function (ellipsometry) and the intensity and lineshape of LO, TO and 2LO phonons (Raman spectra) were analysed. The results reveal that damage and the build up of surface films strongly depend on the plasma etch used. Furthermore, the relationship between the damage and the plasma power was found to be very complex.

In recent years, interest in reactive ion etching (RIE) of III–V semiconductors for the fabrication of microwave and optoelectronic devices has grown. This technique involves subjecting the semiconductor to a plasma produced by a reactive gas at a low pressure [1].

The kinetics of such an arrangement ensure energetic ions and chemically reactive radicals impinge on the semiconductor's surface with an enhanced perpendicular component. RIE offers advantages over 'wet etching' such as greater control of feature size, etch rate, side-wall profile and etch uniformity [2]. However, RIE has been found to cause crystal damage [3].

The starting material was commercial semi-insulating GaAs(100) wafer. Three different etchings were used: Freon 12, $SiCl_4$ and CH_4:H_2. RIE with Ar gas was also used for comparison. The plasma power was varied while keeping all other plasma parameters, i.e. flow, pressure, temperature, constant. Table 1 shows the conditions for each gas. The etch processes at the lower plasma powers are of device fabrication standard and hence the expected damage is low.

For analysis of the etched surfaces, spectroscopic ellipsometry and Raman spectroscopy were used. The ellipsometry data were evaluated in terms of a pseudo-dielectric function $\langle\varepsilon\rangle$ (assuming a homogeneous semi-infinite space). The measured $\langle\varepsilon\rangle$ was compared with that of samples prepared by wet etching and data reported in the literature as standards [4]. The height of the imaginary part of $\langle\varepsilon\rangle$ at the inter-band critical points

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Table 1. The gases and plasma powers used.

Gas	Power used (W)
$CH_4:H_2$	20, 50, 100, 150
$SiCl_4$	20, 35, 50, 100
Freon 12	50, 100, 300
Ar	50

(E_1, $E_1 + \Delta_1$ and E_2 gap) decreases either when the GaAs surface is damaged or when a surface film is present [4].

In the Raman scattering experiments the intensities and linewidths of the LO, TO and 2LO phonons were investigated. The occurrence of the forbidden TO phonon indicates a high level of damage, while the 2LO phonon intensity is very sensitive to and decreases with relatively low damage level [5]. Both the ellipsometric and the Raman data together allow assessment of the surface damage and the presence of surface films generated by the etching process.

All samples appeared mirror like. No simple linear relationship between sample quality and increasing plasma power could be observed. In every ellipsometric spectrum the inter-band critical points E_1, $E_1 + \Delta_1$ and E_2 were observed. In the Raman spectra, symmetry-allowed and symmetry-forbidden LO phonon scattering and 2LO phonon scattering were always present. The forbidden TO phonon could be observed as a weak shoulder in a few cases. Only small variations in the spectral half-width of the phonons were detected. Consequently the damage caused by the etching process is low in all samples as expected.

For the $CH_4:H_2$ etched samples the height of $\mathrm{Im}(\langle\varepsilon\rangle)$ at E_2 is reduced compared with wet-etched samples and the $E_1 + \Delta_1$ gap is observable only as a shoulder on the E_1 gap. Together with the strongest 2LO phonon intensity compared with all other etchants this indicates good surface quality but also that a surface film is present.

This film possibly consists of C–H compounds and from the variation in $\mathrm{Im}(\langle\varepsilon\rangle)$ with increasing plasma power it can be concluded that the thickness of this film first increases but at higher plasma powers finally decreases. At the same time the surface quality increases first and then decreases as indicated by the increasing and then decreasing 2LO phonon intensity. It is speculated that this arises because the surface film protects the GaAs surface against the impact of the ions. The data give an optimum plasma power for highest-quality surfaces of around 50 W.

In contrast with $CH_4:H_2$ no sign of a protecting surface film was detected for the $SiCl_4$ series. We found a less pronounced maximum in the 2LO phonon intensity as a function of plasma power than for the $CH_4:H_2$ series. It follows that the surface quality is somewhat worse with the $SiCl_4$ etch.

For Freon 12, as for $CH_4:H_2$ a thin surface film was observed, but the 2LO phonon intensity was the lowest of all the plasma-etched samples. It decreased linearly with increasing plasma power. This indicates strong surface damage. In agreement with this, for the sample etched at the higher power an increased roughness relative to the other samples was found by scanning electron microscopy.

Considering Ar sputtering the Raman spectra revealed an even lower 2LO phonon intensity and as expected the worst quality was obtained for this sample.

We conclude that because of the sensitivity of ellipsometry and Raman scattering to surface and bulk quality, a combination of these two techniques is an excellent tool for studying the plasma-etching process. Ar sputtering leads to enhanced damage compared with plasma etching. From the first few experiments, it seems that $SiCl_4$ and $CH_4:H_2$ are more suitable etchants than Freon 12.

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