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UV Cleaning Effect of GaAs Surface in NH_3 Gas Prior to Photo CVD

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The UV cleaning effect of the GaAs surface in NH_3 gas has been investigated. It is found that the UV treatment in NH_3 gas enhances the photoluminescence intensity. The Auger electron spectroscopy indicates that the excess As near the surface can be removed by this treatment. These results imply that the As free surface leads to the reduction of the surface recombination velocity and the surface electric field. This treatment is successfully applied to High Electron Mobility Transistor (HEMT) passivation.

1. Introduction

In the surface passivation, it is important to reduce surface states which may be responsible for carrier recombination, leakage current and surface Fermi level pinning. Compound semiconductors such as GaAs and InP easily decompose at a relatively low temperature, so that the passivation film has been deposited mainly by the plasma-CVD method. However, the irradiation damage has been often produced by the ion bombardment.[1)]

Recently, a photo CVD has attracted a great interest as a process for passivation films deposition because it has some advantages such as a low temperature and no irradiation damage. An additional significant advantage is that the substrate surface can be in-situ cleaned photochemically prior to deposition. In the previous report, we demonstrated the effectiveness of in-situ UV/ozone cleaning in SiO_2-InP MIS structures.[2)]

In this paper, we report the GaAs surface cleaning effect of UV irradiation in NH_3 gas and its successful application to HEMT passivation.

2. Experimental

The UV treatment was carried out in the mixture of NH_3 and N_2 at a total pressure of 6 Torr, using the photo CVD apparatus which has been described elsewhere.[2)] The UV source is a low pressure Hg lamp. Gas flow rates of NH_3 and N_2 were 350 sccm and 2 slm, respectively. The effect of surface treatment was examined by photoluminescence (PL) measurement at 300 K and 4.2 K using Ar^+ laser (488 nm), and Auger electron spectroscopy (AES).

The samples in this experiment were undoped n-type GaAs epitaxitial wafers ($n=1\times10^{15}$ cm^{-3}) grown by MOCVD. They were cleaned with HCl solution before the UV treatment.

3. Results and Discussion

Figure 1 shows the PL intensity at 300 K vs the laser-irradiated time for the samples with and without the UV treatment. Large enhancement of the intensity is observed for the UV-treated sample. This enhancement is considered to be due to the reduction of surface recombination and the electric field caused by surface states. The gradual decrease of the intensity with time is due to the laser-enhanced oxidation of the surface.[3)]

The effect of the surface field may be explained from the results of 4.2 K PL measurement. Figure 2 shows the 4.2 K PL spectra of both samples. Each spectrum has two peaks of

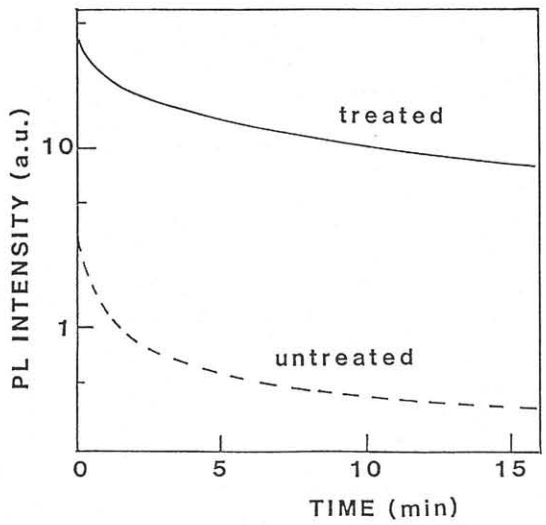

Fig. 1 PL intensity at 300 K vs laser-irradiated time for samples with and without the UV treatment.

the exciton peak (X) and the peak related to the carbon acceptor (A). Figure 3 shows the (X) and (A) peak intensity of the treated sample relative to the untreated one at varied excitation power density. The relative intensity of the (A) peak is constant at 1 independent of excitation power, but the (X) peak intensity of the treated sample is remarkably larger than that of the untreated one, and its relative intensity decreases with excitation power. The photo-generated carrier reduces band bending, and an almost flat band region will be established near the surface. This flat band region contributes mainly to the observed luminescence, since the near-band edge excitons are easily dissociated at an electric field as low as 1 V/cm.[4] Horikoshi et al.[5] have reported that the exciton luminescence intensity strongly depends on an applied electric field and drastically decreases with the increase of the electric field strength, while the acceptor luminescence is insensitive to the field. They have also suggested that this dependence is due to a small but finite electric field within the flat band region established under illumination. In our experiment, no external field was applied, but surface states will also produce the electric field to reduce the exciton luminescence. Therefore, it is considered that the UV treatment reduces the electric field caused by surface states and enhances the (X) peak intensity. It also seems that the increase of photo-generated carrier with excitation power blinds the effect of the electric field and the relative intensity of the (X) peak decreases.

A possible explanation of this UV cleaning effect is as follows. The native oxide on the GaAs surface consists of Ga_2O_3, As_2O_3 and As. According to recent effective work function (EWF) model for surface pinning,[6] the excess As works as effective Schottky metal. Moreover the fractinal As layer will lead to enhanced surface recombination velocity. We consider that the excess As reacts with atomic hydrogen which is generated from photo-chemical process as

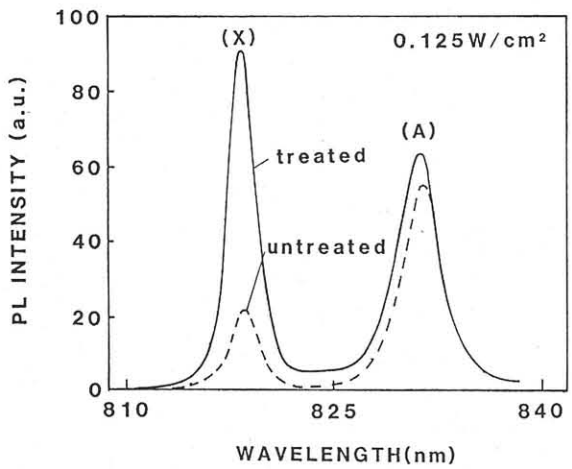

Fig. 2 The 4.2 K PL spectra for samples with and without the UV treatment. (X) and (A) show the peak of the exciton and the carbon acceptor, respectively.

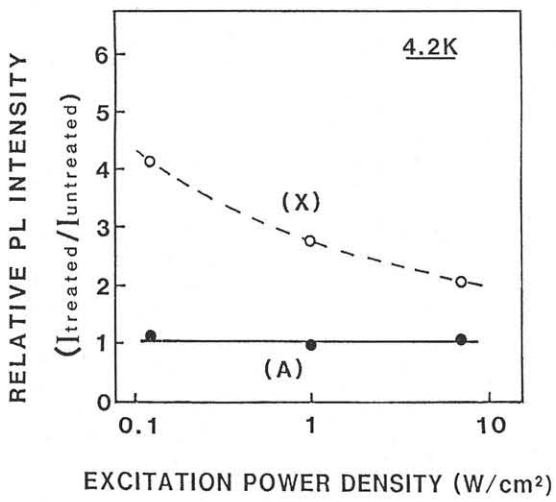

Fig. 3 The 4.2 K PL intensity of the treated sample relative to the untreated one. (X) and (A) show the relative intensity of the exciton and the carbon acceptor, respectively.

described below;[7),8)]

$$NH_3 \xrightarrow{\lambda < 280\ nm} NH_2 + [H]$$

$$As + 3[H] \longrightarrow AsH_3 \uparrow$$

These process remove As on the surface and As free surface results in the low density of surface states.

Our explanation of the UV cleaning effect based on surface reaction model is supported by the results of AES. Figure 4 shows the depth profile of As to Ga peak to peak ratio from AES combined with Ar sputter etching. For the untreated sample the As rich region is observed near the surface, but by UV treatment the As/Ga ratio of the surface region comes near to that of the bulk.

We also observed the nitrogen peak for the treated sample. If the wide gap GaN layer is formed, this GaN surface will reduce the surface recombination velocity.

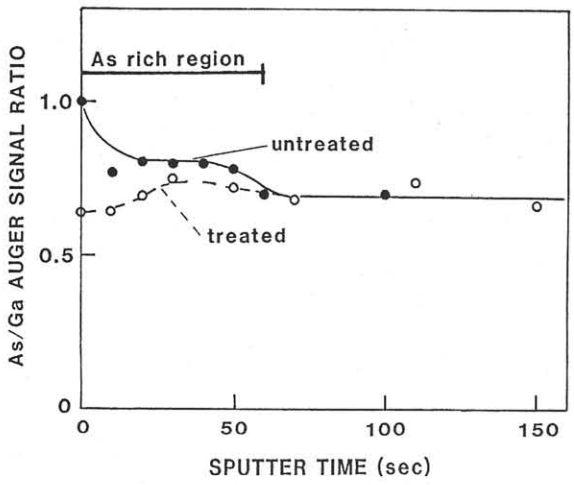

Fig. 4 Auger depth profile of As to Ga peak to peak ratio for the treated and untreated sample.

4. Application to HEMT passivation

This UV cleaning method was applied to planar type HEMT devices, because their active layers are so thin (~ 40 nm) that the characteristics depend strongly on surface conditions. The HEMTs used in this experiment were fabricated by the

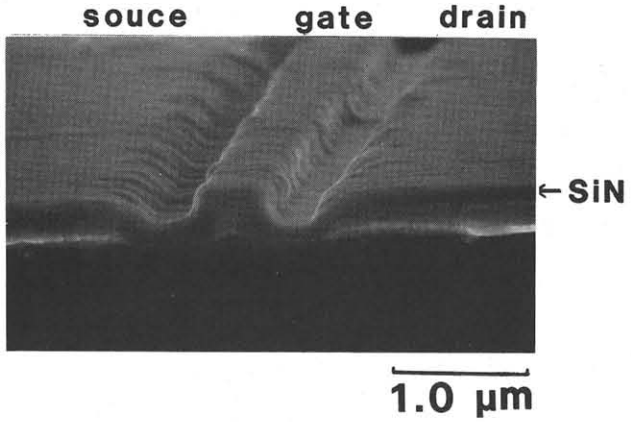

Fig. 5 The SEM photograph of the HEMT cross section.

planar self-alignment process,[9)] using Al side etching on the MBE epitaxial wafer. Following the UV treatment, the SiN film was in-situ deposited on HEMTs by the photo CVD. The deposition was carried out by Hg-photosensitization of the reactant gases of SiH_4 and NH_3. After deposition, the films on ohmic and gate pads were removed by reactive ion etching and then the characteristics were investigated.

Figure 5 shows a SEM photograph of the fabricated HEMT cross section. The gate length and width are 0.5 μm and 60 μm, respectively.

Figure 6 shows I-V characteristics before and

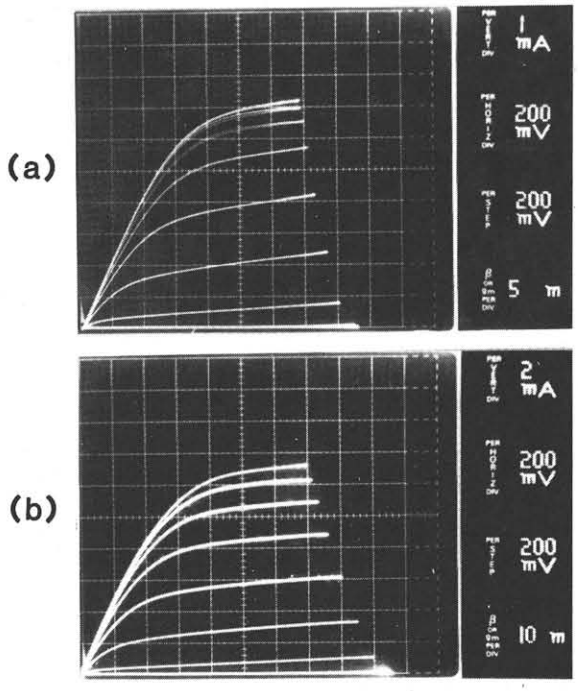

Fig. 6 I-V characteristics of the HEMT (a) before and (b) after SiN deposition.

	before depo.	after depo.
I_{ds} (mA) [V_{ds}=1V]	6 - 7	12 - 13
$g_{m\,max}$ (mS/mm)	140 - 160	240 - 270

Table 1 The comparison of DC device parameters between before and after SiN deposition.

after deposition. As shown, after deposition the drain current considerably increase, although the pinch off voltage remains unchanged. Table 1 shows the comparison of DC device parameters before and after deposition. The maximum transconductances are drastically improved due to the increase of the drain current. The similar improvement was observed by only the UV treatment without deposition. This increase of the drain current is probably due to the decrease of sheet resistance resulting from the reduction of band bending at the surface between gate and source (and drain) electrodes.

5. Conclusions

It has been shown that the UV treatment of the GaAs surface in NH_3 gas enhances the PL intensity. The Auger electron spectroscopy indicates that the excess As near the surface can be removed by this treatment. It is considered that the As free surface leads to the reduction of the surface states and results in this enhanced luminescence.

This treatment is applied to HEMT devices prior to photo CVD SiN passivation film deposition and the electrical characteristics are drastically improved.

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