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Effect of Plasma Processes on the Characteristics of GaAs Related Optical Device Structure

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1. Introduction

At present, sub-micron scale semiconductor devices are manufactured utilizing dry etching or ashing technology with a number of process steps[1]. While, compound semiconductors represented by GaAs are employed for the fabrication of optical devices, which is still difficult for Si technology. The state of the art nanofabrication for the compound semiconductors shows the prospect of upcoming next generation devices, such as photonic crystal and nanowires devices[2,3,4,5]. For the realization of those devices, the etching technique is required to have its accuracy of several nm, as well as adequate selectivity of the target materials with strong anisotropic nature[3,4,5]. Further, the process damage induced by the etching or ashing becomes more effective on the device characteristics[1,6,7]. The damage becomes more effective with the decrease of the devices sizes. Then, that comes to be essential for the above mentioned nano-scale devices. Then, detailed investigation of process damage on the optical and electrical characteristics of the device structure is required for the realization of ideal device performance [2,3].

In this study, we report the effect of plasma process damages on the optical and electrical characteristics of GaAs related optical device structure.

2. Experimental

We investigate the process damage of inductively coupled plasma (ICP) ashing with O_2 gas. The process was usually carried out for the removal of resist. The source power was 800 W. The flow rate of the O_2 gas is 50 sccm. The chamber pressure was 2.0 Pa at the condition. The effect of the ashing was investigated varying the RF powers or ashing time. Figure 1 (a) shows the sample structure for the investigation of optical characteristics. The sample has a standard laser structure with an active layer of GaInAs. The impact of the upper AlGaAs layer was examined by preparing a sample without the layer. The effect of the ashing was examined by photoluminescence (PL) measured at room temperature. We used two excitation light sources having different wavelengths, enabling the selective excitation of the consisting layers as schematically illustrated in Fig. 1 (b). Effect of the ashing damage on the electrical characteristics were studied for p-type GaAs sample with its hole concentration of 2×10^{19} cm^{-3}. We made Au/Cr (300/20 nm) Ohmic electrode on the etched surface, and then evaluate specific contact resistance (ρ_c) with transmission line model [8].

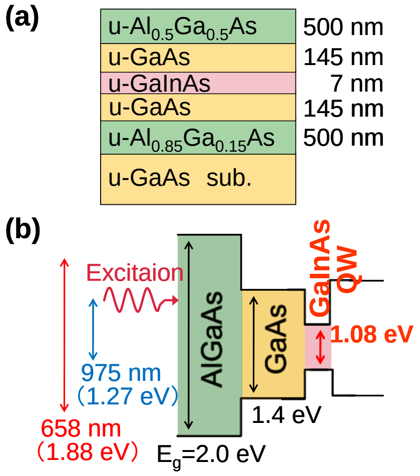

Fig. 1. (a) Sample structure for the investigation of etching damage on the optical characteristics. The structure is a standard GaAs-related laser structure. (b) Schematically illustrated physical status at the PL measurement. The GaInAs QW is resonantly excited with the laser of 975 nm wavelengths.

Similarly, we investigated the impact of etching with the gas mixture of C_3F_8 and O_2. That is conventionally employed for the etching of SiO_2 mask[3]. We performed capacitively coupled plasma etching with C_3F_8/ O_2 (15/5 sccm) plasma at a pressure of 2.0 Pa for various RF powers.

3. Results and Discussion

Figure 2 shows the PL result after the ashing with O_2 gas, for the samples with or without top AlGaAs layer. The measurement was carried out with the excitation light of 658 nm wavelength. The etching shows a negligible effect on the PL intensity when there is the upper AlGaAs. In contrast, for the sample without upper AlGaAs, the intensi-

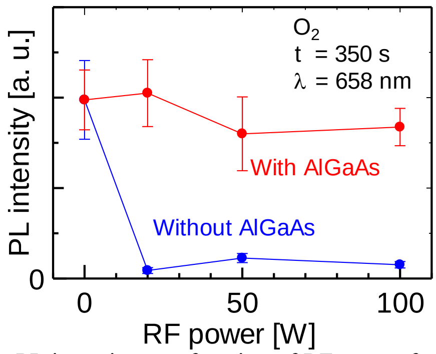

Fig. 2. PL intensity as a function of RF power for the samples with or without top AlGaAs layer.

ty clearly decreases at the RF power of 20 W and that becomes constant up to 100 W. The result suggests that the ashing induces nonradiative recombination centers close to the sample surface. The effect of the damage will not affect directly on the GaInAs QW when there is AlGaAs cap layer, which keeps the sufficient separation between the damaged surface and the GaInAs active layer.

Figure 3 shows the result of ashing for the sample without the upper AlGaAs. The PL intensity obtained from the sample at different excitation sources is plotted as a function of the etching time. At the measurement with the light source of 658 nm wavelength, the intensity significantly decreases at the ashing time of 10 s. On the other hand, with the excitation light of 975 nm wavelength, the decrease of the intensity is much slower. That suggests the ashing results in the formation of nonradiative centers intensively at the GaAs surface. That gradually affects on the buried GaInAs layer with the progress of ashing.

Figure 4 shows ρ_c after the O_2 plasma ashing. The ρ_c is strongly affected by the increase of the RF power. At the bias power of 20 or 50 W, the ρ_c was about 3-5$\times 10^{-6}$ Ωcm^2. At the RF power of 100 W, the ρ_c was about 3.5$\times 10^{-5}$ Ωcm^2. Those differences can be due to the structural variation of the sample surface induced by the ashing.

Figure 5 shows the PL intensities for the samples of optical characterization after the etching with C_3F_8/ O_2 gas mixture. The intensities are plotted as a function of RF power. As seen in Fig. 2, the etching induces small damage when there is the upper AlGaAs, however, the impact is strong for the sample without the upper AlGaAs. That probably stems from the damage close to the surface induced by the etching.

Figure 6 shows the result of etching for the sample of electronic characterization. That plots ρ_c and the etching depth as a function of the bias power. The etching induced a limited effect on ρ_c. Note that the root-mean-square surface roughness was under 1 nm for all the samples. Consequently, the impact of the etching is not critical on the structural characteristics of the samples.

4. Summary

We have investigated the effect of plasma processes on the optical and electrical characteristics of GaAs related optical device structure. Both of the O_2 ashing and C_3F_8/ O_2 etching can induce the degradations of optical characteristics of the sample. The damage intensively exist at the sample surface, hence the active layer buried inside was protected from that. The processes also affect on the ρ_c of the electrodes, having small correlation between the surface roughness.

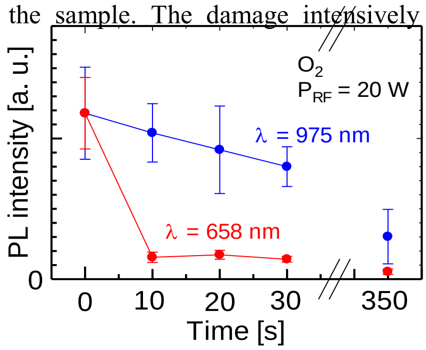

Fig. 3. PL intensity as a function of etching time measured with the different excitation sources.

Acknowledgement

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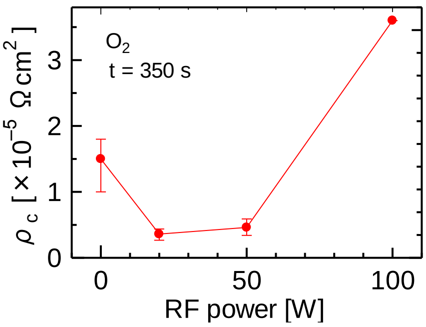

Fig. 4. ρ_c as a function of RF power.

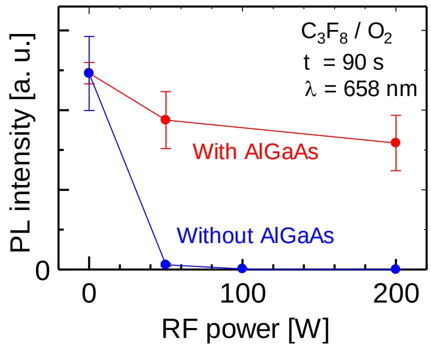

Fig. 5. PL intensity as a function of RF power for samples with or without top AlGaAs layer.

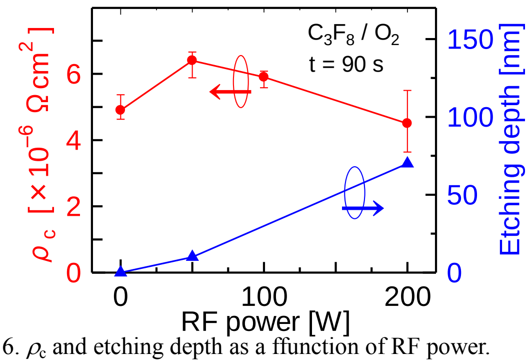

Fig. 6. ρ_c and etching depth as a ffunction of RF power.