The Surface and Optical Properties of Passivated GaSb with Different Passivating Agents

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In this paper, (NH₄)₂S and Na₂S were used as passivating agent for the sulphuration treatment of GaSb. Although the oxide layer can be removed by both (NH₄)₂S and Na₂S, the etching rate of Na₂S was faster than (NH₄)₂S, which caused the high RMS. After passivation treatment, PL intensity of GaSb increased, however, if the passivation time was too long, PL intensity would decrease. At low temperature PL spectrum, the emission located at 777meV and 795meV, which can be associated with the transition from the conduction band to the native acceptor level V_GaGaSb and the other peak corresponds to bound-edge-related transitions can be observed.

Keywords Component; GaSb; passivation; photoluminescence

1. Introduction

With the developing of the optoelectronic devices, III-V compounds be widely used in progress in micro- and optoelectronics. Featured with many special physical properties, GaSb has attracted much attention for optoelectronic applications [1,2]. In particular, envisioned as an important III-V semiconductor candidate for high-speed and optoelectronic device applications, plenty of attention has been given to GaSb for optoelectronic devices with low-threshold voltage, photodetectors with applications to optical fiber communication systems in the near-to middle-infrared wavelength range, high-frequency devices and high-efficiency thermo-photovoltaic. [3–5] However, the chemical property of GaSb surface is much more reactive than that of GaAs. Which can be oxidized quickly under atmospheric conditions, form the surface states density. Surface states density induced by native oxides and wafer atomic defects can cause high surface recombination velocity and large leakage currents [6–8].

Many methods of reduce the surface states density have been researched, such as methods of dry passivation and wet-chemical passivation [9–11]. Ar ion bombardment and coating passivation are the dry passivation method, and wet passivation including anodic oxidation and sulphuration treatment. For the dry passivation, it is difficult to operate...
and control the passivation process. However, with simple, controllable advantages, wet-chemical passivation method such as sulphuration treatment is widely used. And many sulfide can be used as passivating agents [12~17].

In this work, (NH₄)₂S and Na₂S were used as passivating agent to reduce the surface states of GaSb. The surface of passivated GaSb was investigated by AFM. Then, PL was used to examine optical property of passivated GaSb, and low temperature PL was used to characterize origination of PL emission.

2. Experiment Details

The PL measurements were carried out using a Nanometrics RPM2000 photoluminescence spectrometer with a resolution of 0.2 mm. A frequency doubled Nd:YAG laser (532 nm) with 100 mW is used as the excitation source. Low-temperature PL measurements were done by PL9000 Fourier transform spectrometer with the samples mounted in a He cryostat at 10 K to 300 K. Using 514 nm emission line from an Ar. Ion laser and liquid nitrogen cooled Ge detector. The laser power was set at 40 mW. In order to characterize the surface morphology, we performed the AFM (Atomic Force Microscopy) test. AFM micrographs of the samples were obtained from CSPM5500, in the contact mode.

Un-doped p-type with the thickness of 500 um, 8% (NH₄)₂S solution, pH = 9, and Na₂S solution, pH = 14 were used in this study. The etching rate of the Na₂S is faster than that of (NH₄)₂S. Surface chemistry and etching experiments were done with the samples cleaved into 8 mm × 8 mm pieces and soaked in acetone for 60s to remove organic contaminants and the natural oxide layer, rinsed in deionized (DI) water, and dried with compressed N₂. All the sample are divided into two groups one for the (NH₄)₂S the other for the Na₂S.

One group of samples labeled from 1 to 10. Sample 1 as a comparison sample received no treatment. The remaining samples were 2 to 10 soaked in (NH₄)₂S solution corrosive for 60, 120, 180, 240, 300, 360, 420, 480 and 540 s at 60°C. All the samples were rinsed in deionized (DI) water to remove sulfur crystal and finally blown dry with compressed N₂. The other one soaked in Na₂S solution corrosive for 60, 120s, 180, 210, 240, 270, 300, 360 and 420 s at 60°C.

3. Results and Discussion

Figure 1 shows the AFM test results of untreated GaSb, passivated by (NH₄)₂S and Na₂S samples. For the untreated sample, the RMS (Root Mean Square) is ~0.0355 nm, RMS of

![Figure 1](https://example.com/figure1.png)

**Figure 1.** AFM images of the GaSb untreated, passivated by (NH₄)₂S and Na₂S, respectively. (Figure available in color online)
sample treated by (NH$_4$)$_2$S solution is ∼0.0324 nm, and RMS of sample treated by Na$_2$S treated is 10 nm. We can clearly see the roughness of the (NH$_4$)$_2$S treated sample is better than the untreated one, and the surface of the Na$_2$S treated sample is very rough with the biggest RMS. From the AFM results, although the oxide layer of GaSb could be removed by (NH$_4$)$_2$S and Na$_2$S, the surface of GaSb changed significantly.

Figure 2 PL intensity of p-type GaSb treated with different passivation time. Figure 2(a) shows the PL intensity of p-type GaSb passivated by (NH$_4$)$_2$S. With passivation time increasing, the PL intensity increased. When passivation time was 300 s, GaSb had the strongest PL intensity. Then, with the passivation time extending, the PL intensity decreased. Fig. 2(b) shows the PL intensity of p-type GaSb passivated by Na$_2$S. Similar with (NH$_4$)$_2$S solution, the PL intensity increased firstly, then decreased. When passivation time was 210s, the PL intensity was strongest. From the PL results, compared with two passivation solution, Na$_2$S solution had the faster etching rate than (NH$_4$)$_2$S solution.

Figure 3 shows the PL spectrum of p-type of GaSb passivated by (NH$_4$)$_2$S and Na$_2$S. The emission located at 1062 nm can be detected, which is assigned to NBE emission.

Figure 3. (a) The PL spectrum of p-type of GaSb passivated by (NH$_4$)$_2$S for 180, 240, 300, 360 and 480s. (b) The PL spectrum of p-type of GaSb passivated by Na$_2$S for 60, 180, 210, 270 and 420s. (Figure available in color online)
The FWHM of emission of GaSb treated by Na$_2$S is smaller than that treated by (NH$_4$)$_2$S, which indicated that surface corrosion rate of (NH$_4$)$_2$S solution is more easily controlled even than the Na$_2$S solution.

Figure 3 shows the PL spectrum of p-type of GaSb passivated by (NH$_4$)$_2$S and Na$_2$S. The emission located at 1620 nm can be detected, which is assigned to NBE emission. In order to further study the optical property, the samples were measured by low-temperature PL (as shown in Fig. 4). For the untreated sample, two broad emissions centered at 777 meV and 794 meV can be observed, which is associated with the transition from the conduction band to the native acceptor level V$_{GaGaSb}$ (A) and bound-edge-related transitions (BE$_4$). For the samples passivated by (NH$_4$)$_2$S and Na$_2$S, except for the two main peaks we can also observe a emission peak at 757 meV which is corresponding to the acceptor transition called B peak, from previous reports which is associated with the complex V$_{GaGaSb}$V$_{Ga}$, and other new one located at 749 meV is supposed to be A-LO peak, which as accompanied by an LO photo replica 30 meV below the A level, and 798 meV, 801 meV are corresponding to the BE1 and BE2[18–20]. When the temperature rising, besides A and BE$_4$ emission, other emission disappeared gradually. At room temperature the main emission peak is BE (as shown in Fig. 3).

4. Conclusion

In this work, in order to remove the oxide layer and improve the optical property of GaSb, (NH$_4$)$_2$S and Na$_2$S were used as passivating agent, for the passivation treatment of GaSb. For GaSb, the PL intensity at room temperature was 15 times larger than the untreated one. However, AFM and PL results indicated that Na$_2$S had the faster etching rate, but after Na$_2$S passivation treatment, the surface of GaSb became roughness. In low temperature PL, the emission located at 777 meV and 795 meV were observed which can be assigned to A and BE$_4$. From these results, compared with Na$_2$S, (NH$_4$)$_2$S would be more suitable for GaSb passivation treatment.

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