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

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In this paper, $(NH_4)_2S$ and Na_2S were used as passivating agent for the sulphuration treatment of GaSb. Although the oxide layer can be removed by both $(NH_4)_2S$ and Na_2S, the etching rate of Na_2S was faster than $(NH_4)_2S$, which caused the high RMS. After passivation treatment, PL instensity of GaSb increased, however, if the passivation time was too long, PL instensity 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 $V_{Ga}Ga_{Sb}$ and the other peak corresponds to bound-edge-related transitions can be observed.

Keywords Component; GaSb; passivation; photoluminescence

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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

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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% $(NH_4)_2S$ solution, pH = 9, and Na_2S solution, pH = 14 were used in this study. The etching rate of the Na_2S is faster than that of $(NH_4)_2S$. 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 N_2. All the sample are divided into two groups one for the $(NH_4)_2S$ the other for the Na_2S.

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 $(NH_4)_2S$ 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 N_2. The other one soaked in Na_2S 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 $(NH_4)_2S$ and Na_2S samples. For the untreated sample, the RMS (Root Mean Square) is ∼0.0355 nm, RMS of

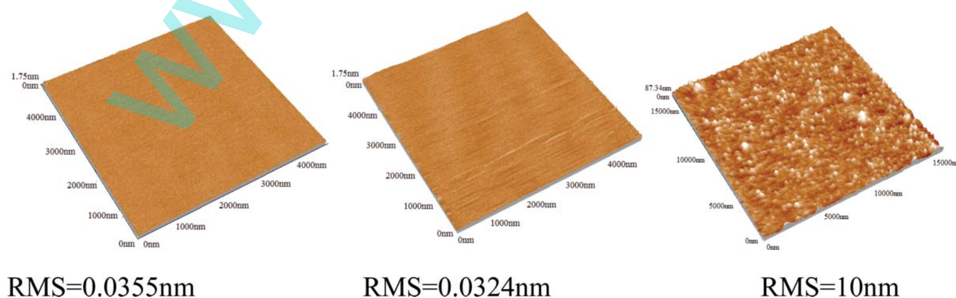

Figure 1. AFM images of the GaSb untreated, passivated by $(NH_4)_2S$ and Na_2S, respectively. (Figure available in color online)

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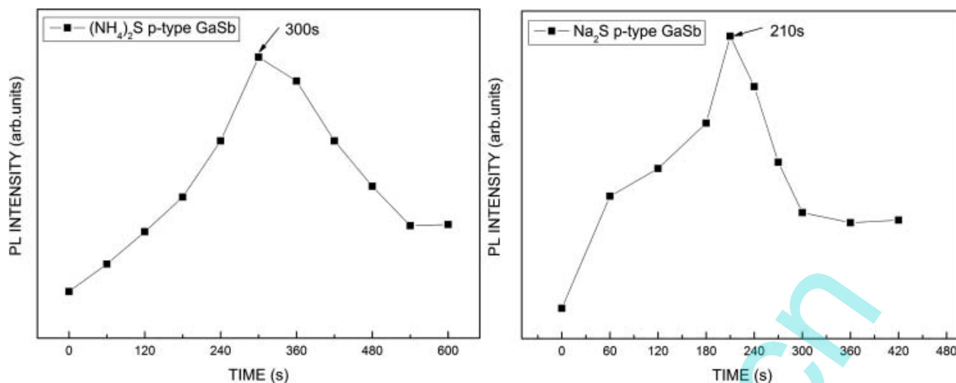

Figure 2. The PL intensity of p-type of GaSb sulfide by $(NH_4)_2S$ (a) and Na_2S (b) distribution map changes with time.

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sample treated by $(NH_4)_2S$ solution is ∼0.0324 nm, and RMS of sample treated by Na_2S treated is 10 nm. We can clearly see the roughness of the $(NH_4)_2S$ treated sample is better than the untreated one, and the surface of the Na_2S treated sample is very rough with the biggest RMS. From the AFM results, although the oxide layer of GaSb could be removed by $(NH_4)_2S$ and Na_2S, 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 $(NH_4)_2S$. 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_2S, Similar with $(NH_4)_2S$ 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_2S solution had the faster etching rate than $(NH_4)_2S$ solution.

Figure 3 shows the PL spectrum of p-type of GaSb passivated by $(NH_4)_2S$ and Na_2S. The emission located at 1062 nm can be detected, which is assigned to NBE emission.

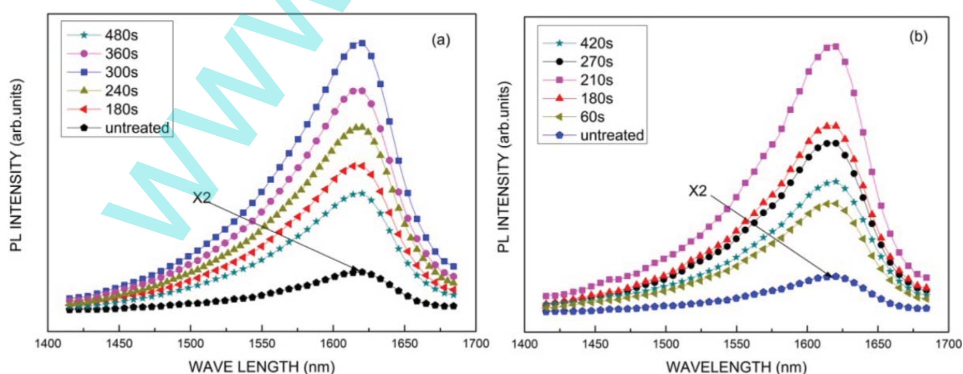

Figure 3. (a) The PL spectrum of p-type of GaSb passivated by $(NH_4)_2S$ for 180, 240, 300, 360 and 480s. (b) The PL spectrum of p-type of GaSb passivated by Na_2S for 60, 180, 210, 270 and 420s. (Figure available in color online)

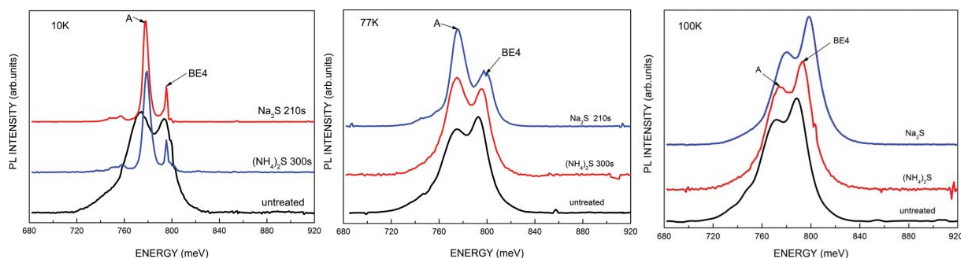

Figure 4. Low-temperature PL spectrum of p-type of GaSb that untreated, 300 s $(NH_4)_2S$ passivated and 210s Na_2S passivated GaSb samples at 10 K, 77 K and 100 K. (Figure available in color online)

The FWHM of emission of GaSb treated by Na_2S is smaller than that treated by $(NH_4)_2S$, which indicated that surface corrosion rate of $(NH_4)_2S$ solution is more easily controlled even than the Na_2S solution.

Figure 3 shows the PL spectrum of p-type of GaSb passivated by $(NH_4)_2S$ and Na_2S. 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 $V_{Ga}Ga_{Sb}$ (A) and bound-edge-related transitions (BE_4). For the samples passivated by $(NH_4)_2S$ and Na_2S, 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 previously reports which is associated with the complex $V_{Ga}Ga_{Sb}V_{Ga}$, 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, $(NH_4)_2S$ and Na_2S 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_2S had the faster etching rate, but after Na_2S 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_2S, $(NH_4)_2S$ would be more suitable for GaSb passivation treatment.

Acknowledgments

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