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Photoluminescence Properties of the GaSb Nanostructures Irradiated by Femtosecond Laser

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We have systematically investigated photoluminescence properties of surface microstructure of Te-doped *n*-type gallium antimonide (GaSb) irradiated by femtosecond laser, observe the surface topography with SEM (scanning electron microscope). Following the previous work, choose the optimal condition for passivation. Then passivated the sample with ammonium sulfide ($(NH_4)_2S$) for analyse Photoluminescence Characterisation easily. Compare with the unlaser treatment sample, laser irradiated sample's main luminous peak is slightly blue shift about 14 meV in 300 K. It can be attribute to the change in the source of the emission peak. The laser-induced sample show a new strong peak appeared at 781 meV in 150 K. We assume this enhanced peak is a response of surface micro-structure.

Keywords: Te-Doped GaSb, Surface Morphology, Femtosecond Laser, Sulfur Passivation, Photoluminescence.

1. INTRODUCTION

GaSb is an important III–V compound semiconductor and is applied on the field of high-speed and optoelectronic devices. A native oxide layer (Sb_2O_3, Ga_2O_3) and fraction monolayer of Sb will be formed when GaSb is exposed in air atmosphere.[1] To avoid this problem, many surface passivation methods have been investigated and developed, such as chemical sulfuration methods. In these methods, the wet methods of sulphide passivation in sulphide solutions, as $(NH_4)_2S$, Na_2S, S_2Cl_2 have proved to be effective in reducing the density of surface states.[2]

On the other hand, since Birnbaum first observed laser ablated surface in 1960's, laser-induced surface ripples have been extensively studied in a wide range of materials. The ablation processes of various materials have also widely investigated recent decades. In various laser ablation techniques, femtosecond laser has great potentialities in inducing microstructure because of its high precision.[3–5] To our knowledge, microstructure on GaSb surface induced by femtosecond laser has not been reported. Strong correlation between mircrostrure and surface photoluminescence properties is usually observed. In this study, we have reported an investigation on photoluminescence properties of sulphide passivated Te-doped *n*-type gallium antimonide (GaSb) irradiated by femtosecond laser.

2. EXPERIMENTAL DETAILS

A 500-μm-thickness Te-doped *n*-type GaSb ($n = 9.082 \times 10^{16}$ cm^{-3}) wafer was irradiated in vacuum using linearly polarised femtosecond laser.

Figure 1 show the schematic diagram of femtosecond system in our experimental. The femtosecond system consists of a an amplified Ti: sapphire femtosecond laser system, the central wavelength is 800 nm, with reptition rate of 1 kHz, pulse duration is 50 fs, scanning speed is 3 mm/s, scanning spacing is 50 μm and pulse energy is reduce to 60 mJ using neutral density filters.[6]

The GaSb sample irradiated by laser is denoted as 1. Another sample without laser irradiation is denoted as 2 for comparison. The surface morphologies of the samples were observed using scanning electron microscope (S-4200).

There are many method for passivation, but the etch rate of $(NH_4)_2S$ solution is the most easily controlled. The smaples were put in 2.8% $(NH_4)_2S$ solution for the surface

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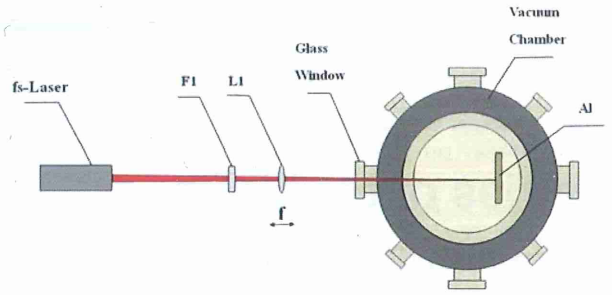

Fig. 1. The schematic diagram of femtosecond system.

passivation treatment. The passivating process of chemical sulfide treatments consists of four steps:

(1) Soak the sample in acetone for 60 s to remove organic contamination and nature oxide layer.

(2) Soak in absolute ethyl alcohol for 60 s, then rinsed in deionized (DI) water.

(3) Soaked in the $(NH_4)_2S$ solution corrosive for 180 s at 60 °C.

(4) Rinsed in deionized (DI) water and the sample is blown in dry N_2.

The photoluminescence (PL) mapping spectra were measured by Nanometrics RPM2000 photoluminescence spectrometer with a resolution of 0.2 mm. The excitation source is frequency doubled Nd:YAG laser (532 nm) with 100 mW. Low-temperature PL measurement was used to study the photoluminescence properties after passivation. PL9000 Fourier transform spectrometer was used to temperature dependent PL measurements from 20 K to 300 K using a He cryostat. In the measurement process, an Ar ion laser with 514 nm line and a liquid nitrogen cooled Ge detector was used as well as laser power was set to 40 mW.

3. EXPERIMENTAL RESULT

The surface appearance of sample was observed after the femtosecond laser irradiation, as shown in Figure 2. It is found there are some erosion gullies on the sample surface due to laser ablation.

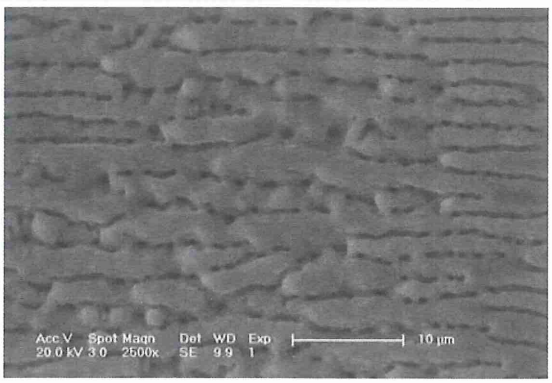

Fig. 2. SEM image of ablated *n*-GaSb sample.

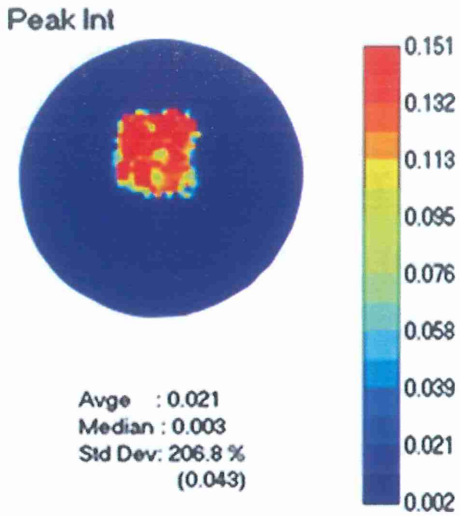

Fig. 3. PL mapping of the sample 1 at room temperature.

It is well known that GaSb has very active surface, they must not neglect the influence of the surface states on semiconductor device. One reason that produce surface states and influence the luminescence quality the Ga defects complex. In early research, reaction between GaSb surface and oxygen can be summarized as two steps[7]

$$2GaSb + 3O_2 \rightarrow Ga_2O_3 + Sb_2O_3 \quad (1)$$

$$2GaSb + Sb_2O_3 \rightarrow Ga_2O_3 + 4Sb \quad (2)$$

This is a widely accepted models of seminconductor treatment in sulphide solutions, as following chemical reaction:[8]

$$A^{III}B^{V} + HS^- + H_2O \rightarrow (A^{III})_xS_y + (B^{V})_xS_y + OH^- + H_2\uparrow \quad (3)$$

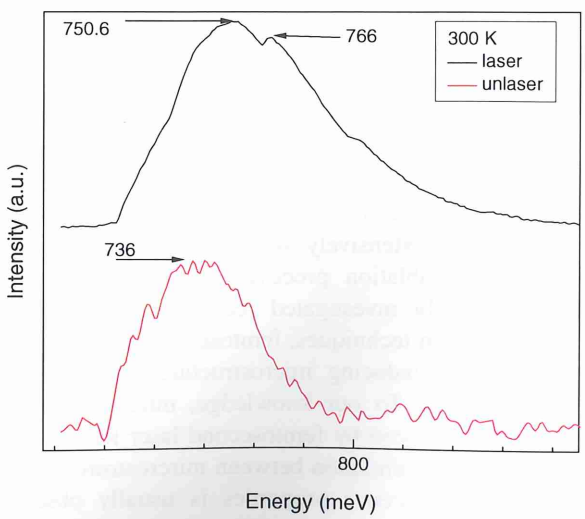

Fig. 4. Spectra of GaSb after surface passivation compared with laser treated at room temperature.

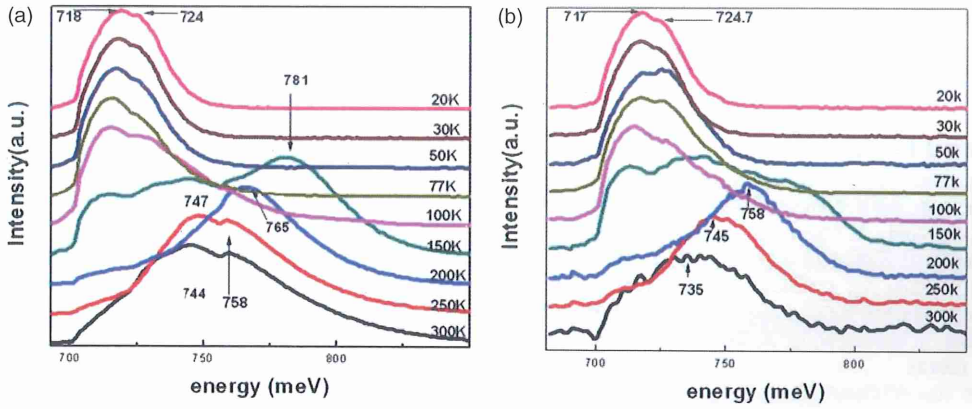

Fig. 5. Photoluminescence spectra of the femtosecond laser irradiated Te doped n-GaSb sample by sulfur passivated at various temperatures between 20 and 300 K (sample 1). (b) Photoluminescence spectra of the Te doped n-GaSb sample by sulfur passivated at various temperatures between 20 and 300 K (sample 2).

The value of x and y can assume between 1 and 5, for example GaS, Sb_2S_3.[9, 10]

It has been proved that sulfur passivation treatment removed the native oxide layer from the surface and stabilized surface state by the formation of Ga—S and As—S stable bonds. The aim of sulfur passivation is to improve the luminescence characteristics of the sample, ensure to observe spectral changes more easy.[1]

In order to get a good passivation effect, we choose 60 °C and 180 s as the suflur treatment condition.[11] An amorphous Ga—S layer forms during passivation, the sulfuration treatment improves the deoxidation step. Photoluminescence (PL) was used to investigate the effect of the Te doping and describe the characterization of semiconductor materials, such as information related to the band-to-band energy, excitonic recombination, and transitions involving impurity levels, etc.[12, 13]

Figure 3 shows the PL mapping of the sample 1 dipped in ammonium sulfide solution. It is obvious the picture show the luminescence higher than untreated sample. However, it is also show the asymmetrical luminescence because of the laser ablation surface.

In Figure 4 we can easily discover the spectra of laser treatment sample 1 have a slightly blue shift about 14 meV compared with the sample 2. We speculate this phenomenon concerns about the change in the source of the emission peak.

Figure 5 shows the variety of PL intensity with the changing of temperature of the two samples after $(NH_4)_2S$ solution treatment. The semiconductor surface on the luminous intensity was obviously increased after sulfur treatment, the PL curves are normalized to the PL line intensity, respectively. In Figure 5(a), as $T = 20$ K, the main luminous peaks are located at 718 meV and 724 meV. With the increasing of test temperature, the two peaks 718 meV and 724 meV are decreased. The two peaks are attribute to the electron–phonon interaction typical for the Sb–Te compounds. This situation is corresponding to deep level of the doubly ionizable acceptor and deep acceptor level respectively. At 150 K a new strong peak appeared at 781 meV. This dominance of the peak is from the Te-related acceptor level. The microstructure enhance its luminous intensity.[14–21] Figure 5(b) shows variation temperature PL spectra of the sample that etched for 180 s but without laser ablation. The curves are similar to the Figure 5(a), however, the peak locate in 781 meV is not so obvious at 150 K. We assume this enhance of peak of sample 1 is a response of surface micro-structure.

4. CONCLUSIONS

In conclusion, we first try to use linearly polarised femtosecond laser ablated Te-doped n-type gallium antimonide (GaSb) ($n = 9.082 \times 10^{16}$ cm^{-3}) wafer in vacuum. The micro-structure occurs on the surface of the irradiated GaSb sample. Contrast with the unlaser treatment sample, laser irradiated sample's main luminescent peak is slightly blue shift about 14 meV in room temperature due to the different origin of the emission peaks. The low temperature PL measurements indicate the main peaks are located at 718 meV and 724 meV, which are ascribed to the typical electron–phonon interaction of the Sb–Te compounds, this situation is corresponding to deep level of the doubly ionizable acceptor and deep acceptor level, respectively.[14–19] However, at 150 K, the peak located at 781 meV is not obvious in unlaser treatment sample, we speculate that this enhancement of peak is relevant to a response of surface micro-structure.

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