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Mechanism investigation of $(NH_4)_2S_x$ -treated III–V compounds multi-junction solar cell

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Abstract

Tandem-type solar cells consisit of different band gap semiconductors which can achieve high conversion efficiencies and reduce the cost as photovoltaic electricity. In order to fabricate high quality III–V compounds multi-junction solar cell, we use the passivation mechanism to an $(NH_4)_2S_x$ -treated window layer (AlInP) of III–V solar cell. The native oxide on the n-type AlInP surface removed by the $(NH_4)_2S_x$-treated process were investigated using X-ray photoelectron spectroscopy. Furthermore, the short circuit current (Isc) is advanced and conversion efficiency of the InGaP / InGaAs / Ge multi-junction solar cell devices promoted 3.8 % after $(NH_4)_2S_x$-treatment. This performance improvement is attributed to the reduce of the surface states by sulfide passivation. Therefore, the $(NH_4)_2S_x$ treatment is an effective method for passivating and promoting the III–V compounds multi-junction solar cell.

1. Introduction

Recently, tandem structures of solar cells have been studied actively, because they can achieve a higher conversion efficiencies than that of single junction cells[1]. However, high surface state density and high surface recombination velocity would deteriorate the performances of III–V semiconductors. To improve performances, sulfide surface treatment has been widely used for the compound semiconductors[2-4]. In this study, an X-ray photoelectron spectroscopy (XPS) was used to analyze the surface of $(NH_4)_2S_x$-treated window layer (n-AlInP) of solar cells. The electrical and bonding configurations of the III–V compounds multi-junction solar cells with and without $(NH_4)_2S_x$-surface treatment were measured and analyzed.

2. Experimental procedure

The InGaP / InGaAs / Ge triple-junction solar cell structures shown in Fig.1 were grown on p-type Ge substrates by metal organic chemical vapor deposition (MOCVD) system. The samples were cleaned with chemical solutions of trichlorethylene, acetone and methanol, and then the contact layer InGaAs were etched approximately 500 nm to AlInP layer by using selective etching solution of NH_4OH / H_2O_2 / H_2O (1/1/50). The as-etched sample was dipped into an $(NH_4)_2S_x$ solution (with 6% of S) at 60°C for 30 min, rinsed with deionized water and blown dry with N_2. The $(NH_4)_2S_x$-treated area on AlInP surface is 92.5% in each definition pattern. To further investigate the $(NH_4)_2S_x$-treated mechanism, both as-etched and $(NH_4)_2S_x$-treated specimens were immediately inserted into the ESCA vacuum chamber for XPS examination. The current-voltage characteristics of the solar cells is measured using a continuous solar simulator system (AM 1.5G and 100 mW/cm^2 at 25 °C).

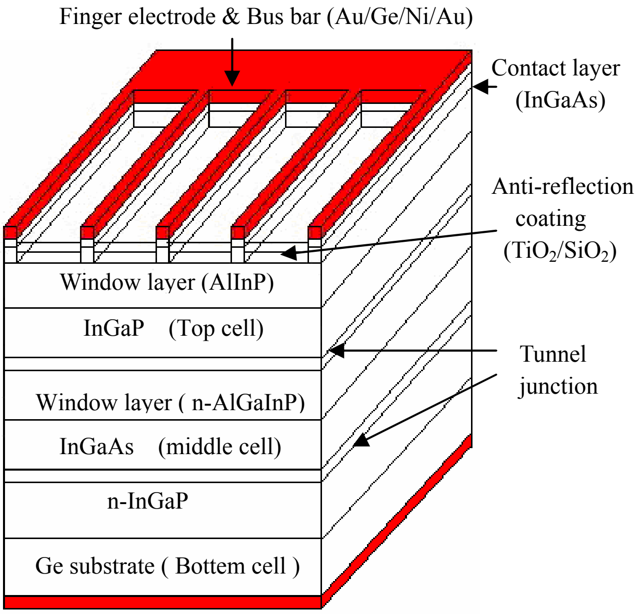

Fig.1 The structure of InGaP/InGaAs/Ge triple-junction solar cell

3. Experimental Results and Discussion

Fig.1 shows the xps spectra of In $3d_{5/2}$ core levels of the as-etched and $(NH_4)_2S_x$-treated samples. All binding energies have been corrected for the charging effect with reference to the adventitious carbon 1s peak at 284.6 eV. By using an interative least-square computer program, the XPS spectra of In $3d_{5/2}$ were deconvolved into three components associated 444.5, 444.9 and 445.1 eV, respectively. All the In$3d_{5/2}$ core level peaks located at 444.5 eV is associated with the In-P bonds, and the In-O and In-S set at 444.9 and 445.1 eV, respectively [4]. Although it is difficult to measure the distinction between S and O bonding to In, it still can be seen that the higher binding energy shoulder was broadened for the as-etched sample than the $(NH_4)_2S_x$-treated sample. This phenomenon is similar to the experimental results reported previously[4] which indicates that InO_x composition was removed by the $(NH_4)_2S_x$ solution. From this experimental results, we deduce that the Schotty mechanism for $(NH_4)_2S_x$ surface treatment from further I-V characteristics is proved by xps experiments.

Fig.3 shows the current-voltage characteristics of the

III–V compounds solar cells with and without $(NH_4)_2S_x$ treatment under a continuous solar simulator system (AM 1.5G and 100 mW/cm^2 at 25 °C). From Fig.3, the calculated fill factor (FF) and conversion efficiencies (η) are listed in Table I. The short circuit current (Isc) of 0.137 and 0.112 mA was obtained for the solar cells with and without $(NH_4)_2S_x$ treatment, respectively. Besides, after the $(NH_4)_2S_x$ surface treatment, the conversion efficiencies was promoted to the 23.1% than that without sulfide treatment 19.3%.

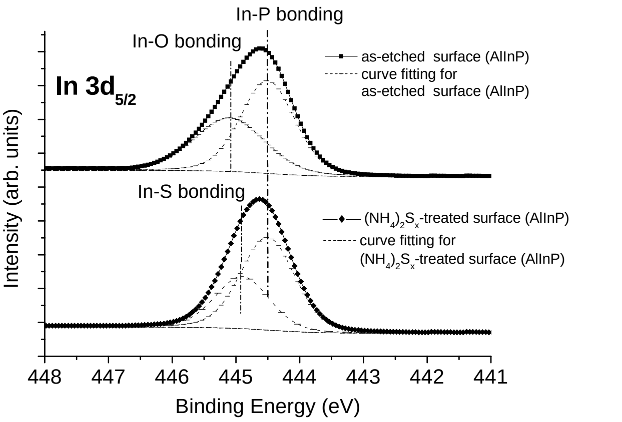

Fig.2 The In $3d_{5/2}$ core level XPS spectra for AlInP surfaces with and without $(NH_4)_2S_x$ treatment.

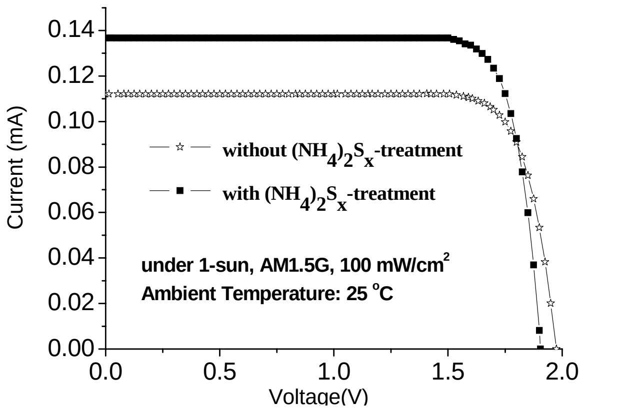

Fig.3 The current-voltage characteristics of the III–V compounds solar cell with and without $(NH_4)_2S_x$ treatment.

Table I Performances of III–V compounds multi-junction solar cell with and without $(NH_4)_2S_x$ surface treatment

$(NH_4)_2S_x$-treated	Isc(mA)	Voc(V)	FF	η(%)
without	0.112	1.98	0.77	19.3%
with	0.137	1.91	0.79	23.1%

By using the HP4145B semiconductor parameter analyzer, the various temperature current-voltage characteristics of the Schottky diodes were measured and shown in Fig.4. According to the equation (1), the current (I) transport over the Schottky barrier height Φ_B as a function of various temperatures (T) can be expressed as

$$I=A^*ST^2\exp(-q\Phi_B/KT)\qquad(1)$$

where the calculated A* of 2x 10^{-7} A cm^{-2} K^{-2} is the effective Richardson constant of AlInP, S is the Schottky contact area, T is the absolute temperature and q is the electronic charge. From the Napierian logarithm plot of $[\ln(J/T^2)]$ as a function of various temperature, the associated Schottky barrier height Φ_B of 0.77 eV and 0.57 eV was obtained for the III–V compounds multi-junction solar cell with and without $(NH_4)_2S_x$ surface treatment, respectively. This result indicates that the as-etched sample surface, using selective etching solution $NH_4OH/H_2O_2/H_2O$ (1/1/50), is induced many In dangling bonds and the occupation of P vacancies as a result of InO_x formation. In general, the presence of surface states tends to lower the Schottky barrier height[5]. Therefore, the $(NH_4)_2S_x$ surface treatment can effectively reduce the surface states. This phenomenon can be identified from xps experiments.

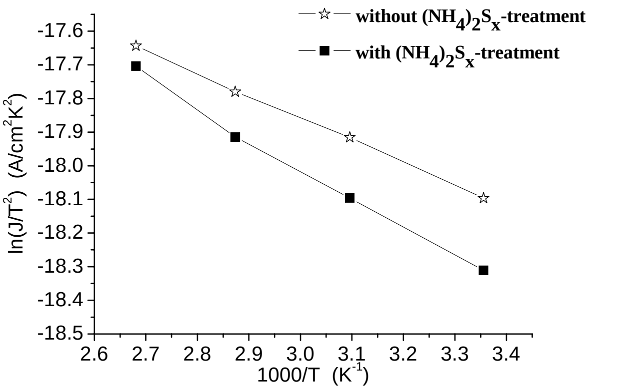

Fig.4 The various temperature current-voltage characteristics of the Schottky diodes with and without $(NH_4)_2S_x$ treatment.

4. Conclusions

In summary, the Schottky mechanism for $(NH_4)_2S_x$-treated III–V compounds multi-junction solar cell were investigated. The $(NH_4)_2S_x$ surface treatment can obtain high conversion efficiencies due to the reduce of the In dangling bonds and promote higher Schottky barrier hight by using the $(NH_4)_2S_x$ treatment. Therefore, the higher photovoltaic electricity performances of the III–V compounds multi-junction solar cell can be obtained.

Acknowledgement

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