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Improvement in Conversion Efficiency of MOCVD GaAs Solar Cells using AlGaAs Buffer Layers

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A 22.5% (AM0,1sun) efficient 2×2cm^2 AlGaAs/GaAs heteroface solar cell grown by MOCVD have been obtained by employing the AlGaAs buffer layer. The AlGaAs buffer layer increases both an open-circuit voltage(Voc) and a short-circuit current (Isc). The former is attributed to a back surface field (BSF) effect, as expected, but the latter is attributed, unexpectedly, to the improvement of the AlGaAs window layer.

1. Introduction

GaAs solar cells are suitable for space applications, since they have high conversion efficiency and high radiation resistance. LPE technology has been developed for mass production of heteroface solar cell whose average and maximum efficiencies are 17.5% and 19.3%, respectively.[1)]

Recent attention has been given to MOCVD technology which allows precise control of design parameters such as layer structure, layer thickness and impurity doping.

In a laboratory scale, AM0 efficiency of 21.1% has been reported, utilizing n^+-GaAs buffer layer which gives rise to the back surface field (BSF).[2)]

On the other hand, a heteroface AlGaAs solar cell incorporating a heterostructure BSF has been reported. However, the efficiency is still behind the conventional one.[3)]

In this paper we focused on the AlGaAs buffer layer to grow high quality active layers for heteroface AlGaAs/GaAs solar cells using a barrel shaped MOCVD reactor suitable for mass production. AlGaAs buffer layers have been found to be effective to raise both Voc by BSF effect and Isc by improvement of the AlGaAs window layer. The highest AM0 efficiency of 22.5% and AM1 efficiency of 24.1% have been achieved.

2. Experimental

The AlGaAs/GaAs heteroface solar cell structures were grown by barrel shaped MOCVD reactor which has a growth capacity of 40 wafers of 4.4×5.0 cm^2.

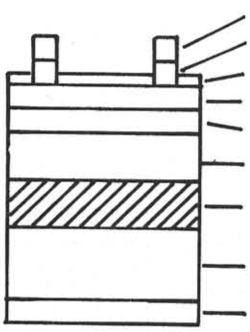

Fig. 1, The schematic cross-section of the solar cell structures.

Table 1, The list of the structures of buffer layers.

SAMPLE	STRUCTURE of BUFFER LAYER
A	N^+-GaAs 0.5 μm
B	500 Å $Al_{0.6}Ga_{0.4}As$/ N^+-GaAs 0.5 μm
C	(100 Å $Al_{0.6}Ga_{0.4}As$/100 Å GaAs)x5 / N^+-GaAs 0.4 μm
D	(100 Å $Al_{0.6}Ga_{0.4}As$/100 Å GaAs) x20 / N^+-GaAs 0.1 μm

The substrate temperature and the reactor pressure were 780°C and 130 torr, respectively. The flow rate of H_2 carrier gas was 70 SLM. Trimethyl gallium (TMG), trimethyl aluminum (TMA) and 100% arsine (AsH_3) were used as Ga, Al and As sources, respectively. The doping of n- and p-type layers were carried out using hydrogen selenide (H_2Se) and diethylzinc(DEZn), respectively.

The cross-sectional structure of the solar cell is shown in Fig. 1 . The size of solar cell is 2×2cm^2. The details of the buffer layer structures are shown in Table 1. Solar cell performances were measured at 28°C under AM0 (135mW/cm^2) and AM1 (93mW/cm^2) conditions, which represent solar spectra outside the earth's atomosphere and on earth, respectively.

3. Results and discussion

A. Solar cell performance

Table 2 shows the typical performance of solar cells with and without AlGaAs buffer layers. Voc, Isc, and fill factor (FF) are increased by employing the AlGaAs buffer

Table 2, The typical value of the solar cell performance.

SAMPLE	Voc (V)	Isc (mA)	FF	η (%)
A	1.01	132	0.828	20.3
B	1.03	136	0.842	21.6

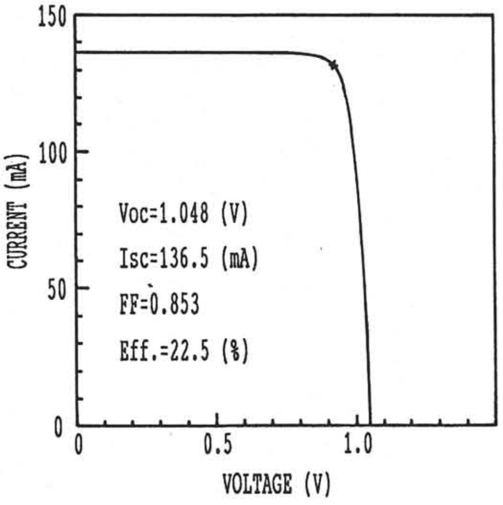

Fig. 2. The I-V curve of solar cell.

layers. As a result, the conversion efficiency is improved from 20.3% to 21.6%. The conversion efficiency of our best solar cell is 22.5%(AM0), which is the highest so far reported. Figure 2 shows the I-V curve of this solar cell. The efficiency under one sun, AM1 conditions is 24.1%, which is close to the theoretical limit of 27%, taking into account the electrode obscuration of 4.5%.

B. Voc and reverse saturation current

Figure 3 shows the dependence of Voc on the buffer layer structures. The structures of samples A~D are shown in Table 1. The plotted values are the average of each growth lot. The Voc of solar cells with the

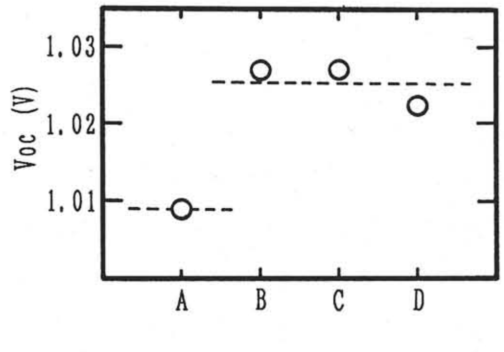

Fig. 3, The average value of Voc. A-D indicate the structures of buffer layers listed in table 1.

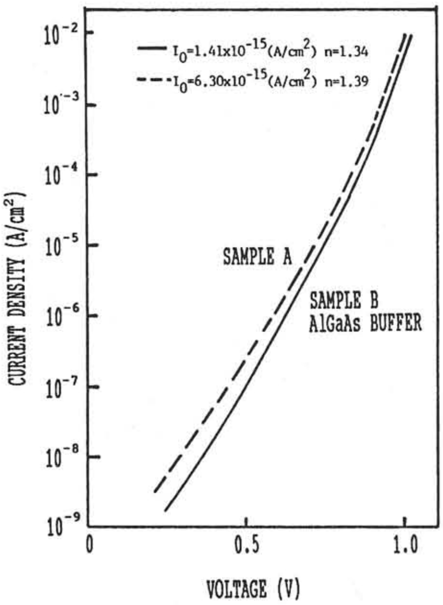

Fig. 4, The dark I-V curves of soler cells.

AlGaAs buffer layer are larger than that of conventional cells with n^+-GaAs buffer layer. The AlGaAs buffer layer raises Voc by about 20mV, being independent of the buffer layer structures. These results indicate that the improvement of Voc is due to the so-called BSF effect caused by AlGaAs buffer layer,i.e. n-AlGaAs layer acts as a potential barrier and the minority carriers are reflected at the heterointerface.

In order to confirm the BSF effect, we also measured the reverse saturation current (Io). Figure 4 shows the dark I-V curves of solar cells with and without AlGaAs buffer layer. The reverse saturation currents (Io) extrapolated from the curve around 30mA/cm^2 are 6.30×10^{-15}A/cm^2 and 1.41×10^{-15} A/cm^2 for samples A and B, respectively. This Io reduction means that the recombination velocity at backside is reduced by the BSF effect.

C. Spectral response and PL measurements

Figure 5 shows the dependence of Isc on the buffer layer structures. Every sample with AlGaAs layers increases Isc by about 4mA. Figure 6 shows the spectral response of the solar cells with and without the AlGaAs buffer layer.If the BSF effect is the origin of Isc enhancement, the response in the long wavelength region should be enhanced. The experimental result is opposite, i.e., the response in short wavelength region is enhanced by AlGaAs buffer layer.

The absorption coefficient of GaAs is so large that most of the incident light in the short wavelength region is absorbed near the surface. Therefore, the heterointerface recombination near the surface is an important factor to understand the enhancement of response in the short wavelength region. By theoretical curve fitting to the experi-

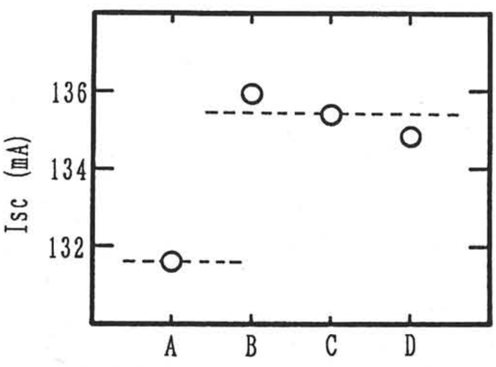

Fig. 5, The average value of Isc.

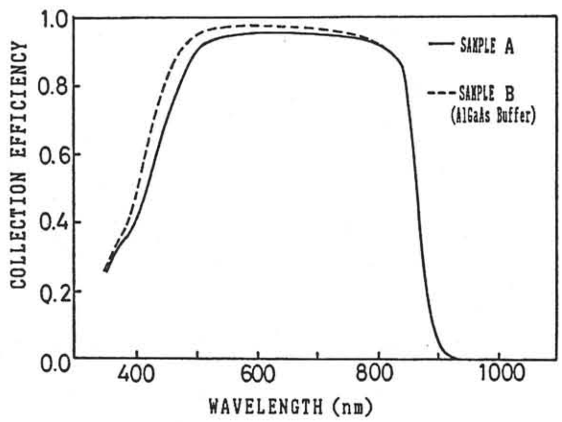

Fig. 6, The spectral response of solar cell.

mental spectral response, it was estimated that the S value decreased from 10^5cm/s to 10^4 cm/s by incorporating AlGaAs buffer layer.

To confirm the change of S value by employing the AlGaAs buffer layer, photoluminescence study was carried out using two samples shown at the inset of Fig.7. Sample F has an AlGaAs buffer layer and sample E has no buffer layer. All spectra were traced in a same scale. The solid lines show the spectra of as-grown samples with the window layers. The broken lines show the spectra of samples whose AlGaAs window layers were etched off. The bound exiton peak intensity of spectrum (b) of sample F is about two times larger than that of sample E, probably due to the BSF effect. The enhancement of PL intensity of samples with AlGaAs window layer are due to the reduction of surface recombination velocity. This enhancement factor of bound exiton peak intensity are 5.8 and 7.7 for samples E and F, respectively. The large enhancement observed in the sample with the AlGaAs buffer layer indicates that the buffer layer brings high quality heterointerface of AlGaAs window layer and GaAs layer. This result is consistent with the increase of Isc of the solar cell by the AlGaAs

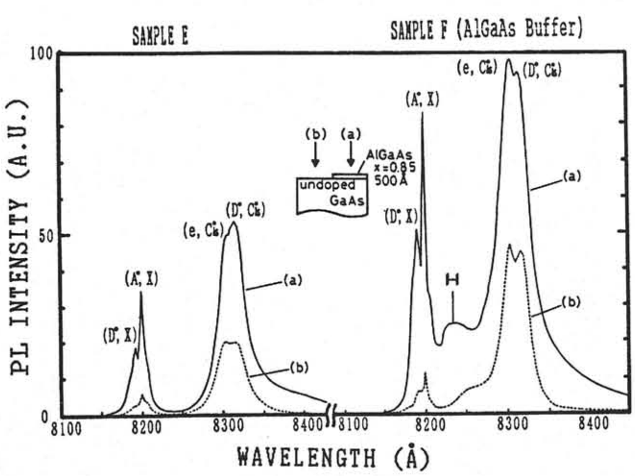

Fig. 7, The PL spectra at 4.2°K.

buffer layer. The broad peak indicated H is due to the confined carriers at the interface between undope GaAs and AlGaAs buffer layer.

AlGaAs window layer has high Al content of 0.85, so this layer is very sensitive to residual oxygen impurity. Yeh et al.[4] demonstrated that the increase of oxygen concentration in the AlGaAs window layer reduce the Isc in the AlGaAs/GaAs heteroface solar cells.During the growth of AlGaAs buffer layer, ambient impurity such as oxygen is probably reduced by gettering, so the crystalline quality of the subsequently grown layers can be improved.

4. Conclusion

The AlGaAs buffer layers were appplied to MOCVD AlGaAs/GaAs heteroface solar cells. The maximum efficiency of 22.5% (AM0) was achieved for 2×2cm^2 solar cell. The AlGaAs buffer layer acts as a potential barrier to reduce the leakage current. It also acts as the oxygen gettering layer to improve the quality of heterointerface of the window AlGaAs and active GaAs layer.

Acknowledgement

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