論文 90-27-1-6

Heteroface AlGaAs/GaAs Solar Cells grown by MBE

(MBE에 의해 성장된 Heteroface AlGaAs/GaAs 태양전지)

張 淏 星*, 林 聖 奎**

(Ho Sung Chang and Sung Kyoo Lim)

要 約

MBE 장치를 이용하여 heteroface AlGaAs/GaAs 드리프트 태양전지와 conventional 태양전지를 제작하였다. 드리프트 태양전지는 베이스와 이미터내의 불순물 농도가 선형적으로 변화되며 conventional 태양전지의 경우는 각 영역의 농도가 일정하게 되도록 하였다. 여러가지 가정을 통한 간략한 시뮬레이션 결과를 이용하여 설계된 0.39cm×0.39cm 크기의 태양전지의 유효수광면적에 대한 효율은 드리프트 태양전지의 경우 AM 1.5 조건에서 15.9% 이었으며 단락전류밀도 (J_{sc})는 19.00 mA/cm², 개방전압 (V_{oc})은 0.93V, 충실도는 0.78이었다.

Abstract

Heteroface AlGaAs/GaAs drift solar cells with an active area conversion efficiency of 15.9 % under one sun and AM 1.5 condition have been grown by molecular beam epitaxy (MBE). These drift solar cells have linearly graded doping profiles in the base and emitter regions. The cells have a short circuit current density (J_{SC}) of 19.00 mA/cm^2, an open circuit voltage (V_{OC}) of 0.93 V, and a fill factor (FF) of 0.78, respectively. Conventional solar cells with fixed doping profiles were also grown by MBE for comparison with the drift solar cells. Even though the fabrication cost of MBE grown solar cell is higher, the expected highest conversion efficiency of the single or multiple cells could compensate for the increased cost, particularly in case of space applications.

I. Introduction

A number of AlGaAs/GaAs heteroface solar cells with high conversion efficiency have been fabricated by liquid phase epitaxy (LPE) [1,2,3,4] and metalorganic chemical vapor deposition (MOCVD) [5,6]. MEB grown solar cells with conversion efficiency of 15.8% (AM1.5, 100 mW/cm^2), without an antireflective coating have been demonstrated [7]. The conversion efficiency of AlGaAs/GaAs solar cells have been improved continuously. The most recent report shows the conversion efficiency of 21% under one sun and AMO condition for an MOCVD grown solar cell [6].

In this paper, we report MBE grown AlGaAs/GaAs drift solar cells (0.39 cm × 0.39 cm) with active area conversion efficiency of 15.9% under one sun, AM1.5 condition. The doping concentration of a conventional solar cell was constant while that of a drift cell gradually changed from

---

*正會員, 明知大學校 電子工學科

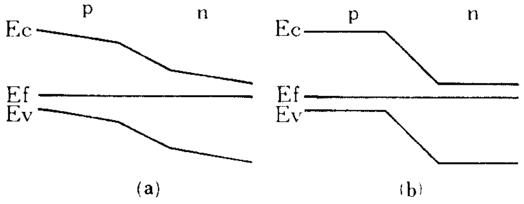
(Dept. of Elec. Eng., Myongji Univ.)

**正會員, 檀國大學校 電子工學科

(Dept. of Elec. Eng., Dankook Univ.)

接受日字：1989年 6月 30日

high to low in the base and from low to high in the emitter to create field-aided regions. It is reported that the presence of a field-aided region leads to a high collection efficiency of photogenerated carriers and increased open circuit voltage[8]. Eenergy band diagrams of the active layers of conventional and drift solar cells are shown in Fig.1.



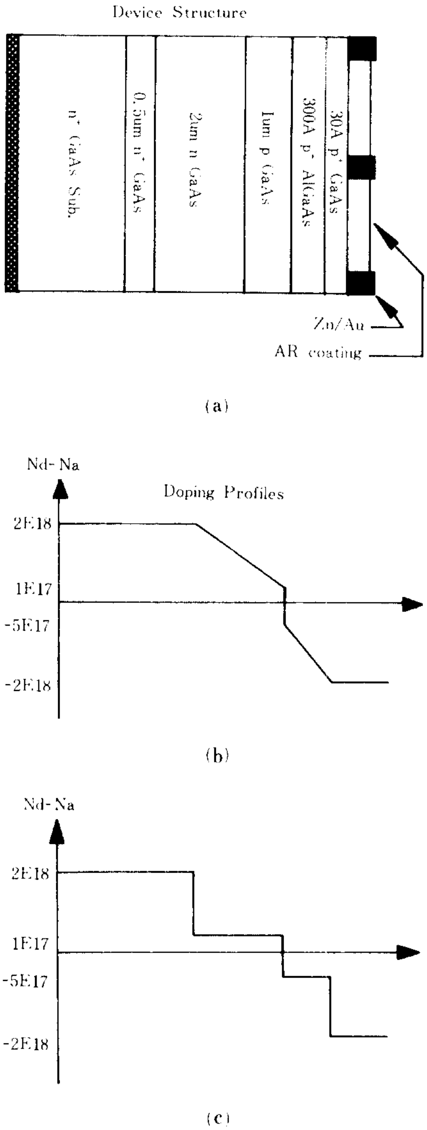
(a) (b)

Fig.1. Active layer energy band diagram
(a) Drift, and (b) Conventional solar cell

In conventional cells, only the electron-hole pairs (EHP) generated within the minority carrier diffusion length from the depletion region or in a depletion region contribute to the photovoltaic effect. In drift cells, however, EHP's generated outside a diffusion length may also contribute to the photovoltaic effect. This is due to the drift field created by the intentional doping gradient in the active layer. In a conventional solar cell, current within a minority carrier diffusion length of the space charge region is due to diffusion while for the drift cell it is due to both diffusion and drift. The drift field also reduces the transit time of minority carriers, which results a lower recombination rate of the carriers. The structure was designed using a simple computer simulation. Therefore, the present structure may not be completely optimized.

Ⅱ. Fabrication

The solar cells were fabricated by MBE on n-type (100) GaAs Bridgeman substrate with concentration of 2 x 10^{18} cm^{-3}. The structure and doping profiles of the fabricated solar cells are shown in Fig.2. Before the substrate was loaded into MBE, it was cleaned in boiled trichloroethylene, and rinsed in aceton, methanol and deionized water. After removing oxide by wet etching it was rinsed in deionized water agan and blow dried with filtered nitrogen gas. The cleaned substrate was then mounted on a preheated Mo sample holder with In soldering for adhesion and loaded into MBE system. The MBE system was pumped down and cooled with liquid nitrogen, and by using a combination of ion, cryo, diffusion, sorption, and sublimation pumps, high vacuum condition of 4 x 10^{-8} Torr in the growth chamber was maintained.



(a)

(b)

(c)

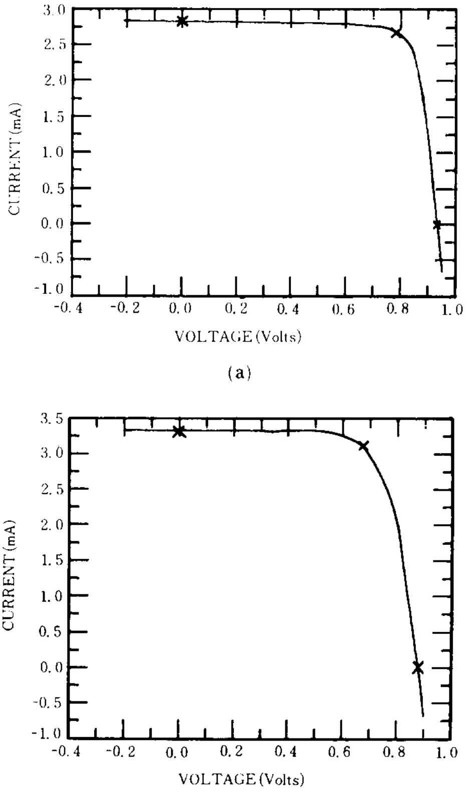
Fig.2. Solar cell
(a) Device Structure (b) Drift, and
(c) Conventional doping profiles

A Si doped 0.5 μm thick n^+ buffer layer was grown with the concentration of 1 x 10^{18} cm^{-3}, and the 2 μm thick Si doped n^+ layer with gradually changing doping concentration from 1 x 10^{18} cm^{-3} to 1 x 10^{17} cm^{-3} was grown. By varying the effusion cell temperature it was possible to grow epitaxtial layers with graded doping concentration.

A 1 μm thick p layer was then grown with Be doping concentration gradually changing from 5 x 10^{17} cm^{-3} to 2 x 10^{18} cm^{-3}. The substrate temperature was kept at 560 °C during the growing of GaAs layers. A 300 Å thick $Al_xGa_{1-x}As$ (x=0.9) p layer with doping concentration of 2 x 10^{18} cm^{-3} was grown and was capped with a 30 Å thick high conductivity p GaAs layer with doping concentration of 2 x 10^{18} cm^{-3}. While growing AlGaAs layer, the substrate temperature was 680 °C. The epilayer growing speed was about 1 μm/hr. The thickness of the conventional cell was the same as above, but the doping pofiles were kept constant. The base was doped with Si to 1 x 10^{17} cm^{-3} and the p type emitter was doped with Be and the doping level was 5 x 10^{17} cm^{-3}. $Al_xGa_{1-x}As$ (x=0.9) layer was used as window. The n^+ buffer layer was essential for the successive growth of high quality epitaxial layers. The doping concentration gradient in the base and emitter creates drift field in the region. A 30 Å thick capping layer was grown to protect AlGaAs surface during the fabrication process and from oxidation and for ohmic contact. Other researchers used 500 Å GaAs capping layer for ohmic contact to the top electrode and the other parts were removed for better light absorption. The grid pattern occupied 13% of the solar cell area. The recent report showed that the grid area could be reduced to 4% of solar cell area[9]. 0.2 μm thick Au-Zn(10% Zn) layer was evaporated on the p^+ GaAs capping layer for ohmic contact in drift solar cell and then annealed at 450 °C for 5 minutes. In conventional solar cell Mn-Au was used for p type ohmic contact. The annealing was carried out at 450 °C for 20 sec. Lift-off technology was used for the metal electrode. Mn-Au was used to minimize perturbation of the doping profile during ohmic contacts annealing in the conventional solar cells. The back of the cell was soldered with In to thin Cu plate for n type ohmic contact and for heat sinking. SiO_2 layer was deposited by plasma enhanced chemical vapor deposition (PECVD) for AR coating and passivation layer.

III. Results and Discussion

The active area conversion efficiency of our best drift cell was 15.9% under one sun, AM 1.5 illumination (100 mW/cm^2) while that of conventional cell was 16.0% under the same condition. Fig. 3(a) shows the current-voltage relationship of a drift cell under illuminated condition (The numbers in parentheses are for the conventional solar cell.). The short circuit current density (J_{SC}) was 19.00 (22.17) mA/cm^2 and the open circuit voltage (V_{OC}) was 0.93 (0.86) V. The fill factor (FF) was 0.78 (0.72) resulting in a conversion efficiency of 15.9 (16.0) %. The fill factor of 0.78 (0.72) of the fabricated solar cell was lower than optimal because of the series resistance associated with the very thin p type ohmic contact layer. If the contact grid was plated to a thickness of 3 μm, the series resistance of the solar cell could be reduced and would yield higher



(a)

(b)

Fig.3. I-V Characteristics of
(a) Drift, and (b) Conventional solar cell

efficiency. Contrary to our expectation, the conversion efficiency of the drift solar cell was a bit lower than that of the conventional solar cell. The reason was due to the lower quantum efficiency of the drift solar cell as shown in Fig.4. The external quantium efficiency of the conventional solar cell was higher than than that of the drift solar cell. The lower quantium efficiency of the drift solar cell was believed mainly to be due to the poor surface state of the AR coating layer. If the same external quantum efficiency is assumed, the expected conversion efficiency of drift solar cell will be 17.8% which is much greater than that of the conventional solar cell. All the measurements were performed at the SERI (Solar Energy Research Institute). The important parameters including short-circuit current density (J_{SC}), open-circuit voltage (V_{OC}), fill factor (FF), and conversion efficiency for the fabricated solar cells are listed in Table 1.

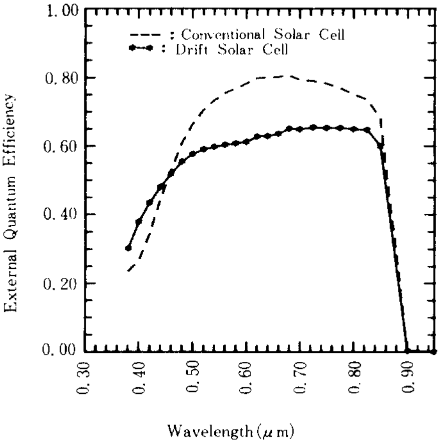


Fig.4. External quantum efficiency of drift and conventional solar cell

Table 1. Measured solar cell performance parameters under one-sun, AM 1.5 condition at 25℃.

Cell No.	J_{sc} (mA/cm²)	V_{oc} (V)	FF (%)	Efficiency (%)
C1	23.17	0.877	71.72	16.0
C2	22.46	0.872	60.62	13.7
D1	18.57	0.927	78.80	15.6
D2	19.00	0.927	78.19	15.9
D3	18.79	0.923	77.79	15.5
D4	19.07	0.927	76.72	15.6

The AlGaAs/GaAs solar cells grown by MOCVD showed 18.7% and 21% of conversion efficiency under one sun, AM 0 condition [5,6]. And these values were very close to the maximum conversion efficiency of 21% derived by computer calculation[10]. High series resistance and large grid contact area caused lower conversion efficiency of MBE grown AlGaAs/GaAs solar cells. By choosing optimized performance parameters it will be possible to fabricate high quality solar cells by MBE.

IV. Conclusion

In conclusion, AlGaAs/GaAs heteroface drift solar cell with a conversion efficiency of 15.9% was fabricated by MBE. The best conventional cell efficiency was 16.0%. Because of the consistent quality of MBE material, large area solar cell may have the same high efficiency as that of small area solar cell. Much research has been done on AlGaAs solar cell for its application as an upper cell in the development of high-efficiency multiple solar cell [8,9]. The work described herein was done for a first step to the fabrication of high efficiency cascade solar cells. The expected conversion efficiency of the two junction or three junction cascade solar cells could be greater than 30%[1].

References

[1] J. Ewan, R.C. Knechtli, R. Loo, and G.S. Kamath, Tenth IEEE Photovoltaic Specialist Conf., p. 941, 1978.

[2] H.A. Vander Plas, L.W. James, R.L. Moon, and N.J. Nelson, Tenth IEEE Photovoltaic Specialist Conf., p. 934, 1978.

[3] R.C. Knechtli, R.Y. Loo, and G.S. Kamath, IEEE Trans. Electron Devices, ED-31, p. 577, 1984.

[4] S. Yoshida, K. Mitsui, T. Oda, M. Kato, Y. Yukimoto, and S. Matsuda, 17th IEEE Photovoltaic Specialist Conf., p. 36, 1984.

[5] J.G. Werthen, H.C. Hamaker, G.F. Virshup, and C.W. Ford, Appl. Phys. Lett. 46(8), p. 776, 1985.

[6] J.G. Werthen, H.C. Hamaker, G.F. Virshup, and C.W. Ford, Appl. Phys. Lett. 48(1), p. 74, 1986.

[7] A. Saltes, J.P. Contour, M. Leroux, J. Massies, N.Defranould, and G. Pelous, Solar Cells, 17, p. 373, 1986.

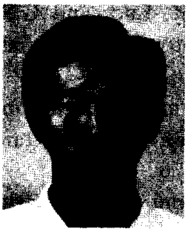
[8] G.F. Virshup, C.W. Ford, and J.G. Werthen, Appl. Phys. Lett. 47(12), p. 1319, 1985.

[9] B.C. Chung, H.C. Hamaker, G.F. Virshup, and J.G. Werthen, Appl. Phys. Lett. 52(8), p. 631, 1988.

[10] H.C. Hamaker, J. Appl. Phys. 58(6), p. 2344, 1985.

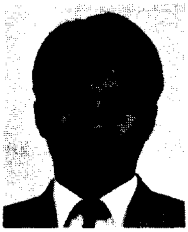
[11] T.J. Coutts, J.D. Meakin (editors), Current Topics in Photovoltaics, Academic Press, p. 196, 1985.

著者紹介



張 淏 星(正會員)

1978年 2月 서강대학교 전자공학과 졸업. 1985年 6月 Oregon State University Dept. of Electrical Eng. 석사 학위취득. 1987年 6月 Oregon State University Dept. of Electrical Eng. 박사과정 수료. 1989年 6月 National Corporation의 Engineer. 1989年 9月～현재 명지대학교 강사. 주관심분야는 Compound Semiconductor device 및 MQW Laser 등임.



林 聖 奎(正會員)

1977年 2月 서울대학교 전자공학과 졸업. 1979年 2月 서울대학교 전자공학과 석사. 1981年 1月 해군사관학교 교관. 1982年 2月 삼성전자 반도체연구소 주임연구원. 1982年 3月～단국대학교 이공대학 전자공학과 부교수. 1987年 8月 University of Arizona 및 Oregon State University 객원교수. 주관심분야는 화합물 반도체 소자 등임.