Displacement damage dose approach to analyze ion irradiation effects on homemade GaAs/Ge solar cells*

LIU Yun-Hong(刘运宏)[1,2] WANG Rong(王荣)[1,2,3;1)] CUI Xin-Yu(崔新宇)[4] SUN Xu-Fang(孙旭芳)[1,2]

1 (Key Laboratory of Beam Technology and Materials Modification of Ministry of Education, Beijing Normal University, Beijing 100875, China)
2 (Institute of Low Energy Nuclear Physics, Beijing Normal University, Beijing 100875, China)
3 (Beijing Radiation Center, Beijing 100875, China)
4 (Tianjin Institute of Power Sources, Tianjin 300381, China)

Abstract Displacement damage dose is applied to analyze the irradiation effects of 2 MeV carbon ions and 0.28 ~ 20 MeV protons on homemade GaAs/Ge solar cells. The NIEL for each ion is modified by taking into account the distribution of Bragg damage peak in the active region of the solar cells, and then the corresponding displacement damage dose is obtained. It is found that with the aid of displacement damage dose, the degradation of P_{max} of GaAs/Ge solar cells induced by carbon ions and protons with various energies and fluences could be characterized with a simple curve. Obviously, the displacement damage dose approach simplifies the description of ion irradiation effects on homemade GaAs/Ge solar cells.

Key words GaAs/Ge solar cells, displacement damage dose, carbon ion, proton, irradiation

PACS 61.82.Fk, 84.60.Jt

1 Introduction

Space solar cells have been used as the main power sources by many satellites and played an important part in space missions. Since solar cells on satellites are exposed to severe space radiation environment and their output powers are decreased due to energetic ion radiations, several studies[1—6] on ion irradiation effects of homemade GaAs solar cells are performed on ground laboratories so as to evaluate their radiation-resistant characteristics. These studies use some specific ions generated at accelerators to irradiate solar cells, and measure the changes in electronic properties of the cells under different ion energies or fluences. The space irradiation response of GaAs solar cells can then be estimated from the obtained data. However, solar cells in an actual space environment are irradiated by tremendous kinds of ions with broad spectra of energies, so a large number of ground irradiation experiments must be required for accurate performance predictions of solar cells, which will cost lots of expenses and time.Moreover,it is hard to generate ultrahigh-energy ions at ion accelerators.

As a matter of fact, the degradation of solar cells is mainly due to displacement damage effects caused by ion irradiations[7]. Thus, some researchers[8, 9] make use of the concept of displacement damage dose, D_d, to analyze the irradiation effects of solar cells and successfully estimate the cells responses in space radiation environment with little ground experimental data. D_d is a quality that describes the total displacement damage energy deposited per unit mass of material, and can be obtained through multiplying the ion fluence Φ by the respective non-ionizing energy loss (NIEL) in material ($D_d = \mathrm{NIEL} \times \Phi$). NIEL is a new concept in space radiation research, which

Received 8 July 2008
* Supported by National Natural Science Foundation of China (10675023) and Beijing Excellent Personality Foundation
1) E-mail: wangr@bnu.edu.cn

describes the energy loss due to atomic displacement as an ion transverses a material. In this paper, we apply the displacement damage dose to analyze ion irradiation effects on homemade GaAs/Ge solar cells.

2 Experiments and results

GaAs/Ge space solar cells used in this study were fabricated by metalorganic chemical vapor deposition (MOCVD) technique. Fig. 1 shows the cross-sectional view of p^+-n-n^+ GaAs/Ge solar cells. The doping concentrations of n-base layer and p^+-emitter layer are 1.5×10^{17} and $3\times10^{18}\text{cm}^{-3}$, respectively. The junction depth is about 0.5 μm. The beginning-of-life (BOL) efficiencies of the cells with antireflective (AR) coating were tested at AM0 to be about 18%.

The solar cells were irradiated with 0.28 to 2.80 MeV protons using a 2×1.7 MV tandem accelerator at Beijing Normal University. Proton fluences ranged from 1×10^{10} to 1×10^{13} cm^{-2} with a flux of about 5×10^{8} $\text{cm}^{-2}\cdot\text{s}^{-1}$, low enough to avoid heating of the cells during irradiations. The details of 5— 20 MeV protons and 2 MeV carbon ions irradiation experiments for the solar cells had been described elsewhere in Refs. [4] and [6].

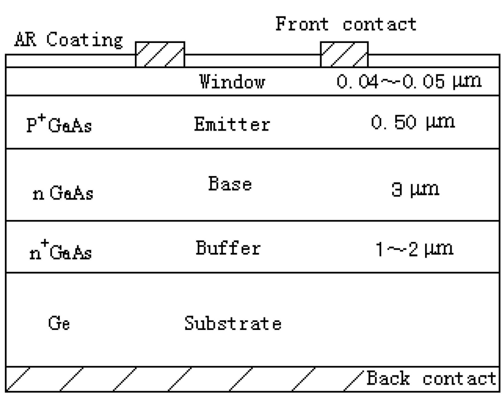

Fig. 1. Schematic diagram of GaAs/Ge solar cell.

I-V characristics of the solar cells before and after irradiations were measured at 25° under AM0 using a solar simulator with a illumination of 136.7 mWcm^{-2}. Fig. 2 shows the degradation of normalized maximum power ($P_{\max}$) of solar cells due to ion irradiations (normalized to its initial value). It can be seen that the degradation rate of $P_{\max}$ increases with ion fluence, and the degradation caused by carbon ions is most severe, and protons at lower energy causes more degradation.

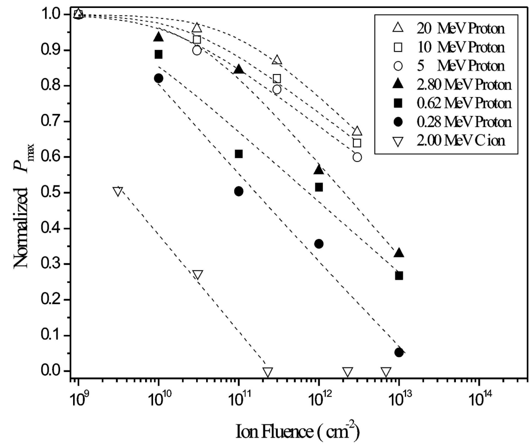

Fig. 2. The degradation of normalized $P_{\max}$ of GaAs/Ge solar cells due to ion irradiations.

3 NIEL calculations

The NIEL values for different ions play an important role in the application of displacement damage dose to analyze irradiation effects of solar cells. S.R.Messenger etc.[8] proposed an approach that using Monte Carlo program to calculate the NIEL for ions in materials, but experimental data[9] indicated that such approach only worked well when ions traversed the active region of cells with little energy left in it. When ions are stopped within or nearby the active region of GaAs/Ge solar cells, such as 2 MeV carbon ions (the project range is 2.18±0.26 μm) and 0.28 MeV protons (the project range is 2.28±0.21 μm), their Bragg damage peaks will lie in the active region and their energies will change noticeably across the region, so that the NIEL values calculated from above approach are not accurate. As a consequence, when applying D_d to analyze irradiation effects of specific solar cells, it is necessary to take into account of the distribution of Bragg damage peak in the active region and make some reasonable modifications for NIEL.

In SRIM 2006[10] simulations, the solar cell is equally divided into a number of micro partitions, and vacancies that produced by incident ions in each micro partition along the track are recorded, then the non-ionizing energy deposited in each partition can be acquired[8]. The total non-ionizing energy deposited in the active region is the summation of the non-ionizing energy in each partition. If this summation energy is divided by the width of the active region (3.5μm) and the density of GaAs crystal (5.32 g/cm^3), we can obtain the modified NIEL values. Fig. 3 shows the unmodified and modified NIEL values for carbon ions and protons in GaAs/Ge solar cells.

In Fig. 3, it can be seen that if ions are stopped far outside the active region of GaAs/Ge solar cells, their energies can be assumed to be unchanged throughout the active region, such as 2.80 to 20 MeV protons, and the NIEL values before and after modified are nearly coincided with each other. However, if ions terminate in or nearby the active region of the cells, they lose most or total of their energy in the active region, and then the modified NIEL values are larger than the unmodified ones, such as the case of 0.28 MeV proton, 0.62 MeV proton (the project range is 6.18± 0.38 μm) and 2 MeV carbon ion.

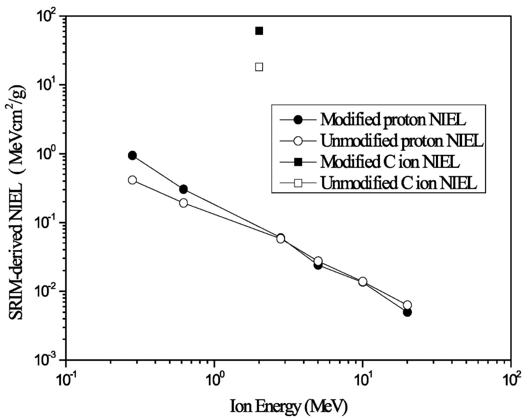

Fig. 3. Comparison between the unmodified and modified NIEL values for carbon ions and protons in GaAs/Ge cells.

4 Applications of displacement damage dose approach

The displacement damage dose can be obtained by multiplying the ion fluence by the respective NIEL at a specific energy in GaAs/Ge solar cells. Fig. 4 shows the correlation of normalized $P_{\max}$ of the solar cells and the displacement damage dose.

It is clear that although the irradiations were performed with carbon ions and protons at different energies, the degradation of $P_{\max}$ due to irradiations can be characterized with a simple curve. The correlation between the degradation of $P_{\max}$ and the displacement damage dose is fitted by the following simple analytic function:

$$\frac{P_{\max}}{P_{\max 0}}=1-k\times\log\left(1+\frac{D_d}{D_x}\right) ,$$

where $P_{\max0}$ and $P_{\max}$ are the maximum power of solar cells before and after irradiation, D_d is the displacement damage dose, and k and D_x are fitting parameters. The parameters $k$and D_x fit for the experimental data are 0.097 and 1.14×10^9 MeV/g, respectively.

Obviously, the irradiation effects of the cells caused by carbon ions and protons at various energies can be correlated well by the displacement damage dose. This can be explained that atomic displacement damages and lattice defects are produced by the deposited non-ionizing energy in the materials [7]. These defects acting as recombination centers may cause a decrease in the lifetime and diffusion length of the minority carrier, and result in the performance degradation of solar cells. It is found that the degradation rate of $P_{\max}$ is closely related to the total non-ionizing energy deposited in the active region of the cells, that is, the more total non-ionizing energy (corresponding to the displacement damage dose, D_d=NIEL×Φ) that ions deposited, the more severe degradation that $P_{\max}$ of the cells will be. Thus, it can be conceived that ion irradiation with same displacement damage dose causes the same degradation of $P_{\max}$ of solar cells.

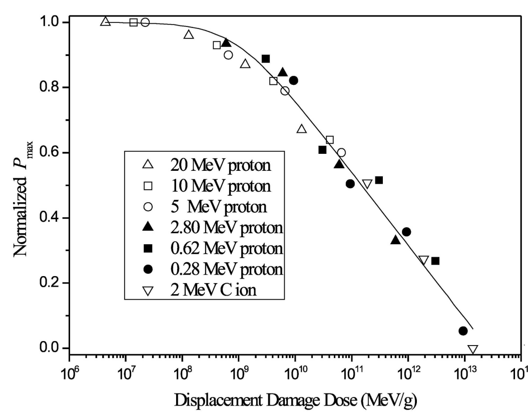

Fig. 4. Normalized $P_{\max}$ of GaAs/Ge solar cells as a function of displacement damage dose.

5 Conclusions

In summary, it has been shown that the NIEL value for each ion in GaAs/Ge soalr cells should be modified by taking into account the distribution of Bragg damage peak in the active region of solar cells. Then the displacement damage dose is calculated with the modified NIEL value. It is found that with the aid of displacement damage dose, the degradation of $P_{\max}$ of GaAs/Ge solar cells induced by carbon ions and protons with various energies and fluences could be characterized with a simple curve. This indicates that the approach of displacement damage dose makes it convenient to describe the ion irradiation effects of homemade GaAs/Ge solar cells.

References

1 XIANG Xian-Bi et al. Solar Energy Materials & Solar Cells, 1998, **55**(4): 313

2 XIANG Xian-Bi et al. Chinese Journal of Semiconductors, 2001, **22**(6): 710

3 WANG Rong et al. Solar Energy Materials & Solar Cells, 2006, **90**: 1052

4 WANG Rong et al. Solar Energy Materials & Solar Cells, 2003, **77**: 351

5 Erkin, GUO Qi et al. Nuclear Techniques, 2003, **26**(9): 697 (in Chinese)

6 LIU Yun-Hong, WANG Rong, SUN Xu-Fang. Nuclear Techniques, 2007, **30**(4): 259—261 (in Chinese)

7 Anspaugh B E. GaAs Solar Cell Radiation Handbook. California: JPL Publication, 1996

8 Messenger S R et al. IEEE Transactions on Nuclear Science, 1999, **46**(6): 1595

9 Messenger S R et al. IEEE Transactions on Nuclear Science, 2002, **49**(6): 2690

10 Ziegler J F, Biersack J P, Littmark U. The Stopping and Range of Ions in Material. Pergamon Press: New York, 1995