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Short Communication

A study on the electric properties of single-junction GaAs solar cells under the combined radiation of low-energy protons and electrons

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Abstract

Displacement damage induced by charged particle radiation is the main cause of degradation of orbital-service solar cells, while the radiation-induced ionization shows no permanent damage effect on their electrical properties. It is reported that in single crystal silicon solar cells, low-energy electron radiation does not exert permanent degradation of their properties, but the fluence of electron radiation exerts an influence on the damage magnitude under the combined radiation of protons and electrons. The electrical properties of the single-junction GaAs/Ge solar cells were investigated after irradiation by sequential and synchronous electron and proton beams. Low-energy electron radiation showed no effects on the change of the solar cell properties during sequential or synchronous irradiation, implying ionization during particle radiation could not exert influence on the displacement damage process to the solar cells under the experimental conditions.

Keywords: GaAs/Ge solar cells; Combined irradiation; Damage; Synergistic effects

1. Introduction

As key elements to provide spacecraft with electrical energy in orbit, solar cells should be stable under a space environment such as various particle radiations. The electrical properties of solar cells can be degraded by space radiation [1–5]. However, more investigation was done for higher-energy (above 1 MeV) particle radiation, so an improved knowledge of lower-energy proton irradiation effects is required [6]. It is necessary to characterize the effects of charge particles with energy lower than 200 keV because there are large numbers of low-energy particles in the Earth's radiation belts. On the other hand, solar cells in orbit are subjected not only to single charged particles such as protons or electrons but also to their combined effects. Thus the aim of this study was to investigate the combined radiation effects of protons and electrons on electrical properties of single-junction GaAs/Ge solar cells.

2. Experimental details

Single-junction GaAs/Ge solar cells were chosen for study, with their structure shown in Fig. 1. The experimental cell area is $3.0 \times 4.0\,\text{cm}^2$. The 3 μm-thick base area is doped with $(1–1.5) \times 10^{17}\,\text{cm}^{-3}$ Si. The I–V curve of an as-received cell is shown in Fig. 2 under AM0 illumination, where we measured its properties such as short circuit current (I_{sc}) of 0.38 A, open circuit voltage (V_{oc}) of 1.04 V, filled factor of 0.73 and conversion efficient of 19.9%.

Irradiation was performed using a ground-based simulator for combined space radiation. The vacuum was 10^{-4} Pa in the chamber and the sample temperature was 298 K. In the light of previous reports on the irradiation damage

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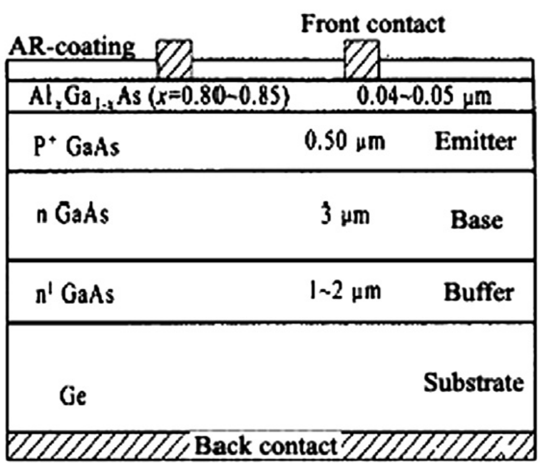

Fig. 1. Structural schematic diagram of GaAs/Ge solar cell.

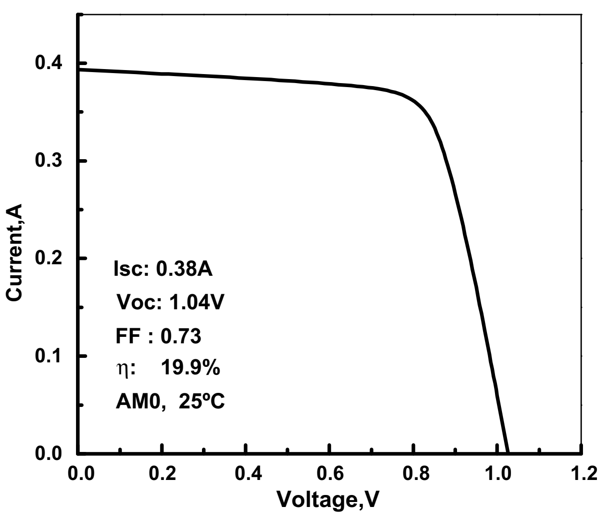

Fig. 2. $I–V$ curve of the as-received GaAs/Ge solar cell.

tendency of low-energy protons [7] and 1 MeV electrons to solar cells [1], proton fluences from 1×10^{10} to 3×10^{12} cm^{-2} were chosen with a flux of 1×10^{9} cm^{-2} s^{-1}, while the electron fluence was set from 1×10^{14} to 1×10^{16} cm^{-2} with a flux of 1×10^{14} cm^{-2} s^{-1}. With reference to the international measurement standard reported in the literature [8], the electric properties such as short circuit current (I_{sc}) and open circuit voltage (V_{oc}) were in-situ measured during irradiation, under the AM0 solar spectrum condition (using a standard solar simulator). The maximum output power (P_{max}) and the filled factor (FF) of the irradiated cells were calculated through the measured $I–V$ data.

3. Electrical properties after combination irradiation

Radiation in space orbit is not due to only a single electron or proton beam but a combination. However, it is difficult to simulate combined irradiation of various energies. Consequently, three combined irradiation experiments

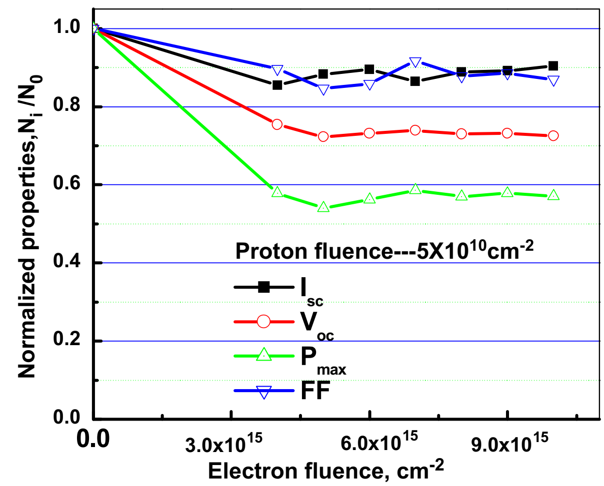

Fig. 3. Normalized electric properties of the GaAs solar cells after sequential irradiation of protons followed by electrons.

were designed to evaluate the degradation behaviors of the solar cells, namely radiation of protons sequentially followed by electrons, radiation of electrons sequentially followed by protons and synchronous radiation of both protons and electrons.

Consider first proton radiation sequentially followed by electrons. The charged particle energy is set at 100 keV. During experiments, solar cells were irradiated firstly by protons to a fluence of 5×10^{10} cm^{-2}, followed by various fluences of electrons from 0 to 1×10^{16} cm^{-2}. The electric properties were measured and shown in Fig. 3. The first proton irradiation (fluence of 5×10^{10} cm^{-2}) degrades I_{sc}, V_{oc}, P_{max} and FF to about 0.82, 0.72, 0.58 and 0.82 respectively. This means that low-energy proton radiation can induce severe damage of the solar cells. Afterwards, the proton-damaged solar cell was subjected to the electron irradiation. During the electron irradiation the electrical properties of the solar cells do not change, implying that

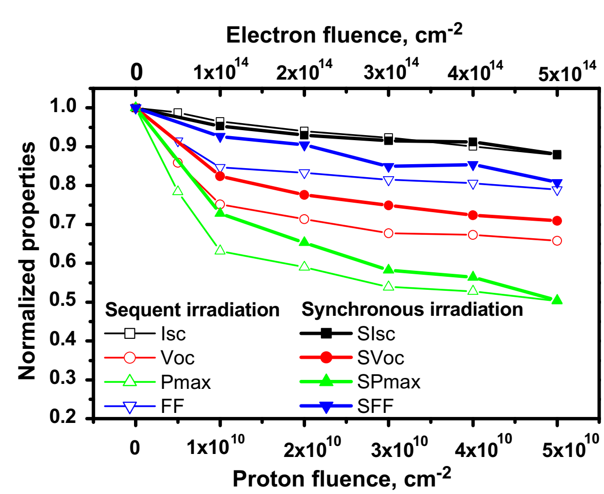

Fig. 4. Normalized electrical properties of the GaAs solar cells after sequential irradiation of electrons followed by protons and also synchronous irradiation of both protons and electrons.

it neither further degrades the properties nor induces a recovery effect on the damaged cells. Theoretically, the threshold energy for electrons is over 260 keV to produce the displacement damage in GaAs materials, while lower-energy electrons can produce only ionization effects in cells. The results indicate that ionization process shows no effect on the degradation.

Then consider electron irradiation sequentially followed by protons. Solar cells were subjected to the irradiation of electrons with energy of 100 keV to a constant fluence of $1 \times 10^{16}\,cm^{-2}$. As mentioned before, there is no change detected in the electrical properties. Thereafter proton irradiation degrades the solar cell in a mode as those irradiated by the single proton radiation, similar to the previous report in the literature [7].

Now consider synchronous irradiation with both electrons and protons. In this case, the energy of both electron and proton is set as 100 keV, with maximum fluences of $5 \times 10^{14}\,cm^{-2}$ and $5 \times 10^{10}\,cm^{-2}$, respectively. Fig. 4 shows also the degradation of the electrical properties of the solar cells with fluence. Compared to sequential irradiation, there are similar degradation processes occurring with synchronous irradiation. It is also interesting to notice that, as the fluence is lower, the properties V_{oc}, P_{max} and FF were degraded less than for sequential irradiation. This implies a kind of synergistic effect occurring during the synchronous irradiation, namely strong ionization in the solar cell shows some influence on the displacement process induced by the proton impacts. As the irradiation fluence increases, this synergistic effect weakens. The reason for this synergistic effect is not presently clear.

4. Conclusions

Irradiation with electrons followed by protons (both at energies of 100 keV) degrades the properties of single-junction GaAs solar cells in the same manner as for only 100 keV proton irradiation. However, under synchronous irradiation the induced degradation is similar to that of the sequential irradiation, but a smaller decrease in electrical properties was observed in the earlier stage of irradiation. It implies that strong ionization in the solar cell shows some influence on the displacement process induced by the proton impacts.

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