Radiation Effects of Protons and Electrons on Backfield Silicon Solar Cells

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Abstract. Radiation effects of protons and electrons on the backfield silicon solar cells were investigated. The samples without cover glass were irradiated by the protons and electrons with 30–180 keV and a given flux of $1.2 \times 10^{12}$ cm$^{-2}$·s$^{-1}$ for various fluences at 77 K. Experimental results show that the short circuit current decreases gradually with increasing the proton fluence, while the open circuit voltage degrades severely under lower fluences. No obvious changes appear in the electric properties before and after the irradiation by electrons, and there exists a recovery effect in the in situ measurement for the irradiated samples. The effect of the combined radiation of protons and electrons does not show simple additivity. The damage extent of proton radiation is larger than that of combined radiation under lower electron fluences, while the combined radiation results in more severe damage under higher fluences. The DLTS analysis verified that the primary defects induced by protons were the H1 or [V+B] type at the energy level of +0.45 eV, which would result in formation of a resistance layer in the base region and degradation of the backfield Si solar cells.

Key words: Radiation effects, Protons, Electrons, Solar cells

1. Introduction

Since solar cells are key elements to provide spacecraft with electric energy in orbit, the degradation in their properties could directly influence the working condition and lifetime of spacecraft. The electric properties of solar cells would be degenerated under the space radiations [1]. It is important to improve the radiation resistance of the solar cells [2–5]. In order to evaluate the performance of the solar cells in the geostationary Earth orbit, it is necessary to characterize the effects of charged particles with the energy less than 200 keV, which exist in large amount in the Earth’s radiation belts. Also, when spacecraft passes into the Earth shadow, the solar cells are subjected to the effect of low temperatures. The
aim of this study was to examine the change in electric properties of the silicon solar cells under the radiations of protons and electrons with <200 keV at 77 K, as well as the radiation damage mechanism.

2. Experimental

The sample of the backfield silicon solar cell is schematically shown in figure 1, which is 250 μm thick and has the base layer resistivity of 10–12 Ω·cm. The samples with the size of 20 × 20 mm² were not covered with glass. The phosphorus doped Si emitter junction depth from the surface is 0.2 μm. The parameters of samples before irradiation are shown in table 1.

The ground-based simulation equipment used in this study can simulate the radiations of solar electromagnetic rays, electrons and protons in orbit, independently and simultaneously. The irradiation energy of protons and electrons was chosen as 60–180 keV, the flux $1.2 \times 10^{12}$ cm⁻²·s⁻¹ and the fluence from $2 \times 10^{13}$ to $2 \times 10^{16}$ cm⁻². The homogeneity of the irradiation flux is more than 95% in the area of 100 × 100 mm² by scanning the proton and electron beam. During the irradiations, the chamber was kept at vacuum $10^{-4}$ Pa and temperature of 77 K. The electric properties of the samples were characterized by $I–V$ curves, which were measured before and after the irradiations. In order to analyze the radiation-induced defects, DLTS analysis (deep level transient spectroscopy) was carried out in the temperature range of 77–450 K.

![Figure 1. Schematic diagram of the samples](image)

<table>
<thead>
<tr>
<th>$I_{sc}$ (mA)</th>
<th>$V_{oc}$ (mV)</th>
<th>$P_{m}$ (mV)</th>
<th>FF</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>138.7</td>
<td>552</td>
<td>59.97</td>
<td>0.78</td>
<td>15</td>
</tr>
</tbody>
</table>

TABLE 1. The parameters of the samples before irradiation