Radiation Resistance of a-Si Solar Cells Evaluated for SPS Use

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Abstract

Solar Power Satellite(SPS) is expected as one of the potential candidates for a sustainable energy system in the 21st century. The major component of the SPS is a huge-scale solar power generator, as well as a wireless power transmitter to the ground. Amorphous silicon(a-Si) solar cell module, a thin film type, is regarded as a realistic power generator for the SPS, considering space transportation and deployment on orbit. Since a-Si solar cells are relatively newborn for ground use, their operational data in space environment are not sufficiently available. We have investigated the resistance of a-Si solar cells to high energy radiation. According to the preliminary test results, it is concluded that the a-Si solar cell is promising for SPS use.

1. Introduction

The Solar Power Satellite Working Group at the Institute of Space and Astronautical Science(ISAS) is making a conceptual design for a 10 MWatt-class solar power satellite, named SPS 2000, as a near-term SPS model using existing technologies[1]. It aims to demonstrate the feasibility of the SPS as a clean and economical energy system. Although SPS 2000 has not been accepted as a budgeted program, it has been extensively studied and evaluated in terms of space energy technologies, utilities on ground, and global environmental aspects[2,3].

A circular orbit of 1100 km equatorial has been selected for SPS 2000, compromising the transportation cost, orbiting life, power transmission efficiency, and influence of space radiation and debris impact. The generated power is converted to the microwave power beam and is re-

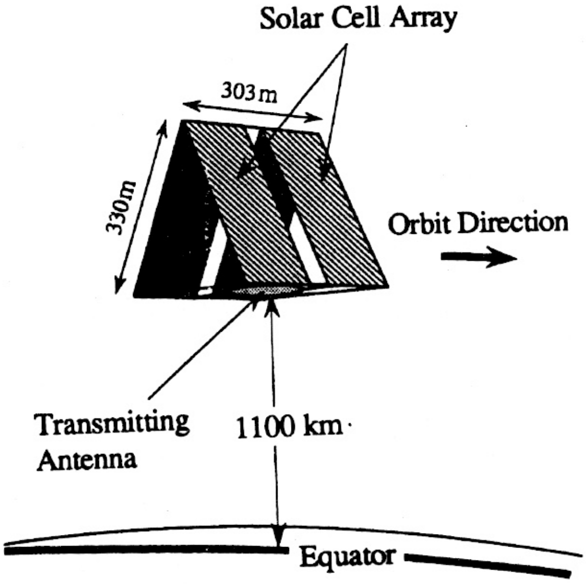

Fig.1 Concept of SPS 2000.

ceived by the rectennas on ground. The power from space could be utilized effectively by the people living near the equator. The shape of the satellite is a trigonal prism with a length of approximately 300 m each side as shown in Fig.1. The gravity gradient force stabilizes the satellite attitude with respect to the earth. The solar cell arrays are attached to the upper two planes of the prism, while the power transmitting antenna is installed at the bottom plane, facing the ground all the time.

The solar cell array consists of 180 rolls of 3 m x 300 m strips of solar cell panel, operated at 1000 Volt. Since the earth pointing attitude is maintained, the power generation depends on the sun angle or orbital local time with the maximum power of 18 MWatt. For transportation from ground and assembly on orbit, the deployable a-Si solar cells, a thin film type, have been considered as the design element. The a-Si solar cell came forward in 1976 as a potentially low cost solar cell. This type of solar cell is extremely thin so that it has a higher specific power per unit weight(~kw/kg) than the another types. The conversion efficiency of the a-Si solar cell is approximately 10 % at present which is lower than that of the crystalline cells, but is expected to be improved more than 15 % in the near future.

Since a long life is highly required for the SPS elements as an energy system economically materialized, high resistance to space radiation needs to be fully assured for the solar cells. In the design of SPS 2000, the degradation of the power generator is assumed to be less than 10 % during 10 years. The a-Si thin solar cell has been reported to have higher radiation resistance as compared with the crystalline cell[4]. The purpose of this research is to confirm the high radiation resistance of the a-Si solar cells

Table 1 Characteristic features of the test cells.

Type	Amorphous Silicon
Dimension	113 x 120 x 0.12(0.25) mm
Area	$135.6 cm^2$
Weight	2.3(4.5) gram
Protective Cover	PET(0.05 mm thick)
Temperature Coefficient	Voc -0.4~-0.2 Isc +0.1~+0.2 Pmax -0.2~-0.03

which have been newly developed in Japan. The test cell is a potential candidate for SPS 2000, considering the possibility for mass production and low cost, although the conversion efficiency right now is considerably lower than that used in the conceptual design. The research has been conducted under collaboration of ISAS, Japan Atomic Energy Research Institute(JAERI), Tokyo Engineering University, and Sanyo Electric Co.,Ltd.

2. Radiation Experiment

The characteristic features of the a-Si solar cell module used in the irradiation experiments are listed in Table 1. Figure 2 shows the equivalent damage fluence during 1 year for electrons and protons for the low equatorial orbit. The effect

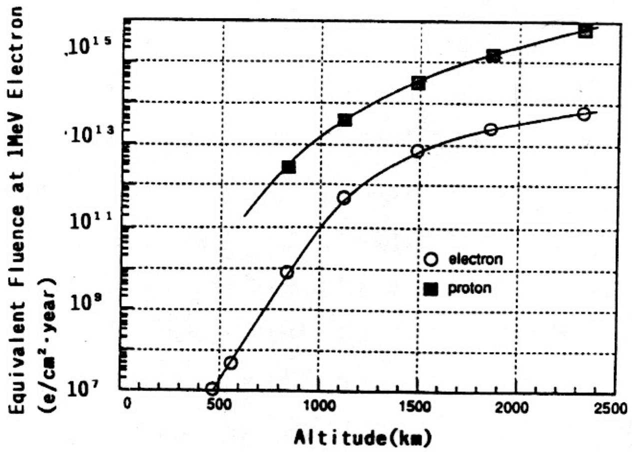

Fig.2 Equivalent damage fluence for electrons and protons for the low equatorial orbit.

of the protons is larger than the electrons in this altitude range. The equivalent fluence during 1 year for SPS 2000 at 1100 km is estimated as 6.4×10^{13} electrons/cm^2 at 1 MeV . This is a reference value calculated for the crystalline Si solar cell using the Solar Cell Radiation Handbook by NASA JPL[5].

The radiation experiments have been conducted by the electron and proton beam accelerators of JAERI. The effect of 0.15-3.0 MeV electron irradiation was studied up to the fluence of 1×10^{16} electrons/cm^2 in the atmosphere. For ion irradiation, the effect of the energy at 3-10 MeV was studied up to 2.5×10^{14} ions/cm^2 in vacuum.

The performance of the solar cell before and after the irradiation test was evaluated by a pulse solar simulator of ISAS for electron irradiation and by conventional DC solar simulators at JAERI and Tokyo Engineering Univ. for proton irradiation. In order to obtain the net effect of the irradiation on the solar cell, the transmittance of the protective cover(Polyethylene Terephthalate;PET) was independently measured by a multi-channel spectroscope from 300 nm to 1100 nm. The evaluation test was performed 1 or 2 days after the irradiation test. The test cells were stored in dry atmosphere at room temperature.

3. Experimental Results

3.1 Electron Irradiation

Figure 3 shows a typical example of the change of the transmission coefficient which was obtained at the fluence of 1×10^{15} electrons/cm^2 in the energy range from 0.5 to 3.0 MeV. The transmittance from 300 nm to 1100 nm is normalized by that of before the irradiation test. The degradation of transmittance is prominent at the wave length below 400 nm. Since the sensitivity of the test cell below 400 nm is relatively low, the effect of degradation of the protective cover is not so significant in the evaluation of the solar cell performance.

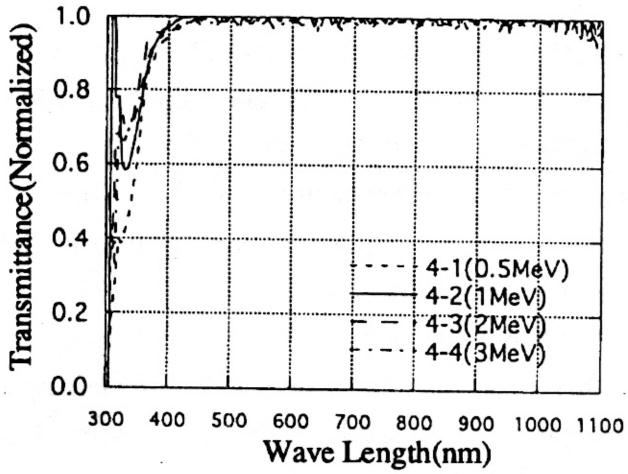

Fig.3 Effect of the electron irradiation on the transmittance of PET at 1×10^{15} electrons/cm^2

Figure 4 shows the change of the conversion efficiency with 1 MeV electron irradiation. Totally 6 cells have been tested up to the fluence of 5×10^{15} electrons/cm^2. The test cells commonly kept more than 90 % of the initial performance up to the fluence of 4×10^{15} electrons/cm^2. The efficiency was strongly degraded at the fluence of 5×10^{15} electrons/cm^2. The data at 5×10^{15} electrons/cm^2 are scattered from 5 to 88 %. The degradation is strongly dependent on the nature of

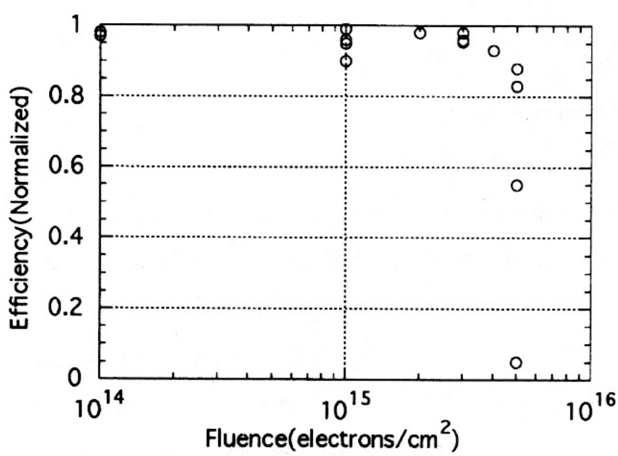

Fig.4 Degradation of the a-Si solar cells by the electron irradiation at 1.0 MeV.

the individual cell when considerably degraded. If we directly apply this result to SPS 2000 at 1100 km, using the equivalent fluence of 6.4x10^{13} electrons/cm^2 · year at 1MeV electron, the performance of power generation is maintained more than 90 % of the initial performance for 10 years.

Figure 5 shows the dependence of conversion efficiency on the electron energy from 0.15 to 1.0 MeV with the fluence of 3x10^{15} electrons/cm^2. Totally 7 cells have been tested. The degradation increases with energy in the low energy range less than 0.3 MeV, but it decreases at 1.0 MeV. There seems to be a critical energy between 0.3 and 1.0 MeV at which the cell is most degraded. The cause of the energy dependence has not been identified yet, but could be explained by the depth and thickness of the a-Si layer inside the cell.

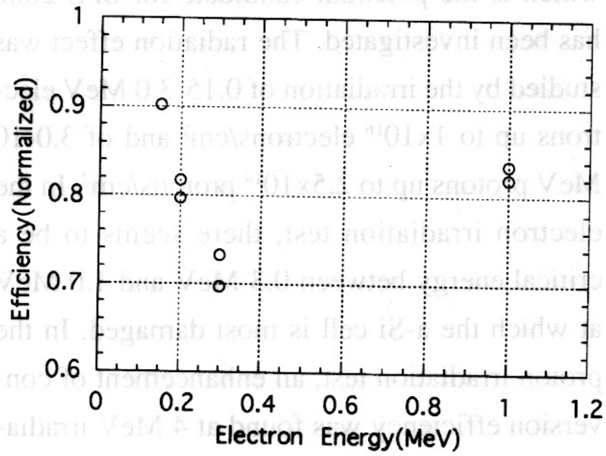

Fig.5 Dependence of conversion efficiency on the electron energy.

3.2 Proton Irradiation

The effect of the proton irradiation on the transmittance of the PET protective cover was very similar to the case of electron irradiation. The degradation was prominent below 400 nm. Figure 6 shows the degradation of the cells for proton irradiation at 3,4 and 10 MeV. The efficiency for 4 MeV irradiation increased almost 50% near the fluence of 10^{13} protons/cm^2 and decreased above it. On the other hand, the efficiency for 3 and 10 MeV irradiation decreased monotonously with the fluence.

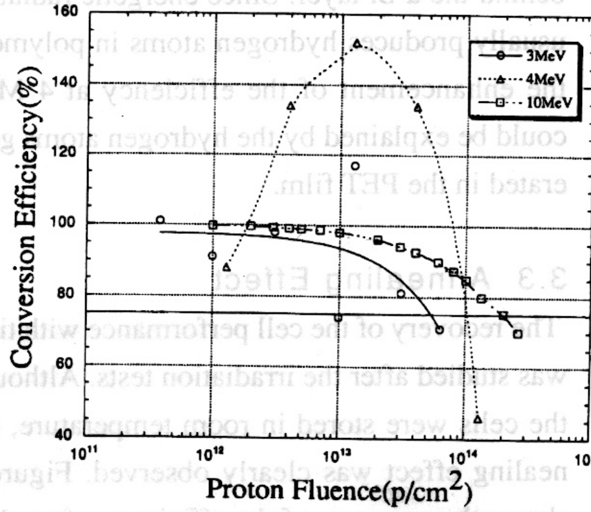

Fig.6 Degradation of the cells for proton irradiation at 3,4, and 10 MeV.

Figure 7 shows the energy loss of protons in the a-Si cell layer, calculated by a Monte Carlo simulation software(TRIM). The loss rate in the cell layer is 3.5 eV/Å for 3 MeV, 1.8 eV/Å for 4 MeV, and 0.7 eV/Å for 10 MeV. The ratio of the efficiency degradation for 3 and 10 MeV protons in Fig.6 is consistent with that of the energy loss for the protons with these energies. The simulation result indicates that the protons at 4 MeV lose most energy in the PET film just

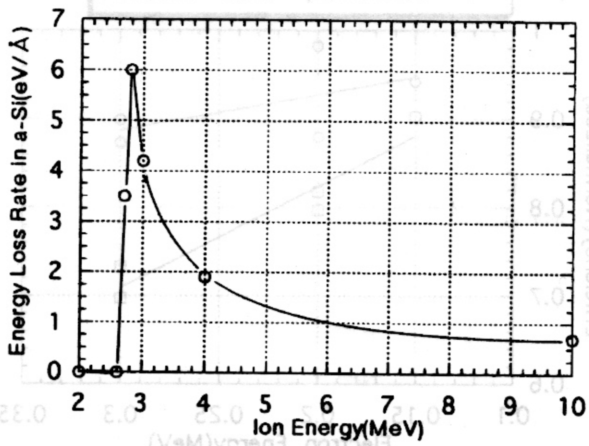

Fig.7 Calculated energy loss in the a-Si layer for 2-10 MeV proton.

behind the a-Si layer. Since energetic radiation usually produces hydrogen atoms in polymers, the enhancement of the efficiency at 4 MeV could be explained by the hydrogen atoms generated in the PET film.

3.3 Annealing Effect

The recovery of the cell performance with time was studied after the irradiation tests. Although the cells were stored in room temperature, annealing effect was clearly observed. Figure 8 shows the recovery of the efficiency after electron irradiation. The conversion efficiency recovered almost 50 % of degradation 20 days after irradiation.

The annealing effect indicates that there is a mechanism to remove the defects which are generated during the irradiation. Abdulaziz and Woodyard proposed a thermally activated dispersive transport mechanism to explain the annealing effect[6]. One possible mechanism to explain the annealing effect at room temperature is the recombination of hydrogen atoms in the cell. In order to confirm this, we have studied the performance of the cells stored in the hydrogen gas after the irradiation tests. The results are shown in Fig.9. Although further assessment is required, the conversion efficiency returned remarkably in the hydrogen gas.

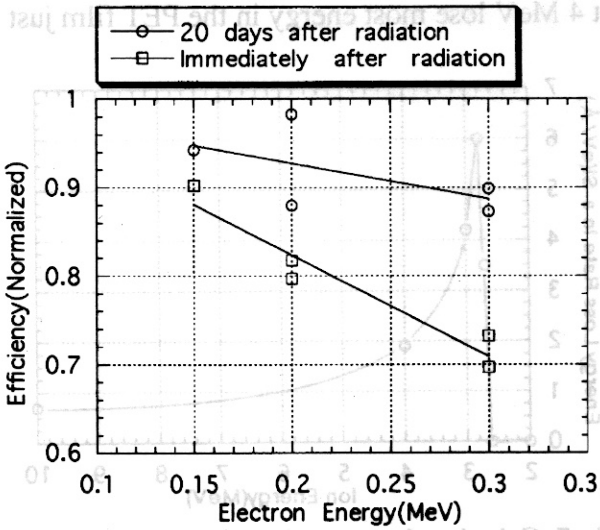

Fig.8 Annealing effect stored at room temperature in the atmosphere.

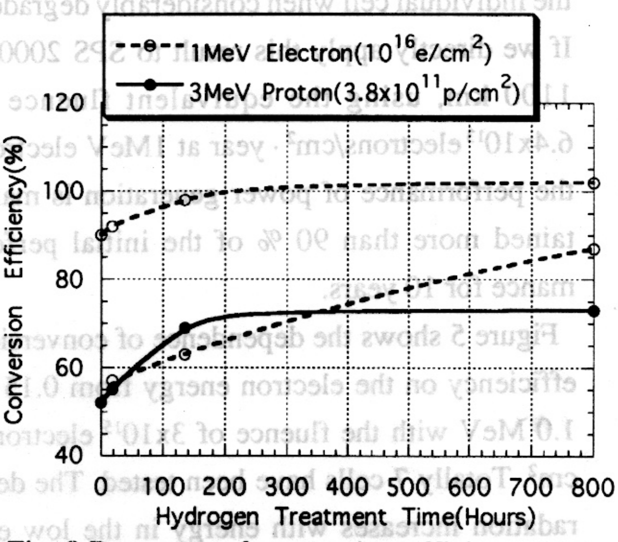

Fig. 9 Recovery of conversion efficiency in the hydrogen gas.

4. Conclusion

The radiation resistance of the a-Si solar cell which is the potential candidate for SPS 2000 has been investigated. The radiation effect was studied by the irradiation of 0.15-3.0 MeV electrons up to $1x10^{16}$ electrons/cm^2 and of 3.0-10 MeV protons up to $2.5x10^{14}$ protons/cm^2. In the electron irradiation test, there seems to be a critical energy between 0.3 MeV and 1.0 MeV at which the a-Si cell is most damaged. In the proton irradiation test, an enhancement of conversion efficiency was found at 4 MeV irradiation, which could be explained by the hydrogen atoms produced in the PET. The annealing effect at room temperature was observed after both electron and proton irradiation tests. Although the mechanism for the annealing effect has not been well identified yet, the recombination of hydrogen atoms in the cell could play an important role in the effect. If we apply the test results to evaluate the degradation of the power generation system of SPS 2000, more than 90 % of the initial performance will be maintained during 10 years. Considering the annealing effect at low temperature, the degradation in space will be further reduced. It is concluded that the a-Si solar cell we tested is quite promising for SPS use from the standpoint of radiation resistance if the conversion efficiency is improved as is now expected.

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