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INVESTIGATION OF SOLAR CELLS FOR SOLAR POWER SATELLITE SPS 2000

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Abstract

The ISAS Solar Power Satellite Working Group is making a conceptual design for a 10 MWatt solar power satellite named SPS 2000. For the SPS 2000, amorphous silicon(a-Si) solar cell, a thin film type developed for ground use, is selected as a potential candidate for its power generator. Since the a-Si solar cells are relatively newborn, their operational data in space are not sufficiently available. We have tested the a-Si solar cells from a standpoint of space use. The resistance to high energy radiation and the effect of debris impact have been investigated. According to the experimental results, it is concluded that the a-Si solar cell is potentially promising for the SPS use.

Introduction

The SPS 2000 has been designed as a realistic Solar Power Satellite(SPS) model, to be constructed in early 2000's using existing technologies[1,2]. It aims to demonstrate the feasibility of the SPS as an energy system in terms of whether it will resolve the problems of the global environment and energy.

A 1100 km altitude equatorial orbit has been selected for the SPS2000, considering the transportation cost, orbiting life and environmental concerns. It has the shape of a triangular prism with a length of 300 m each side as shown in Fig.1, which is stabilized by the gravity gradient. The solar arrays are attached on the two upper planes of the prism, while the transmitting antenna is installed on the bottom plane, facing the ground all the time.

The solar array consists of 180 rolls of 3m x 300m strips of solar panel. For transportation from ground and assembly in space, the deployable a-Si solar cells, a thin film type, have been selected 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 other types. The conversion efficiency of the a-Si solar cells is approximately 10 % at present which is lower than that of the crystalline cells, but is expected to be considerably improved in the near future.

Since a long life, typically more than ten years, is re-

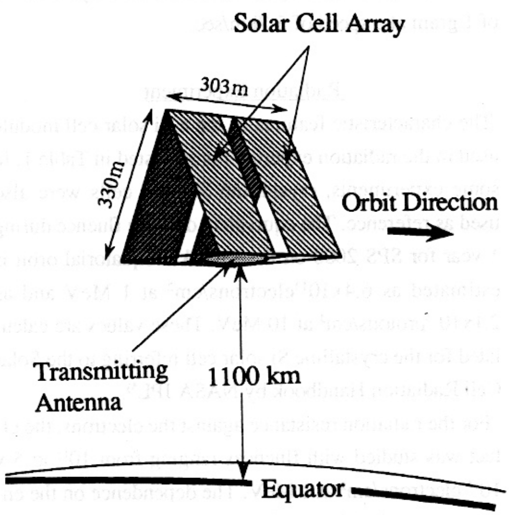

Fig.1 Concept of the SPS 2000.

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quired for the SPS use, the resistance to space environment needs to be fully investigated for the solar arrays. There are two major factors to degrade the performance of the power generation in a long term; high energy radiation to decrease the conversion efficiency of the solar cell and impact of the space debris to damage the solar array elements. The a-Si thin solar cell has been reported to have generally a higher radiation resistance as compared with the crystalline cell due to the thin film nature of the cell[3]. The a-Si solar cells which we have as the candidate for the SPS 2000 have been newly developed for ground use. Its radiation resistance needs to be verified for the SPS use. The impact of space debris damages the elements of the solar array physically. In order to evaluate the power loss by the debris impact, we need to know the damage size of the solar array by the impact. According to the population model of the space debris[4], the debris smaller than 10 mm will play a major role in the power loss considering the collision probability.

The radiation resistance has been studied using electron and proton accelerators of Japan Atomic Energy Research Institute. The effect of 0.5-3 MeV electron irradiation was studied up to a fluence of 5 x 10^{15}electrons/cm^2. The effect of 10 MeV proton was studied up to 10^{13}protons/cm^2. The performance of the solar cells was measured by a pulse solar simulator of the ISAS with and without the irradiation. The damage by the space debris has been studied by impacting a high speed projectile to the a-Si solar cell module and equivalent thin films. The impact experiment was conducted by a rail-gun at ISAS, which can accelerate a projectile made of polycarbonate of 1 gram at a speed of 5-7km/sec.

Radiation Experiment

The characteristic features of the a-Si solar cell module used in the radiation experiments are listed in Table 1. In some experiments, crystalline Si solar cells were also used as reference. The equivalent damage fluence during 1 year for SPS 2000 on the 1100 km equatorial orbit is estimated as 6.4x10^{13}electrons/cm^2 at 1 MeV and as 2.1x10^{10}protons/cm^2 at 10 MeV. These values are calculated for the crystalline Si solar cell referring to the Solar Cell Radiation Handbook by NASA JPL[5].

For the radiation resistance against the electrons, the effect was studied with fluences ranging from 10^{11} to 5 x 10^{15} electrons/cm^2 at 1 MeV. The dependence on the energy was studied from 0.5MeV to 3MeV in 4 steps for the fluences of 1x10^{15} and 5x10^{15} electrons/cm^2.

Table 1 Characteristic features of the test cells.

Type	Amorphous Silicon	
Dimension	113 x 120 x 0.25 mm	
Area	135.6cm^2	
Weight	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

In order to obtain the net effect of the radiation on the solar cell, the radiation effect on the protective cover(Polyethylene Terephthalate;PET) was measured independently. Fig.2 shows an example of the change of the transmission coefficient with the fluence of 1x10^{15}electrons/cm^2. The degradation of transmittance is prominent at the wave length below 400nm.

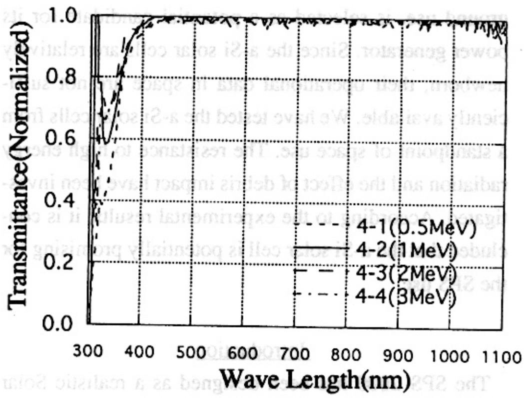

Fig.2 Effect of the electron irradiation on the transmittance of PET(1x10^{15}electrons/cm^2).

Fig.3 shows the degradation curve with respect to the fluence. The test cells commonly keep more than 85% of the initial performance with the fluence less than 10^{15} electrons/cm^2. The data considerably scatter for each sample with the fluence beyond 10^{15} electrons/cm^2. The degradation in that range is strongly dependent on the nature of the individual cell rather than the fluence.

Fig.4 shows the dependence of conversion efficiency on the electron energy with the fluences of 10^{15} and 5x10^{15} electrons/cm^2. Although there is no definite dependence on the energy, the degradation seems to be less for higher energy for 10^{15} electrons/cm^2. In the case of crystalline

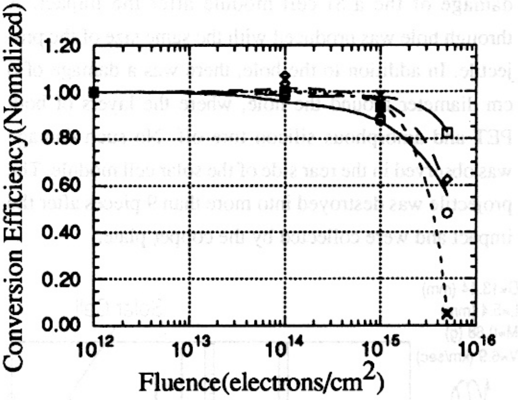

Fig.3 Effect of 1MeV electron irradiation on the relative conversion efficiency of a-Si solar cells.

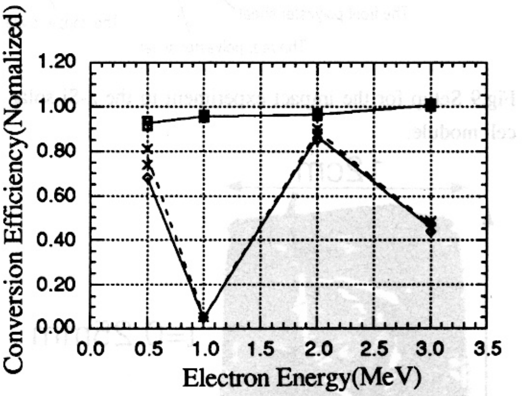

Fig.4 Dependence of conversion efficiency on the energy. □:10^{15} electrons/cm². ◇ and X: 5×10^{15} electrons/cm².

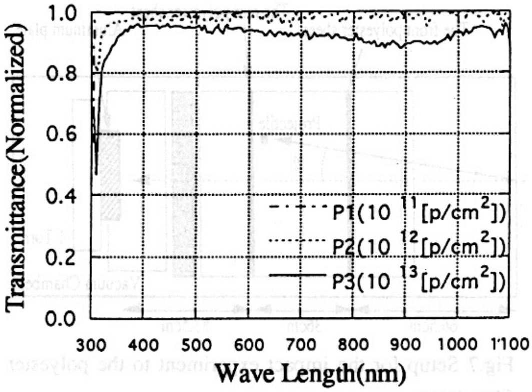

Fig.5 Effect of 10MeV proton irradiation on the transmittance of PET.

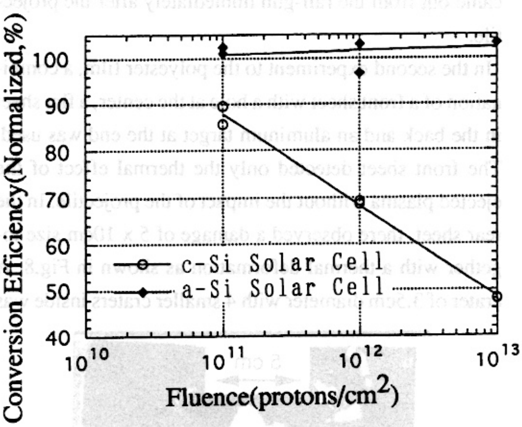

Fig.6 Effct of 10 MeV proton iiradiation on the relative conversion efficiency of a-Si and c-Si. solar cells.

cells, an inverse dependence was observed.

For the radiation resistance against the protons, the degradation effect was studied ranging from 10^{11} to 10^{13} protons/cm² at 10MeV. The effect on the protective cover was measured independently to evaluate the net radiation effect on the solar cells, which is shown in Fig.5. The effect of proton irradiation on the conversion efficiency is shown in Fig.6, together with the results for crystalline Si solar cells.

Although the number of the test cells are limited, the experimental results indicate that the a-Si cells have a higher radiation resistance than the conventional crystalline cells. In the study of the effect of 10 MeV protons, the a-Si solar cells have a higher resistance by a factor of 180 than the single crystalline cells. One of the reasons for the higher resistance could come from extremely thin structure of the cell layer. The a-Si solar cells we tested are degraded typically by 5-10% with the fluence of 1×10^{15}electrons/cm² at 1MeV, which corresponds to the total fluence for the SPS2000 during 15 years.

Debris Impact Experiment

The impact experiment was carried out twice for polyester film sheets[6] and once for the a-Si solar cell module of Table 1. The experiment was conducted in a vacuum. The speed of the projectile ranged from 5.3 to 7.0km/sec.

In the first impact experiment to the polyester film, two flat polyester sheets(200 x 200 x 0.20 mm thick) were set in front of an aluminum plate. The experimental configuration is shown in Fig.7. The impact produced a hole of 9cm diameter in the front sheet and a hole of 4.5 cm diameter in the rear sheet. On the aluminum plate, a crater of 2.5cm diameter was generated and 6 smaller craters were found inside the crater. The front sheet had a ther-

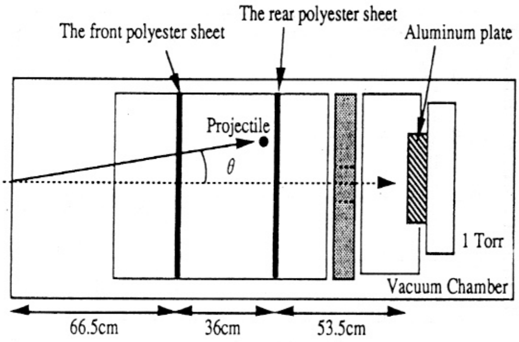

Fig.7 Setup for the impact experiment to the polyester film sheets.

mal deformation caused by the impact of plasma which came out from the rail-gun immediately after the projectile.

In the second experiment to the polyester film, a combination of a front sheet with a hole at the center, a flat sheet in the back and an aluminum target at the end was used. The front sheet detected only the thermal effect of the ejected plasma without the impact of the projectile. In the rear sheet, there observed a damage of 5 x 10cm size together with a thermal deformation as shown in Fig.8. A crater of 3.5cm diameter with 4 smaller craters inside was

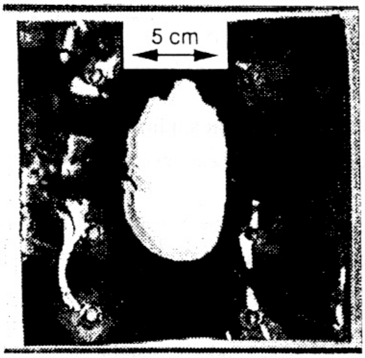

Fig.8 Damage of the polyester sheet by the impact.

found on the aluminum target behind the two polyester sheets.

The setup for the impact experiment to the a-Si solar cell module is shown in Fig.9. The first two metal plates with a hole at the center are used to stop the plasma ejected from the gun. The two sheets of polyester with a hole at the center are set in front of the solar cell module to detect the plasma propagating through the metal plates. Behind the solar cell module, a copper plate target is installed to catch the projectile after the impact. Fig.10 shows the damage of the a-Si cell module after the impact. A through hole was produced with the same size of the projectile. In addition to the hole, there was a damage of 6 cm diameter around the hole, where the layers of both PET and amorphous silicon tore off. No such damage was observed in the rear side of the solar cell module. The projectile was destroyed into more than 9 pieces after the impact and were collected by the copper plate.

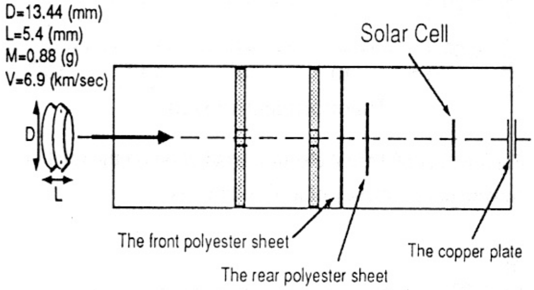

Fig.9 Setup for the impact experiment to the a-Si solar cell module.

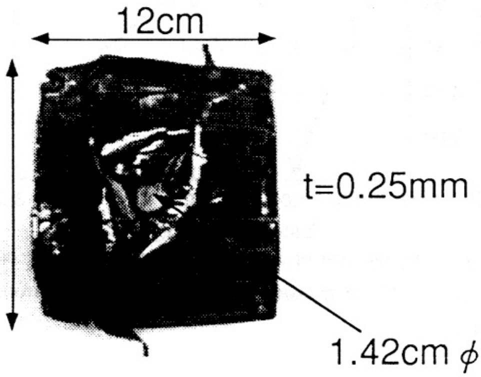

Fig.10 Damage of the a-Si solar cell module by the impact.

The impact experiments have shown that the damage on the film is typically 10 times larger than the size of the projectile with 1 gram weight, 1 cm size and 5-7 km/sec velocity. The scale of the impact damage must be dependent on the mass, size and velocity of the debris. If we apply the experimental result directly to the SPS 2000 on the 1100 km equatorial orbit, approximately 1% of the initial power is estimated to be lost by the debris impact during 10 years.

Conclusion

The environmental effects, the high energy radiation and space debris, on the a-Si solar cells which are the potential candidate for the SPS2000 have been investigated.

The radiation effect was studied by the irradiation of 0.5-3.0 MeV electrons and 10MeV protons. It has been found that the a-Si solar cell has a higher radiation resistance than the crystalline Si cell. The damage by the debris impact was studied by colliding a 1cm-scale projectile to the a-Si solar cell module at 5-7 km/sec. The damage size was roughly 10 times larger than the projectile. These results were applied to evaluate the degradation of the power system of the SPS2000 composed of a-Si solar cell arrays. The capability of power generation is estimated to maintain more than 90 % of the initial level during 10 years. It is concluded that the a-Si solar cells are quite promising for SPS use if the conversion efficiency is improved in future.

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