ANNEALING RADIATION DAMAGED SILICON SOLAR CELLS WITH A COPPER HALIDE LASER

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ABSTRACT

A multiply pulsed copper halide laser has been used to significantly anneal out the damage to silicon solar cells caused by a simulated space radiation environment. Preliminary experiments have demonstrated that the amount of damage can be decreased by 41% as measured by the maximum power generated.

INTRODUCTION

The performance of silicon solar cells is degraded in the radiation environment of space by energetic particles such as electrons, protons, neutrons and ions. This degradation increases with time and results in a reduced power generation capability of the irradiated solar array. To overcome this degradation effect on mission performance the solar panels are generally built large enough to supply the spacecraft power required at the end of the mission. This solution results in overly large and heavy solar panels at launch and an excess initial output power.

An alternative approach to this problem would be a provision for periodically annealing the damaged cells in situ. This could be conveniently accomplished with a high efficiency laser which has an output wave length that is readily absorbed by silicon. This approach could result in a lower launch weight, simplified power conditioning, and extended mission life times.

Some previous experimental studies of the ability of various lasers to anneal radiation damaged silicon solar cells have been reported[1,2]. The lasers used were: 1) CO_2 with a wave length (λ) of about 10 μm and an absorption length (a^{-1}) in silicon of about 10^4 μm; 2) YAG with a λ of 1.06 μm and a a^{-1} of 80 μm; and 3) Ruby with a λ of 0.694 μm and an a^{-1} of 10 μm. Performance recovery, as measured by the maximum generated power, of from 20 to 80% was observed.

Because of the encouraging results of the previous work it was felt that a copper halide laser (CHL) should be investigated for this application because of: 1) the small absorption length for the CHL radiation in silicon;

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2) the potential scalability to very high average powers; and 3) its demonstrated high efficiency. The absorption length, in silicon, of the two CHL output wave lengths (511 and 578 nm) is about 1 μ. This short absorption length will become more important as the thickness of the silicon cells decreases in the future. The potentially high average power will decrease the time required to fully anneal large solar panels in space and the high efficiency will reduce the size and weight of the laser power supply and heat rejection system.

EXPERIMENTAL APPROACH

A preliminary experiment, utilizing existing equipment, was developed to test the feasibility of the CHL for solar cell annealing. The CHL used in these experiments had a maximum pulse energy of 1.5 mj, a pulse width of about 20 ns, peak pulse intensity of 75 kW/cm^2 (with 60% of this intensity at 511 nm and the remainder at 578 nm), a beam diameter of about 1 cm, a pulse repetition rate variable between about 10 and 30 kHz, an average power of 15 watts and an efficiency of about 1%.

As shown in Figure 1, the laser beam was reflected into the vertical plane, for convenience, then focused with an achromatic lens to the desired spot diameter at the solar cell surface. The solar cell was housed in a small vacuum chamber to prevent oxidation of the hot silicon and to partially simulate the heat transfer conditions in space. The vacuum chamber was mounted on a motor driven, traversing platform. This platform could sweep the cell through the focused beam in the X direction at a pre-determined speed and move in the Y direction with pre-determined step sizes. In this way the entire cell surface could be treated with an approximately uniform energy density.

RESULTS

Preliminary tests of this system were performed on cells manufactured by Spectrolab Inc. (K6 3/4, BSF, BSR, MLAR). The I-V characteristics of the cells were measured three times: firstly, as received from Spectrolab; secondly, after irradiation with 1 Mev electrons to a fluence of 10^{15} e/cm^2 and a room temperature cure; and then a third time after annealing with the CHL. Typical results are shown in Figs. 2 and 3. In both of these experiments the spot size was 0.17 cm with a spot overlap, in the Y direction, of 2/3. The average energy density in the spot was 0.013 j/cm^2. The average power was 4.3 watts and the pulse repetition rate was 14.3 kHz. For the results of Fig. 2, the traversing speed was 0.16 cm/sec, resulting in a total applied energy density of about 500 j/cm^2 on the cell surface. The corresponding data for the results of Fig. 3 are 0.13 cm/sec and 690 j/cm^2.

The results shown in Fig. 1 and 2 clearly indicate that the damaged cells were partially annealed in these preliminary experiments. The shape of the characteristic was altered by the annealing process in the experiment of Fig. 2, but the performance recovery was substantial. In Fig. 3 it is seen that, although the performance recovery is not as great as that shown in Fig. 2, the shape of the characteristic was retained. These results are in general agreement with those obtained with a YAG and Ruby laser and reported on in Ref. 1 and 2.

DISCUSSION

Once the feasibility of using a CHL for annealing radiation damaged silicon solar cells was established by these preliminary experiments, an improved experimental set-up was developed. This new set-up includes: 1) an oscillator-amplifier system with a 25 watt average power and 2.5 mj/pulse capability; 2) near-optimum optical elements including an unstable resonator which produces a near-diffraction-limited beam for better focusing at the solar cell surface; and 3) an automatic traversing and indexing system with a much wider range of speed and step size and a larger capacity. With the new set-up the deficiencies of the preliminary set-up have been overcome and the parametric range, such as spot diameter, traversing speed and amount of spot overlap, has been greatly increased.

Additional experiments with this set-up should indicate the amount of solar cell performance recovery which could be expected in an operational environment. With these improvements in experimental equipment and procedure, it is expected that the CHL annealing process can be made more efficient and that the solar cell performance can be increased to near its pre-radiation level.

CONCLUSIONS

It has been demonstrated that a Copper Halide Laser can be used to anneal radiation damaged silicon solar cells. To date 41% of the loss of maximum power, due to radiation damage, was recovered by annealing with a CHL. Future experiments with the improved experimental set-up should establish the potential of the CHL for this application.

REFERENCES

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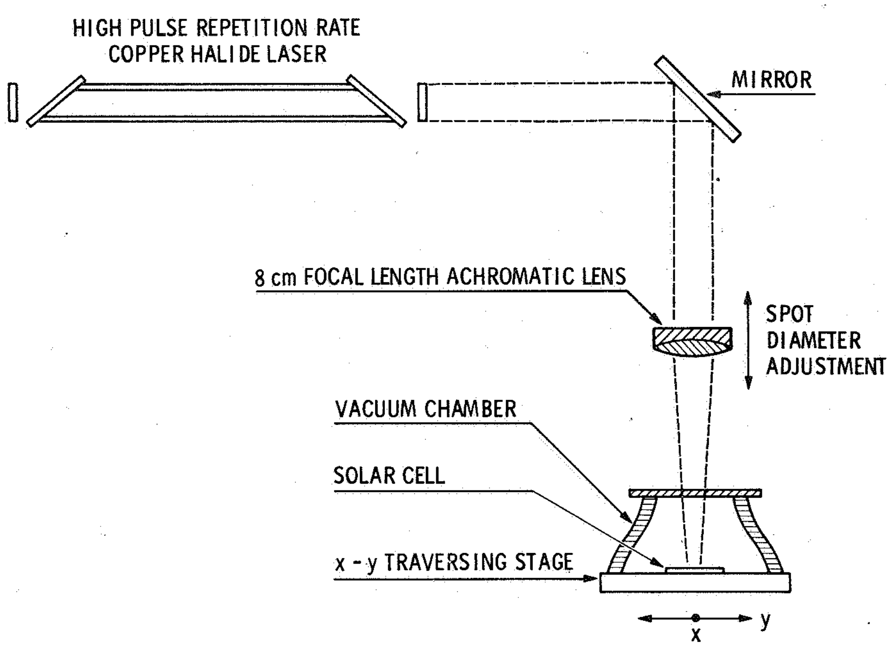

Figure 1. Schematic of Solar Cell Annealing Experiment

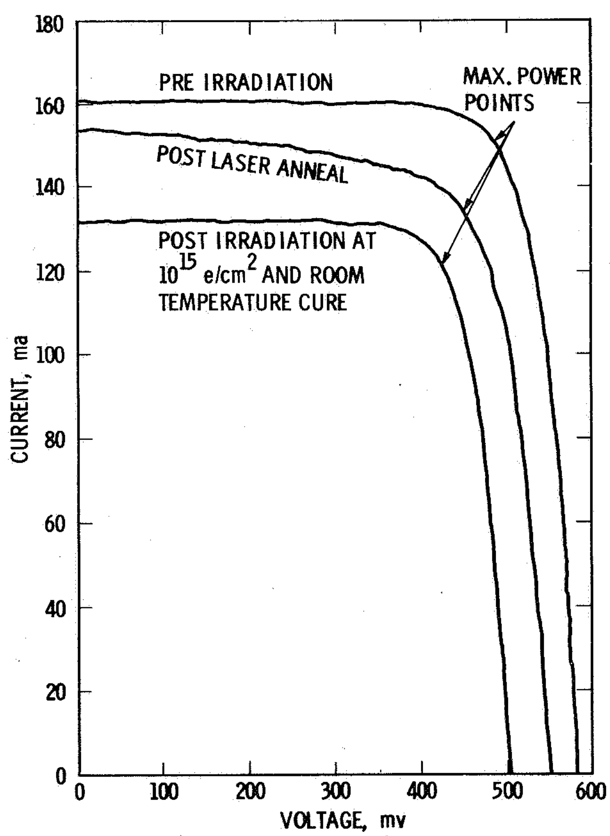

Figure 2. Effect of Annealing Radiation Damaged Silicon Solar Cells with a Copper Halide Laser

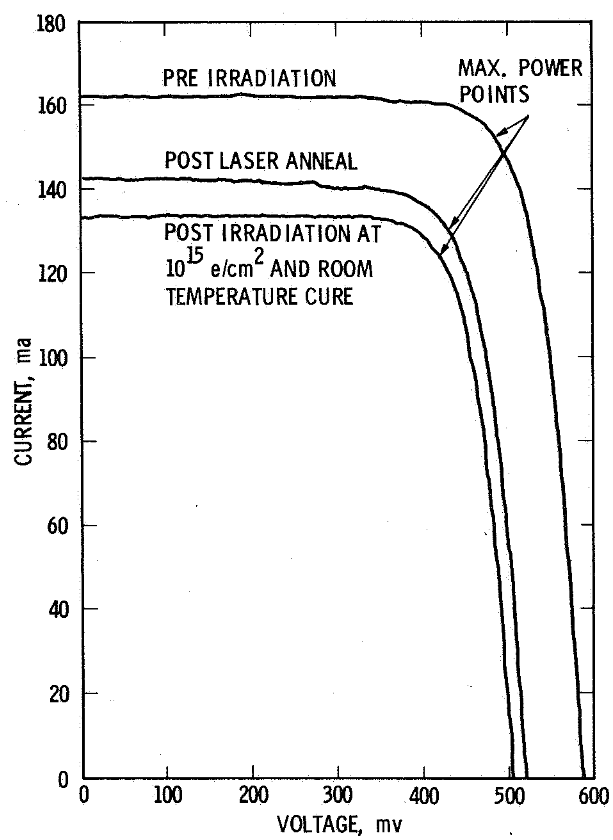

Figure 3. Effect of Annealing Radiation Damaged Silicon Solar Cells with a Copper Halide Laser