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PROTON RADIATION EFFECTS ON $CdS/CuInSe_2$ THIN FILM SOLAR CELLS

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Previous studies have shown that $CdS/CuInSe_2$ solar cells have an inherent tolerance to irradiation by 1 MeV electrons up to at least 2×10^{16} electrons/cm^2. Because of the unknown tolerance of $CuInSe_2$ cells to proton irradiation, the following test was performed at Boeing Radiation Effects Laboratory.

Eleven, unencapsulated, 1 cm^2 cells deposited on alumina substrates were irradiated with 1 MeV protons at normal incidence. The cells were exposed to six fluences ranging from 2.5×10^{10} protons/cm^2 to 5.0×10^{13} protons/cm^2. After each interval of exposure, the cells were removed from the radiation chamber to undergo current/voltage (I-V) characterization. Results show that none of the cells' electrical characteristics exhibited any degradation up to and including a fluence of 1×10^{11} protons/cm^2. At fluences greater than this, the damage to the $CuInSe_2$ cells' V_{oc} and fill factor (FF) was more severe than that exhibited by the I_{sc}. The $CuInSe_2$ cells proved to be approximately a factor of 50 more resistant to 1 MeV proton irradiation than silicon or gallium arsenide cells previously reported (reference 1). Annealing of a $CuInSe_2$ cell at 225°C for six minutes restored it to within 95% of its initial efficiency.

INTRODUCTION

Polycrystalline thin film $CdS/CuInSe_2$ solar cells have been undergoing development in our laboratory since 1976. Air mass-1 (AM 1) photovoltaic conversion efficiencies of 11% have been achieved on 1 cm^2 cells with anti-reflection coating. Monolithic modules of 20 cm^2 area comprised of two series connected cells and 91 cm^2 area comprised of four series connected cells have exhibited AM 1 efficiencies of 8.0% and 6.1% respectively without anti-reflection coating. The 20 cm^2 modules have been encapsulated with ethylene vinyl acetate (EVA) and glass, and efficiencies of 9.2% have been achieved. These cells require such small amounts of material that with the use of lightweight substrates and superstrates, power-to-weight ratios of over 350 W/kg can be achieved.

Because of the potential for space power application, studies to characterize the $CuInSe_2$ cell in the space environment were performed. Cells were irradiated by 1 MeV electrons up to a fluence of 2×10^{16} electrons/cm^2 with no loss of efficiency. Reference 2 describes the results of a similar effort conducted at JPL on $CuInSe_2$ cells with the same results. To further characterize the $CuInSe_2$ cells, 1 MeV proton radiation testing was performed in our laboratories. This paper describes the results of that test.

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EXPERIMENTAL

Cell Description - Figure 1 shows a schematic cross-section of the completed $CuInSe_2$ cell structure. The alumina substrate is metalized with a molybdenum conductor film. A $CuInSe_2$ film of 3-4 μm is deposited by simultaneous elemental evaporation onto the substrate which is heated to 350°C and 450°C. Following the selenide deposition, a 3 μm film of CdS is evaporated onto the substrate which is heated to 200°C. The semiconductor films are then patterned and an aluminum grid deposited to complete the cell structure. The details of the film properties and deposition processes have been discussed in greater detail elsewhere (reference 3).

To provide a good statistical sampling, eleven 1 cm^2 cells with efficiences ranging between 7.7-9.6% (AM 1) were irradiated. Two other cells with equivalent efficiencies were used as control cells. One cell was kept in the laboratory and the other cell was placed in the radiation chamber, but shielded from the proton beam. These two cells were used to determine if there were effects other than proton irradiation causing changes in cell performance. Both cells were characterized at the same intervals as the other eleven. These two cells retained their initial I-V characteristics throughout the duration of the proton test.

Proton Irradiation Techniques - The proton radiation testing was performed using a Dynamitron accelerator as the source of 1 MeV protons. The proton beam is directed into the vacuum chamber by a beam handling system that includes 90° momentum analysis and quadrupole beam focusing. The proton beam passes through a high purity aluminum foil after entering the vacuum chamber. The scattering by this foil improves the beam uniformity and provides the desired beam profile at the sample plane.

The beam uniformity is determined by rotating a Faraday cup across the sample plane and recording the output vs. position (figure 2). The variation of proton flux across the mounted cells was less than 4%. The required current from the accelerator is controlled by a second Faraday cup mounted in the sample plane.

The cells were exposed to 1 MeV proton fluences of 2.5×10^{10}, 1.0×10^{11}, 1.0×10^{12}, 5.0×10^{12}, 1.0×10^{13} and 5.0×10^{13} protons/cm^2. All cells were irradiated at normal incidence. After each interval of exposure the cells were removed from the vacuum chamber to undergo I-V characterization. All characterization tests were performed within three hours of irradiation.

RESULTS AND DISCUSSION

Figure 3 shows the effects of 1 MeV proton radiation averaged over the eleven $CuInSe_2$ cells. Also shown are silicon and gallium arsenide cells that were previously reported (reference 1). The silicon cells were 10 ohm-cm, 200 microns thick with dual anti-reflection coatings and aluminum back-surface reflectors. The GaAs cells were made with the liquid phase epitaxy process incorporating GaAlAs windows. From figure 3 it is determined that $CuInSe_2$ cells are approximately a factor of 50 more resistant to 1 MeV protons than GaAs and Si cells.

Figure 4 shows the I-V characteristics of an individual cell before and after irradiation at fluences of 1.0×10^{13} and 5.0×10^{13} protons/cm^2. Figure 5 shows the average degradation of the I_{sc}, V_{oc} and FF for the eleven cells vs. increasing proton fluence. The main cause of the cells' degradation was decreasing V_{oc} and

FF. This indicates that the damage to $CuInSe_2$ cells occurs near the junction of the cell and, therefore, raises the dark current which lowers the V_{OC} and FF. In contrast, the main cause of degradation of the Si and GaAs cells is the decreasing I_{SC} which tends to be a bulk material problem.

Initial spectral response measurements were taken, but due to negligible degradation of the I_{SC}, no follow up measurements were taken. Annealing experiments were performed at 225°C. After a short duration of 6 minutes, cell efficiency was restored from 13% to 95% of its initial value. No attempt was made to optimize the annealing parameters.

CONCLUSIONS

The $CuInSe_2$ cell proved to be approximately a factor of 50 more resistant to 1 MeV protons than Si or GaAs cells. The cell had previously been proven to be inherently stable to 1 MeV electrons up to a fluence of 2 x 10^{16}e/cm^2. Combined with potential of high specific power, $CuInSe_2$ cells show an excellent potential for generating electric power in space applications.

Detailed characterization of the proton damage as a function of proton energy and fluence is needed to determine the damage mechanism. Because the damage appears to take place at the junction, redesigning the cell window layer by changing thickness or material could lead to further enhancement of the cell radiation hardness.

REFERENCES

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2. Gay, C. F. et al: Radiation Effects on Thin Film Solar Cells, Proc. 17th IEEE Photovoltaic Specialist Conference, 1984, p. 151.

3. Mickelsen, R. A. and Chen, W. S.: Development of a 9.4% Efficient Thin Film $CuInSe_2$/CdS Solar Cell, Proc. 15th IEEE Photovoltaic Specialist Conference, 1981, p. 800.

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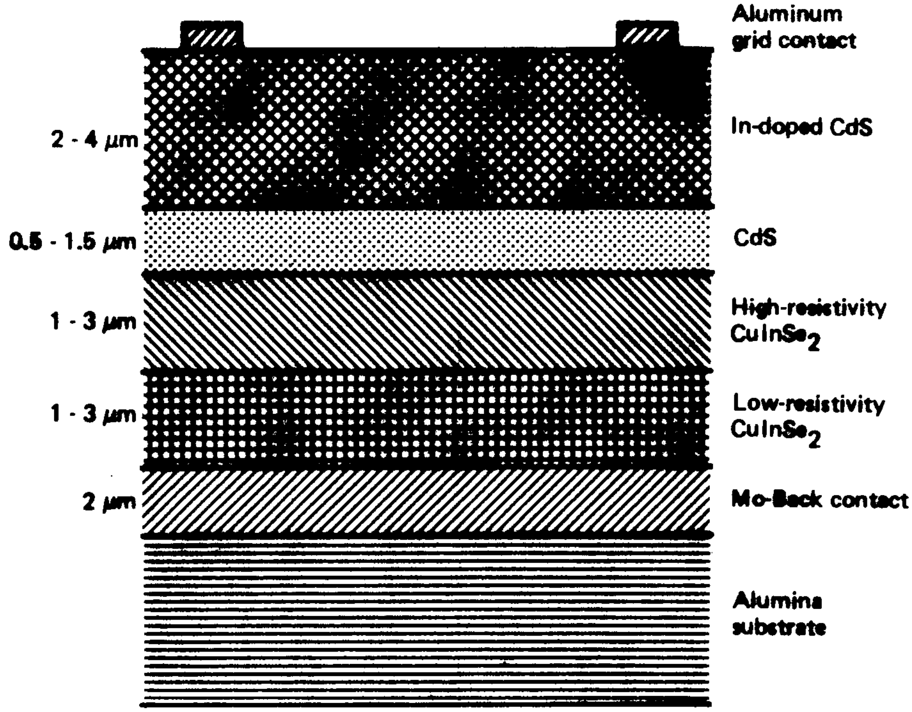

Figure 1. CdS/CuInSe$_2$ Thin-Film Cell Structure

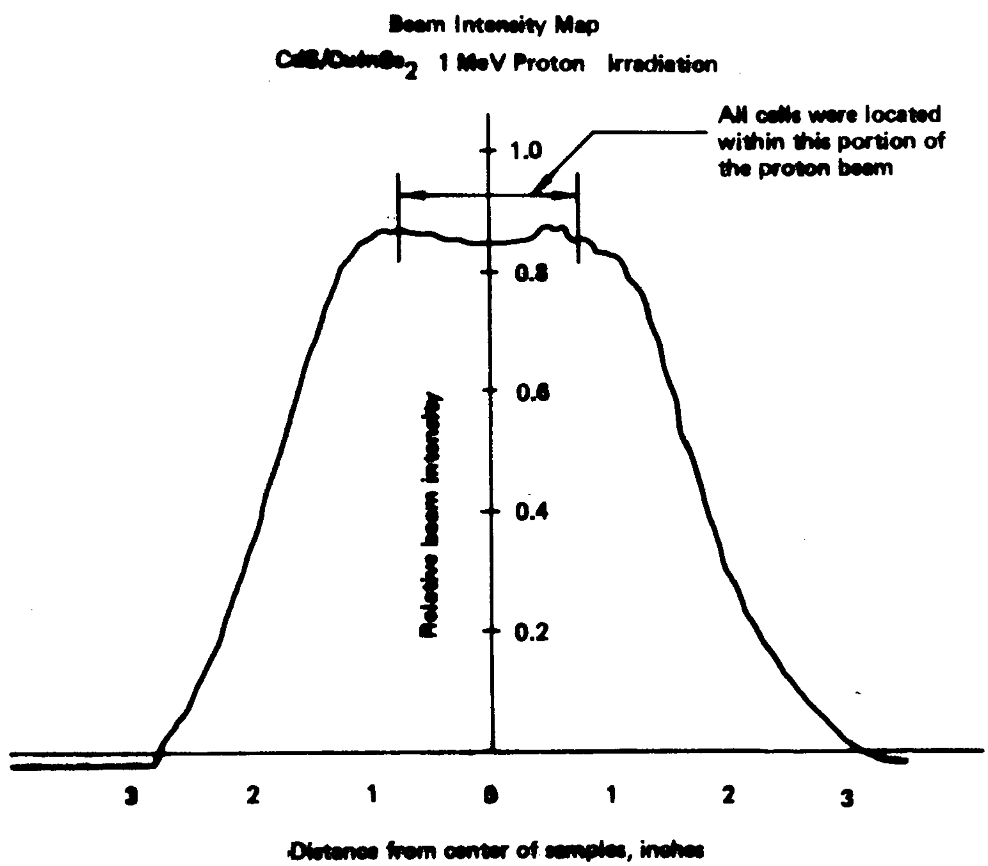

Figure 2. Proton Beam Intensity Map

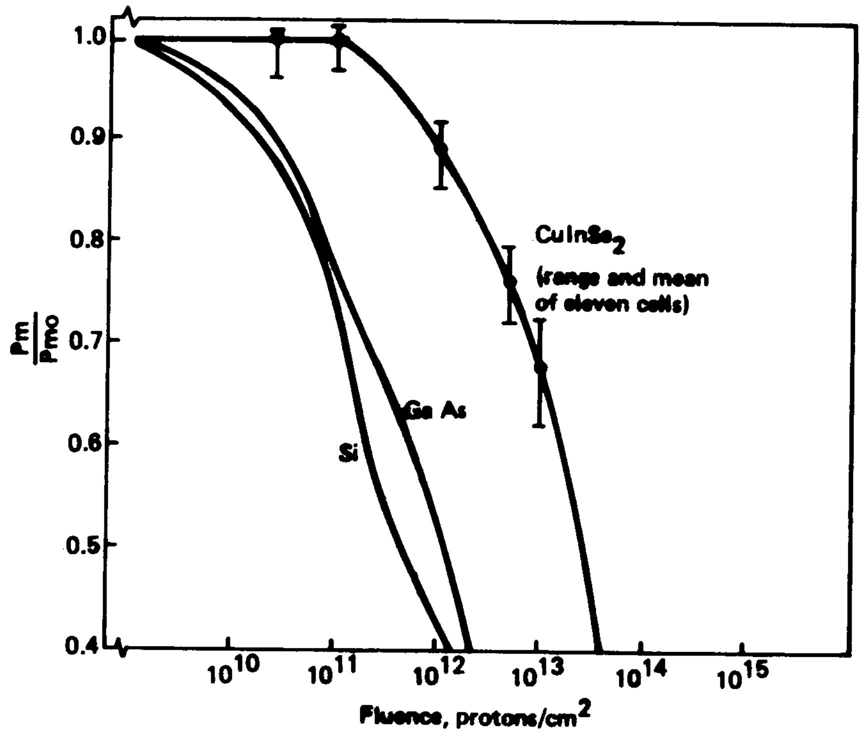

Figure 3. Degradation of Thin-Film CdS/$CuInSe_2$ Solar Cells as Function of 1 MeV Proton Fluence

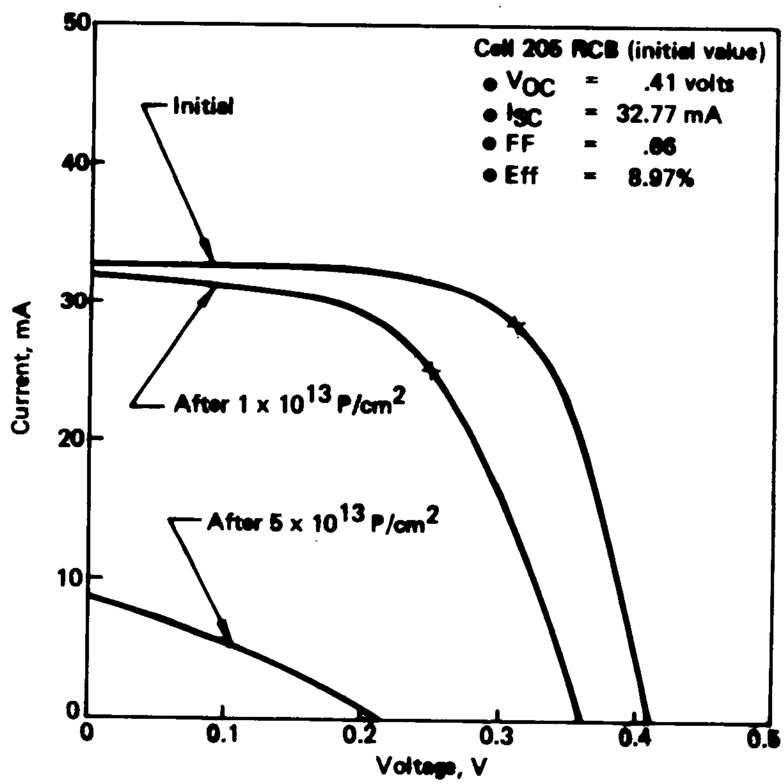

Figure 4. Degradation of a CdS/$CuInSe_2$ Solar Cell Under 1 MeV Proton Irradiation

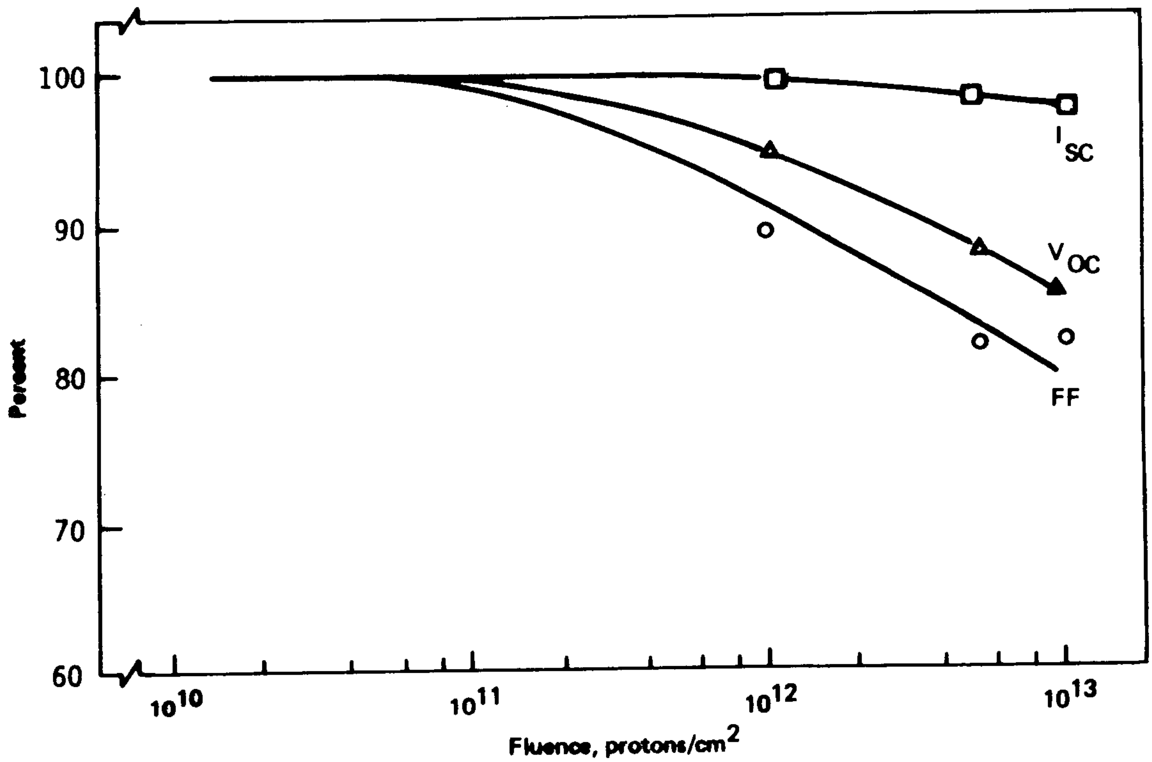

Figure 5. Degradation of Photovoltaic Parameters of Thin-Film CdS/CuInSe$_2$ Solar Cells as Function of 1 MeV Proton Fluence