RADIATION DAMAGE AND ANNEALING IN LARGE AREA $n^+/p/p^+$ GaAs SHALLOW HOMOJUNCTION SOLAR CELLS

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SUMMARY

Annealing of radiation damage has been observed for the first time in VPE-grown, 2- by 2-cm, $n^+/p/p^+$ GaAs shallow homojunction solar cells. Electrical performance of several cells was determined as a function of 1-MeV electron fluence in the range of 10^{13} to 10^{15} e^-/cm^2 and as a function of thermal annealing time at various temperatures. Degradation of normalized power output after a fluence of 10^{15} 1-MeV electrons/cm^2 ranged from a low of 24 to 31 percent of initial maximum power. Normalized short circuit current degradation was limited to the range from 10 to 19 percent of preirradiated values. Thermal annealing was carried out in a flowing nitrogen gas ambient, with annealing temperatures spanning the range from 125° to 200° C. Substantial recovery of short circuit current was observed at tempertures as low as 175° C. In one case improvement by as much as 10 percent of the postirradiated value was observed. The key features of these cells are their extremely thin emitter layers (approximately 0.05 μm), the absence of any $Al_xGa_{1-x}As$ passivating window layer, and their fabrication by vapor phase epitaxy.

INTRODUCTION

The GaAs shallow homojunction solar cell (refs. 1 and 2) is a potentially superior structure for space applications. Among the features of the cell which contribute to such performance are (1) the extremely thin (0.05 μm), highly doped n^+ emitter; (2) absence of the $Al_xGa_{1-x}As$ surface passivating layer; and (3) incorporation of the p-type base and p^+ back surface field region. The thin n^+ emitter assures that most of the electron hole pairs, created by incident photons with energies greater than the 1.43-eV bandgap of GaAs, are generated in the p-type base region of the cell. Since electrons are the minority carriers in the p-type base, minority carrier diffusion lengths are expected to be greater than in n-type material with the same doping density; hence, collection efficiency and resistance to radiation damage should be higher than in an equivalent $p^+/n/n^+$ structure.

The cells incorporated in this study were fabricated at the Lincoln Laboratory (ref. 3) using the chloride transport method of vapor phase epitaxy (VPE). All are 2 by 2 cm in total area with anodic oxide antireflection coatings and electroplated tin front contacts. Back contacts are electroplated gold. A cross section of the cell structure is shown in figure 1. The shallow n^+ emitter is sulfur doped to 5×10^{18}, while the p region dopant varied from 4×10^{16} to 6×10^{17} cm^{-3}.

RESULTS AND DISCUSSION

Irradiations by 1-MeV electrons were conducted at room temperature using the Lewis Research Center Dynamitron accelerator at five fluences ranging from 1x10^{13} to 1x10^{15} e$^-$/cm^2. Characteristics were determined after each irradiation using a xenon arc solar simulator with a flight-calibrated GaAs reference cell as a standard. Six cells were irradiated in this study, these original efficiencies ranging from 13.6 to 15.6 percent AMO. Figure 2 shows the normalized short-circuit current as a function of 1-MeV electron fluence for its "best" cell (that cell showing minimum degradation after 10^{15} e$^-$/cm^2 fluence). The short-circuit current was normalized to preirradiated values. The best cell degraded 10 percent, the worst cell 19 percent at a fluence of 10^{15}/cm^2 with an average degradation of 13.5 percent. Normalized maximum power degradation as a function of fluence is shown in figure 3. The best cell here, the same cell of figure 2, showed a degradation of 24 percent at a fluence of 10^{15} e$^-$/cm^2. The worst cell degraded 31 percent while the average was 26.2 percent. A slight drop in fill factor was noticed in the cells when comparing preirradiation and postirradiation values, although the differences are barely outside the range of experimental error (±1.0 percent).

Annealing of this radiation damage has been observed for the first time in shallow homojunction solar cells. To date, annealing has only been reported in heteroface, liquid phase, epitaxially (LPE) grown cells. Thermal annealing was done in a flowing nitrogen gas ambient at room temperatures ranging from 125° to 200° C. Periodic measurements of I-V and spectral response were made to monitor cell performance. No annealing was seen at 125° C. Figure 4 shows the normalized short-circuit current as a function of annealing time at 175° and 200° C after irradiation at a fluence of 10^{15}e$^-$/cm^2. The cell annealed at 175° C showed the largest degradation after irradiation, to 81 percent of the original value. It recovered to 88 percent after 15 hr; further annealing to 40 hr showed no additional increase. The cell annealed at 200° C exhibited less initial degradation, to 85 percent of preirradiated value, and recovered to 95 percent after 15 hr. Again, further annealing to 40 hr did not increase the response. Normalized maximum power as a function of annealing time is shown in figure 5. Twenty-five hours at 175° C raised the maximum power from 70 to 76 percent of preirradiation values. Recovery at 200° C was from 75 to 90 percent after 20 hr of annealing. Further annealing did not increase recovery. Figure 6 is the spectral response of a cell irradiated to a fluence of 10^{15} e$^-$/cm^2 before and after annealing for 40 hr at 200° C. The data indicate that the loss in photocurrent is attributable entirely to damage in the base region of the cell. The shape of this recovery is compatible with the spectral response degradation seen in these cells as a function of 1-MeV fluence (ref. 4).

CONCLUSION

The GaAs shallow homojunction solar cells tested show good radiation tolerance. Annealing of radiation damage has been seen for the first time in these cells at temperatures at low as 175° C. Spectral response measurements indicate that the observed damage and subsequent annealing occurs entirely in the p-type base region of the cell. These results are an early indication that VPE-grown, shallow homojunction GaAs solar cells have great promise for use in space solar arrays in radiation environments

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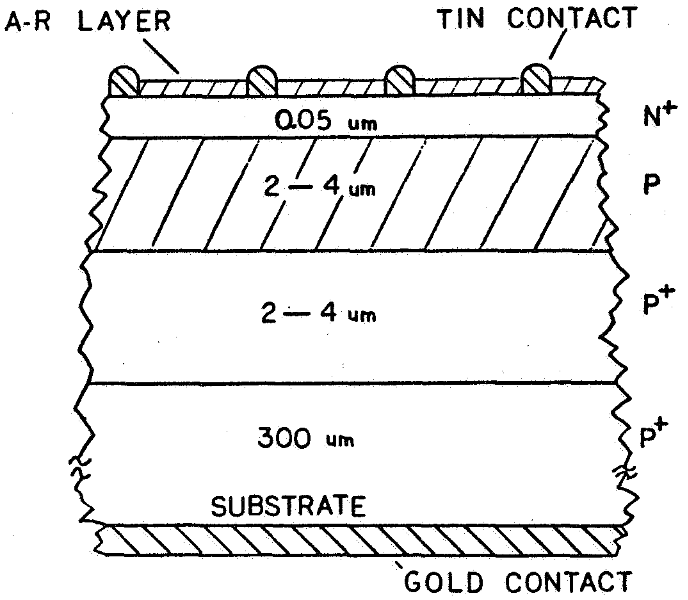

Figure 1. - Shallow homojunction cell structure.

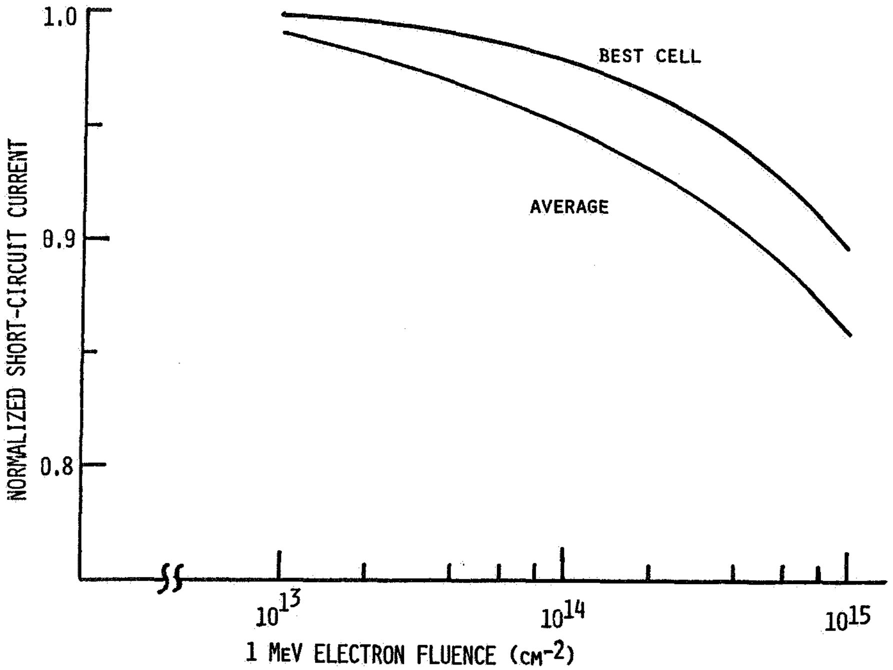

Figure 2. - Normalized short-circuit degradation in GaAs shallow homojunction solar cells.

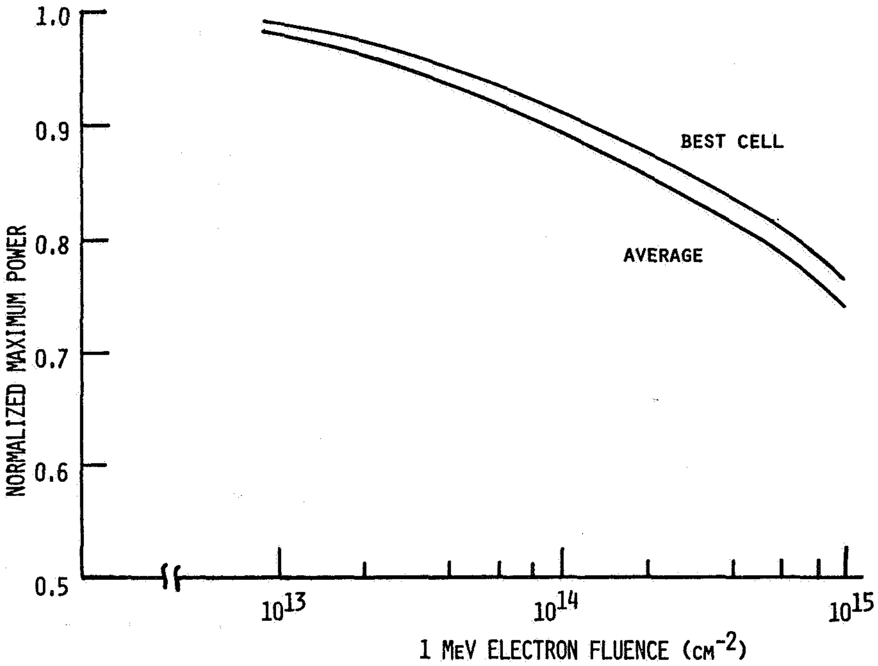

Figure 3. - Normalized maximum power degradation in GaAs shallow homojunction cells.

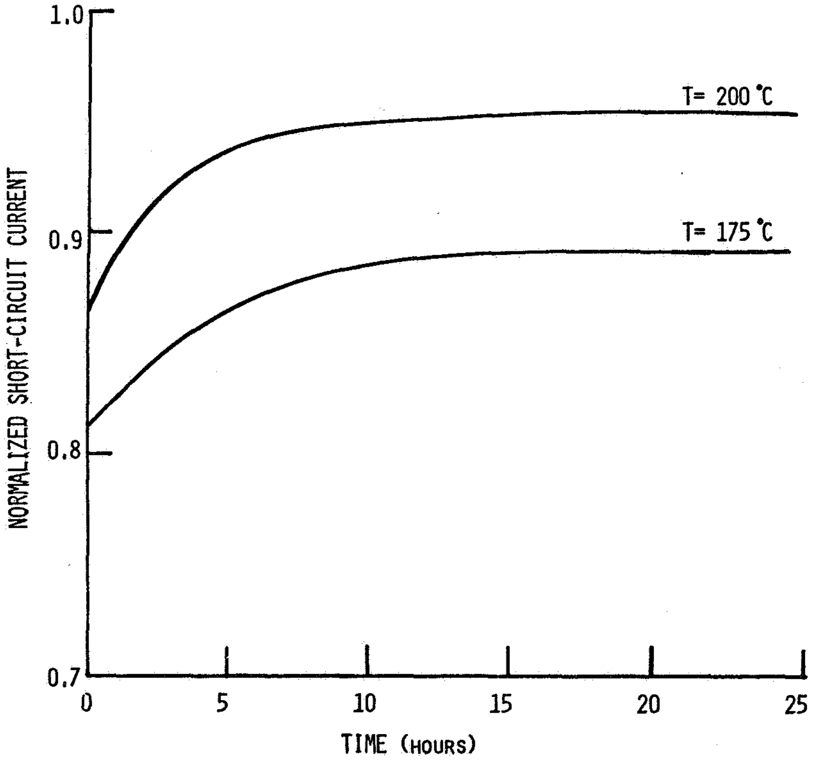

Figure 4. - Normalized short-circuit current versus annealing time.

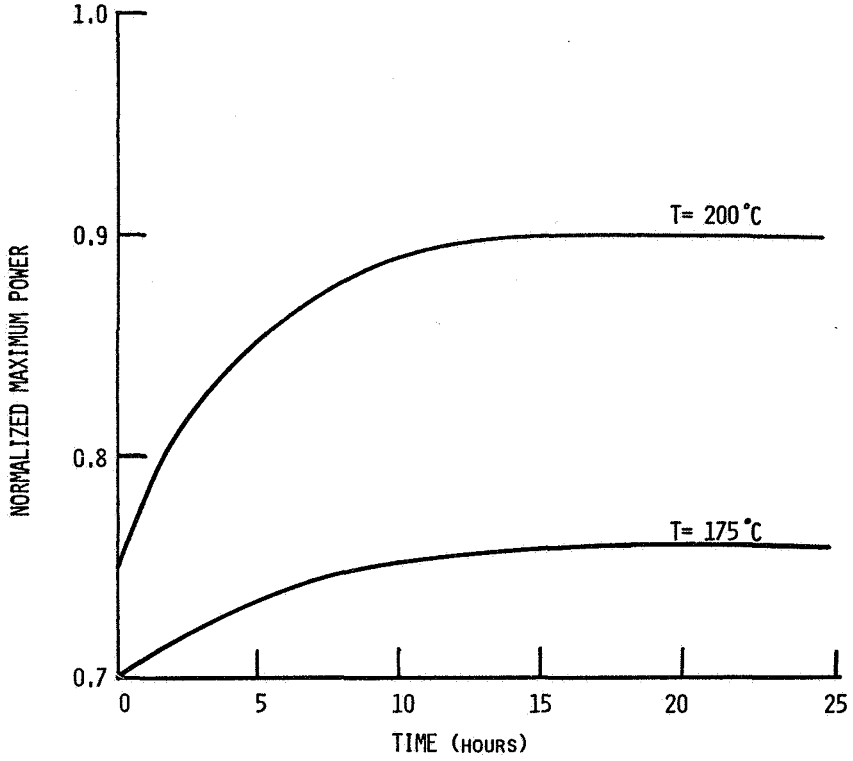

Figure 5. - Normalized maximum power versus annealing time.

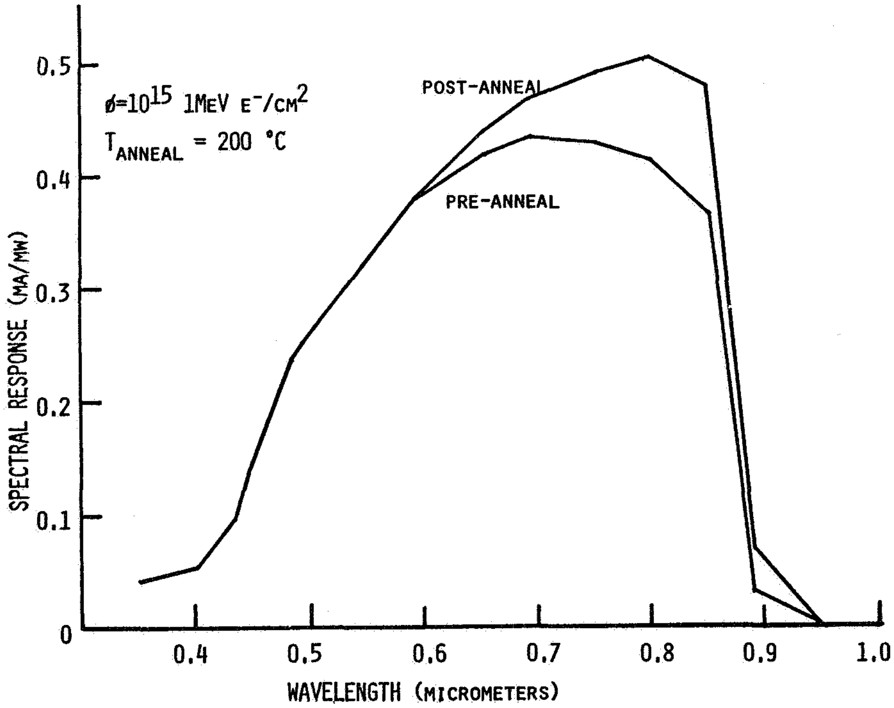

Figure 6. - Spectral response of an irradiated cell before and after annealing.