81

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High-Efficiency, Radiation-Resistant GaAs Space Cells

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Although many GaAs solar cells are intended for space applications, few measurements of cell degradation after radiation are available, particularly for cells with efficiencies exceeding 20% (one-sun, AM0). Often the cell performance is optimized for the highest beginning-of-life (BOL) efficiency, despite the unknown effect of such design on end-of-life (EOL) efficiencies. In this paper, the results of a study of the radiation effects on p-n GaAs cells are presented.

The large-area (4-cm^2) cells were processed in the Varian pilot line facility after growth in a multiwafer organometallic vapor phase epitaxy (OMVPE) reactor. The effects of varying the (1)emitter thickness and (2) base doping in a p-n structure were investigated. A typical Varian space cell has an emitter thickness of 0.6μm and a base doping level of 3×10^{17} cm^{-2}. In separate growths, the thickness was reduced and the doping level decreased. As shown in Figure 1, the median efficiency of the cells prior to irradiation is 21.2%. Furthermore, the cell efficiencies were not significantly affected by emitter thickness, although improvement from lowering the base doping was apparent.

Eight cells representative of the original group were exposed to 1-MeV electron radiation for a total fluence of 10^{15} cm^{-2}. The cell efficiencies after radiation have a significantly wider distribution, as shown in Figure 2. A combination of high BOL efficiency and radiation resistance for the cell with lower base doping resulted in an EOL efficiency of 15.9% (one-sun, AM0)-the best EOL efficiency reported to date.

More details of the radiation losses in efficiency and other cell performance parameters are given in Figure 3. Those cells grown with thick emitters or with high base doping suffered the largest efficiency loss, resulting in EOL/BOL ratios of about 69%. Cells with thinner emitters only dropped to 76% of their BOL efficiency. For all cells, most of the efficiency loss results from decreases in the open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}). The cells with the largest decreases in efficiency differ from the more radiation resistant ones in that they also suffer from a significant loss in fill factor.

Although all cells with emitter thicknesses of 0.5μm or less performed equally well after irradiation, the quantum efficiency of those cells differed dramatically, as shown in Figure 4. The tradeoff between blue response and red response is explained by the fact that as the emitter thickness is increased, the p-n junction moves deeper into the material. A deeper junction increases the distance which minority carriers generated near the surface (by blue light) must travel to be collected while decreasing the distance to be traveled by carriers generated deep in the material (by red light).

The differences only become apparent when radiation has decreased the minority carrier diffusion lengths to the same dimensions as the emitter layer thickness. When calibration cells with a better spectral match to the irradiated cells are obtained, it may well be found that thinner emitter cells have a better actual efficiency because of their higher blue responsivity.

In summary, the end-of-life (EOL) efficiency of GaAs space cells can be increased by adjusting materials growth parameters, resulting in a demonstration of 16% EOL efficiency at one-sun, AM0. Reducing base doping levels to below 3×10^{17} cm^{-3} and decreasing emitter thickness to 0.3 to $0.5\mu m$ for p-n cells led to significant improvements in radiation hardness as measured by EOL/BOL efficiency ratios for irradiation of 10^{15} cm^{-2} electrons at 1MeV. BOL efficiency was not affected by changes in emitter thickness but did improve with lower base doping.

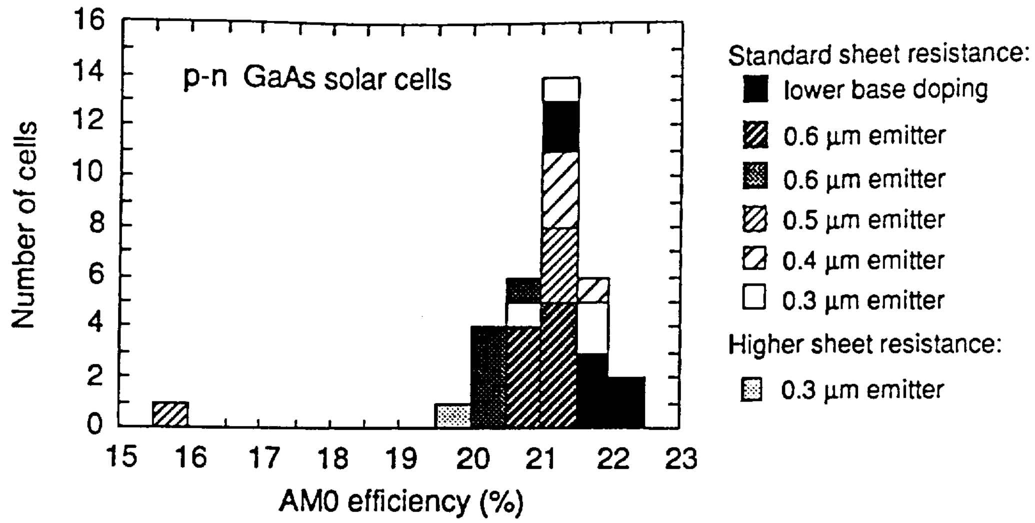

Figure 1. One-sun, AM0 efficiency histogram of 2x2-cm^2 GaAs solar cells grown for radiation tests prior to irradiation.

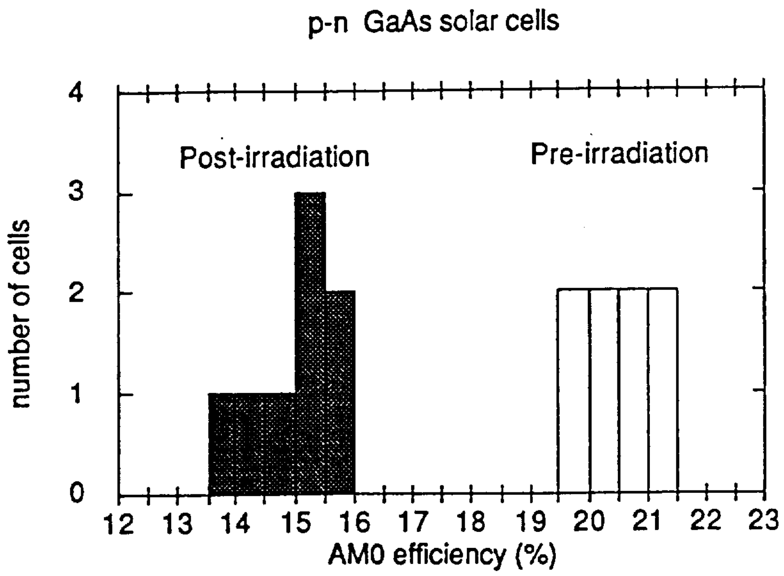

Figure 2. Cell efficiencies before and after irradiation with 1-MeV electrons for a total fluence of 10^{15} cm^{-2}.

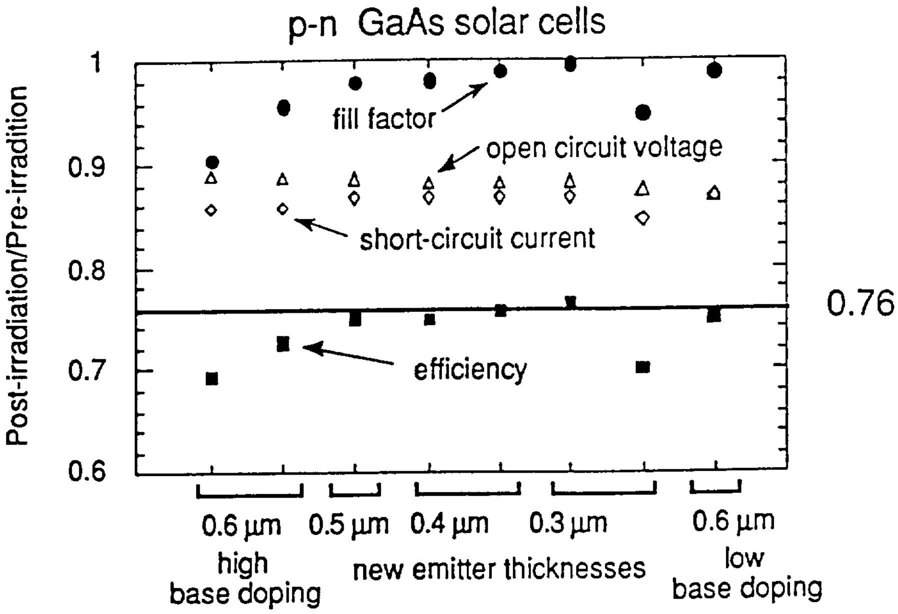

Figure 3. Ratio of cell electrical parameters before and after irradiation with 1-MeV electrons for a total fluence of 10^{15} cm^{-2}.

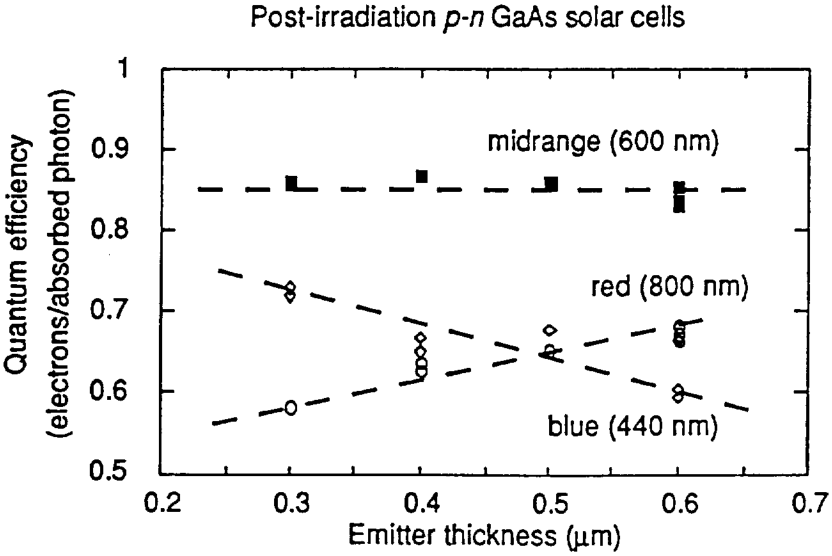

Figure 4. Spectral dependence of post-irradiation quantum efficiency as a function of emitter thickness.