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THE EFFECTS OF ELECTRON AND PROTON RADIATION ON GaSb INFRARED SOLAR CELLS

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Gallium Antimonide (GaSb) infrared solar cells were exposed to 1 MeV electrons and protons up to fluences of $1x10^{15}$ cm^{-2} and $1x10^{12}$ cm^{-2} respectively. In between exposures, current-voltage and spectral response curves were taken. The GaSb cells were found to degrade slightly less than typical GaAs cells under electron irradiation, and calculations from spectral response curves showed that the damage coefficient for the minority carrier diffusion length was $3.5x10^8$. The cells degraded faster than GaAs cells under proton irradiation, but we expect the top cell and coverglass to protect the GaSb cell from most damaging protons. Also, some annealing of proton damage was observed at low temperatures (80-160°C).

Introduction

Mechanically stacked Gallium Arsenide (GaAs) and Gallium Antimonide (GaSb) solar cell assemblies have been shown to have efficiencies over 30% under concentrated AM0 conditions (ref. 1) . In this design, the GaAs cell converts the visible light, but passes infrared light through to the GaSb cell underneath, which has a bandgap of 0.7 eV. The GaSb cell will provide an extra 6% to the GaAs cell's 24% efficiency. In combination with light-weight concentrator structures, these assemblies have the potential for providing power in space using significantly less area and weight than standard silicon space cells. However, in order to survive the space environment, the cells must be able to withstand high energy electrons and protons. GaAs cells have been shown to be more radiation resistant than silicon cells, but the effects on GaSb have never been studied previously. In this paper, we report the effects of 1 MeV electrons and protons on GaSb solar cells measured by current-voltage and spectral response curves.

Experimental Details

The 5.4 mm diameter GaSb cells used in this experiment were processed as described in reference 2. They consist of n-type tellurium-doped substrates with a zinc diffusion on the front. The zinc diffusion was partially etched off between the gridlines to reduce heavy doping effects, and then an antireflection coating was deposited. Cells with various beginning of life efficiencies were used for each type of exposure. The cells were soldered down to ceramic pads, and the front of the cells were contacted by wirebonds. With some of these, GaAs cells were added, creating a finished assembly (except for a coverglass). This assembly is shown in Fig. 1.

Spectral response and current-voltage curves were taken before and after each radiation exposure. The one-sun short-circuit current was calculated by convolving the spectral response with the AM0 spectrum (and for the bare GaSb cells, convolving the transmission of a GaAs filter as well). A small correction factor (1.06) was required to match the calculated currents before radiation exposure with the currents measured under a GaAs filter using an XT-10 simulator calibrated with a balloon-flight standard. Voltage and fill factor values were found from current-voltage curves taken under concentrated light. The short circuit current was approximately 50 times the one-sun current. The assemblies were measured on a temperature-controlled plate at 25°C.

Cells were exposed to 1 MeV electrons and 1 MeV protons in a Dynamitron system. The total exposure was $1x10^{15}$ cm^{-2} for electrons and $1x10^{12}$ cm^{-2} for protons. (The electron and proton irradiations were made

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possible by Dennis Russell and Tom Nirider of the Boeing Radiation Effects Laboratory.) All annealing after exposure was done in air.

Results

Tables I and II show the average values from the measurements between each radiation exposure for 1 MeV electrons and 1 MeV protons. (Note that these are average values, and some low efficiency cells were included. Good GaSb cells have efficiencies over 6% in AM0 sunlight under a GaAs filter.) Figures 2 and 3 show these measurements normalized to their beginning of life values. The error bars indicate the spread in data among the different cells. Note that the electron-irradiated cells degraded uniformly, but the proton-irradiated cells had some variations. No correlation with beginning of life values was found, so the spread may be due to non-uniformities in the proton beam.

For GaSb cells in tandem assemblies, the damage due to 1 MeV electrons was reduced significantly due to absorption by the GaAs cell. Figure 4 compares the degradation in efficiency for cells in assemblies vs. bare cells. For 1 MeV protons, no degradation was observed for GaSb cells in tandem assemblies.

The spectral response curves for GaSb cells during electron exposure is shown in Figure 5. These show a decrease in the infrared region during electron irradiation, which suggests that the bulk minority carrier lifetime is being decreased. By modeling the cells, we have been able to calculate the hole diffusion length L_p (ref. 3) ; according to our calculations, it begins at 3.2 μm and ends at 1.5 μm after $1x10^{15}$ electrons/cm^2. (Electron beam induced current measurements done by R. Matson of the Solar Energy Research Institute have confirmed a beginning of life diffusion length of about 3 μm.) Plotting $1/L_p^2$ vs. dose (fig. 6) has allowed us to find a damage coefficient of $3.5x10^8$ (compared to $7x10^8$ for GaAs found in reference 4).

The spectral response curves for 1 MeV proton exposure is shown in Fig. 7. It also shows a decrease in the bulk lifetime, although we cannot assume it is uniform as we did with electron exposure (ref. 5) , so we cannot calculate a valid damage coefficient.

We have performed annealing experiments in order to determine if the radiation damage can be reversed. Since these particular assemblies can only withstand temperatures below 180°C, the maximum temperature applied to them was 160°C. In one case, we annealed samples for one hour at increasing temperatures; we observed no effect on the electron-irradiated samples, but the proton-irradiated samples partially recovered (Fig. 8). Partial recovery of proton-damaged cells has been observed at temperatures as low as 80°C, which is what we calculate is the maximum operating temperature of the assembly under concentrated sunlight in space.

Discussion

For 1 MeV electron exposure, the normalized degradation of the GaSb cells is slightly better than a typical GaAs cell (ref. 6) . However, proton exposures have shown that GaSb cells are more susceptible to 1 MeV protons than GaAs. Protons do most of their damage where they stop, so we are most concerned with low energy protons that are absorbed near the junction (ref. 5) . Fig. 9 shows the minimum proton energy required to get through a coverglass and 450 μm of GaAs at normal incidence. (This is calculated from data in reference 7.) Although the low energy protons do not reach the GaSb cell, some higher energy protons will lose their energy in the coverglass and the top cell, and become low energy protons by the time they reach the GaSb cell. Nonetheless, the proton flux decreases rapidly with higher energies, often down an order of magnitude from 1 MeV to 30 MeV (ref. 8) . In a concentrator system the coverglass can be considerably thicker than in a flat-plate system; since only the area where the light is focused needs to be covered, the weight is significantly reduced. The choice of coverglass thickness would depend on the orbit, but we expect to be able to heavily protect the GaSb cell from protons. In addition to the protection, there may be some annealing of proton damage.

We conclude that GaAs/GaSb tandem assemblies are a very good candidate for space concentrator photovoltaic arrays since GaAs cells are known to be radiation resistant, and we have shown that GaSb cells have good electron resistance and are protected from protons. Further radiation tests and annealing experiments will improve our estimates of how much the GaSb cells will degrade in a space environment.

References

1. Avery, J.E. ; Fraas, L.M. ; Sundaram, V.S. ; Mansoori, N. ; Yerkes, J.W. ; Brinker, D.J. ; Curtis, H.B.; and O'Neill, M.J. : Lightweight Concentrator Module with 30% AM0 Efficient GaAs/GaSb Tandem Cells. *Proc. 21st IEEE Photovoltaic Specialists Conf.* (Kissimimee, FA), May 1990, p. 1277.

2. Fraas, L.M. ; Girard, G.R. ; Avery, J.E. ; Arau, B.A. ; Sundaram, V.S. ; Thomson, A.G. ; and Gee, J.M.: GaSb Booster Cells for over 30% Efficient Solar-Cell Stacks. *J. Appl. Phys.*, vol. 66, no. 8, Oct. 1989, p. 3866.

3. Sze, S.M.: *Physics of Semiconductor Devices,* 2nd ed., John Wiley and Sons, Inc., 1981.

4. Loo, R.; Goldhammer, L.; Anspaugh, B.; Knechtli, R.C.; and Kamath, G.S.: Electron and Proton Degradation in (AlGa)As-GaAs Solar cells. *Proc. 13th IEEE Photovoltaic Specialists Conf.* (Washington, DC), January 1978, p. 562.

5. Tada, H.Y.; Carter, J.R.; Anspaugh, B.E.; and Downing, R.G.: *Solar Cell Radiation Handbook* , 3rd ed., JPL Publication 82-69, Nov. 1, 1982.

6. Bertness, K.A.; Ristow, J. Ladle; Klausmeier-Brown, M.E.; Grounner, M.; Kuryla, M.S.; and Werthen, J.G.: 16% Efficient GaAs Solar Cell after 10^{15} cm^{-2}, 1 MeV Radiation. *Proc. 21st IEEE Photovoltaic Specialists Conf.* (Kissimimee, FA), May 1990, p. 1231.

7. Janni, J.F.: *Atomic Data and Nuclear Data Tables,* vol. 27 (Academic Press Inc.), p. 268 (1982).

8. Sawyer, D.M.; Chan, K.W.; Teague, M.J.; and Schofield, J.J. Jr.: *Proc. 13th IEEE Photovoltaic Specialists Conf.* (Washington, DC), January 1978, p. 545.

Table I. – AVERAGE CHARACTERISTICS FOR GaSb CELLS EXPOSED TO 1 MeV ELECTRONS. (Efficiency, open-circuit voltage and fill factor were measured at 50X AM0 concentration.)

Dose, e/cm^2	Efficiency, %	J_{sc} (1-sun), mA/cm^2	V_{oc}, V	Fill factor
0	4.7	23.8	0.408	0.654
1×10^{14}	4.5	22.9	0.403	0.647
3×10^{14}	4.1	21.8	0.396	0.643
1×10^{15}	3.7	19.9	0.386	0.642

Table II. – AVERAGE CHARACTERISTICS FOR GaSb CELLS EXPOSED TO 1 MeV PROTONS. (Efficiency, open-circuit voltage and fill factor were measured at 50X AM0 concentration.)

Dose, p/cm^2	Efficiency, %	J_{sc} (1-sun), mA/cm^2	V_{oc}, V	Fill factor
0	4.8	23.8	0.410	0.665
$3x10^{10}$	3.9	20.3	0.400	0.660
$1x10^{11}$	3.3	18.0	0.390	0.630
$3x10^{11}$	2.3	15.1	0.360	0.590
$1x10^{12}$	1.5	12.4	0.300	0.520

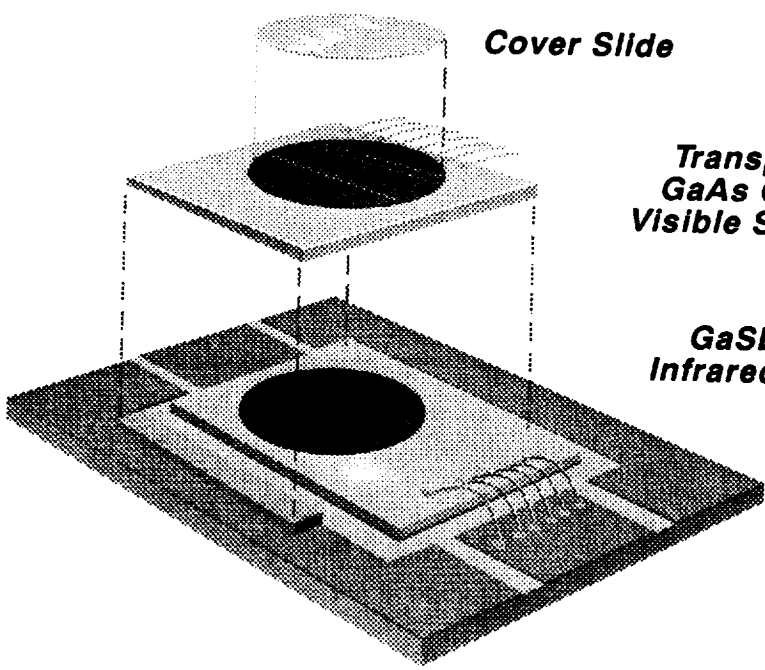

Figure 1. The GaAs/GaSb tandem assembly. The two cells are mechanically stacked, but electrically isolated.

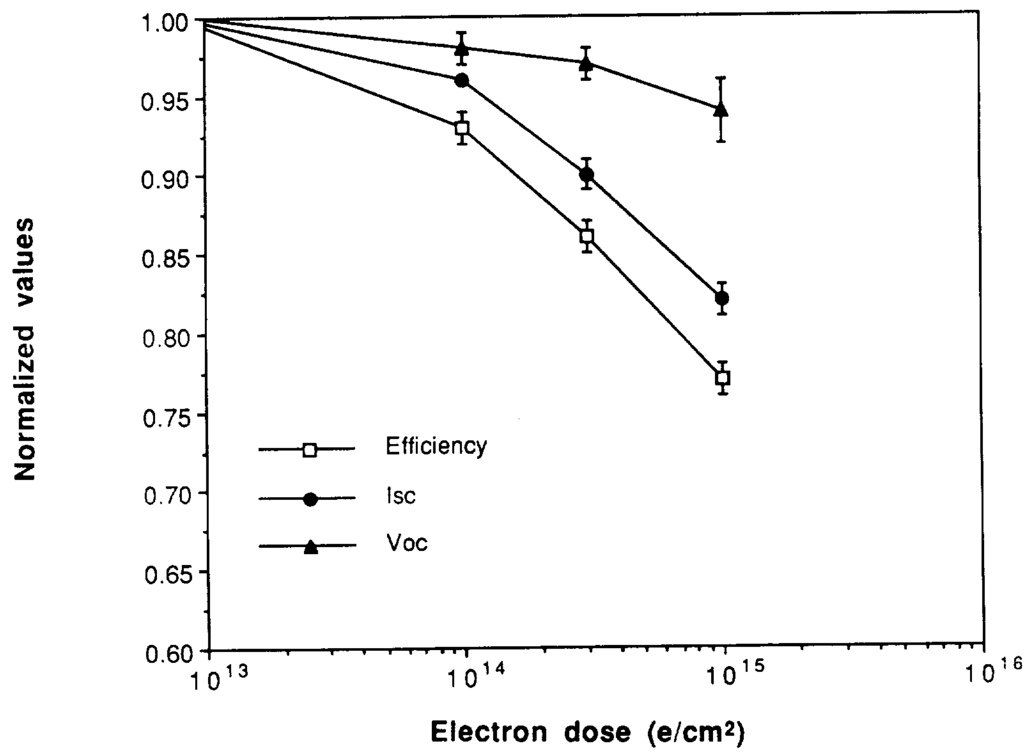

Figure 2. Normalized efficiency, short-circuit current an open-circuit voltage for GaSb cells during 1 MeV electron irradiation.

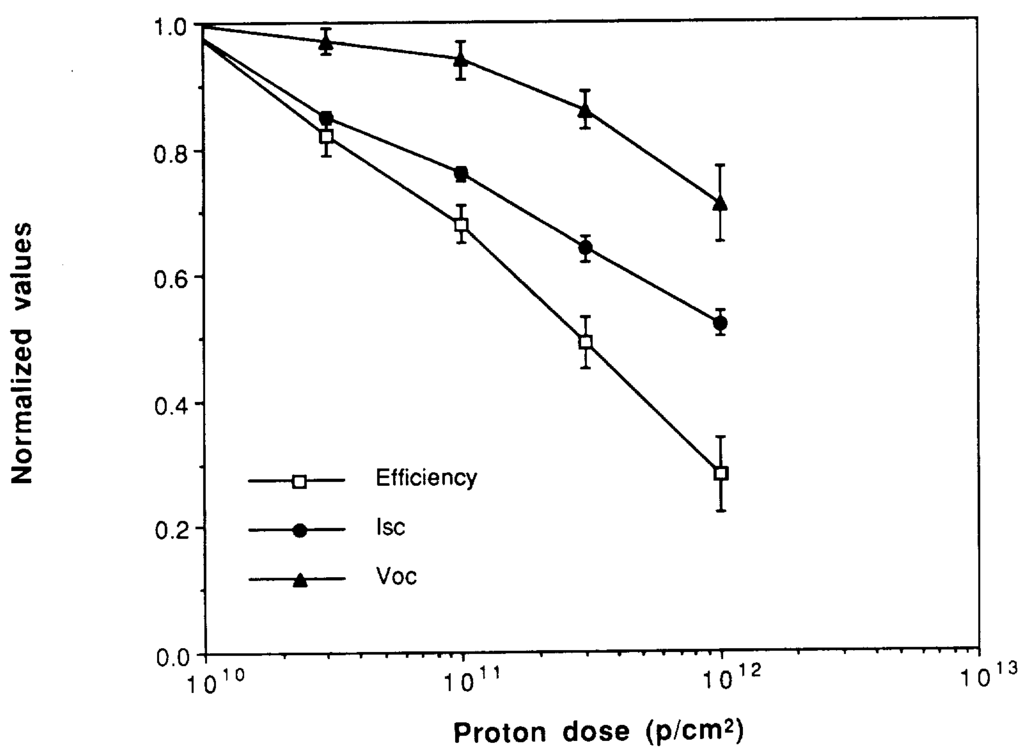

Figure 3. Normalized efficiency, short-circuit current and open circuit voltage for GaSb cells during 1 MeV proton irradiation.

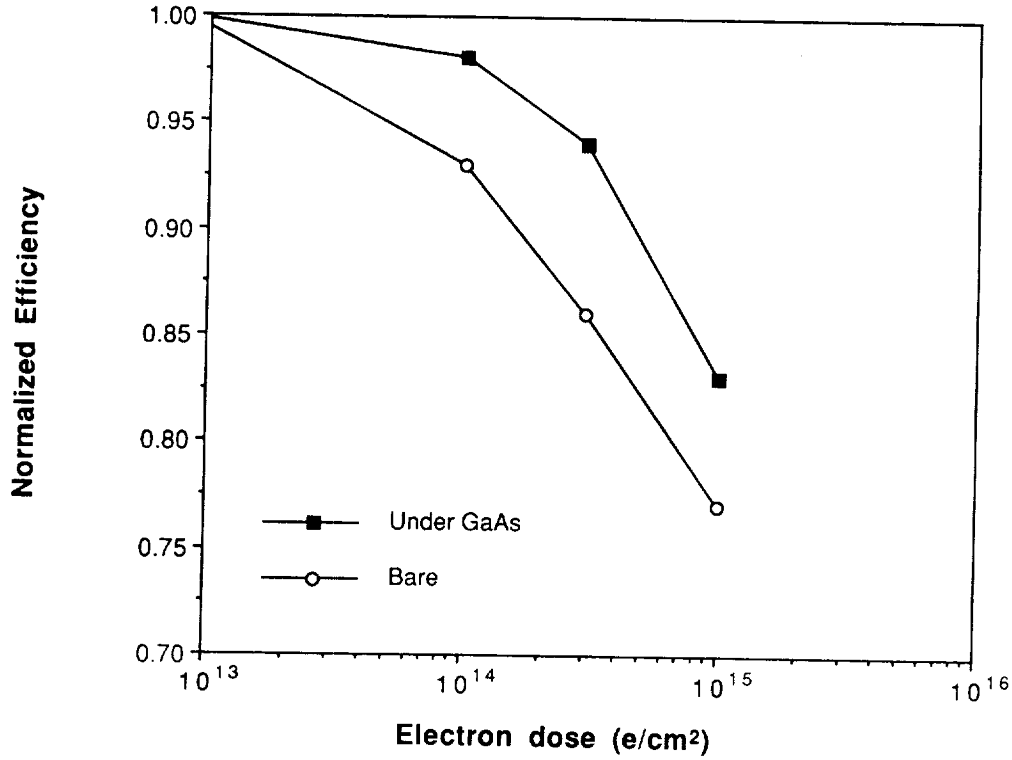

Figure 4. The efficiency degradation of GaSb cells exposed to 1 MeV electrons. The data is averaged and normalized to the beginning of life values, and compares bare GaSb cells with those in a tandem assembly.

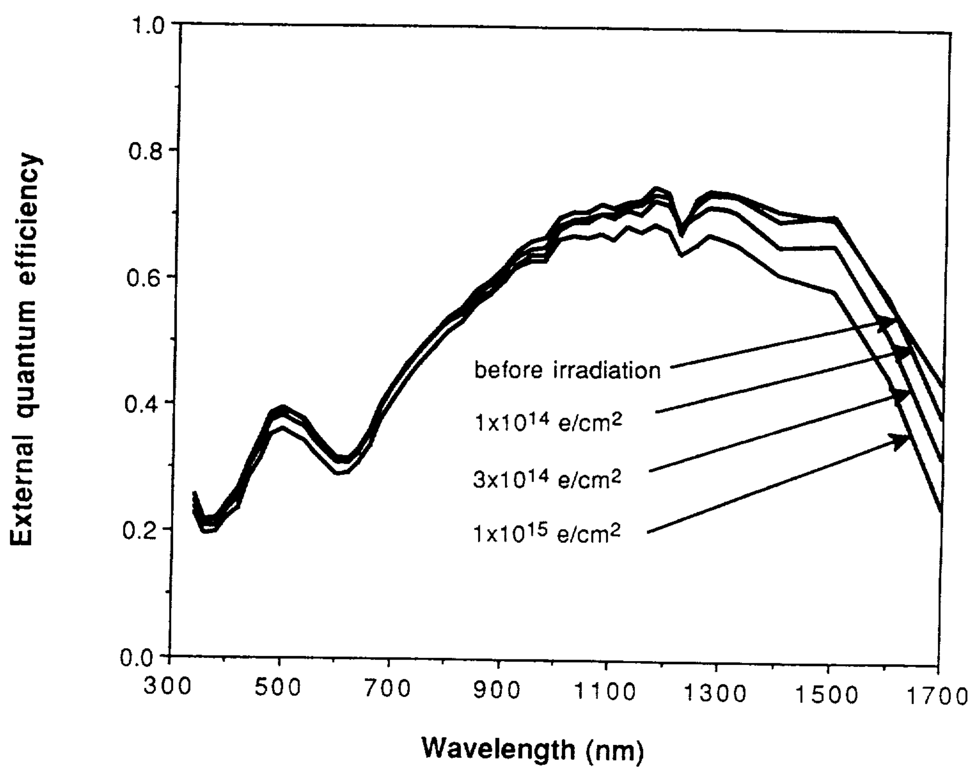

Figure 5. The spectral response curves for a GaSb cell as a function of 1 MeV electron exposure.

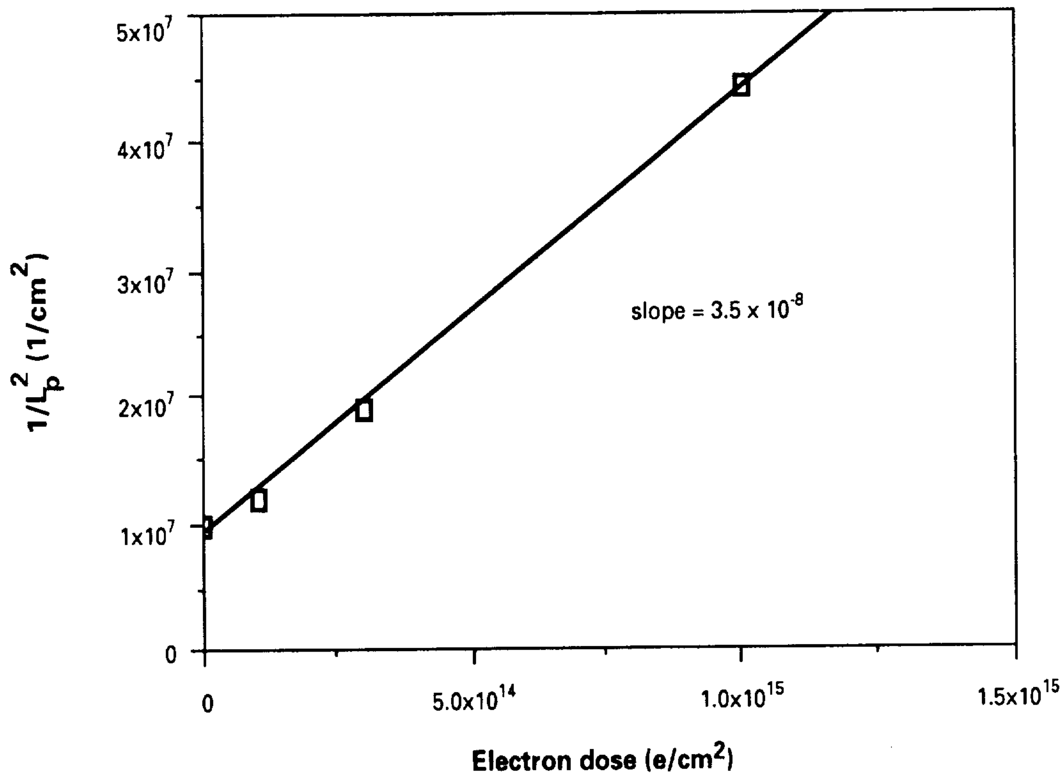

Figure 6. The calculation of the diffusion length damage coefficient from the slope of $1/Lp^2$ vs. the electron dose.

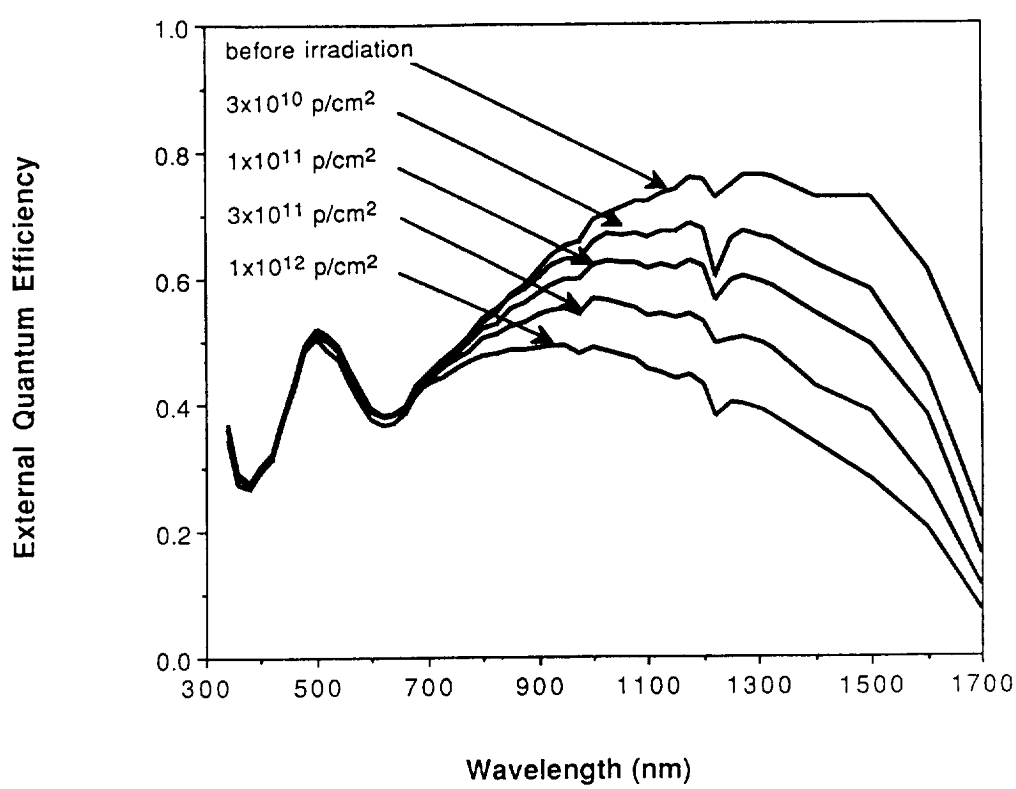

Figure 7. The spectral response curves for a GaSb cell as a function of 1 MeV proton exposure.

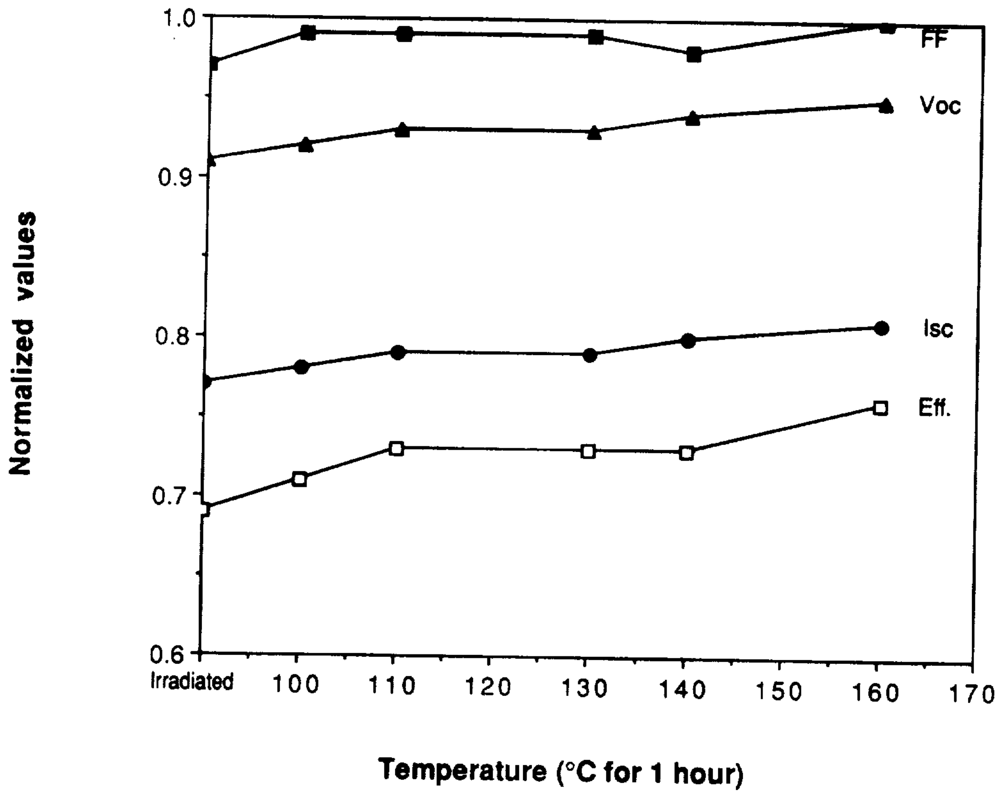

Figure 8. Isochronal annealing (1 hour at each temperature) shows partial recovery of proton-damage GaSb cells at temperatures below 160°C.

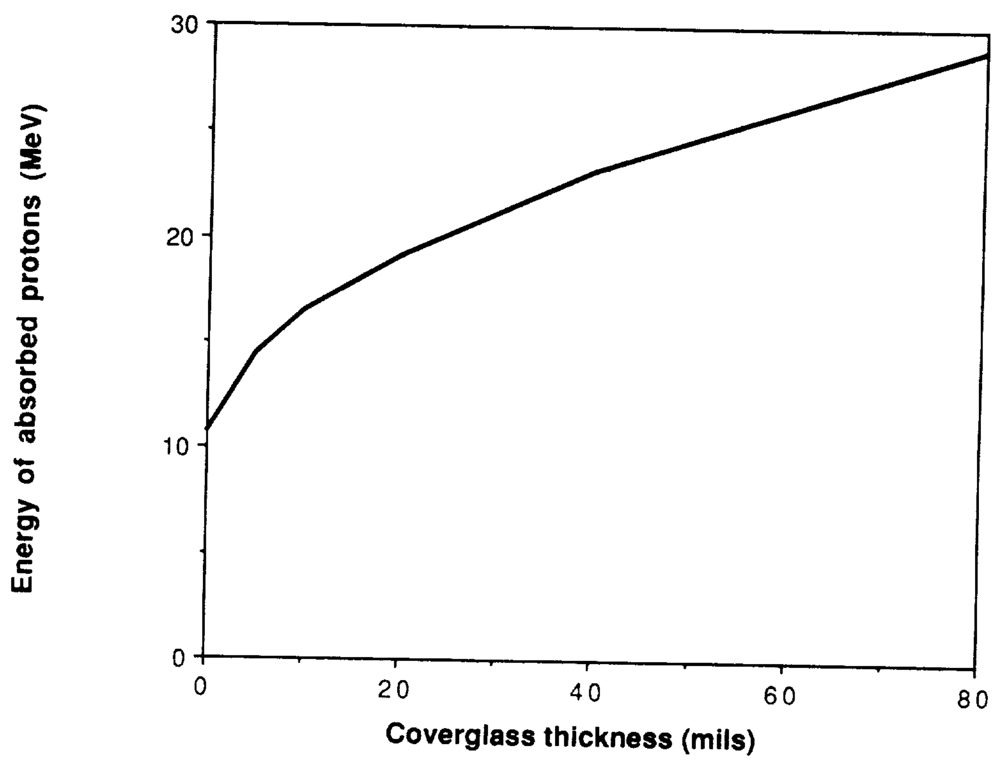

Figure 9. The minimum proton energy required to pass through a coverglass and a 450 µm GaAs cell.