RADIATION DAMAGE IN GaAs SOLAR CELLS

E. J. Conway and G. H. Walker
National Aeronautics and Space Administration
Langley Research Center

INTRODUCTION

Radiation damage of space borne equipment is an important consideration for almost all systems which fly higher than the bottom of the radiation belts. Without geomagnetic shielding, spacecraft face a radiation environment which varies in particle type, intensity, energy, and time. Electron and proton radiation provide the greatest damage hazard. This paper will report recent results of electron and proton irradiation and annealing of GaAs solar cells, and also will speculate on some implications of these results.

Langley Research Center has been actively involved in GaAs solar cell research for several years. Our space radiation effects effort began approximately two years ago. Its goal is to improve the radiation stability of the cells. Thus, in general, unshielded shallow junction, p-GaAℓAs/p-GaAs/n-GaAs cells and materials are studied.

In the following sections, we will report on an inhouse effort at LaRC, on contractual studies at Hughes Research Laboratory, and on grant research at University of Florida.

I. Electron Irradiation Damage and Annealing

Langley Research Center

Inhouse studies have emphasized 1 MeV electron damage (irradiations performed at LeRC) and thermal annealing of GaAs solar cells. We have studied both the damage and annealing as a function of electron fluence and of junction depth. Cell degradation was found to be less severe for shallow junction cells. Also, the degree of recovery (due to thermal annealing) was greater for shallow junction cells.

In this report we will emphasize the annealing studies. Our results are in the form of short circuit current (I_{SC}), normalized to initial short circuit current (I_{SCO}), because this is a simple measurable quantity (not the product of several) and is the more radiation and annealing sensitive simple quantity.

Figure 1 shows the effect on relative short circuit current of annealing 0.8 μm junction depth cells, at 200°C for 10, 20, and 30 hours. For damage due to fluences from 10^{14} and 10^{15} 1 MeV electrons cm^{-2}, recovery was essentially complete. The annealing recovery after a fluence of 10^{16} electrons cm^{-2} appeared to cease upon reaching 0.83. These results suggested that more complex damage occurs at high fluence and leads to more complex annealing characteristics (Ref. 1).

Figure 2 shows the results of annealing several shallow junction cells after irradiation with 10^{15} 1MeV electrons cm^{-2}. Each set of cells was isothermally annealed and the data analyzed for annealing kinetics. Annealing was found to be first order with an activation energy of 1.25 ev. All results indicated that I_{sc}/I_{sco} annealed to only 0.98, confirming an uncompletely recovered component.

Lang, et al. (Ref. 2), had investigated 1 MeV electron irradiation and annealing of GaAs using deep level transient spectroscopy (DLTS). He found six levels, three of which annealed at an activation energy of 1.4 eV, and two more at 1.75 eV. Our values are in good agreement with those of Lang for the low activation energy annealing stage, and (based on Lang's results) we should have seen no further annealing for the times and temperatures used. Thus, we believe that two important annealing stages exist for GaAs, one associated with a 1.25 eV activation energy and another with an activation of 1.75 eV.

We are currently finishing a calculational study on simultaneous irradiation and annealing. Using the activation energies and frequency factors from our work and Lang's, we are estimating the significance of the expected degradation. We expect the results to show that when irradiation occurs at its natural rate in space, continuous thermal annealing can be very effective in reducing the resulting damage.

II. Proton Irradiation of GaAs Solar Cells
Hughes Research Laboratory

In space, solar cells are not only subject to electron irradiation, but also to bombardment from protons trapped in the radiation belts and from those originating in solar flares. The proton energy spectrum is very wide, from less than 100 KeV to more than 100 MeV. However, there are many more protons at low energy than at high energy.

For the last two years, Hughes Research Laboratory has been measuring the effect of various proton energies and fluences on GaAℓAs/GaAs solar cells. These cells were generally irradiated unshielded to permit unambiguous interpretation of results and to provide a firm basis for shielding studies.

Cells with junction depths less than 0.5 μm were irradiated at high energy (15 MeV and 40 MeV) and at low energy (50 KeV, 100 KeV and 290 KeV). Silicon solar cells were also irradiated to permit a direct comparison between the effects on GaAs cells and Si cells. Figure 3 summarizes the available results. At high proton energies, the performance of GaAs cells does not degrade as rapidly with increasing fluence as does the performance of Si cells. However, at low energies, GaAs cells degrade more rapidly than Si. At some intermediate energy, shown schematically by crossing of dashed lines, the two kinds of cells must be equally sensitive. With a 12 mil cover glass, GaAs cells show no degradation with energy (to 290 KeV) at a fluence of 10^{12} cm^{-2} as shown by the 100% line at low energy in Figure 3. This is expected since the range of 290 KeV protons is much less than one mil.

Analysis of spectral response measurements indicate that neither 50 KeV (range ∿ 0.4 μm) nor 100 KeV (range ∿ 0.8 μm) protons cause much damage below the junction. This is the case because both the window thickness and the junction depth (measured from the inside of the window) provide shielding to the junction. This observation suggests that a benefit might be derived from using a thick window. For example, a 2 mil window could stop protons up to 5 MeV. Windows have been kept thin in the past to permit extended blue response for enhanced beginning-of-life (BOL) efficiency. Preliminary indications are that with a thick window and reduced BOL efficiency, a high end-of-life efficiency could be maintained with low weight and great simplicity in comparison with cover glass shielding. The major problems appear to be the effects of radiation on the optical and electrical properties of the conductive GaAℓAs window.

III. Electronic Property Changes of GaAℓAs and GaAs Solar Cell Materials due to Proton and Electron Irradiation -

Univ. of Florida

This fundamental effort supports the more empirical radiation studies performed on cells. Independent measurements are made of macroscopic parameters, such as efficiency and short circuit current. Fundamental microscopic-level measurements of radiation induced defect characteristics, such as trap energy, density and capture cross section, are correlated with macroscopic measurements and important new information is developed.

The University of Florida and Hughes Research Laboratory performed some cooperative studies on low energy proton (.05, .10 and .29 MeV) irradiated diodes and cells. Deep level transient spectroscopy (DLTS) measurements were made of radiation induced trap density and carrier capture cross sections. The total capture cross section [Σ(TOT)] was computed by multiplying each trap density by its electron or hole cross section and adding. Figure 4 shows the relative short circuit current and relative efficiency plotted against Σ(TOT). The points are labeled for the proton irradiation energy and fluence.

Although Figure 4 is based on some preliminary data, it suggests that one means for comparing irradiation effects at different energies and different fluences is by means of the carrier total capture cross section. Σ(TOT) is a macroscopic parameter and should be correlatable with macroscopic parameters other than those shown in Figure 4, such as diffusion length.

The electron binding energy of radiation induced defects has been measured for some sets of radiation and material parameters. For low energy proton irradiation, these levels are shown in the first three columns of Figure 5. For 1 MeV proton irradiation of n-GaAs, two electron traps at E_C - 0.14 eV and E_C - 0.46 eV have been measured also (Fig. 5, column 4). An increasing number of levels were measured as the proton energy was increased up to 0.29 MeV. However, at a proton energy of 1 MeV only two electron traps were found (the deeper of which became deeper with increasing fluence). This result suggests that qualitatively different defects could be introduced when low energy protons are stopped in GaAs solar cells.

The last column of Figure 5 illustrates schematically the six-energy levels which Lang, et al. (Ref. 2) found to result from 1 MeV electron irradiation. Lang identified five electron traps and one hold trap. This is significantly different from the number and distribution produced by 1 MeV protons.

Although the results illustrated in Figure 5 do not strongly affect our view of radiation degradation, they do affect our approach to annealing. If different particles and different energies produce qualitatively different damage, for example bound aggregates of defects for low energy protons and isolated simple defects for high energy electrons, then annealing kinetics may be different also. As a first approximation, many of us have assumed that all damage anneals like electron damage; however, this must be checked carefully.

University of Florida studies will be focussing on this in the coming year.

SUMMARY

We are performing a calculational study of the simultaneous 1 MeV electron irradiation and annealing effects in GaAs solar cells. Separate experiments suggest that operation of the cells near 200°C should continuously anneal the damage and significantly reduce the effect of long term electron irradiation.

Under irradiation by high energy protons, GaAs cells do not degrade as rapidly as do Si cells. For low energy protons, GaAs cells degrade more rapidly; however, if the cells are provided with sufficiently thick cover glass radiation shields, then no cell damage occurs. A thick GaAℓAs window might provide a light-weight, integral shield, but severely damaged windows would require effective annealing to make this concept useable.

Degradation of solar cell performance parameters appears to correlate well with increasing total cross section for carrier capture. Deep level transient spectroscopy (DLTS) has identified numerous trap energy-levels produced by protons. A comparison between the energy-levels produced by protons and by electrons which are not stopped in the material indicate that the damage produced by protons and electrons may be qualitatively different. Thus, annealing of proton damage may be very different from the annealing of electron damage.

REFERENCE

1. Walker, G. H.; Conway, E. J.; J. Electrochem. Soc. 25, 10, p. 1726, 1978.

2. Lang, D. V.; Logan, R. A.; and Kimerling, L. C.: Phys. Rev. B 15, 10, p. 4874, 1977.

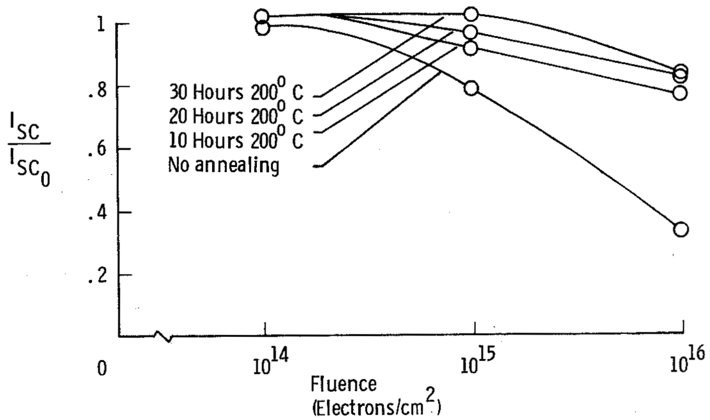

Figure 1. - Annealing recovery of short circuit current for one MeV electron irradiated cells.

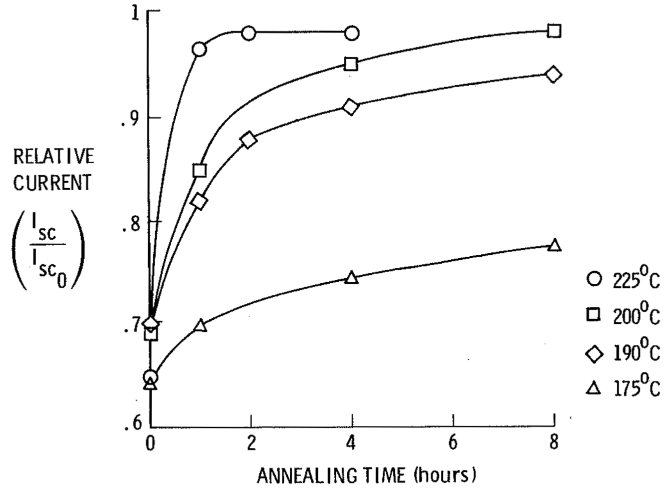

Figure 2. - Recovery of short circuit current as a function of annealing time.

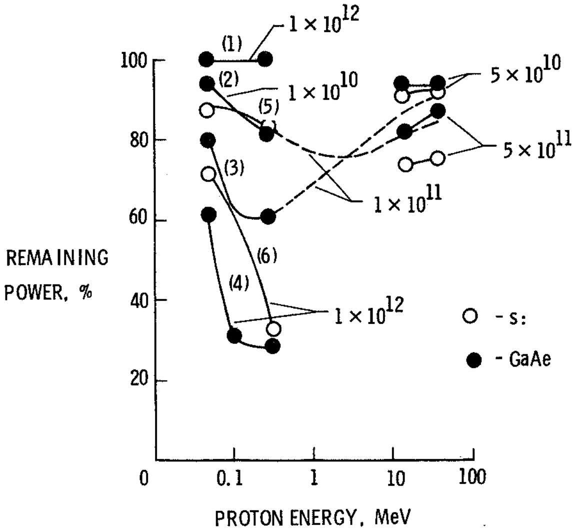

Figure 3. - Proton radiation damage: GaAs and Si solar cells.

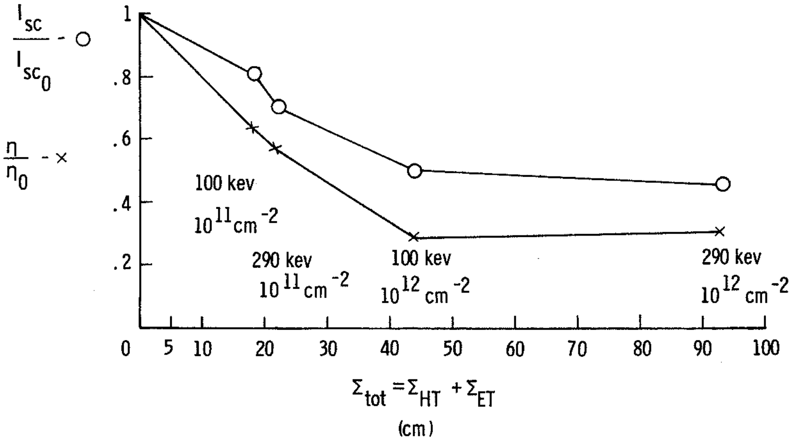

Figure 4. - Total carrier cross section effects for proton irradiated GaAs solar cells.

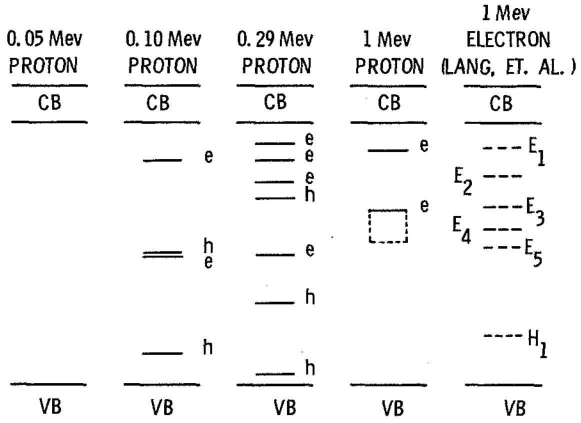

Figure 5. - Comparison of radiation induced trap levels in GaAs.