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Performance and Temperature Dependencies of Proton Irradiated n/p and p/n GaAs and n/p Silicon Cells



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ABSTRACT

n/p homojunction GaAs cells are found to be more radiation resistant than p/n heteroface GaAs under 10 MeV proton irradiation. Both GaAs cell types outperform conventional silicon n/p cells under the same conditions. An increased temperature dependency of maximum power for the GaAs n/p cells is attributed to differences in V_{oc} between the two GaAs cell types. These results and diffusion length considerations are consistent with the conclusion that p-type GaAs is more radiation resistant than n-type and therefore that the n/p configuration is possibly favored for use in the space radiation environment. However, it is concluded that additional work is required in order to choose between the two GaAs cell configurations.

INTRODUCTION

The discovery, in the early days of the space program, that p-type silicon was more radiation resistant than n-type silicon led to the present exclusive use of the n/p configuration for silicon solar cells in space (1). With regard to GaAs, the available experimental data indicates that the diffusion length for holes is significantly greater than that observed for electrons (2). Hence it would appear that the GaAs n/p configuration may be preferable in terms of radiation resistance. Although most GaAs cells have been of the p/n variety, some reasonably good quality n/p cells have surfaced (3 and 4). Hence cells of both types are available for comparison under laboratory conditions. In this respect, GaAs p/n cells have previously been subjected to both proton and electron irradiations (5) while n/p cells have undergone electron irradiations (3 and 6). However, to the best of our knowledge, there have been no reported results in the open literature concerning the performance of n/p GaAs cells under proton irradiation. Therefore, in an attempt to alleviate this apparent deficiency, we have determined the performance of n/p GaAs cells after proton irradiation. At the same time, for comparison purposes, we have proton irradiated p/n GaAs cells and conventional n/p

silicon cells. In addition, we have determined the temperature dependencies of these cells in both the irradiated and unirradiated states. Our principal objective lies in contributing to a data base for proton irradiated n/p GaAs cells and at the same time, understanding and comparing their performance and temperature dependencies to both p/n GaAs and conventional silicon solar cells.

EXPERIMENTAL

Pertinent cell details are shown in Fig. 1 and Table I. The heteroface p/n GaAs cells were fabricated by liquid phase epitaxy (5). The n/p cells were homojunctions fabricated using the chloride method of vapor phase epitaxy (3). The silicon cells were conventional n/p, 10 ohm-cm 200 μ m thick. One set of silicon cells had both a BSR and RSR while the other had only a BSR. The p/n GaAs cells were obtained from the Hughes Research Laboratories, while the n/p cells were obtained from the MIT Lincoln Laboratories. The cells were irradiated by 10 MeV protons in the Lewis Cyclotron. Temperature dependency runs, from 0 to 80 °C, were carried out prior to, and periodically, during the irradiations. Cell electrical characteristics were determined before and after irradiation using an air mass zero Xenon arc solar simulator.

RESULTS

From the plot of cell maximum power versus proton fluence in Fig. 2 it is readily seen that the n/p GaAs cells outperform all of the other cell types over the indicated fluence range. Variation of cell maximum power with temperature was linear over the temperature range covered (Fig. 3). Pre-irradiation temperature variations are shown in Table II while Fig. 4 displays the variation of dP_m/dT with fluence. It is noted that the latter quantity is relatively constant for GaAs while considerable change, with increasing fluence, is noted for silicon. From Table II, it is seen that dP_m/dT is significantly less for the p/n GaAs cells as compared to the n/p cells. However, the homojunction cell still maintains its superiority, at higher temperatures, over most of the fluence range (Fig. 5).

DISCUSSION

Comparison of Radiation Resistance

Despite the indicated superiority of the n/p cells, the data is not conclusive regarding the possible superior radiation resistance of p-type GaAs. This follows from the dependency of the radiation resistance of heteroface p/n GaAs cells on the p-type emitter depth (5). In this latter research, a decided improvement in the radiation resistance of these cells was observed when the emitter depth was reduced from 1 to 0.5 μm . On the other hand, the improvement was relatively small when the emitter depth was decreased from 0.5 to 0.3 μm (5). By analogy it is inferred that the effect of decreasing emitter depth on radiation resistance is relatively small for depths less than 0.3 μm . Extrapolating to the present case, it is assumed that the increased radiation resistance of the homojunction cell is not predominantly due to the large reduction in emitter depth.

An additional argument arises from relative diffusion length considerations. Using published literature values (7, 8 and 9) Weiser and Godlewski have summarized the measured data for both conductivity types in GaAs (Fig. 6) (2). The data shows that, for a given dopant concentration, the minority carrier diffusion length for p-type GaAs is significantly greater than for n-type. Using the curve fitting formulae of Goradia and Curtis (10), it is found that L_p , the minority carrier diffusion length, is 28 μm in the p-region of the present n/p cell while L_n is 6 μm in the n-region of the present GaAs p/n cell. The preceding would tend to favor the increased radiation resistance of p-type over n-type GaAs under 10 MeV proton irradiation. However, it is noted that different radiation induced defects are formed in n-type as compared to p-type GaAs. Thus consideration of pre-irradiation diffusion lengths alone is not entirely conclusive in favoring one conductivity type over another. However, the present results are not inconsistent with the conclusion that, for approximately equal doping concentrations, p-type GaAs is more radiation resistant than n-type.

Variation With Temperature at Constant Fluence

The temperature variation of V_{oc} can be discussed by considering the relation (11)

$$dV_{oc}/dT = \frac{V_{oc} - E_{go}}{T} - \frac{3k}{q} \quad (1)$$

where E_{go} is the extrapolated value of the semiconductor band gap at absolute zero, expressed in volts, and k is Boltzmann's constant. Calculated values of dV_{oc}/dT from Eq. (1) are in fair agreement with measured values (Table III). In general for cells with the same value of E_{go} , smaller values of V_{oc} lead to increasingly negative values of dV_{oc}/dT . This

follows from the dominance of the first term in Eq. (1) and the fact that $V_{oc} < E_{go}$.

With regard to P_{max} , from the usual relation for fill factor it is shown that

$$dP_m/dT = V_{oc} FF (dI_{sc}/dT) + V_{oc} I_{sc} (dFF/dT) + FF I_{sc} (dV_{oc}/dT) \quad (2)$$

At constant fluence, the preceding relation predicts a linear relation, over a limited temperature range, between dP_m/dT and the temperature variation of I_{sc} , V_{oc} and FF respectively. This is shown for dV_{oc}/dT in Fig. 7. Similar plots are obtained for dI_{sc}/dT and dFF/dT . Substitution of numerical values in Eq. (2) reveals that, for GaAs, the magnitude of the term in dV_{oc}/dT is approximately three times the magnitude obtained for either of the remaining two terms. Although the third term in Eq. (2) is not overwhelmingly predominant, the preceding can be interpreted as indicating that the temperature variation of V_{oc} is the largest contributor to dP_m/dT . This being the case and considering Eq. (1), the difference in V_{oc} behavior between the two GaAs cell types would tend toward explaining the difference in dP_m/dT observed between the p/n and n/p GaAs cells (Table II). The preceding argument applies to the present GaAs cells. However it breaks down for the present silicon cells where V_{oc} differences exist yet the P_{max} temperature variations are approximately equal. However, in the latter case, the voltage difference is essentially due to an effective back surface field.

Temperature Effects at Variable Fluence

Previous results for the heteroface p/n GaAs cells indicate that dP_m/dT decreases with increasing fluence under 1 MeV electron irradiation (12). For similar cells, in the present case, this quantity is relatively constant, under proton irradiation, over the entire proton fluence range. The difference between the results of electron and proton irradiations could possibly be due to the generation of different defects by the two radiation types. Aside from this, Figs. 8 and 9 indicate a rough correlation between the fluence dependent behavior of dP_m/dT and both dI_{sc}/dT and dV_{oc}/dT for the present GaAs cells. In the case of silicon, the fluence dependent behavior of dP_m/dT correlates with dI_{sc}/dT only (Fig. 9). It is speculated that, for silicon, this behavior is due to a fluence dependent defect property in proton irradiated p-type silicon. At the present time, insufficient information exists to make a more definitive statement.

CONCLUSION

The present results would, at first glance, appear to favor the contention that, for approximately equal dopant concentrations, p-type GaAs is more radiation resistant than n-type. Hence, it would appear to follow that n/p GaAs cells are

preferable to p/n cells. However, despite the evidence for increased diffusion lengths in the p-type semiconductor, the radiation induced defects in this material could possibly be more effective lifetime killers than those formed in n-type GaAs. Exercising caution, it seems best to state that the present results do not contradict the conclusion that, for the appropriate doping concentrations, p-type GaAs is more radiation resistance than n-type and that the n/p configuration is preferable.

The larger temperature variation observed for the n/p GaAs cell appears to be dependent, to a large extent, on V_{oc} which in turn is dependent on cell design and processing. It is our understanding that improved cells of the present n/p configuration exhibit V_{oc} values equal to or greater than those measured for the present heterojunction p/n cells. Unfortunately these cells were not available to us at the time that this research was completed. In view of the present results it would be of great interest to determine the temperature dependencies of the improved n/p cells. In addition, future comparisons would most fruitfully be made between n/p and p/n cells of the same design. Such cells are now becoming available (4) and one can anticipate more definitive comparative radiation damage studies in the near future. In lieu of such studies, it is concluded that;

In addition to improved efficiencies, the radiation resistance of GaAs cells are greater than that of conventional silicon cells.

The present results are consistent with the conclusion that, given approximately equal doping concentrations, p-type GaAs is more radiation resistant than n-type. However, additional effort is required to definitively determine the relative radiation resistance and thus to choose between the p/n and n/p solar cell configurations for space use.

The difference in dP_m/dT between the two types of GaAs cells is due largely to differences in open circuit voltage.

For silicon, it is speculated that the large, fluence dependent variation in dP_m/dT is due to a fluence dependent defect property.

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TABLE I. - PRE-IRRADIATION ELECTRICAL CHARACTERISTICS

T = 25 °C

Cell	Number of cells	Efficiency, %	Voc, v	Isc ma/cm ²	FF, %
GaAs (p/n)	4	16.4	1.022	28.5	77.3
GaAs (n/p)	2	16.6	0.96	29	81.8
Si (BSF/BSR)	2	14.6	0.616	42.43	76.6
Si (BSR)	2	12.7	0.559	39.58	78.8

TABLE II. - PRE-IRRADIATION VARIATION OF CELL ELECTRICAL CHARACTERISTICS WITH TEMPERATURE

Cell	$\frac{dP_m}{dT}$, mW/cm ² °C	$\frac{dVoc}{dT}$, mV/°C	$\frac{dIsc}{dT}$, ma/cm ² °C	$\frac{dFF}{dT}$, %/°C
p/n-GaAs	-4.4×10^{-2}	-2.03	2.03×10^{-2}	-5.25×10^{-2}
n/p-GaAs	-6.04×10^{-2}	-2.3	2.06×10^{-2}	-7.35×10^{-2}
BSF/BSR-Si	-9.17×10^{-2}	-2.4	1.94×10^{-2}	-12.2×10^{-2}
BSR-Si	-9.11×10^{-2}	-2.59	2.3×10^{-2}	-14×10^{-2}

TABLE III. - CALCULATED AND MEASURED Voc TEMPERATURE VARIATION (PRE-IRRADIATION VALUES)

Cell	Voc, V	$\frac{dVoc}{dT}$, mV/K	
		Measured	Calculated
p/n GaAs	1.022	-2.03	-1.98
n/p GaAs	0.960	-2.3	-2.21
Si BSF/BSR	0.616	-2.4	-2.17
Si BSR	0.559	-2.59	-2.39

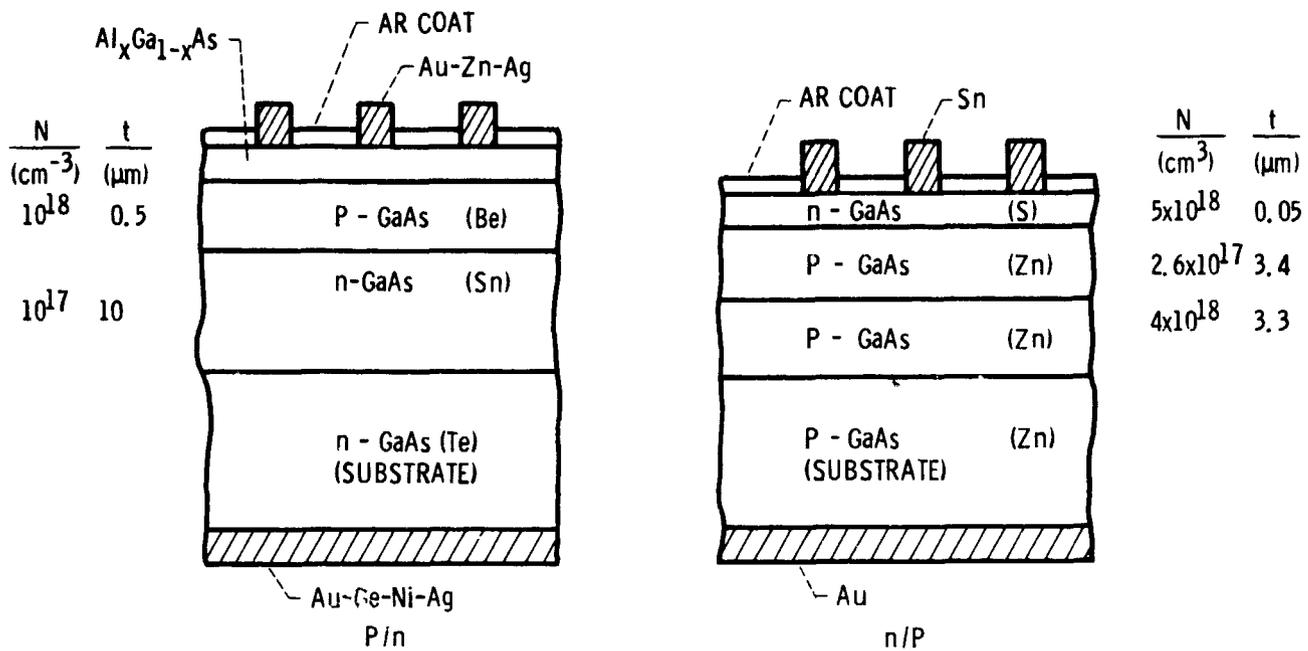


Figure 1. - GaAs cell configurations.

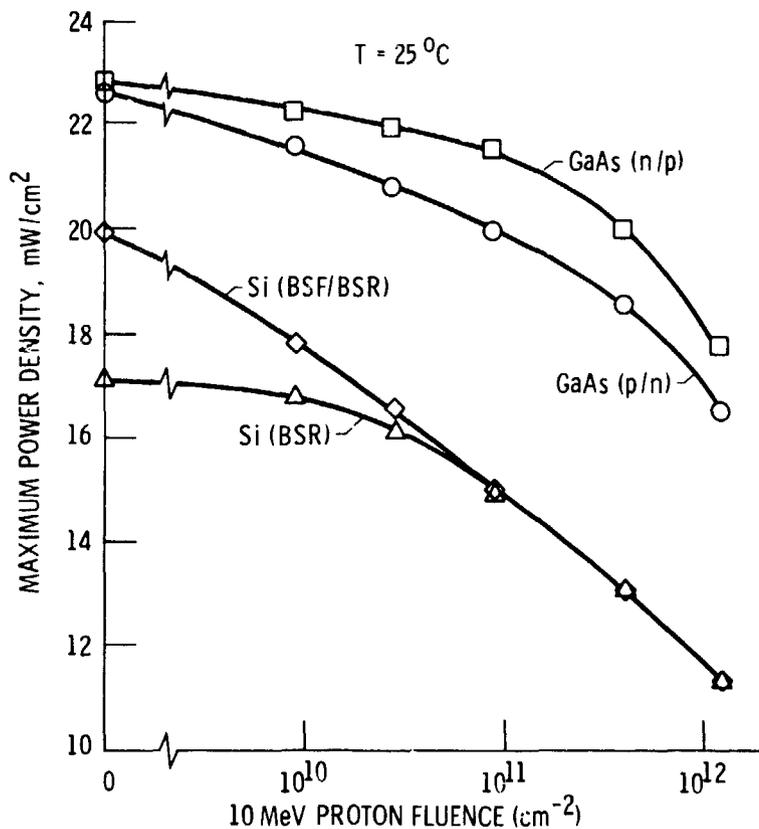


Figure 2. - Maximum power density versus 10 MeV proton fluence.

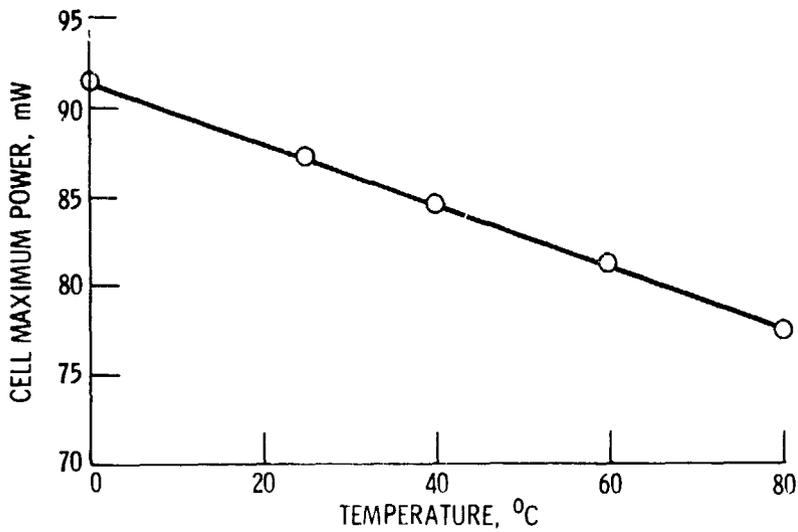


Figure 3. - Temperature variation of cell P_{max} (p/n GaAs).

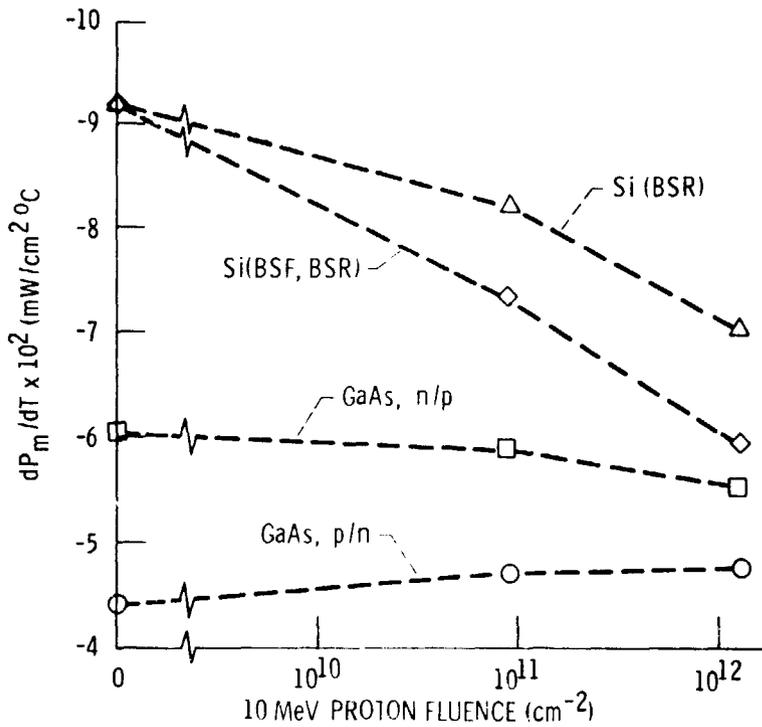


Figure 4. - Temperature variation of maximum power density at different fluences.

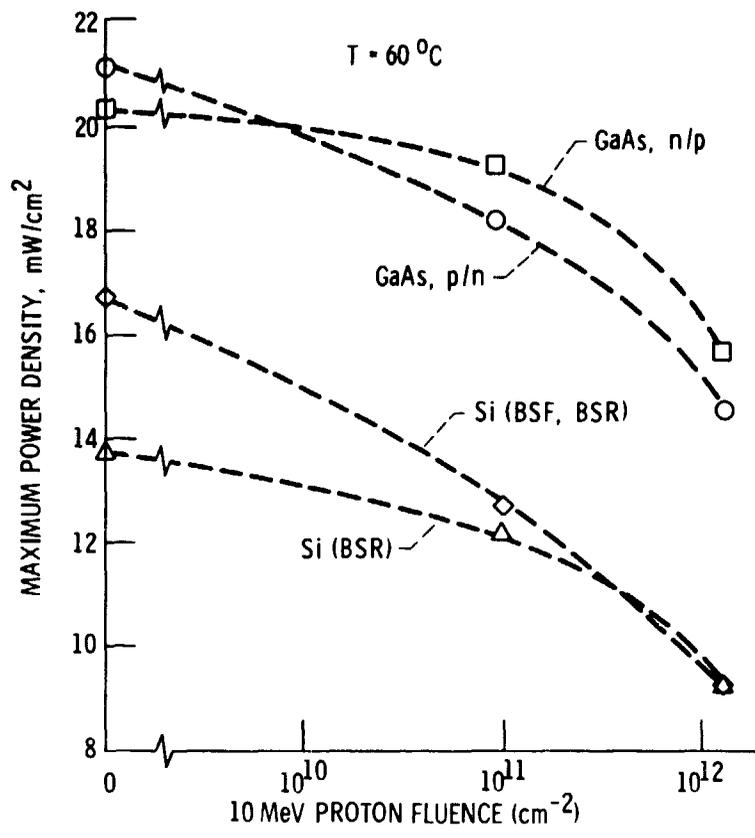


Figure 5. - Maximum power density at different fluences.

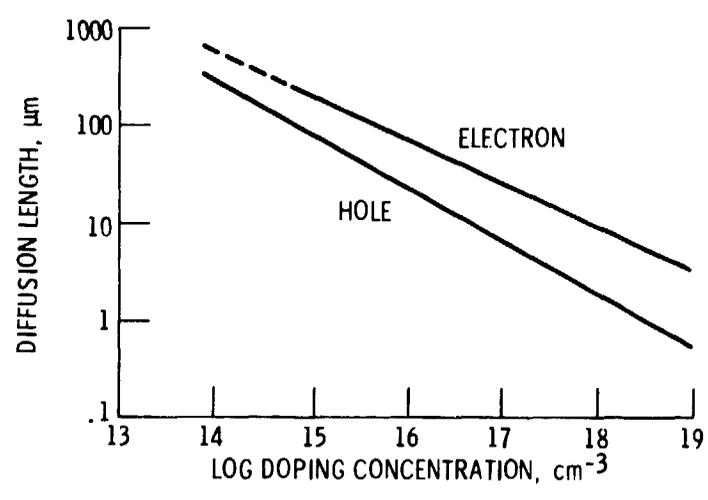


Figure 6. - Electron and hole diffusion lengths in GaAs. (Weizer and Godlewski (ref. 2))

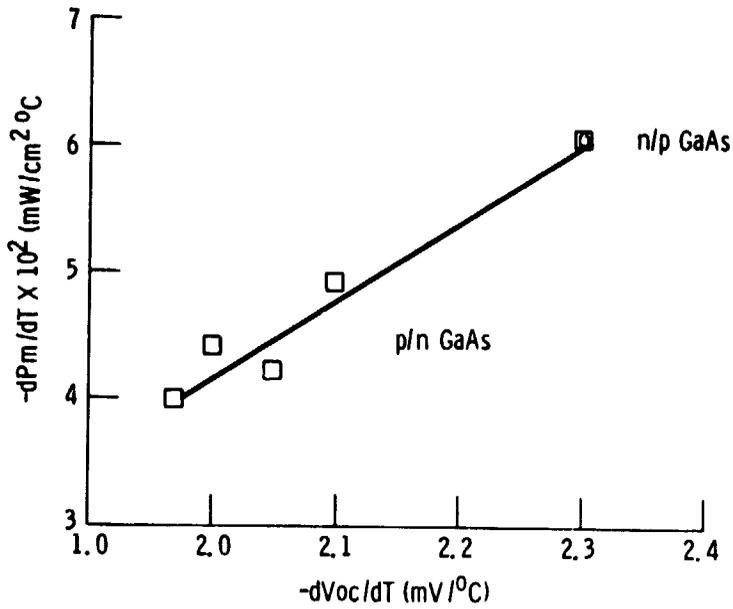


Figure 7. - Pre-irradiation P_{max} temperature variation versus Voc temperature variation (GaAs).

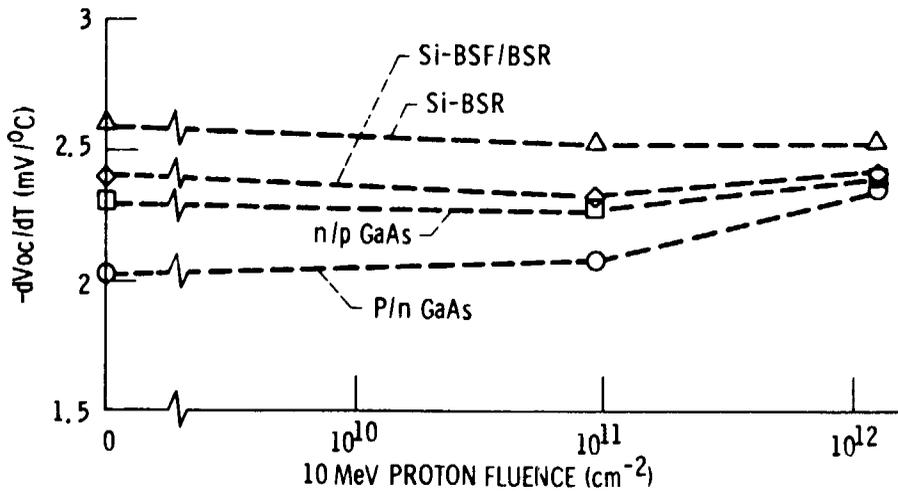


Figure 8. - dVoc/dT versus fluence for all cells.

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