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# EFFECT OF 1.0 MeV ELECTRON IRRADIATION ON SHUNT RESISTANCE IN Si-MINP SOLAR CELLS*

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Shunt resistance from 100 K-400°K is compared for diffused and ion-implanted cells, before and after irradiation. $R_{sh}$ decreases from $>10^7 \Omega\text{-cm}^2$ for T<250°K to $10^4 \Omega\text{-cm}^2$ at 400°K for non-irradiated diffused cells. Electron irradiation causes a more rapid decrease in $R_{sh}$ for T>250°K. Ion-implanted cells exhibit a similar trend except that $R_{sh}$ is significantly less for T<250°K and is more sensitive to irradiation at these low temperatures. The mechanism of $R_{sh}$ appears to be a combination of multistep tunneling and trapping - detrapping in the defect states of the semiconductor. Radiation serves to increase the density of these states to decrease $R_{sh}$.

## INTRODUCTION

Metal-Insulator-$N^+$ silicon -p silicon (MINP) solar cells are basically a surface passivated cell offering high efficiency due to a reduction in loss mechanisms such as surface recombination. This type of cell now produces an efficiency in excess of 20% which makes it a likely candidate for space applications. Thus, a study of radiation effects becomes important.

This paper deals with the effects of 1.0 MeV electron irradiation on the shunt resistance ($R_{sh}$) of MINP solar cells which has not previously been well characterized. Since $R_{sh}$ must be high to avoid loss in efficiency, any decrease in high $R_{sh}$ due to irradiation becomes an area of concern for the designer of solar cells for space applications.

## EXPERIMENTAL TECHNIQUES

MINP solar cells were fabricated by ion implantation or diffusion. Diffused junctions were formed in 0.1-0.3 Ω-cm, (100), p-type Si using a Carborundum phosphorous solid source at 950°C for 5 minutes (ref. 1). A junction depth of about 0.3 μm gave good UV response. Figure 1 shows the cell structure which utilizes a reduced-area Al ohmic contact, Yb-Cr-Al layered grid, and a single layer SiO antireflection (AR) coating. Other cells were implanted through the

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courtesy of Mark Spitzer of Spire Corp., with 5 keV phosphorous to a dose of about $2.5x10^{15}/cm^2$. After annealing (ref. 1), the cells were completed as described above. Total area efficiency up to 17% was achieved.

Solar cells were irradiated by 1.0 MeV electrons at fluence levels of $1x10^{14}/cm^2$, $1x10^{15}/cm^2$, and $1x10^{16}/cm^2$. Standard measurements were made of dark I-V, $I_{sc}$-$V_{oc}$, spectral response, diffusion length, and photovoltaic response at AM1.5 and AM0 using an ELH lamp source. In addition, $R_{sh}$ was determined by low voltage dark I-V data or low illumination $I_{sc}$-$V_{oc}$ date (ref. 2) from 100 K to 400 K. A liquid nitrogen cryostat was utilized for refrigeration and a Keithley Model 480 picoammeter for measuring low current values.

## EXPERIMENTAL DATA

Photovoltaic data for a diffused MINP cell, edge-exposed implanted cell, and non-passivated implanted cell are given in Table 1. The diffused cell gave the highest value of $R_{sh}$ before and after irradiation. It also suffered a greater loss in PV data since it was more finely tuned in the initial design. Previous studies (ref. 3) show MINP cells to outperform $N^+$-P cells for electron fluence levels $<1x10^{15}/cm^2$. The lower $R_{sh}$ for implanted cells indicates effects of bulk damage from the implantation.

Figure 2 shows $R_{sh}$ for the diffused cell with temperature as a variable. $R_{sh}$ is independent of T for T<250 °K and decreases thereafter. Irradiation causes a more rapid loss in $R_{sh}$ at increased T. Implanted cell data of Figure 3 indicate $R_{sh}$ to decrease with increased T for T>100 °K. Again, irradiation served to further reduce $R_{sh}$. Shunt current ($I_{sh}$) was seen to depend linearly upon voltage and super-linearly upon radiation fluence as seen in Figure 4.

## DISCUSSION

A number of observations regarding $R_{sh}$ may be listed and compared to a theoretical model.

1) $R_{sh}$ of diffused cells is greater than for implanted ones. This suggests remaining implantation damage after annealing.

2) $R_{sh}$ is independent of temperature below a threshold ($T_t$) after which it decreases rather rapidly with T (ref. 2).

3) Shunt current ($I_{sh}$) is linearly dependent on voltage but increases with T in a super-linear fashion (ref. 2).

4) Electron irradiation causes a decrease in $R_{sh}$ below $T_t$, little change in $T_t$, and a superlinear increase in $I_{sh}$.

A previous publication (ref. 2) explained temperature dependence of $R_{sh}$ by examining the influence of defect states on a captured carrier. A carrier may traverse the space charge region via multistep tunneling which explains the temperature independence for $T<T_t$. Alternatively, $R_{sh}$ may be due to thermal re-emission, the probability of which increases at increased temperatures. The following equations then prevail (ref. 4):

$$N_t(T)=N_{to}\exp[-A\ \exp(-E/kT)]t \qquad (1)$$

where $N_t(T)$ = # carriers trapped
$N_{to}$ = initial # trapped carriers
$E$ = energy of the state.
$t$ = time

Also, $A = N_{eff}\ Sv_{th}$ (2)

where $N_{eff}$ = density of states
$S$ = capture cross section
$v_{th}$ = thermal velocity

Conductivity due to released trapped charge is then given by

$$\Delta\sigma = \Delta N_t(T)q\,\Delta\mu \qquad (3)$$

These equations predict an increase in free carriers above a certain threshold temperature. This increase is dependent upon the defect energy level, defect density, capture cross section, and temperature. Linear dependence on voltage satisfies $V=IR$. A super-linear dependence of $R_{sh}$ and $I_{sh}$ on temperature fits equation 1. The rapid increase of $I_{sh}$ and decrease in $R_{sh}$ with electron fluence indicates the role of defects introduced by irradiation and enforces the original premise that $R_{sh}$ arises from defects in the bandgap.

## REFERENCES

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## TABLE 1

### Photovoltaic Data Before and After Irradiation by 1.0 MeV Electrons to $10^{16}/cm^2$

| | $V_{oc}$(V) | | $J_{sc}$(mA/cm$^2$)[d] | | Shunt Resistance [e]($\Omega$ - cm$^2$) | |
|---|---|---|---|---|---|---|
| Sample | Before | After | Before | After | Before | After |
| 1[a] | 0.632 | 0.494 | 43.1 | 19.7 | $8.4 \times 10^6$ | $9.3 \times 10^5$ |
| 2[b] | 0.608 | 0.506 | 40.8 | 23.8 | $5.0 \times 10^4$ | $1.6 \times 10^4$ |
| 3[c] | 0.626 | 0.489 | 42.9 | 25.7 | $2.4 \times 10^5$ | $1.2 \times 10^5$ |

a) Diffused MINP cell with diffusion performed through a window in the oxide. Area = 2.0 cm$^2$.

b) Ion-implanted MINP cell where junction edges are exposed. Area = 2.1 cm$^2$.

c) Ion-implanted without passivation. Area = 4.0 cm$^2$.

d) Illuminated at 135 MW/cm$^2$.

e) @ 300 °K.

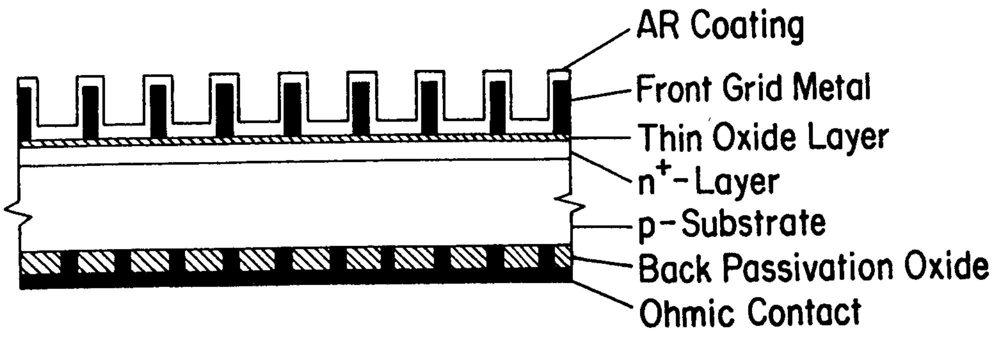

Figure 1. Diagram showing MINP solar cell design.

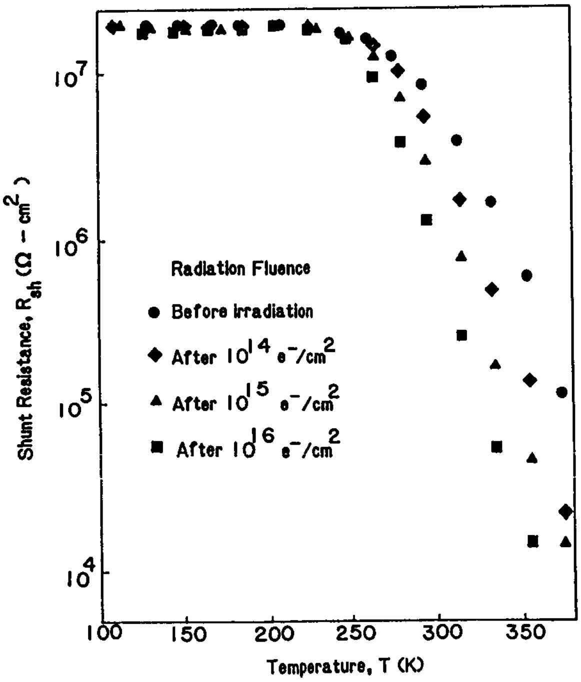

Figure 2. Temperature dependence of $R_{sh}$ for a diffused cell as a function of 1.0 MeV electron fluence.

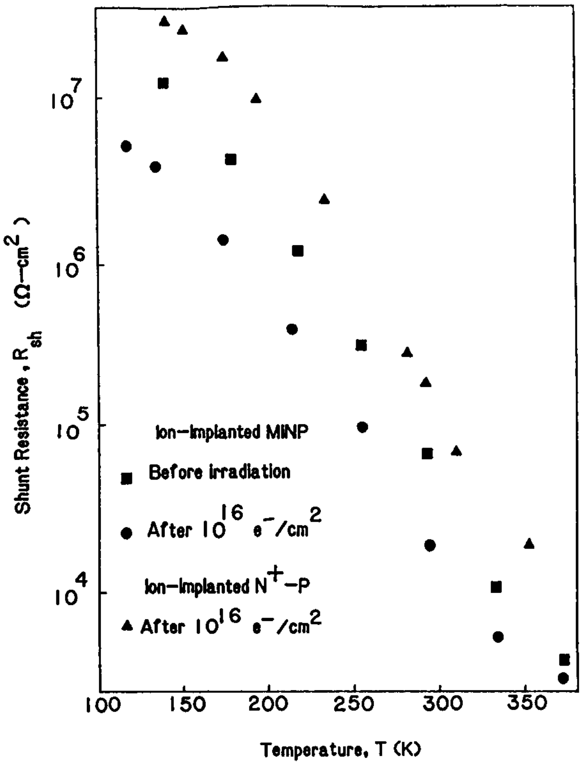

Figure 3. Temperature dependence of $R_{sh}$ for ion-implanted cells as a function of 1.0 MeV electron fluence.

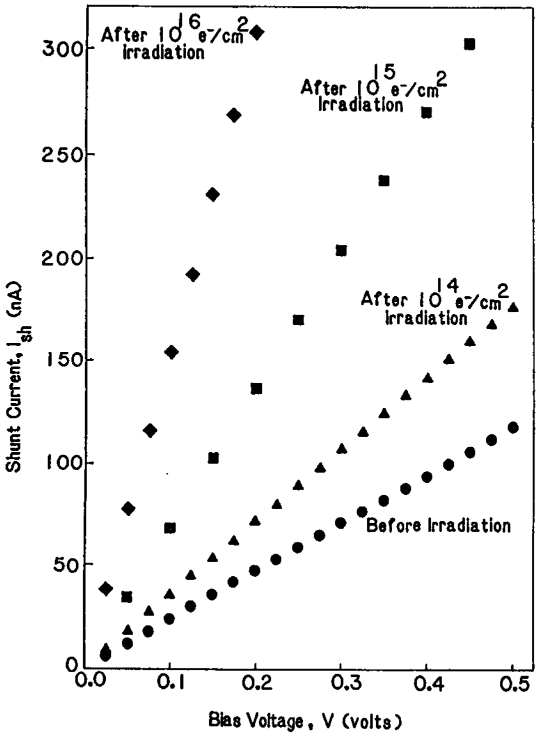

Figure 4. Shunt current variation with bias voltage for a diffused cell as a function of 1.0 MeV electron fluence.