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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 $2.5 \times 10^{15}/cm^2$. 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 $1 \times 10^{14}/cm^2$, $1 \times 10^{15}/cm^2$, and $1 \times 10^{16}/cm^2$. 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 $<1 \times 10^{15}/cm^2$. 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 $T<250\,^\circ K$ 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 $T>100\,^\circ K$. 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.

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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] (Ω- cm^2)	
Sample	Before	After	Before	After	Before	After
1[a]	0.632	0.494	43.1	19.7	8.4×10^6	9.3×10^5
2[b]	0.608	0.506	40.8	23.8	5.0×10^4	1.6×10^4
3[c]	0.626	0.489	42.9	25.7	2.4×10^5	1.2×10^5

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.

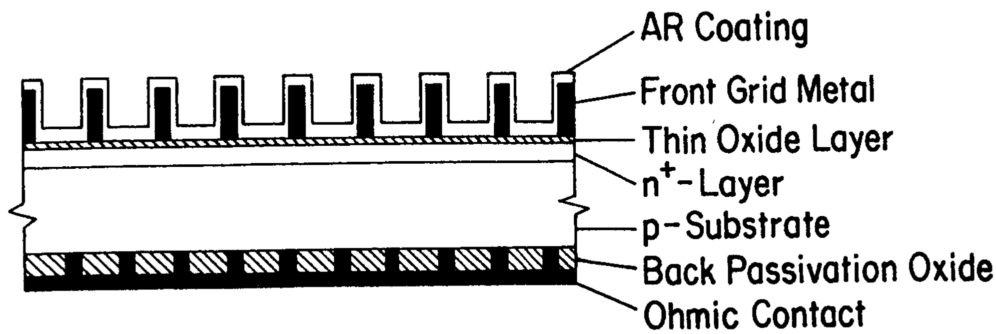

Figure 1. Diagram showing MINP solar cell design.

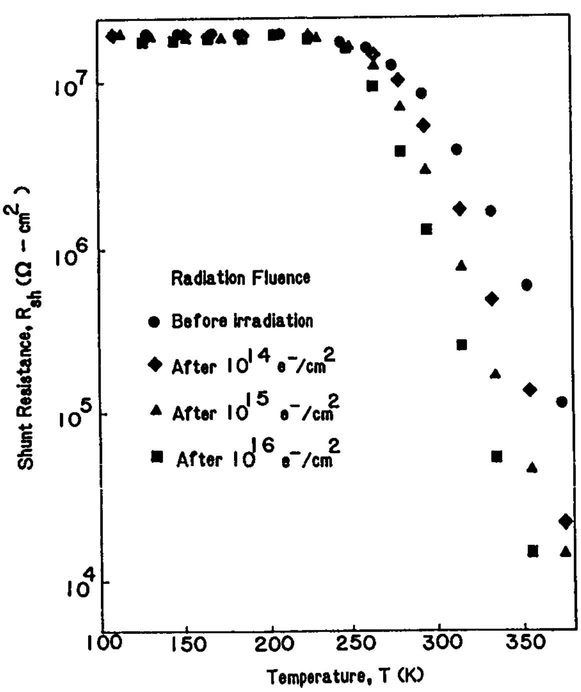

Figure 2. Temperature dependence of R_{sh} for a diffused cell as a function of 1.0 MeV electron fluence.

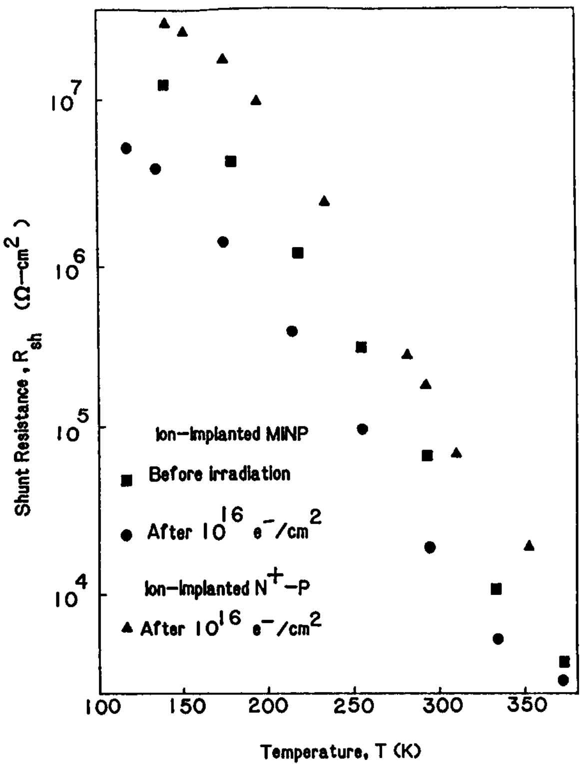

Figure 3. Temperature dependence of R_{sh} for ion-implanted cells as a function of 1.0 MeV electron fluence.

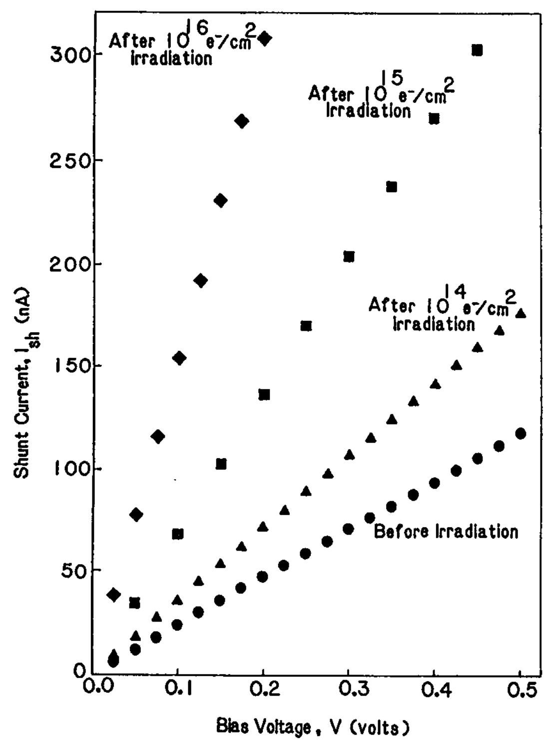

Figure 4. Shunt current variation with bias voltage for a diffused cell as a function of 1.0 MeV electron fluence.