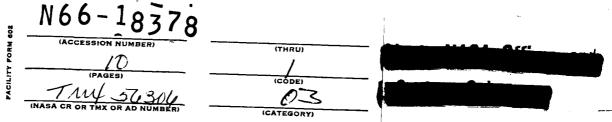# THERMAL ANNEALING OF RADIATION DAMAGED SILICON

by

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We have observed a complete recovery of Silicon solar cells damaged by electron or proton radiation at room temperature by thermal annealing. The technological aspects of these results are very interesting because we can visualize the possibility of rejuvenating solar cells on satellites which have been damaged by space radiation. The purpose of this letter is to report some observations associated with the kinetics of defect annealing in Silicon which have basic physical interest.

In our experiment, the so-called n-on-p solar cells were used. The front surface of the cell, where the light enters, consists of n-type (P-doped) Silicon, about 0.5 μ thick. Under this is an n-p junction of about 0.5 μ thickness. The electrodes are Ag-Ti alloy. The annealing is conducted in a hydrogen atmosphere to avoid the oxidation of the electrodes.

Fig. 1(a) illustrates a histograph of a typical quantum yield (Q.Y.) curve. The base material of this solar cell has 10 Ω-cm resistivity. The curves indicate a profound change of the quantum yield at wavelengths longer than 0.6 μ corresponding to a depth greater than 3 μ, i.e., in the p-region. However, one should not infer a lesser damage susceptibility in the n-region. The appearance of this lesser

damage is due to the p-n junction field which is very near
to the n-region. A complete annealing is demonstrated in
the figure. We have also measured an isochronal annealing.
From room temperature up to 250°C, with annealing time up
48 hours, no annealing in the photovoltaic effect is
observed. We therefore conclude that the E center, which
would be annealed near 200°C, does not contribute significantly
to the photovoltaic effect.

Fig. 1(b) gives the change of Q.Y. from the original
value, due to the radiation of 1 Mev electrons at three
different accumulated flux levels ϕ and consequent annealings
measured at 0.9 μ (with 100Å bandwidth). The results cannot
be explained by an intuitive picture that the number of
annealed defects is proportional to the original number of
defects, as in the model of a radioactive mass decay.
According to this model, larger annealing effects should
be observed in high defect density specimens. Fig. 2 indicates
the opposite.

Fig. 2 shows the isothermal recovery of the short
circuit current. The light source is a Xenon arc. The
curves indicate an initial fast recovery stage, followed
by a slower stage or stages of recovery. Therefore, a single
first or second order kinetics is not adequate to describe
the observation. In the EPR measurement of the rate of defect
production, the flux levels are usually in the order of $10^{17}/cm^2$ (2).
We have shown that even at the 10^{14} electron flux level, the
defect production rate is not a constant. Therefore, it is
not simple to correlate the rate production at high and low
flux levels. In the analysis of radiation damage of solar

cells, with a flux level up to $10^{16}/cm^2$, a tacit assumption of single defect models was made [3]. Since we have shown that there is more than one type of defect, analysis based on a single defect model cannot be accurate.

A strong dependence of the annealing kinetics on the flux level is indicated in Fig. 2. We believe interaction between defects is necessary to explain this effect. If we shift the origins of the time axis for curves of different original damage, and if there is no interaction among different defects, then the consideration of the thermal equilibrium of defects at specific temperatures, and the similarity of the rate of introduction and annealing [4] demands a coalescence of all curves. Our observation cannot be explained by the known kinetics of thermal annealing [4], even generalized by including different species of defects or a distribution of activation energies for annealing [5].

References

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2. G. D. Watkins, Ibid, Ref. 1

3. Simon, Denney and Downing, Phys. Rev. 129, 2454, 1963.

4. Brown, Augustyniak, and Waite, J. Appl. Phys. 30, 1258 (1959).

5. W. Primak, Phys. Rev. 100, 1677, 1965.

List of Figures

Fig. 1(a) - Total quantum yield spectra of a solar cell, original, after radiation and after annealing.

Fig. 1(b) - Successive stage of annealing at $400^{\circ}C$ for different level of damages.

Fig. 2 - Isothermal ($440^{\circ}C$) annealing curve for three levels of damage.

Degradation of Q.Y. (Percent) vs ELECTRON FLUX/cm² — λ=0.9μ, curves for 0 min., 5 min., 10 min. (1b)

Total Q.Y. vs λ(μ) — After Annealing, Before Radiation, φ=4×10¹⁴ (1a)

Figure showing Residual Unannealed Damage % versus Time (min) for three fluence values: $\phi = 1.5 \times 10^{15}$, $\phi = 8 \times 10^{14}$, and $\phi = 4 \times 10^{14}$.

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