

# **ANNEALING AND TEMPERATURE EFFECTS ON MINORITY CARRIERS IN ION IMPLANTED SILICON SOLAR CELLS**

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TABLE 1  
SOLAR CELLS CHARACTERISTICS

EMITTER	
Type	N
Junction Depth	0.2 - 0.3 $\mu\text{m}$
Junction Formation	Implantation of P 5-30 KeV
Doping Level	$10^{19} \text{ cm}^{-3}$
BASE	
Type	P
Crystal Growth	Zone Fusion
Resistivity	10 Ohm.cm
Dopant	Boron
CONTACTS	
Rear	Ti/Pd/Ag
Front	Ti/Pd/Ag

## ABSTRACT

Space use silicon solar cells are devices submitted to annealing procedures during fabrication steps in order to improve their performances and, during their operation, they are submitted to temperatures that can range from  $-200^{\circ}\text{C}$  to  $+200^{\circ}\text{C}$ .

This work studies the impact of annealing procedures and temperature effects on minority carriers lifetime in the bulk of silicon solar cell which will be used in the solar cell experiment of the first brazilian satellite. In the first part we discuss the solar cell fabrication and the annealing procedures adopted and in the second part we discuss the lifetime measurements and analyze the results.

## FABRICATION

A set of space use silicon solar cells were fabricated with parameters detailed in table 1. In order to improve the efficiency of the cells we used a two step procedure which consists of a relatively low temperature conventional annealing (not more than  $500^{\circ}\text{C}$  for half an hour) followed by a rapid thermal procedure. The idea is to avoid high temperature exposures for long time. The conventional anneals defects in the emitter due ion implantation. Keeping time exposures of few seconds in the second procedure one can avoid high temperature defects in the base.

## ANNEALING OF ION IMPLANTED SILICON SOLAR CELLS

The damage type produced by the incident ion in the implantation and its recommended annealing process depends mainly on the dose and substrate temperature. For implantations made at room temperature, three types of damage type are possible: a) presence of moderated desordenated regions due to low doses implantations, b) presence of amorphous layers due to high doses implantations or c) the overlapping of amorphous layers and regions with moderated disorientation (1).

The damage caused by the implantation process is of the c type, which makes annealing a difficult task. In this work it was tried a combination of a conventional with a rapid thermal annealing (RTA) as shown in figure 1. The first part has the aim the recovery of the lattice after the ion implant, temperatures of  $500^{\circ}\text{C}$  are enough. In the other hand, the defects due to the ion beam exposure are not annealed in this first step. A second step, which consists of a short exposition under temperatures of  $650^{\circ}\text{C}$  to  $1000^{\circ}\text{C}$  is done to activate the implanted dopant atoms.

The advantage of the use of this two step procedure become clear by observing that the use a simple RTA although increases the dopant activation in the emitter, as can be seen in the curve of the sheet resistance as function of annealing temperature of figure 2, that shows a decreasing of sheet resistance with temperature, decreases the short circuit current, as can be seen in figure 3, which means that this process increases the defects concentration in the base.

The curves presented in figures 2 and 3 refer to RTA procedures of 15 seconds in the range of  $650$  to  $900^{\circ}\text{C}$ .

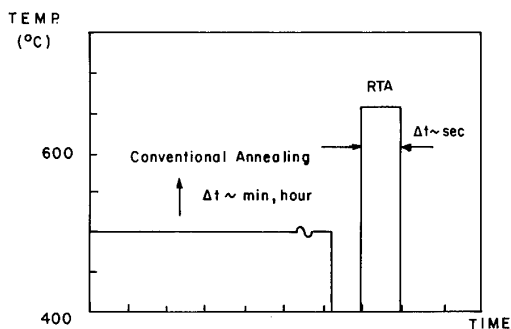


Fig. 1 Two step annealing process combining a conventional low temperature step with a rapid thermal annealing step.

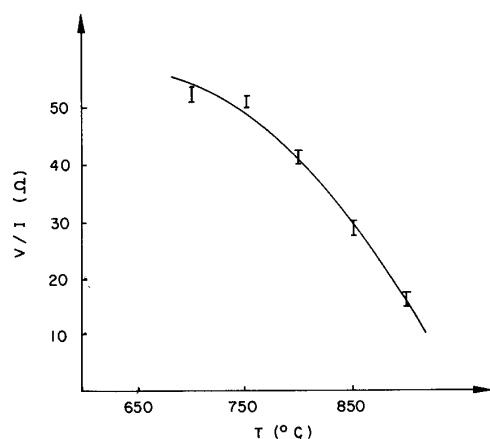


Fig. 2 Sheet resistance as a function of annealing temperature.

#### LIFETIME IN THE BASE OF ION IMPLANTED SOLAR CELLS

Lifetime in the base of silicon solar cells is a parameter largely affected by annealing procedures and operation temperature. Ion implantation tends to damage mainly the surface, which means, the emitter, the depletion region and, perhaps, the base region closed to the depletion zone.

In order to identify if the implantation process affects the base or depletion region, it were used well known transient techniques as ESCCD (Electrical Short Circuit Current Decay)(2), ECVD (Forward Current Voltage Decay)(3) and PVD (Photovoltage Decay)(4) to obtain the lifetime in the bulk and depletion zone.

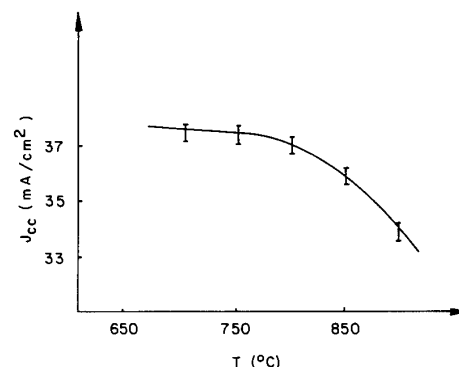


Fig. 3 Short circuit current as a function annealing temperature (RTA, 15 seconds).

The dominant base minority carrier recombination process in a mono crystalline silicon solar cell with base doping concentration in the range of  $10^{14}$  to  $10^{17} \text{ cm}^{-3}$  is that through recombination centers within the energy gap(5). The lifetime due to a single state in the forbidden band, for a  $n^+ \text{ ON P}$  solar cell, is given by.

$$\tau_{nt} = 1/(\sigma_{nt} \cdot v_{th} \cdot N_t) \quad (1)$$

where  $\tau_{nt}$  is the lifetime involving the energy level  $E_t$ ,  $v_{th}$  is the thermal velocity,  $\sigma_{nt}$  is the cross section of the defect and  $N_t$  is the number of states per volume with energy  $E_t$ .

It is of interest to know how is the behavior of lifetime with temperature. All the parameters present in Eq. 1 vary with temperature and only the thermal velocity has its dependence known ( $v_{th} = 3KT/m^{1/2}$ ). The difficulty of know how the cross section and density of defects arise from the fact that each defect can be activate in a given temperature, different from the order.

To verify the behavior of lifetime with operation temperature we measured lifetime for the cells of table 2, and the results are shown in figure 4.

Non-linear effects were verified for cells number 3 and 5. It is probably that in temperatures around  $15^\circ\text{C}$  for cell number 5 and  $40^\circ\text{C}$  for cell number 3 there are defect activation. The range studied, from  $10$  to  $75^\circ\text{C}$  are respectively the low and high limits of cell temperatures for a low orbit (700 km) satellite.

Annealing is another process which affects lifetime of solar cells. Figure 5 shows how a conventional annealing of  $400^\circ\text{C}$  for 10 to 50 minutes can restore the lifetime of a irradiated silicon solar cell.

TABLE 2  
SILICON SOLAR CELLS CHARACTERISTICS

Cell Number	Base Resistivity	Junction	AM0 Efficiency
1	CZ 10 $\Omega$ .cm	D	11.3
2	CZ 0.1 $\Omega$ .cm	D	12.8
3	CZ 10 $\Omega$ .cm	I	11.7
4	FZ 10 $\Omega$ .cm	I	13.3
5	CZ 1 $\Omega$ .cm	D	13.2

CZ = Czochralski, FZ = Fuzion Zone, D = Diffused, I = Implanted.

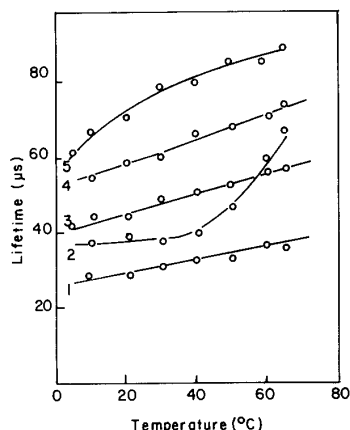


Fig. 4 Curves of lifetime versus temperatures for the solar cells listed in table 2.

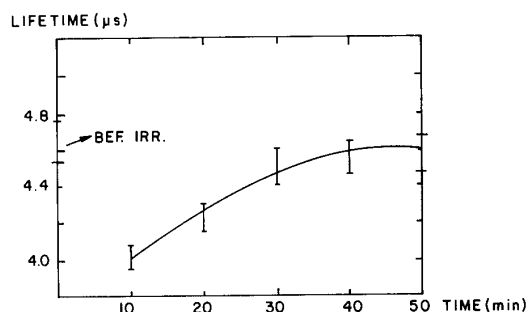


Fig. 5 Lifetime recovery for a conventional annealing for a silicon solar cell irradiated with 1 MeV electrons.

The radiation flux used was  $1 \times 10^{14} \text{ el/cm}^2$ . For this level almost 85% the initial lifetime recovered in fifty minutes. This results shows that even when the solar cell is exposed to high energy electrons, the annealing of defects in the base can be done in relatively low temperatures

(lower than 500°C).

Finally we show the results for a two step thermal annealing (conventional annealing followed by RTA). A set of implanted solar cells were annealed between 2 and 16 seconds in two temperatures: 750°C and 850°C. The lifetime was measured for each cell and the results are shown in figure 6.

The results shows that lifetime in the base of a silicon solar cells decreases with annealing time for both temperatures. Between 2 and 4 seconds the lifetime in the base is not so affected. This result explain why the short circuit current is so affected by the temperature and time in the RTA procedure

The lifetime in the depletion zone is another parameter which can be obtained from transient measurements (6). As the depletion zone is a region closed to the emitter, the lifetime behavior in this region can make a indication of what is happening in the emitter. Figure 7 shows the curves of lifetime in the emitter for the two step procedure.

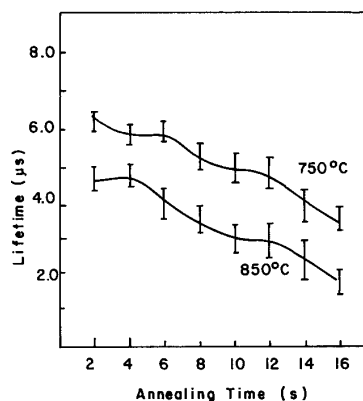


Fig. 6 Lifetime dependence for a two step annealing procedure.

The lower slope of lifetime decreasing with annealing time observed in figure 6 in relation with that observed in figure 7 can be attributed to the detect annealing of the implanted ion in the emitter, which is verified also in the depletion region.

#### CONCLUSION

The lifetime of the tested solar cells increased with operation temperature, but the lifetime variations with respect to the operation temperature seems not to follow a simple function, varying significantly with the fabrication parameters as wafer growing method, wafer resistivity and junction preparation (by diffusion or implantation).

Conventional annealing at 400°C of a irradiated solar cell is enough to restore almost all the lifetime. For implanted so

lar cells, a combination of the conventional annealing and RTA seems to be the most effective procedure to anneal the emitter defects without damaging significantly the base.

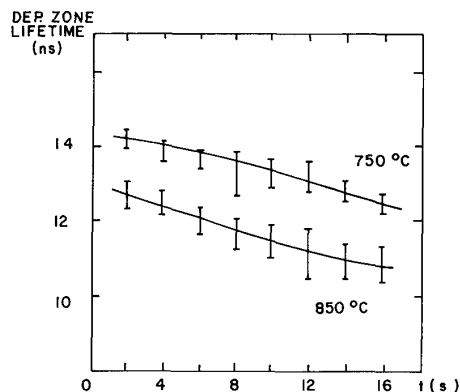


Fig. 7 Lifetime in the depletion region for implanted solar cells annealed in a two step procedure.

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