# MODELING OF RADIATION DAMAGE IN SILICON SOLAR CELLS

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## EXTENDED ABSTRACT

The goal of this program is the quantitative analysis of damage production and annealing in silicon solar cells. This necessitates treating all the defects present in the solar cells. But no measurements monitor all the defects. Silicon solar cell performance depends on the defects responsible for the minority carrier lifetime, but is insensitive (at room temperature) to major defects which have sufficiently shallow electrical levels, such as the [vacancy + oxygen] center in n-type material. Transient capacitance techniques (such as DLTS) monitor only carrier traps, infrared techniques only infrared active defects, EPR only defects with unpaired spins, etc. But the dynamics of defect production and annealing reflect all the defects and hence information from all the sources must be exploited to get as complete a picture as is possible.

The qualitative features of defect production in silicon at room temperature have now emerged (although some aspects need confirming work).

One MeV electron irradiation produces preponderantly isolated vacancy-interstitial pairs. If neither of these defects are mobile, the concentration of each grows linearly with fluence (until extremely high fluences where saturation occurs, a regime we will not consider further here).

Annealing of damage depends on the nature of the damage. Vacancy-interstitial pairs which are bound by an interaction such that they mutually annihilate rather than dissociate are termed close-pairs; close-pair recovery usually occurs at a lower temperature than the temperature at which long distance defect migration occurs. Annealing of the remaining frozen-in damage occurs when a temperature is reached where the vacancy or interstitial is mobile; usually the interstitial is more mobile than the vacancy. The recovery occurs in two regimes which may be resoluable. The first is termed correlated recovery in that the mobile interstitial, say, annihilates with "its own" vacancy, i.e., the one with whom it is spatially correlated because of the damage production process. The interstitials that escape correlated recovery can find other vacancies and undergo annihilation, which process is

called uncorrelated recovery.

If the interstitial is mobile during irradiation and if there is no interstitial agglomeration or trapping, then a steady-state concentration of interstitials and vacancies is established, which decays to zero when irradiation ceases, i.e., there is no permanent damage. If agglomeration can occur then permanent damage will be produced, as is also true if the vacancy is also mobile.

If there is an impurity capable of trapping a mobile defect in the material then the trapping process will compete with defect-annihilation and -agglomeration. The trapping efficiency in the uncorrelated recovery regime is proportional to the impurity concentration until all the uncorrelated recovery is suppressed by trapping. Several experiments suggest that this uncorrelated trapping occurs in n-type silicon. Additional impurity concentration will intrude on the correlated recovery, trapping one of the defects and suppressing some of the correlated recovery. The hall-mark of this process is that the impurity trapping efficiency in the correlated regime is that it is proportional to the square root of the impurity concentration. Several experiments suggest that defect trapping by boron in p-type silicon occurs by this process.

Experimentally we do not have firm identities for all the defects. Progress has been made, however, by the identification of some defects. For example, it has been found that carbon plays an important role in defect-production in p-type silicon, which has led to the thrust to obtain low-carbon, low-oxygen silicon. We have found (on the basis of experimentation with the small amounts of this material available to us) that indeed the damage (as monitored by DLTS measurements) is reduced in this material. (See Fig. 1.) Clearly further experimentation of this type is warranted.

The quantitative analysis of all the electrically active defects has thus far proven illusive, because of the complexity of the processes and many parameters involved. We have consequently gone to high fluence experiments where we have determined the capture parameters for the substitutional carbon, interstitial carbon, and interstitial oxygen. Of particular interest is the enhancement of vacancy-oxygen production by increased boron concentration, which we explain by the substitutional-boron (with the Coulomb interaction radius of 70 Å) attracting the interstitial from the correlated-recovery and freeing the vacancy to interact with oxygen.

The quantitative modeling of damage production and annealing is continuing.

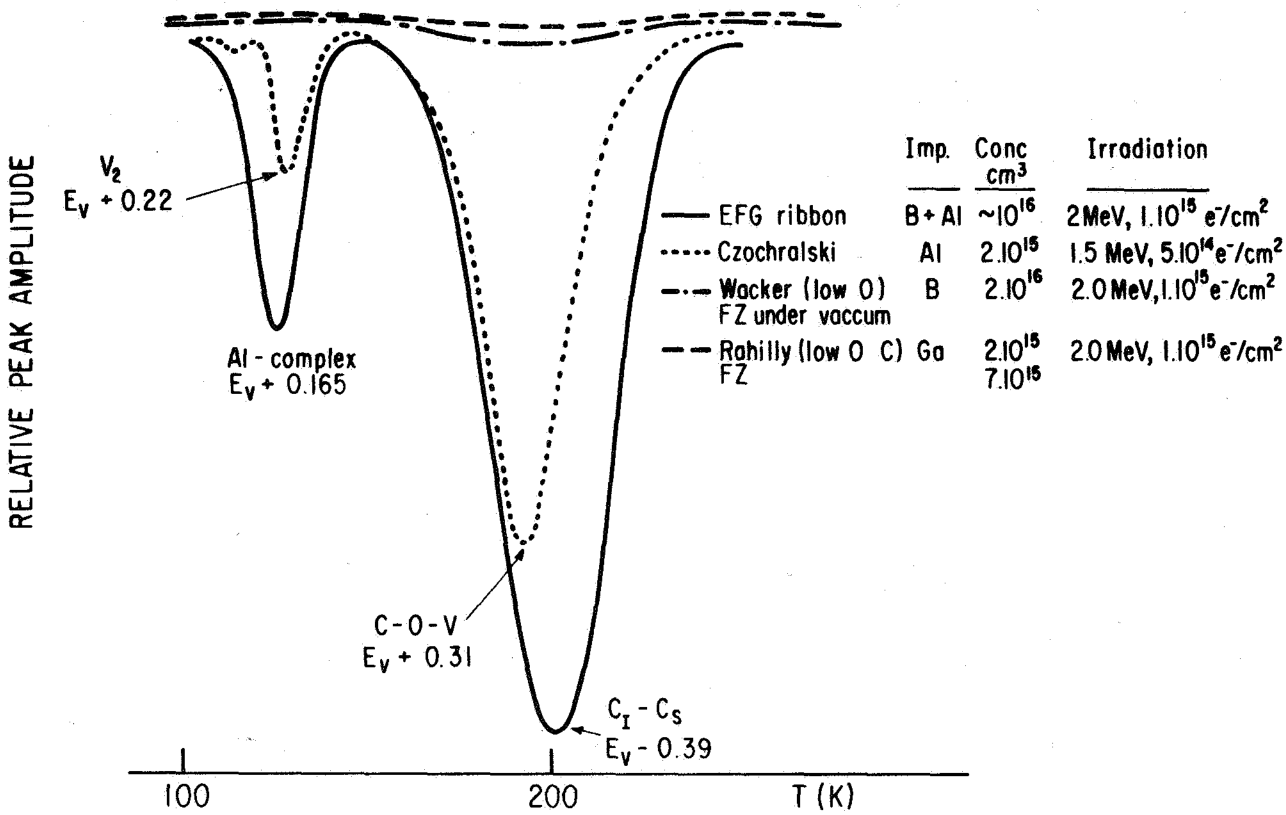


Figure 1. Pulsed Capacitance (DLTS) measurements vs Temperature (T) for several types of silicon samples.