Measuring Defects in Silicon Damage Cascades

by ***R. M. Fleming***

Motivation—The QASPR program seeks to predict the performance of silicon transistors following fast neutron irradiation we must first measure the device response following an alternative radiation such as heavy ions. Data from the alternate sources provide input to models that predict the response of the device to fast neutrons. Atomistic inputs to the models are based both on physical information about defects from the literature and from measurements of defects in a clustered-defect environment typical of neutron damage. The primary experimental source of atomistic information is deep level transient spectroscopy (DLTS). DLTS was originally developed to study modest damage from a uniform distribution of point defects. In this program we have needed to both extend the DLTS technique to include clustered damage characteristic of neutrons and to apply the technique to actual devices, here silicon bipolar transistors.

Accomplishment—Defects that are important in modeling radiation-induced gain reduction of a bipolar transistor are located near the emitter-base junction. Two important defects have been identified; the vacancy-phosphorus (VP) and the divacancy (V_2), and both defects can be seen in DLTS of n-type silicon. Deconvolution of these two defects from DLTS spectra in the base is difficult because of overlap of the VP and V_2 signals. We have been able to attack this problem by analysis of DLTS spectra from the collector. The number of VP defects in the collector is much smaller, allowing one to study the behavior of the V_2 in neutron damage cascades.

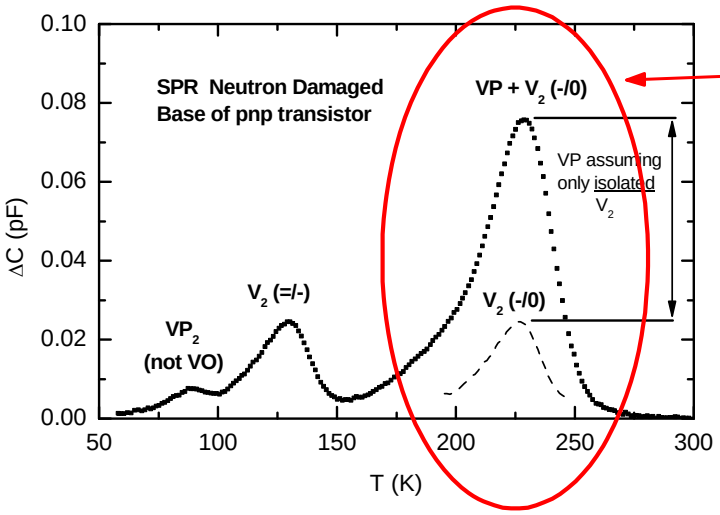
Using careful studies of the annealing of V_2 in the collector following neutron irradiation, we have found at least three types of V_2 defects. These are: (1) normal V_2 defects also seen in the case of uniform damage (2) strained V_2 defects located within a damage cascade and (3) bistable V_2 defects also located within the cascade.[1,2] The bistable V_2 is only seen if one first injects minority carriers at room temperature.

Two fortuitous properties of the bistable V_2 allow us to use it to deconvolve the VP and V_2 signals in the base. First, the positions of the two bistable V_2 peaks are sufficiently shifted to allow easy measurement and second, we have shown in the collector that one can predict the normal plus strained V_2 DLTS by a simple scaling of the bistable V_2 signal. Measurements of the bistable V_2 in the base thus allow us to determine the annealing behavior of the V_2 which is obscured by the VP defect. We subtract a scaled bistable V_2 signal (representing the normal plus strained V_2) from the total signal, and this allows us to deduce the fraction of deep defects that are comprised of VP.

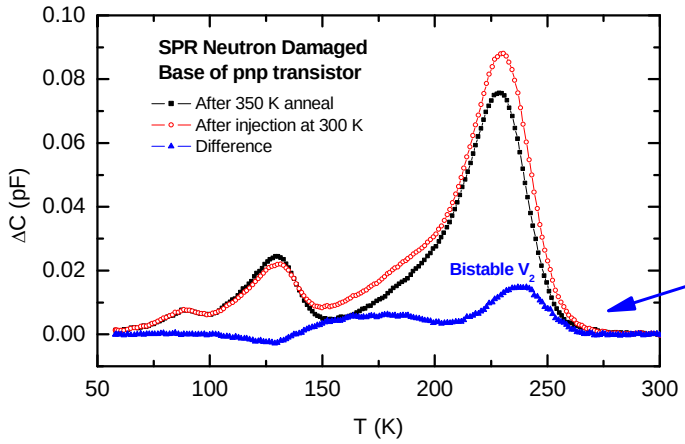
Significance—Our results provide critical information and are part of the validation of the QASPR models. In the case of silicon devices, DLTS data are the only source of independent experimental data from actual devices in a neutron environment. We have also shown that one can extend DLTS, a technique designed to examine dilute impurities, in a clustered environment characteristic of neutron damage.

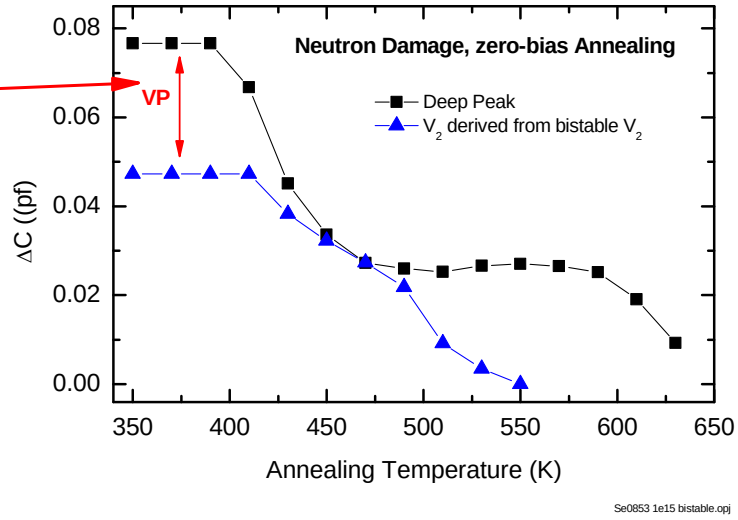
[1] R. M. Fleming, C. H. Seager, D. V. Lang et al., Appl. Phys. Lett. *90*, 172105 (2007).
[2] R. M. Fleming, C. H. Seager, D. V. Lang et al., J. Appl. Phys, in press (2008).

Sponsors for various phases of this work include: Nuclear Weapons Program: Nuclear Survivability Campaign
Contact: Robert M. Fleming, Semiconductor Materials and Device Sciences, Dept. 1123
Phone: (505) 284-8460, Fax: (505) 844-1197, Email: rmflemi@sandia.gov



Problem: DLTS of the transistor base contains at least two defects that degrade gain, VP and V2, and both have the same emission energy.



Solution: Use the bistable V_2 obtained by minority carrier injection to estimate the amount of normal plus strained V_2 in the transistor base.

Measurement and scaling of the bistable V_2 allows one to determine amount of normal + strained V_2 and consequently the amount of VP.