Resolving Neutron Induced Defects in the Silicon Bipolar Transistor

by R. M. Fleming

Motivation—A number of issues complicate the accurate measurement of defects responsible for gain reduction in neutron irradiated silicon devices. These include the clustered nature of neutron displacement damage, the higher doping of the base, and an understanding of the types of defects in neutron damage cascades. A particularly difficult issue is that the deep level transient spectroscopy (DLTS) signatures of the important defects overlap making the relative contribution of the various defects difficult to assess.

Accomplishment—From earlier work on silicon point defects, it is well known that two deep levels in silicon, the vacancy phosphorous (VP) and the divacancy (V_2) contribute to gain reduction following irradiation. We showed earlier that an additional defect can be found within neutron damage cascades that is not present when the defects are uniformly distributed. We term this additional defect V_2^*. The structure of V_2^* is not known, and the name is chosen to reflect the fact that it has the same broad annealing characteristic seen using infrared absorption of V_2 after neutron irradiation. V_2^* may contain other primary defects, e.g. the interstitial, but it does not contain impurity atoms. It is the goal of this work to separate the overlapping DLTS signature of VP, V_2 and V_2^* in the transistor base into its constitutive components.

We accomplished this task by understanding the annealing characteristics of each of these defects at annealing temperature above room temperature. The annealing characteristics of V_2^* were obtained from our own measurements in the transistor collector where little VP is present. The annealing characteristics of VP were taken from the literature where it is shown that VP anneals faster in the zero charge state and from our own measurements of transistor irradiated with non-end of range (EOR) 36 MeV silicon ions where less V_2^* is present. Based on the literature and our own measurements, we assume that the single acceptor level of the isolated V_2 defects does not anneal over the temperature region of interest.

We constructed polynomial functions that give the proper shape of the annealing functions and we fit the amplitude of these functions to measured DLTS spectra as a function of annealing temperature and junction bias. The results for neutron irradiation in the Sandia Pulsed Reactor (SPR) are shown in Fig. 1 where the black squares represent the DLTS spectrum before annealing and the red triangles are the spectrum after annealing at 530 K. VP_2 grows as the annealing temperature is raised because VP becomes mobile and moves to a P^+ donor. V_2 (=/-) decreases because V_2 becomes mobile above 500 K and it may also move to a P^+ donor. Our analysis shows that the deep defects responsible for gain reduction after neutrons consist of about 42% VP and equal parts of V_2^* and V_2 (29% each). DLTS spectra of 36 MeV Si ion damaged transistors, which have fewer damage cascades and less V_2^*, are shown in Fig. 2. A similar analysis shows a larger VP and a smaller V_2^* component in this case as expected.

Significance—The separation of the DLTS spectrum into its constitutive components is the first step toward measuring the relative effectiveness of each of these defects in reducing gain. We are currently in the process of correlating these data with similar annealing measurements of transistor gain.

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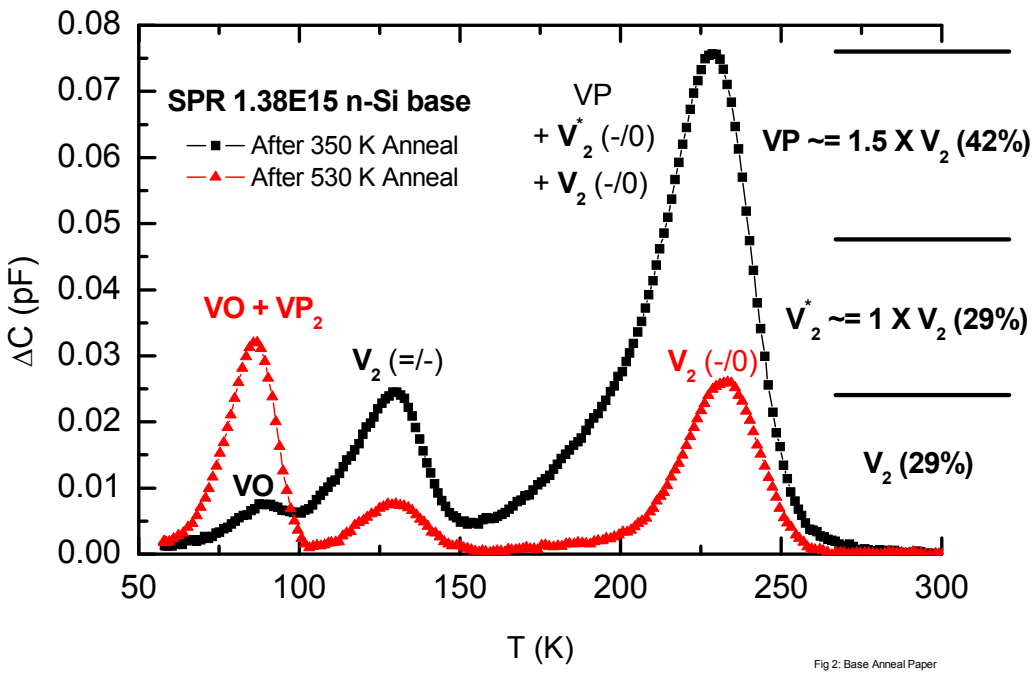

Figure 1. DLTS of the n-type base after annealing a neutron-damaged pnp to 350 and 530 K. Analysis of the deep DLTS peak at about 230 K reveals that it is composed of about 42 % VP and equal parts of V_2^* and V_2.

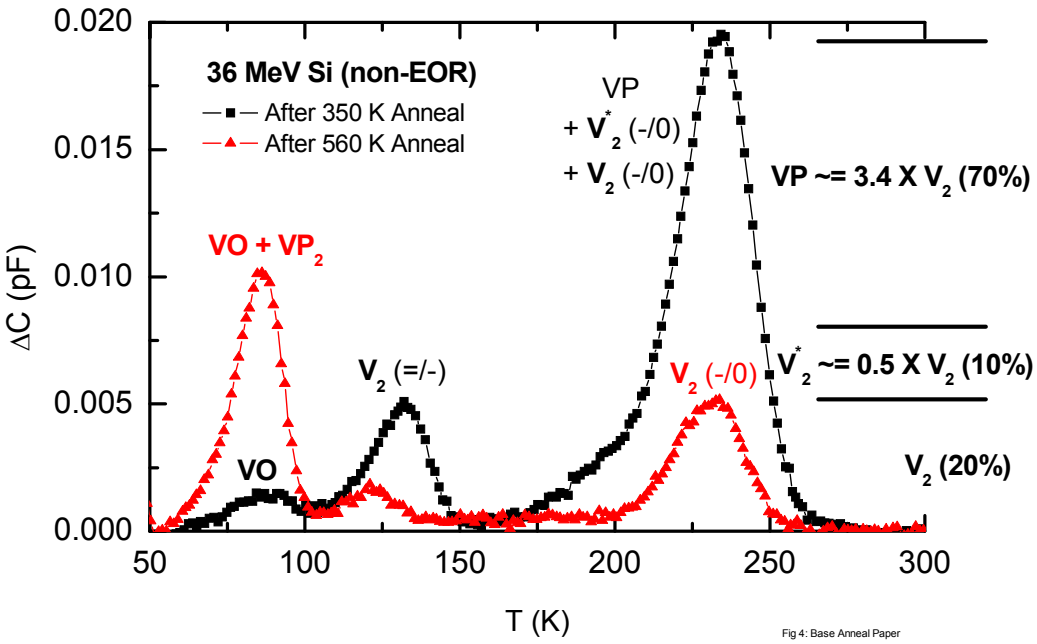

Figure 2. DLTS of the n-type base after annealing a pnp transistor damaged with 36 MeV Si ions to 350 and 530 K. Damage with ions of this energy are expected to produce less clustering and less V_2^*. Here, analysis of the deep DLTS peak at about 230 K reveals that it is composed of about 70 % VP.