DLTS and Gain Measurements of Bipolar Transistors Following Ion Irradiation

by **R. M. Fleming, C. H. Seager and D. V. Lang**

Motivation—As an alternative to testing at the Sandia Pulsed Reactor (SPR), now slated for shutdown, the QASPR program (Qualification Alternatives to SPR) has been initiated to model the time-dependent performance of devices and circuits following transient neutron irradiation. Experimental input to modeling will come from measurements of defects in the devices by deep-level transient spectroscopy (DLTS) and measurements of device performance. Data from a number of facilities will be used to establish damage equivalence between the alternate radiation sources and SPR.

Accomplishment—An apparatus has been constructed at the Ion Beam Lab that allows irradiation of devices at 35 K and the automated acquisition of DLTS, gain, and photocurrent data as the device is warmed. This apparatus will be replicated for use in other facilities such as the SPR. Since the time-dependence of device performance is desired and DLTS is not a real-time probe, the time dependence of the defect concentrations will be extracted from the temperature dependence of the DLTS signal following isochronal anneals. The initial studies will be on silicon bipolar transistors.

The first DLTS data from the ion-beam apparatus are shown in Fig. 1 where we plot the signal from the base/collector junction of a 2N2222 npn transistor following irradiation with 28 MeV Si^{4+} ions. Ten-minute isochronal annealing temperatures as well as the energy levels of common silicon defects are indicated. A prominent, broad feature is seen in the range 140 – 240 K that corresponds to a distribution of states in the gap about 0.3 eV below the conduction band. Most of the broad feature anneals out by 300 K, but a shoulder remains to about 400 K. A second feature of these data is that the carbon interstitial peak appears only after annealing at 250 K, which is much later than expected. Since this peak arises from silicon interstitial motion, we can conclude that motion of the silicon interstitial is inhibited under the conditions of our experiment.

Gain measurements are shown in Fig. 2 where we show Gummel plots measured at 300 K. A recovery of gain is seen after the 550 K anneal, which is accompanied by the loss of DLTS signal from the shoulder mentioned above and from defects identified as vacancy-donor and perhaps boron interstitial. Since DLTS is most sensitive to defects in the base/collector and gain is strongly affected by defects in the base/emitter junction, a full understanding of the response of the transistor to defects will require measurements of both npn and pnp transistors.

Significance—Although defects in silicon have been extensively studied for three decades, these data represent several new aspects. First, the bulk of the previous data were on uniformly damaged silicon, typically using electrons. Here we concentrate on damage by neutrons or ions which are likely to produce clusters of defects as well as different species of defects. Second, the previous studies were done following room temperature irradiation, and the intermediate information on defect evolution was lost. Here, using a new and unique apparatus, we show the intermediate phases of defect evolution. Finally, unlike earlier work, we measure the defects in devices rather than test structures, and we can therefore correlate defect measurements with device performance.

Sponsors for various phases of this work include: Nuclear Weapons Program

Contact: Robert M. Fleming, Semiconductor Material & Device Sciences, Dept. 1123
Phone: (505) 284-8460, Fax: (505) 844-1197, E-mail: rmflemi@sandia.gov

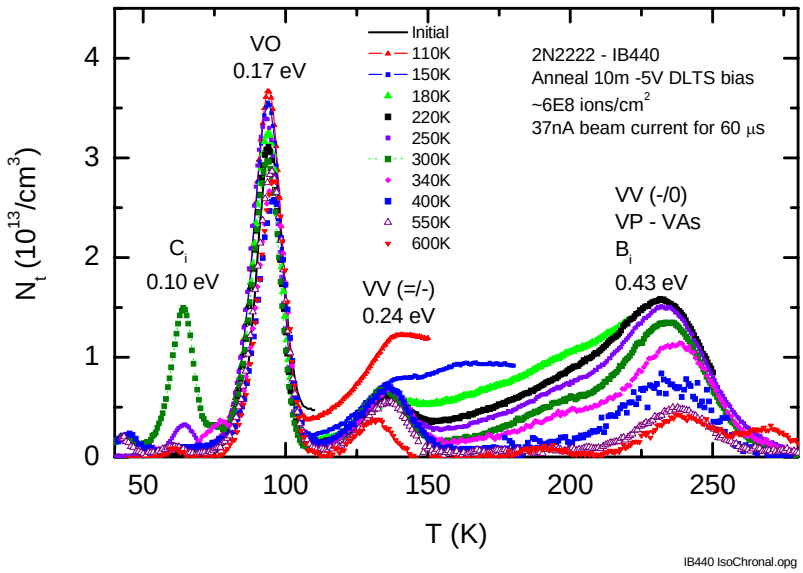

Figure 1. DLTS following 35K irradiation and 10 minute isochronal anneals at the temperatures indicated Energy levels referenced to the conduction band of common silicon defects are shown.

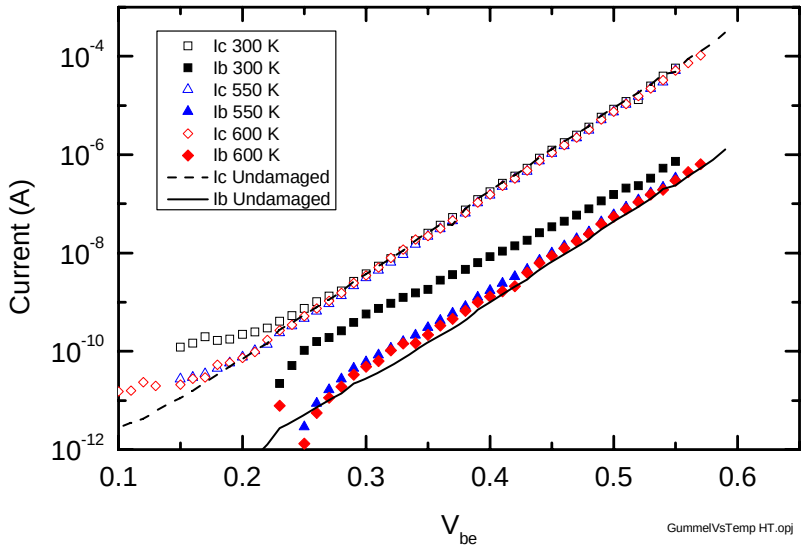

Figure 2. Base and collector current versus V_{be} for an undamaged device and following 300, 550 and 600 K anneals. A significant gain recovery is seen after the 550 K anneal.