The Science of QASPR (Qualification Alternatives to the Sandia Pulsed Reactor) in Sandia's Physical, Chemical, and Nano Sciences Center (PCNSC)

by ***S. M. Myers***

Motivation—The QASPR program is developing means to certify electronic systems for intense bursts of MeV neutrons without the Sandia Pulsed Reactor (SPR), decommissioned in Sept. 2006. Testing in available irradiation facilities will be combined with new, science-based modeling to predict time-dependent device and circuit performance under inaccessible conditions. A central concern is carrier recombination at neutron damage in Si bipolar-junction transistors (BJTs). Gains may be reduced from > 100 to < 1, and rapid damage evolution causes this reduction to vary greatly over times from microseconds to seconds.

The PCNSC has two key roles in QASPR. Our theoretical and experimental studies to characterize the fundamental, interrelated behaviors of defects and carriers – and to devise new methods for their mathematical representation – enable the modeling of devices. Further, research in the Ion Beam Laboratory (IBL) is establishing pulsed ion irradiation as a tool for assessing the transient response of devices to displacement damage.

Accomplishment—IBL is among the primary irradiation facilities to be used in QASPR qualification procedures. Ed Bielejec and George Vizkelethy are developing experimental capabilities to provide ever more intense and better quantified pulses in the µs range. Simultaneously, they are researching the similarities and differences of neutron and ion-beam effects. They have recently focused on the time dependence of gain reductions under ion bombardment and its consistency with results from neutron irradiation and from modeling, as discussed in these Briefs.

I previously developed the code Cluster to describe the time evolution of defects and their carrier reactions in a recoil cascade produced by one neutron collision. With Bill Wampler, I validated this model by comparing its results with electrical and Deep Level Transient Spectroscopy (DLTS) measurements under neutron and electron irradiations where results reflected a single local condition (in contrast to the multiple disparate regions of a BJT). Favorable results, described in the present Briefs, led me to write a new transistor model, 1DC, incorporating multiple instances of Cluster and running parallel on a large machine.

Photocurrents due to gamma ionization and carrier recombination at neutron damage were long considered separately, neglecting the large reduction of photocurrent by the recombination. Bill Wampler has now used our device model 1D to quantitatively describe the combined effects for SPR, as described in these Briefs.

Robert Fleming is successfully extending DLTS to the doubly challenging problem of clustered neutron damage within an actual transistor instead of an idealized structure, as discussed in these Briefs. His characterization and counting of defects is providing unique guidance for the device modeling as well as new fundamental understanding of the defect physics.

QASPR modeling depends critically upon the theoretical calculations of Normand Modine and Alan Wright, who are using density-functional theory (DFT) to obtain defect properties inaccessible to experiment. For example, the bandgap levels and diffusion coefficients of the Si interstitial are taken entirely from DFT, (S. M. Myers, P. J. Cooper, and W. R. Wampler, J. Appl. Phys. *104*, 044507 (2008).

Significance—Work within the PCNSC enabled the success of the Simple Prototype device exercise, the most important milestone of QASPR to date. See Fig.1 .

Sponsors for various phases of this work include: Nuclear Weapons Program: Nuclear Survivability, Advanced Simulation & Computing, Enhanced Surety, and Enhanced Surveillance Campaigns

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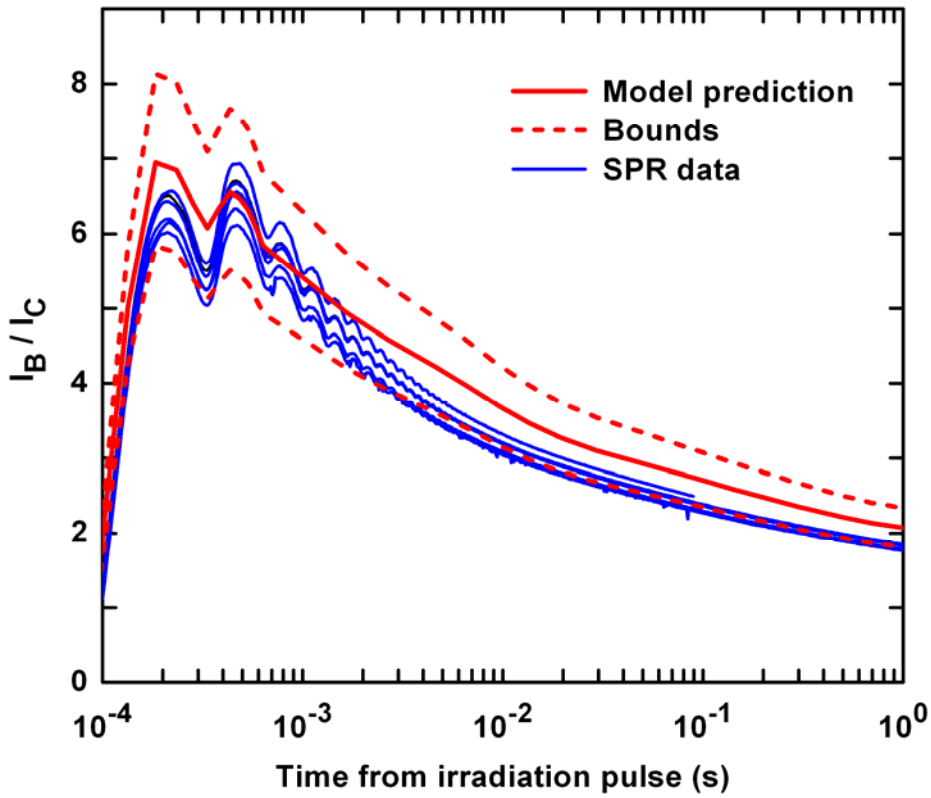

Figure 1. Results from the Simple Prototype device exercise: blind predictions of the test-calibrated model show impressive agreement with experimental results for the inverse gain of a Fairchild 2N2222 npn BJT exposed to a maximum SPR pulse. These exploratory calculations by Bill Wampler, using the physics-development code 1D from 1100, served to prototype the formal Simple Prototype exercise that was subsequently carried out with the ASC code Charon, developed in the Computer and Information Sciences Center. The downward excursion and oscillations at small times are due to photocurrents arising from gammas, an effect included in the modeling. (The SPR reactor experienced minor mechanical instabilities during pulse termination, producing variations in output that led to the observed oscillations.) It is noteworthy that the variation of inverse gain with damage level is increasingly faster than linear as the inverse gain rises above 1, making the test more challenging.