Qualification Alternatives to the Sandia Pulsed Reactor (QASPR) Program Science in Sandia's Physical, Chemical, & Nano Sciences Center (PCNSC): Overview

by **S. M. Myers**

Motivation—QASPR is developing means to certify electronic systems exposed to intense bursts of MeV neutrons without using the Sandia Pulsed Reactor (SPR), which was decommissioned in Sept. 06. Testing in still-available irradiation facilities will be combined with new, science-based modeling to predict device and circuit performance under general conditions of interest. The most immediate concern is carrier recombination at neutron displacement damage in Si bipolar-junction transistors (BJTs). Such carrier loss is offset by additional device currents that, in turn, reduce gain (Fig. 1). The gain reduction is often large–from ~200 to <1 during SPR-cavity irradiations–and varies on the scale of microseconds to seconds after the pulse due to defect annealing.

Such science-based prediction is a challenge requiring new advances in irradiation methods, diffusion-reaction modeling, defect physics, and device characterization. These QASPR developments are occurring largely within Sandia's PCNSC, and engaging a variety of experimental and theoretical expertise within the Center. Recent progress is detailed in the following Briefs.

Accomplishment—The Ion Beam Laboratory (IBL) within Sandia's PCNSC is currently unique in producing SPR-level defect concentrations at multi-µm depths in pulses as short as 10 µs. Ed Bielejec and George Vizkelethy have developed new capabilities within the IBL and have performed extensive experiments characterizing the ion damage in Si and its influence on BJT gain. As a result of their efforts, IBL is currently among the three primary irradiation facilities to be used in QASPR qualification procedures [along with Sandia's Annular Core Research Reactor (ACRR) for longer neutron pulses and the MEDUSA LINAC at Hill AFB, Utah, for pulsed-electron-beam ionization].

Bill Wampler and Sam Myers have developed the defect physics used in QASPR modeling based on the open literature and ongoing experimental and theoretical studies at Sandia. Sam has written a code to model defect evolution within the submicrometer recoil cascades produced by neutrons. Further, he has developed a device-model code that Bill has used extensively to test physics and prototype qualification procedures.

Normand Modine and Alan Wright are applying density-functional theory (DFT) to fundamental defect properties needed for QASPR modeling but inaccessible to experiment, such as the band-gap levels and diffusivities of the Si self-interstitial. Pursuant to the robust fidelity required for system qualification, they have pushed DFT to new levels of rigor and accuracy through in-depth studies of convergence.

Robert Fleming, with consultants Carl Seager and David Lang, has used deep-level transient spectroscopy (DLTS) to characterize neutron and ion damage in QASPR devices and correlate specific features with device gain degradation. Further, Robert, *et al.*, have made fundamental advances in understanding the novel features of neutron damage arising from defect clustering within recoil cascades.

Bas Vaandrager has utilized construction analysis, secondary ion mass spectrometry (SIMS), spreading-resistance, and electron beam induced current (EBIC) to achieve device characterizations sufficiently accurate to reproduce pre-irradiation device properties with slight parameter adjustments. This contrasts with the extensive empiricism typically used in device modeling but problematic for science-based treatments.

Sponsors for various phases of this work include: Nuclear Weapons Program and Advanced Simulation & Computing Technologies (ASC)

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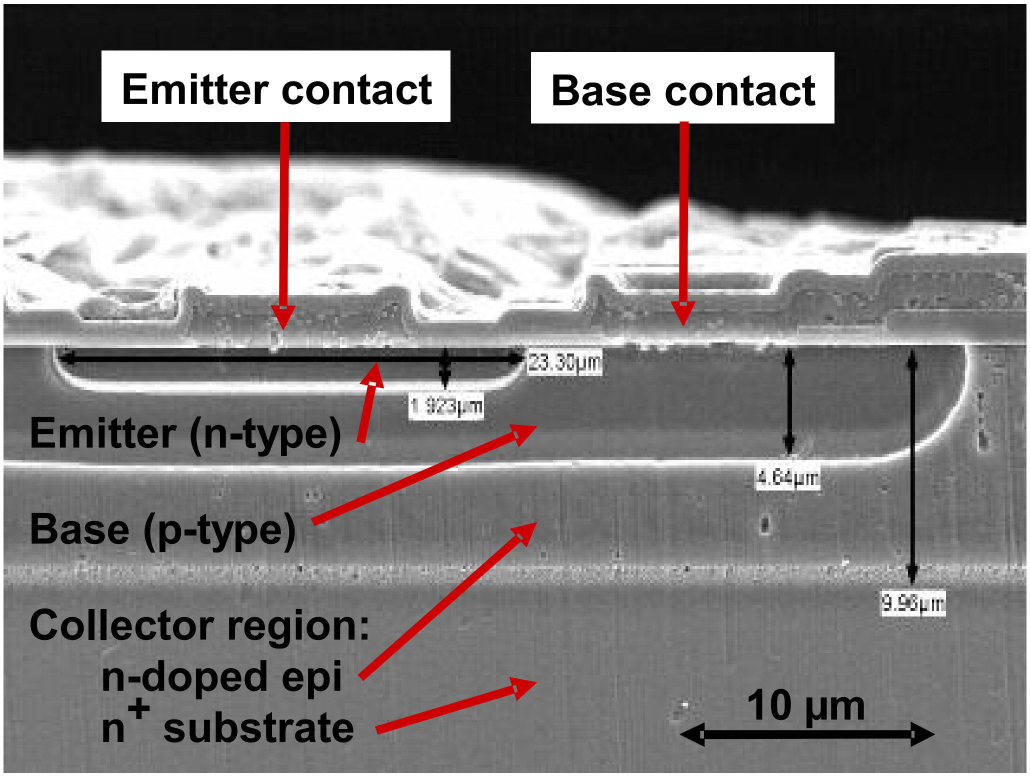

Figure 1. Cross-section of a vertically layered n-p-n bipolar-junction transistor (Microsemi 2N2222) used in QASPR studies of neutron-induced gain reduction. Displacement damage in the vicinity of the emitter-base junction, and secondarily in the underlying base, catalyzes carrier recombination that is offset by increased flow of conduction – electrons from the emitter and holes from the base. The resulting device currents reduce gain by more than two orders of magnitude in the case of SPR irradiation.