Effects of Neutron Damage on Photocurrent in Silicon Bipolar Junction Transistors

by ***W.R. Wampler***

Motivation—The goal of the QASPR project is to simulate the response of semiconductor devices to pulsed radiation. This includes effects of atomic displacements by energetic neutrons or ions and photocurrents from carrier generation by ionizing radiation. Previous simulations have treated damage and photocurrent separately. However, the two effects are interdependent because defects produced by atomic displacements increase carrier recombination, thereby reducing collected photocurrents. Furthermore, defect annealing depends on carrier concentrations which are increased by ionization. New models developed for QASPR now enable damage and photocurrent to be treated together for the first time.

Accomplishment—A one dimensional simulation was done of currents in a Microsemi 2N2222 npn silicon bipolar-junction transistors (BJT). This simulation includes production of vacancies and interstitials by atomic collisions with the energetic neutrons and carrier generation by ionization. The simulation also includes diffusion and reaction of the defects. Conditions were those of a Sandia Pulsed Reactor (SPR) cavity pulse, ionizing dose 10^4 kRad, peak dose rate 10^9 Rad/sec, neutron fluence 4.3×10^{14} /cm^2, constant emitter current = 0.22ma. The time dependence of dose rate and neutron flux in the simulation followed the photoconducting diode (pcd) signal, which is approximately proportional to ionizing dose rate. Because of the low doping and high reverse bias (10V) the depletion region of the base collector junction is much thicker than that of the emitter base junction, so most of the photocurrent comes from ionization in the collector. Therefore, in the 1D simulations the effective area for photocurrent was taken to be that of the base. Figure 1 shows that the photocurrent is much larger than the injected current and that the simulation (black solid curve) agrees well with results from several SPR shots (red curves). The blue curve shows that without displacement damage, the simulated photocurrent is significantly higher than the test results. This difference results largely from increased recombination in the neutral region of the collector rather than in the depletion region. Figure 2 shows the carrier concentrations are increased by the ionization. The simulations show that the reason the effect of damage on photocurrent is modest in this device, is because recombination by the Auger process in the highly doped sub-collector (2×10^{19}/cm^3) gives a short lifetime (10 nsec) and carrier diffusion length (~2 microns) which is smaller than the collector depletion thickness (~6 microns) already in the undamaged material. The photocurrent prior to damage is therefore predicted to be greater, and the reduction from displacement damage greater, in more lightly doped devices.

Significance—These simulations demonstrate the coupled effects of damage and photocurrent in semiconductor devices. The comparison with SPR data provides a validation that the model closely reproduces the photocurrent observed in Microsemi 2N2222 BJTs, with no adjustable parameters.

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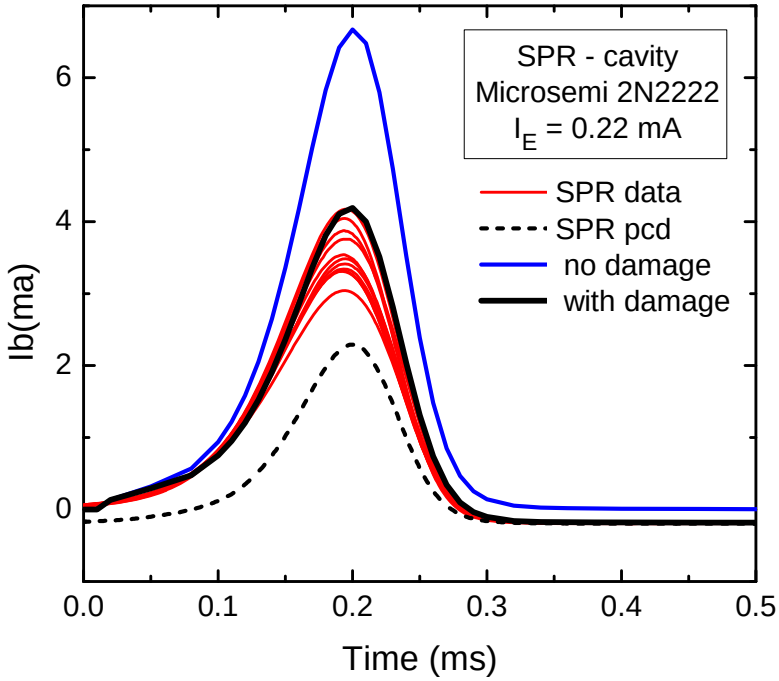

Figure 1. Comparison between measured and simulated photocurrent peak in the base current of Microsemi 2N2222 npn transistors from a SPR pulse. Red curves show measured response. The black and blue solid curves show simulated response with and without displacement damage, and the black dashed curve shows the photoconducting diode response which is proportional to the ionizing dose rate. The origin of the time scale is 0.2 millisecond before the peak of the pcd signal.

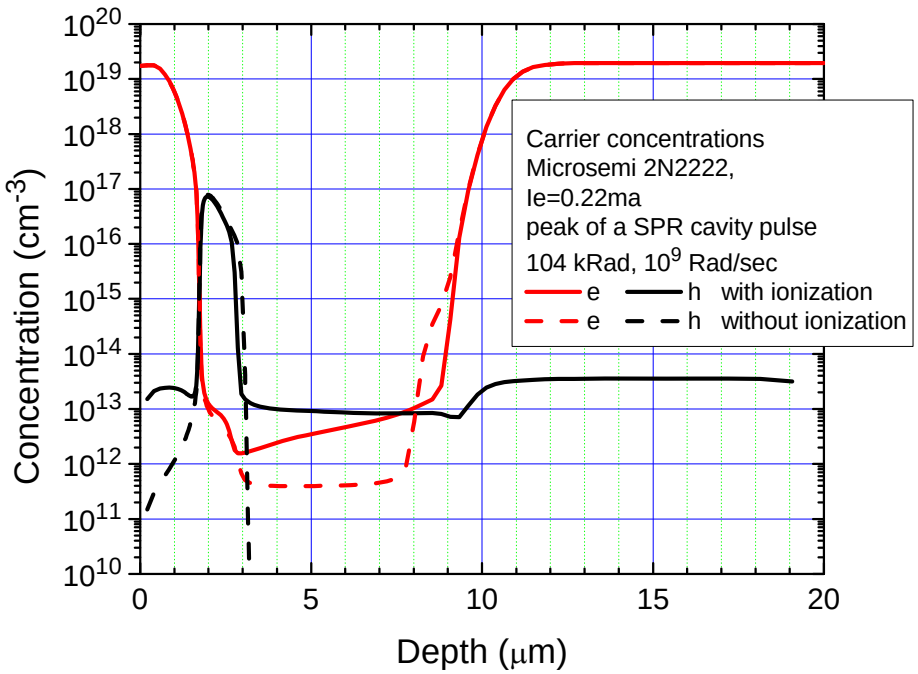

Figure 2. Carrier concentrations before the pulse (dashed) and at the peak of a SPR pulse (solid). The junctions are at 1.7 microns (emitter-base) and 3.8 microns (base-collector).