Ion-Neutron Equivalence: Ion Beam Laboratory (IBL) and Los Alamos Neutron Science Center (LANSCE)

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Motivation—Damage equivalence between different irradiation sources on silicon bipolar junction transistors (BJTs) has been studied for some time. Recently, there is a new demand to determine ion-to-neutron damage equivalence since pulsed nuclear reactors producing high flux short neutron pulses are becoming less and less accessible. An alternative to pulsed neutron beams is to use a pulsed ion beam that produces the same displacement damage. As a first step in this process we will establish the damage equivalency at late times, when the transistor gain is no longer changing.

Accomplishment—We report the first results of our damage equivalency studies on 2n2222 BJTs. We use the Ion Beam Laboratory (IBL) at Sandia National Laboratories to irradiate the BJTs with short, high flux ion pulses and measure the gain degradation as a function of accumulated fluence. We compare the results to similar measurements carried out with ultra-short high neutron flux pulses at the Los Alamos Neutron Science Center (LANSCE). The results are compared to calculations based on SRIM-2003. A comparison between ion irradiated and LANSCE-irradiated samples is an excellent starting point for establishing heavy ion-to-neutron damage equivalency.

In both the ion and neutron irradiations the gain of the transistor is determined from the collector and base currents continuously before and after the irradiation. Using the Messenger-Spratt equation we can relate the inverse gain degradation to the incident fluence through the damage factor (*k*) for each particle:

$$\frac{1}{G_{final}} - \frac{1}{G_{initial}} = k \cdot \Phi$$

where Φ is the fluence, and G_{final} and $G_{initial}$ are the final and initial gain values. Figure 1 shows the inverse gain degradation as a function of fluence for Si ion and a 12 MeV He ion irradiation (inset). All three Si curves follow the Messenger-Spratt equation, and the damage factors are calculated by a linear fit to the data sets. The 12 MeV He irradiation shows non-linear behavior at low fluence. This non-linearity is attributed to the trapped charge in the passivation and field oxide layers. This effect is noticeable for He since the ionization-to-displacement damage ratio is significantly higher for light ions than for heavy ions. The damage factors from the linear fits for the ion irradiations are then scaled by the ratio of the ion-to-neutron damage factors. This allows conversion between the measured ion fluence and an equivalent 1 MeV neutron fluence. Figure 2 shows the inverse gain degradation as a function of the calculated 1 MeV neutron equivalent fluence. The Si data sets are linear, while the He data shows super-linear behavior for low fluence and a linear response for high fluence. For high fluence, where the ionization effect is saturated, the linear response is due to displacement damage which follows the Messenger-Spratt equation.

Significance—In addition to relating the ion to neutron irradiations we have determined the ion-to-neutron equivalency by comparing the measured damage factor ratios to a calculated Non-Ionizing Energy Loss (NIEL) calculation using SRIM-2003 as seen in Fig. 2.

Sponsors for various phases of this work include: Nuclear Weapons/Readiness in Technical Base & Facilities and Laboratory Directed Research & Development

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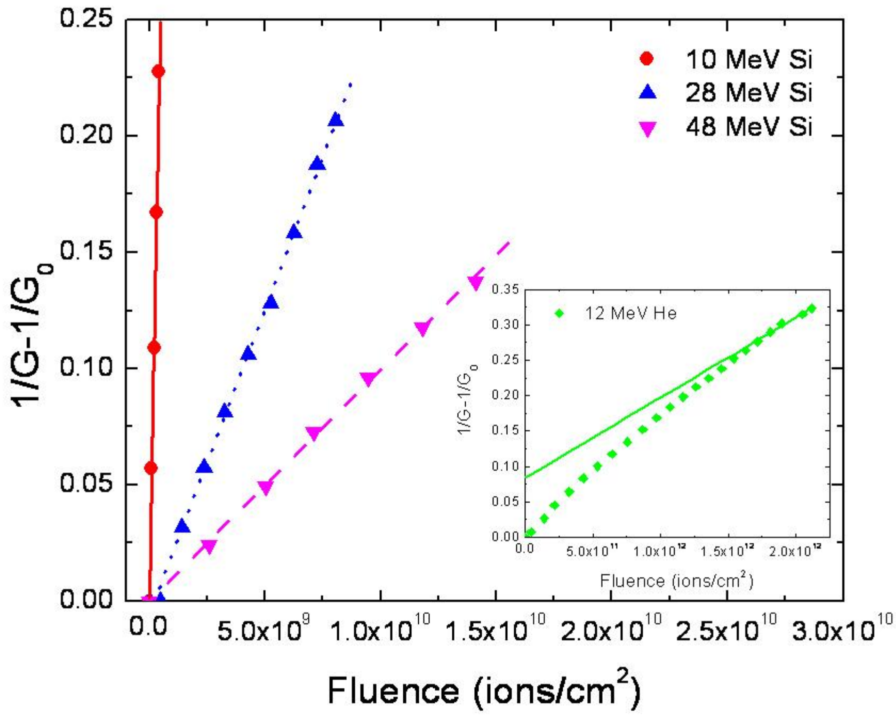
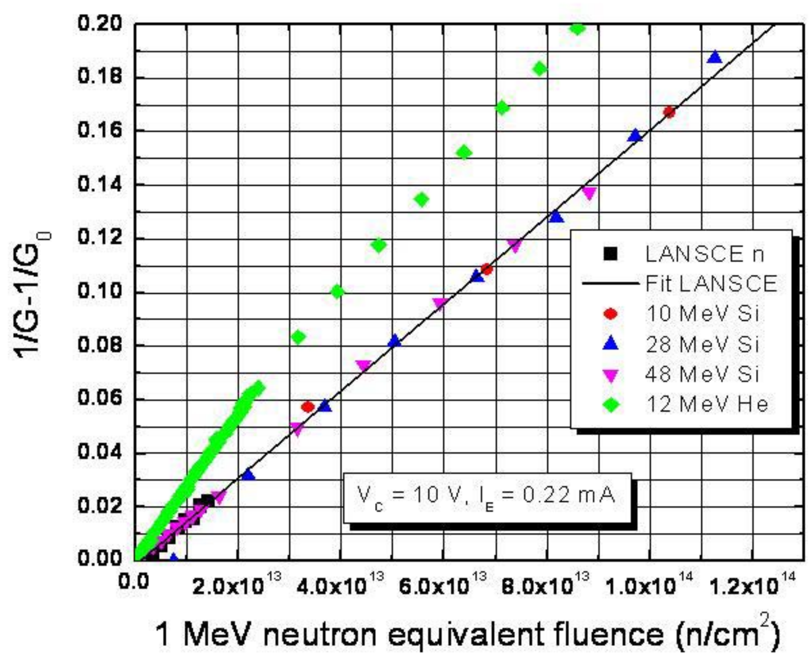


Figure 1. The linear relationship between the inverse gain degradation for three different energy Si ions as a function of fluence. Inset: The non-linear behavior of the inverse gain degradation for 12 MeV He irradiation.



Particle	k/k_n	$NIEL/NIEL_n$
LANSCE	1	1
He (12 MeV)	70	84
Si (10 MeV)	330,000	480,000
Si (28 MeV)	18,000	22,000
Si (48 MeV)	8,100	10,000

Figure 2. Inverse gain degradation for both IBL and LANSCE irradiations as a function of 1 MeV neutron equivalent fluence. The non-linear response at low fluence for He corresponds to ionization effects. Table: Comparison of the experimentally measured damage factor ratio compared to the calculated NIEL ratio for Si and He beams.