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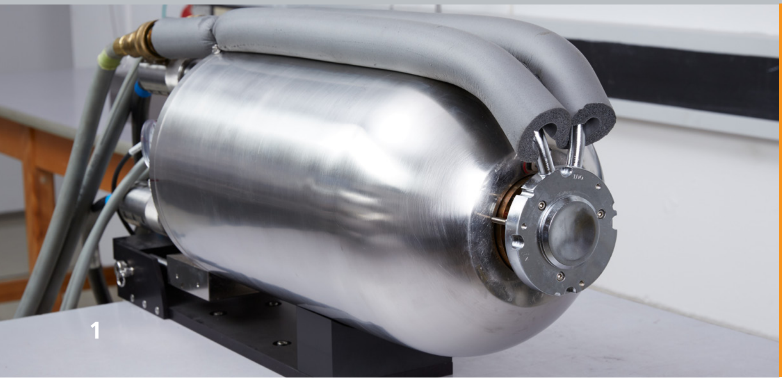
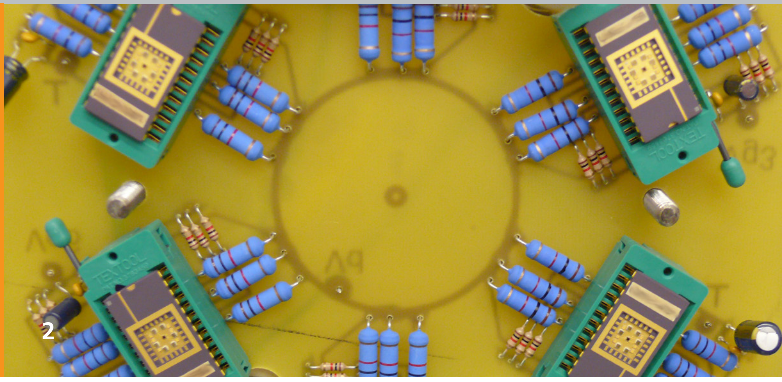
FRAUNHOFER INSTITUTE FOR TECHNOLOGICAL TREND ANALYSIS INT





1 *D-711 neutron generator*
2 *Typical test board for irradiation*

DISPLACEMENT DAMAGE

Nuclear Effects in Electronics and Optics

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Incident energetic particles on a solid experience ionizing and non-ionizing energy loss (NIEL). For charged particles the ionizing energy loss predominates and results in the production of electron-hole pairs. As second effect massive particles transfer momentum on the atoms in the solid, thereby displacing the atoms from their positions in the crystal lattice. The resulting unoccupied lattice site is called *vacancy*. The displaced atom eventually settles in a non-lattice position, a so called *interstitial*. Often the energy of the incoming particle is high enough to displace several atoms and the displaced atoms themselves can displace other atoms on their way through the crystal creating a cluster of defects.

Particles that give rise to displacement damage are mainly protons, neutrons, electrons, and heavy ions. The major particle of concern for displacement damage in the natural space environment is the proton.

Defects in the periodicity of the lattice give rise to new energy levels within the bandgap of a semiconductor resulting in a change of the optical and electrical proper-ties of the material. Those levels lead to (i) generation of electron-hole pairs which increases the leakage current, (ii) act as recombination centers of electron-hole pairs which causes gain degradation in bipolar transistors, (iii) temporarily trap electrons which reduces the charge-transfer efficiency in CCDs, (iv) compensate donors or acceptors which alternates device properties that depend on the carrier concentration, (v) let electrons tunnel though barriers by means of defect levels which causes a reverse current in pn junctions, and (vi) act as scattering centers for charge carriers which decreases their mobility[1].

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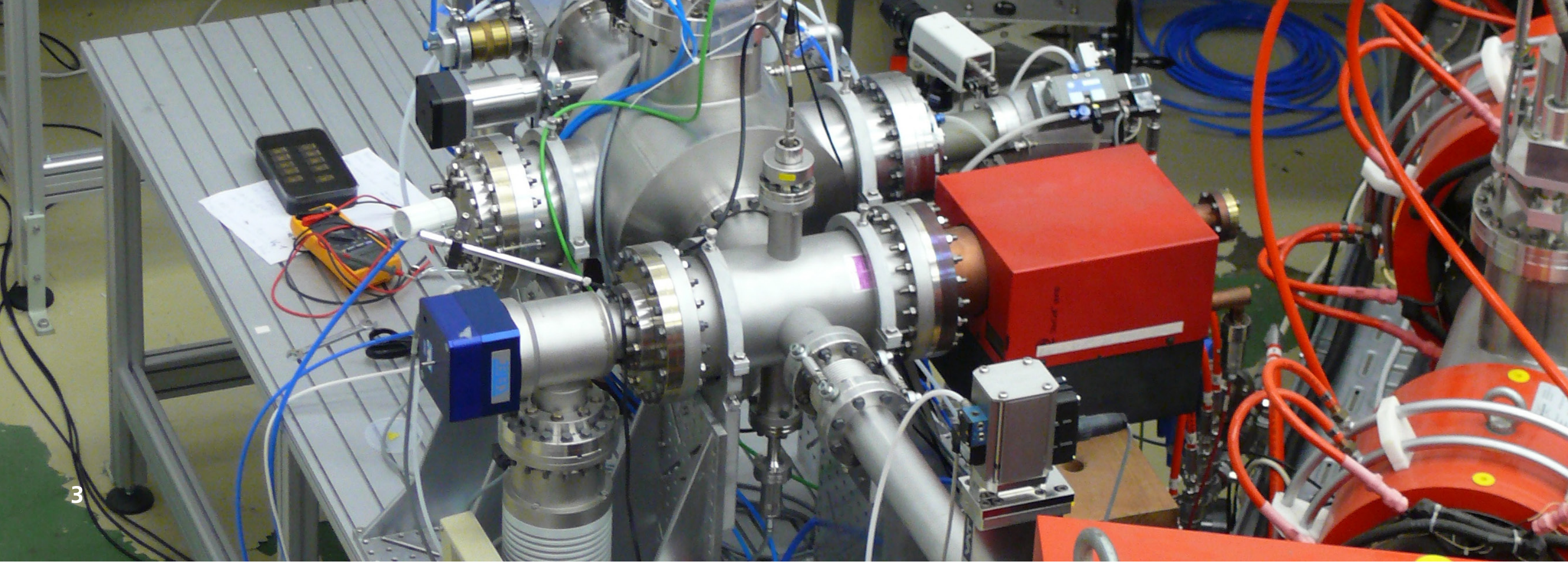
[1] J.R. Sour et al, IEEE Transactions on Nuclear Science, Vol. 50, No. 3, 653 (2003)



3 *JULIC cyclotron at Forschungszentrum Jülich*

The NIEL scaling hypothesis

Displacement damage induced by different particles and different energies can be related by the NIEL scaling hypothesis. This is of major importance as the continuous spectrum of particles in space is usually not available at test facilities. The NIEL scaling hypothesis is based on the assumption that the microscopic character and the concentration of the defects is independent of the properties of the incident particle and that the amount of the defects is proportional to the NIEL. Furthermore it is assumed that the observed electrical or optical effect is proportional to amount of defects (Shockley-Read-Hall Theory). This concept, although empirical founded, satisfies enough applications to be used in the community.

The differential particle fluence $\frac{d\Phi(E)}{dE}$ of the designated environment with particles in the energy range from E_1 to E_2 can be related to the fluence $\Phi(E_{test})$ of test particles at the test energy E_{test} by use of the NIEL value:

$$\mathrm{NIEL}(E_{test})\Phi(E_{test}) = \int_{E_1}^{E_2} \mathrm{NIEL}(E)\frac{d\Phi(E)}{dE}dE$$

As an example we calculate the 1 MeV neutron equivalent fluence of 14 MeV neutrons. From Fig. 4 we extract 1.8 as the conversion factor in silicon, which means that one 14 MeV neutron produces 1.8 times more displacement damage than a 1 MeV neutron in silicon.

Test capabilities at Fraunhofer INT

The testing of displacement damage is usually done with either protons or neutrons. The necessary fluences at these facilities are calculated according to the NIEL scaling hypothesis (see inset).

Fraunhofer INT offers two neutron generators (Fig. 1) which are suitable for investigating displacement-damage effects in electronic or optical components. The energies of the fast neutrons are 2.5 MeV or 14.1 MeV, respectively. The generators can be regarded as a point source and produce up to $3 \cdot 10^{10}$ neutrons/s in 4π. The fluence is monitored online during the irradiation with a calibrated uranium fission chamber.

Additionally, Fraunhofer INT has access to a dedicated irradiation area at the cyclotron JULIC at Forschungszentrum Jülich FZJ (Fig. 3). The protons have an energy of 39 MeV at the irradiation area. Irradiations are done in air. Fraunhofer INT has access to the cyclotron about every two months.

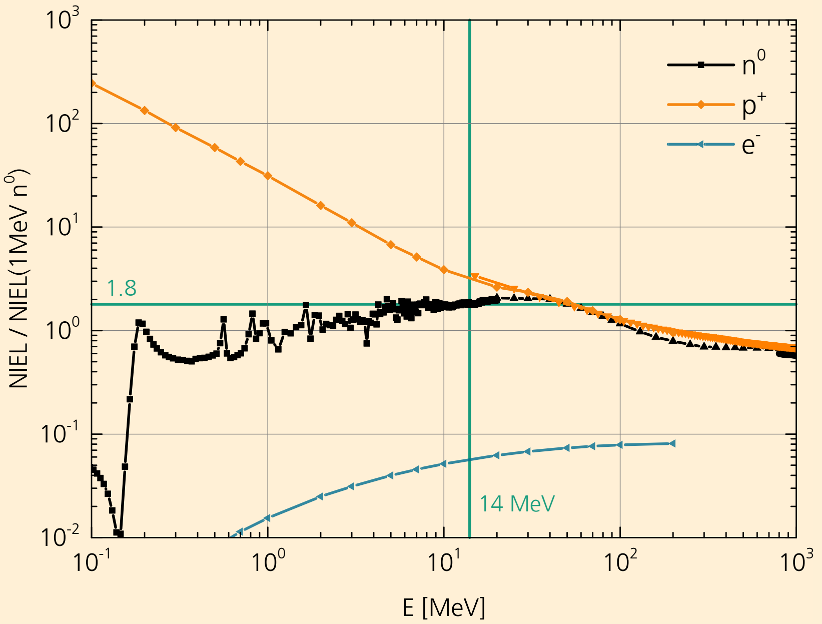


Figure 4: The NIEL value of neutrons, protons, and electrons in silicon at different energies related to the NIEL of neutrons at 1 MeV. [1]

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[1] A. Vasilescu, G. Lindstroem, http://rd50.web.cern.ch/RD50/NIEL/default.html; P.J. Griffin et al, SAND92-0094 (Sandia Natl.Lab 93); A. Konobeyev, J.Nucl.Mater. 186 (1992) 117; M. Huhtinen, P.A. Aarnio, NIM A 335 (1993) 580; G.P. Summers et al, IEEE NS40 (1993) 1372