V. 3. Development of Ion Irradiation Apparatus for Simulation of Cosmic-ray Effect to Semiconductor Devices

Hirabayashi N., Baba M., Hagiwara M., and Itoga T.
Cyclotron and Radioisotope Center, Tohoku University

Introduction

In the space environment, radiation has very severe effects on electronic components such as processors or memories in space crafts. The space radiation consists of several kinds of energetic particles: galaxy cosmic-rays, solar flare particles, particles trapped in the van Allen’s belt, etc. Therefore it is required that the semiconductor parts of a satellite have high reliance against cosmic-ray radiations.

The defects which radiation causes in electronic products are classified into 1) total dose effects (TDE) and 2) single event effects (SEE). TDE is a phenomenon that degrades or destroys the structure of semiconductors gradually with the accumulation of radiation dose. SEE is a temporary soft error or a permanent latch-up of digital circuits caused by a single high energy particle.

In order to withstand such a radiation defects, the electronic products of the apparatus for the space have been developed with special specification. However, these devices have several drawbacks. For example, they are normally very expensive, need long lead times to purchase and the technology employed is several generations older than that of the most advanced commercial off-the-shelf (COTS). Therefore, the cost will be reduced if the COTS products used for PC, a cellular phone, etc. can be used in the space. In order to use COTS parts for space equipment, however, their performance in the space environment especially for radiation should be verified.

For the reasons, we have started evaluation works of SEE in the semiconductor memory using light and heavy charged particle beam from the 930 cyclotron of CYRIC in collaboration with Institute of Unmanned Space Experiment Free Flyer (USEF), and fabricated an experimental device for ion beam irradiation.
Experimental apparatus

For the irradiation experiments of semiconductor device, the following beam conditions are required for the case of proton:

1) Proton flux is around \(5 \times 10^7 \text{#/cm} \cdot \text{sec}\). (It corresponds to 8 pA of beam current)

2) Beam intensity is uniform on a device surface within about 10% on a circle with a diameter of 2 cm.

3) Incident beam intensity can be measured in real-time.

4) The beam energy can be changed easily.

5) Devices can be irradiated in air.

The beam handling system was designed to meet these conditions. In order to uniform the beam intensity and change the energy of the beam, we decided to use copper as a diffuser which spreads the pencil beam from the accelerator and a degrader to reduce the beam energy.

The beam line was fabricated on the basis of the above requirement. Figure 1 shows schematic view of the beam line. The incident beam enters from left-hand side, and passes an aperture with a diameter of 10 mm. Next, the beam passes along the degrader or diffuser. Their thicknesses are chosen according to the beam energy. These are mounted on a ladder which can be controlled remotely.

The beam which is degraded and/or diffused travels to an aperture again. Then the narrow beam defined by the aperture goes into the secondary emission monitor (SEM: Fig.2) which reads the beam intensity during irradiation of devices. SEM is a detector of beam current by taking the secondary electrons from thin aluminum foils as a current signal. SEM needs calibration for absolute measurement because the output of the SEM depends on the beam energy as well as the intensity. Next to the SEM, a remote-controlled Faraday cup is set up, which is made of copper and serves both as a beam dump and an absolute current detector. Measurement of the beam current by the SEM is possible if the relationship of the SEM and the faraday cup is obtained prior to the irradiation experiment. The current of Faraday cup and SEM are read with a IF converter with a sensitivity of 1 pulse/1 pC (Laboratory Equipment Inc.)

Finally, the beam is extracted to the air passing through a Kapton foil (thickness around 200 \(\mu\)m) which separate this beam line from air.
Prospects

We have fabricated and installed the above mentioned apparatus for simulation of cosmic-ray effect to semiconductor devices. Irradiation experiments were carried out a few times and results have been discussed in comparison with the results in other irradiation facilities. We want to establish the method of irradiation and to extend the irradiation by various heavy ion beams.

Fig. 1. Ion irradiation apparatus.

Fig. 2. Secondary emission monitor.