Cosmic rays interacting with biased high power semiconductor devices

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Since several years it is known that biased high power semiconductor devices like diodes, thyristors or IGBTs might fail suddenly without any previous device wear-out or electrical overload condition. Normally this phenomenon is explained by cosmic rays that trigger inside the biased silicon bulk a localized breakdown event, finally destroying the devices [1-4]. These failures are mainly due to the neutron component of the cosmic rays with energies above 10 MeV. Adequate test series for studying device designs are of long duration and expensive. Accelerated tests are feasible at locations with enhanced cosmic ray fluxes (e.g. at Jungfraujoch) or with particle beams. The purpose of the tests at Jungfraujoch is firstly to check the cosmic ray withstand of available devices, secondly to compare these results to corresponding tests at high-flux proton or neutron beams and thirdly to establish suitable design rules for developing future devices.

The test setup is located on a platform (area 0.7 m^2) just below a wooden roof of the Sphinx observatory. The leakage currents of up to 60 biased devices as well as the voltage bias are logged by a PC as function of time. A fuse (32 mA) protects each device. The leakage current of a failed device increases beyond the rating of the fuse. A blown fuse disconnects the device from the bias thus avoiding excessive damages. The time needed for a test run ranges from hours to months.

The failed devices due to cosmic rays have to fulfil two conditions. Firstly the leakage current was constant all the time until the failure occurred and secondly there are characteristic defects like one small spot somewhere on the silicon chip [5]. All failure rates are normalized to the neutron flux of the cosmic rays at New York City (sea level). The used scaling factor of 13 is the ratio of the neutron flux components at Jungfraujoch and New York City [6].

The biased devices were also exposed to neutron and proton beams [5, 7]. The neutron beam had an energy spectrum proportional to the inverse of the energy (like the neutron component of the cosmic rays) and a fixed neutron flux. The monoenergetic proton beam had a variable energy and flux. The corresponding scaling factors are based upon the similarity of the neutron and proton cross section with the silicon material [6]. A typical run at a beam needed about half an hour. The accessible ranges of the failure rates FR depend on the test location: at Jungfraujoch (3580 m) FR is in the range [10^2, 10^5 FIT/cm^2], at Lenzburg (400 m) [10^3, 10^6 FIT/cm^2], at the neutron beam [10^0, 10^4 FIT/cm^2] and at the proton beam [10^{-3}, 10^4 FIT/cm^2]. One FIT (failure in time) corresponds to one failure per 10^9 device·hours. As an example the failure rates of a module diode are compared to the results of tests at the proton beam and model calculations [4] (Fig. 1).

The fact that the failure rates scale with the neutron and the proton fluxes shows that the neutron component of the cosmic rays is the main reason for the observed failures. Note that the failure is triggered by one particle. The model does not predict the sharp drop of the failure rates below a characteristic bias.

In December 2000 the setup was upgraded with a second independent high-voltage power supply. Now devices of two different voltage classes can be simultaneously measured. This shortens significantly the overall test time.

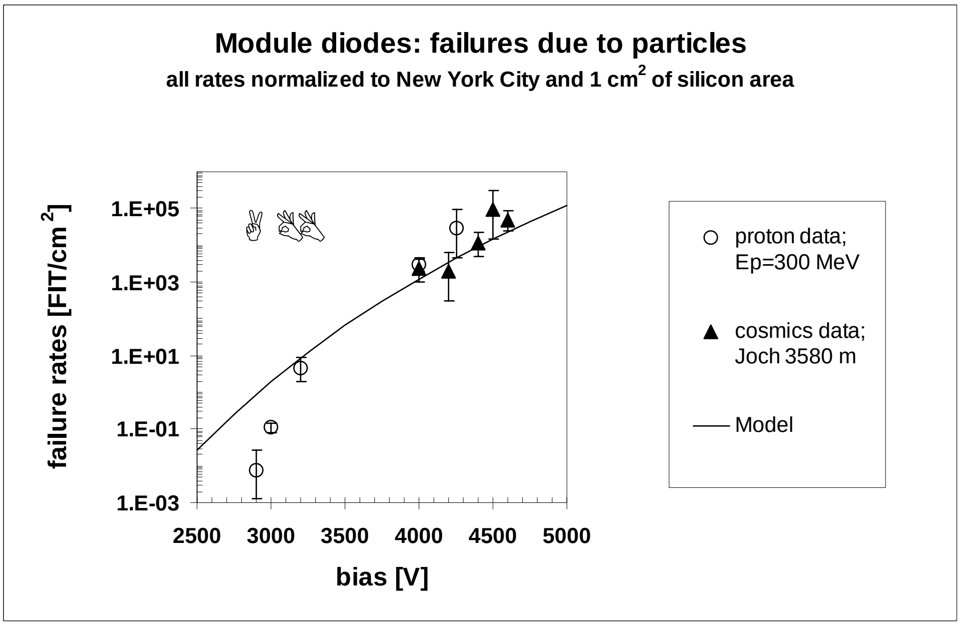

Fig. 1: Failure rates of a module diode due to cosmics and protons. For biases < 3200 V the measured failure rates are significantly smaller than the predicted rates. This feature was observed for practically all types of devices tested with neutron and proton beams. The design goal is that at the normally used biases (for this device < 3000V) the failure rates are less than 1 failure every 10^9 device·hour normalized to one cm^2 silicon area (1 FIT/ cm^2).

Glossary

IGBT: Insulated Gate Bipolar Transistor; voltage controlled power transistor.

Module diode: the junction is abrupt and not deeply diffused. Used together with IGBTs.

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