Performances of the SIRAD axial Ion Electron Emission Microscope

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INTRODUCTION

The Ion Electron Emission Microscope (IEEM), installed in the SIRAD irradiation facility [1] at the Tandem accelerator, is devoted to single event effect (SEE) studies in semiconductor devices and electronic systems for high energy physics and space applications. Global device SEE characterizations are routinely performed at SIRAD using broad beams to uniformly irradiate areas up to several cm² of a device under test (DUT). To improve this capability the group is developing the IEEM technique [2] that will allow the location of SEE sensitive points of a DUT with micrometric resolution. By registering, for each ion, the time and the spatial coordinates of the impact, and correlating them with the observation of a malfunction in the electronic device, it will be possible to map SEE sensitive regions of the DUT. In 2006, the IEEM underwent an important upgrade. Here we report the results of the first tests with the new setup.

THE SIRAD IEEM

In the IEEM a broad beam is sent onto the target. The position of each ionic impact is then reconstructed imaging the secondary electrons emitted by the surface of the DUT as a consequence of the impact. A commercial electronic microscope (PEEM), with a contrast diaphragm of 300μm of diameter, collects and focuses these electrons onto an electron detector (a double stack micro channel plate, MCP, followed by a P47 phosphor screen [3]) placed at the focal plane. Electrons are hence converted into photons, which are extracted from the vacuum chamber and detected by a high-rate and high-resolution position detector.

The intrinsic resolution of the IEEM is set by the aberrations introduced by the microscope and the necessity to maximize the electrons transmission efficiency. Our electron emission microscope can reach a theoretical resolution of 0.6μm over a circular field of view (FOV) of 250μm in diameter with an electron transmission efficiency of about 10-30% [4]. The final sensor should not degrade the resolution and it should also be capable of sustaining rates up to 10 kHz, to manage ion impact rates of ~ 1000 ions/sec in the FOV.

The initial IEEM configuration was such that the ion beam hit the DUT with an angle of 75°, clearly not-optimal as it introduces a parallax error. A parallax-free IEEM configuration is axial with the ions passing through an annular MCP, down along the axis of the IEEM onto the target. An axial IEEM required an important upgrade. A completely new irradiation chamber, suited to this configuration, had to be designed and installed. It is box-like shaped and a whole side opens to allow easy access to the sample holder; the entire sample holder and every item inside the chamber are mounted on the sliding floor of the drawer. Two flanges are oriented at 75° respect to the PEEM-beam axis and are aimed to the target plane. One of this flanges hosts the external UV lamp, the other is dedicated to the optical microscope system. This chamber was installed at the beginning of 2006.

FIG.1: IEEM chamber for axial configuration. The side opens allowing easy access to the sample holder.

A novel position detector has been first developed [5] and is now installed. It replaces the previous, analog, position sensitive detector based on the photodiode principle. The new detector is based on two linear arrays. Commercial CCDs have resolution and sensibility but they are too slow. The solution we developed is based on two orthogonal linear NMOS sensors [6]; a dedicated optical system allows each sensor to “read” just one position coordinate, thereby drastically reducing the amount of data to be handled. This sensor fulfills our requirements both in terms of resolution and rate of acquisition [7].

To prevent spurious charged particles from ionic impact onto the internal surface of the microscope from flooding the MCP, a system of two small diaphragms (~ 500 μm of diameter) had to be added (one before the MCP, the other through its central hole). These diaphragms make the alignment of the IEEM system delicate. The alignment is
performed the following way: a laser beam is sent back up through the contrast diaphragm, passing up through the IEEM and the MCP diaphragms onto a quartz scintillator placed in a chamber some meters upstream. In this same chamber, during ion beam irradiation, the focused beam position is detected with the same quartz and compared with the recorded laser position; the IEEM chamber can be moved until there is perfect overlap.

The ion beam is then defocused, sent down the IEEM and the rate of ions passing through the microscope is measured and adjusted using a diode placed on the sample-holder. The image of a copper grid, with a 40μm pitch, has been reconstructed recording, for each impact, both the spatial and the temporal coordinate.

FIG. 2: Image of a copper grid irradiated with Bromine ions (234MeV). This image is composed of single events, each with a time coordinate.

The incompleteness of the picture is due to a non perfect parallelism between the target and the IEEM focal plane; this problem will be soon corrected for by adding a further tilting motorized stage.

EFFICIENCY OF THE IEEM

We performed a preliminary experiment to measure the ion detection efficiency of the MCP using $^{58}$Ni (212 MeV).

To measure the ion-detection efficiency of the IEEM, a target is needed which both counts the number of ionic impacts and emits secondary electrons to be collected by the electronic microscope. For this purpose a diode is surmounted by a thin gold layer deposited on a silicon nitride membrane (20-40 nm Au on a 100 nm Si$_3$N$_4$). These membranes, used to enhance secondary electron emission from surfaces of electronic devices, degrade the resolution of the IEEM, but they give the following advantages: near independence from the devices under test, hence no need for any sample preparations, reproducible secondary electron emission, complete separation of the IEEM high electrical transfer field from the chip surface.

In our IEEM system, photons from the excited phosphor are extracted from the chamber and enter a beamsplitter, to be detected by a conventional CCD camera and by the bi-linear NMOS readout system. To measure the efficiency the camera was replaced by a photomultiplier tube (PMT); we compared the number of counts from the PMT and from the diode, repeating the measure for different values of FOV. The results (fig. 3) show that, with a 250μm FOV, the MCP efficiency is close to the theoretical value of ~70%, due to geometrical loss. In fact, the different diameters of the diaphragm (300 μm) and of the maximum FOV (250 μm) and the hole in the center of the MCP reduce the efficiency of our IEEM down to 69%; the 30% geometrical inefficiency can be nearly completely removed by using a MCP diaphragm smaller or equal to that of the FOV.

FIG.3: MCP efficiency

CONCLUSIONS

The axial IEEM works and its efficiency is close to 100%. Further tests, for efficiency and resolution measures with different ionic beams, are planned for 2007.

[3] BURLE instruments QS 11983–2: APD 3040PS 12/10/8 I 60:1 6.4CH P47 two stack, 40 mm diameter with 8 mm central hole diameter MCP.