Annealing studies on X-ray and neutron irradiated CMOS MAPS

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Monolithic Active Pixel Sensors (MAPS) are proposed as sensor technology for the vertex detector of the CBM experiment [1]. The development of MAPS towards the radiation hardness required by CBM is the matter of a joint research programme of IPHC Strasbourg, the University of Frankfurt and GSI Darmstadt.

It is a known fact that the lifetime of silicon-based sensors might be extended by recovering radiation damage by means of annealing [2]. A prominent example of this annealing is the recovery of surface and bulk defects. The past studies on MAPS have shown that a thermal treatment may reduce the leakage current of X-ray irradiated diodes [3]. We therefore considered annealing as an interesting method to recover the performances of irradiated sensors. However, it had to be studied if the benefits of annealing would eventually be cancelled by a potential reverse annealing of bulk damage, when defects create a complex defect cluster. Thus we performed a systematic study on the annealing of MAPS.

The annealing studies were carried out with the MIMOSA-19 prototype sensors received from IPHC Strasbourg. The chips were irradiated with $10^{13}\ \mathrm{n_{eq}/cm^2}$ unmoderated fission neutrons [4]. Consecutive to the neutron irradiation, the chips were bonded, characterized and stored for one year at room temperature. Another characterization was then performed to identify potential long-term room temperature annealing, which was not observed. Once those studies were completed, several of the neutron irradiated samples and some not irradiated ones were exposed to $200\ \mathrm{kRad}$ of $10\ \mathrm{keV}$ X-rays at room temperature and their characterization started three hours later. The measurements were regularly repeated in order to study room temperature annealing. As shown later, this effect went mostly into saturation after $\sim 280\ \mathrm{h}$. The sensors were then heated up to $+80\ ^\circ\mathrm{C}$ in order to search for the consequences of annealing at this temperature. This thermal treatment was regularly interrupted in order to perform further measurements. To magnify the radiation-induced leakage current, which was the point of interest, the sensors were kept at $+20^\circ\mathrm{C}$ during the measurements.

The results of our measurements are shown in Fig. 1, which displays the leakage current of the differently irradiated sensors as function of the annealing time. The left part of the plot represents the annealing time at room temperature, the right part the annealing time at $T = +80\ ^\circ\mathrm{C}$. Note that in the second part, the time needed for measurements and the time of room temperature storage are neglected. This explains the step at $t = 290\ \mathrm{h}$, which was caused by few days of room temperature annealing. After X-ray irradiation, an exponential room-temperature annealing occurred, reducing the leakage current by $\sim 20\%$. At $T = +80\ ^\circ\mathrm{C}$, we observed a more pronounced effect. After keeping the sensor in hot atmosphere for $75\ \mathrm{h}$, the leakage current of the pixels was observed to decrease to 30% of the pre-annealing value. For sensors irradiated only with neutrons, the leakage current decreased by $\sim 10\%$. This may be attributed to an annealing of the ionizing damage caused by the γ-background of the neutron beam. The annealing behavior of the sensors irradiated with both X-ray and neutron radiation is mostly determined by the annealing of the ionizing damage.

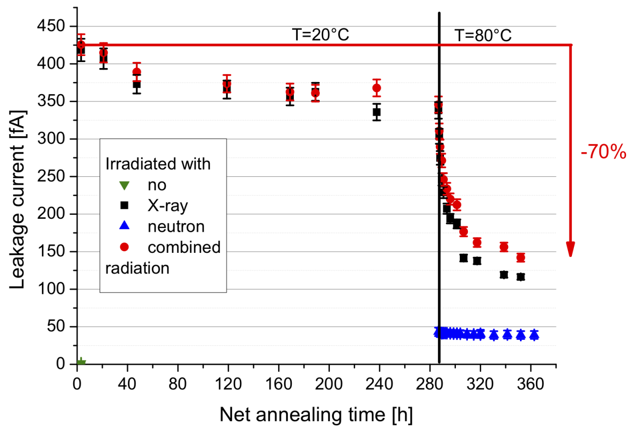

Figure 1: Results of the annealing study

The observed decrease of the leakage current after annealing is likely specific for the chosen sensor prototype. However, the trend which was found should be representative for the general case, and therefore it can be concluded that annealing might be a helpful tool to reduce the effects of ionizing radiation damage in CMOS Monolithic Active Pixel Sensors.

References

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