Irradiation Experiments with X-ray Detectors for Space Telescopes

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1. Introduction

The MPI Halbleiterlabor (MPI HLL) of the Max-Planck-Institutes for extraterrestrial physics and for physics is specialised in the development of silicon detectors for spectroscopy of ionizing radiation, in particular X-ray photons, with high time and position resolution.

One type of such detectors is the fully depleted, back-illuminated X-ray CCD, the so-called PNCCD. It has already been applied as focal plane detector for the ESA satellite project XMM-Newton [1]. Since launch in 1999 it explores continuously the X-ray sky till today and provides excellent measurement results for astronomy.

We developed an advanced PNCCD type with optimized spectroscopic performance for the approved new satellite project eROSITA [2]. Starting in 2012, seven PNCCD cameras in the focus of X-ray optics will perform an all-sky-survey of the X-ray sky up to an energy of 10 keV and explore the nature of dark energy in subsequent observations.

A further detector type developed at MPI HLL is the DEPFET Macropixel array. It is proposed as X-ray sensor for another space born X-ray observatory SIMBOL-X and the planetary XRF instrument MIXS on ESA's Mercury exploration mission BepiColombo. This detector type consists of a monolithic array of silicon drift detector devices, each of which is equipped with a depleted MOS field effect transistor as readout element. An enhanced detector of this type is planned for the 'International X-ray Observatory' (IXO), an joint X-ray astronomy project of ESA, Japan and USA.

2. Irradiation experiments

All of the above mentioned projects are challenging with respect to radiation hardness of the high resolving detectors in space because of their exposure to the fluxes of solar and cosmic protons during mission times of several years. The experimental analysis of radiation damage effects to each of the detector systems is mandatory for minimization of performance degradation and failure risk. Furthermore, the measurement results are needed for fundamental research and progress in detector physics. Therefore, irradiation experiments using 10 MeV protons with fluences estimated for the whole mission lifetime have been performed on DEPFET Macropixel arrays proposed for the BepiColombo and the SIMBOL-X missions.

Main effects on the detector are the increase of leakage current due to non-ionizing energy loss and a shift of threshold voltage of the transistor MOS structure. Models exist for both kinds of radiation damage, but not for the low temperature required by the sensor [3]. Precise knowledge of the radiation damage effects is required to decide if thermal annealing scenarios on the satellite have to be applied.

Representative, small matrix devices were irradiated at a temperature of $-50°$C up to a fluence of $1 \cdot 10^{11}$ 10 MeV protons/cm^2, which is about three times the mission lifetime fluence of the instrument on BepiColombo and even higher relating to SIMBOL-X.

3. Results

Based on the measurements the existing models for both kinds of radiation damage were extended towards lower temperatures. In addition, annealing studies on the irradiated sensors were performed to verify the annealing behaviour predicted by the models. Thus operation scenarios including annealing could be proposed. The threshold voltage shift experienced by the MOS gate structures was determined. It could be verified, that the threshold voltage shift lies within a range easily to be accommodated by the later system [4].

Prototypes of the low-noise signal readout ASIC ASTEROID were exposed to proton radiation up to several times the BepiColombo mission lifetime fluence. As the 0.35 CMOS technology is relatively tolerant with respect to threshold voltage shift, especially the SEU hardness of the memory structures was of interest. The results show the chip internal memory is extremely SEU tolerant [5].

Further irradiation experiments, in particular with the eROSITA PNCCDs, are planned for the next year.

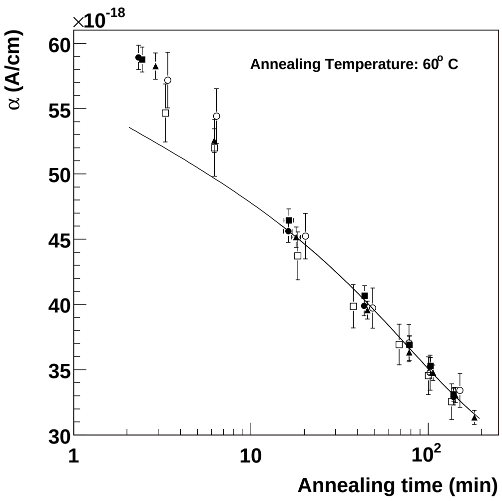

Fig. 1: Annealing behaviour of the silicon bulk material. Shown is the dependence of the damage constant α as a function of the annealing time at a temperature of 60°C.

References

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