MATTER AND TECHNOLOGIES

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Development of HV-CMOS sensors for heavy ion beam application

In 2020, 2.7 million people in the European Union were diagnosed with cancer. When it comes to treating cancer, many aspects have to be considered, for example, the type and stage of cancer and the general health of the patient. Radiotherapy is a globally acknowledged and approved approach independent of the treatment phase. Over the last twenty-five years, more and more different centres have opened worldwide; one was the Heidelberg Ion Beam Therapy Center (HIT) at Heidelberg University Hospital (UKHD) in 2009.
To fully benefit from high-precision ion beam dose delivery, image guidance is mandatory nowadays. Therefore, the development of magnetic resonance imaging (MRI)-guided ion beam therapy is an essential step in tumour therapy.
HV-CMOS sensors are a perfect candidate as an ion beam monitor. As a monolithic sensor based on commercial chip production technologies, it implements readout circuits such as particle counters in every pixel, making it capable of sensing high-intensity beams. HV-CMOS technology is intrinsically more radiation tolerant than other CMOS technologies due to a larger depletion region. This also minimises the charge collection time for signal charge. The sensors can be thinned to 50 µm, providing low material use. Finally, commercial technology grants low prices and wide availability, allowing small projects with limited budgets to be realised.
By the beginning of 2024, several versions of the HitPix chips were developed and produced. The design of these sensors was a derivative of sensors used in HEP with adapted electronics. While those sensors performed well in a low-rate beam, they lost efficiency at the highest ion rates, which could not be explained by pile-up.

Heavy ions and high-energetic protons penetrating the detector induce charge directly and indirectly. Both these mechanisms can lead to the appearance of single-event effects (SEE). SEE can affect the normal operation of the device, usually in the form of current or voltage perturbations. In CMOS, heavy-ion particle-induced charge leads to parasitic p-n-p-n structures, which create latch-up, such as Single Event Latch-Up (SEL). It is a known problem for space applications in CMOS sensors, but it was not investigated for medical ion-beam or HV-CMOS sensors.

This problem required deeper physical investigation, including detailed TCAD simulation of the sensors on the transistor level. Experiments showed that high-energy depositions can drop the baseline of the amplifier. TCAD simulations demonstrated a funnelling effect in the sensors as the primary mechanism for SEE, which was proposed as the reason for baseline drops.
Furthermore, different HV-CMOS sensors (AtlasPix, MuPix, AstroPix) were tested in the ion beam of HIT. These tests provided information about the influence of different architectures, substrates and sensor bias voltages in the beam.
As a result of this investigation, a list of recommendations was made for the further improvement of the HitPix sensor.

Speed talk:

I am unwilling/unable to present a speed talk

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