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Single-event effects calibration using two-photon absorption and a CMOS image sensor

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A two-photon absorption (TPA) laser setup can nowadays be used to imitate radiation effects of high-energy particles by tightly focusing an ultrafast laser on a sensitive node of electronics. At a certain energy per pulse, a single-event effect (SEE) can occur. This paper proposes to measure the amount of electron-hole pairs generated in the component and the characteristics of the laser beam through a CMOS image sensor. This method allows better calibration of the TPA setup and makes the setup more representative for the radiation conditions. This information can then be used to predict or prevent SEE in electronics.

Summary (500 words)

Recently, a TPA laser setup has been proposed as a method to simulate single-event effects (SEEs) in electronics. SEEs are short-term radiation effects caused by a single ionizing particle, striking a sensitive node in an electronic component. They could for example cause a memory register bit flip or single-event latch-up (SEL). TPA is the simultaneous absorption of two photons with an energy between half of the bandgap energy and the bandgap energy, which allows to excite an electron to the conduction band. Most electronics consist of silicon, which has a bandgap of 1.12 eV. Above 1100 nm, TPA is the only way to generate electron-hole pairs in silicon from light. An ultrashort high-power laser beam pulse, focused by a lens, is usually used to generate carriers by TPA because a high local light intensity is required.

In our test setup, a laser beam of 1550 nm and pulse width of 450 fs is focused by a lens. By first inducing a SEE in the device-under-test (DUT) with the TPA setup, we will know how much energy from the laser is needed. If the DUT is then replaced with the now characterized CMOS image sensor with the same laser settings, we will be able to generate a similar amount of electron-hole pairs in the CMOS image sensors and thus read-out an indication of how many electron-hole pairs have been generated.

The setup can also be used to measure the laser spot size and measure the beam profile in the top layer of the epitaxial layer. The active layers in electronics are located in this layer. Effects we see in CMOS image sensors thus might also occur in electronics. The spot size of our laser beam is measured by using the knife edge measurements technique on a photodiode. A 1σ spot size of 1.45 μm was measured for our testsetup. Our used CMOS image sensor has a pixel size of 2.7 μm. The spot size being smaller then the pixel size enables us to measure the pixel profile. A CMOS image sensor is mounted in the focal point on an XYZ-table. By scanning the laser over the pixel in the xy direction, we get a 2D cross section of the pixel profile on a certain height Z. Repeating this multiple times to scan the z-direction results in a 3D pixel profile, as shown in figure 6.

Theoretically, silicon has a quadratic relationship with the light intensity for TPA and a linear dependency with the number of pulses. Both theoretical characteristics are confirmed in our case for large pixels and can be seen in figure 4 and 5. The quadratic relationship does not always occur in small pixels, due to diffraction effects in metallisation on top of the pixels (even with backside illumination). This unexpected behaviour could also be in play in for example SRAMS, when evaluated in a TPA setup.

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