Pulsed Laser System to Simulate the Effects of Cosmics Rays in Semiconductor Devices

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Background

Electronic devices used in spacecraft applications are exposed to various radiation environments. These environments include energetic protons, electrons, gamma rays, X-rays, and heavy ions. High-energy charged particles can pass through and interact with a sensitive portion of the semiconductor device generating a significant amount of charge (electron-hole pairs) along their tracks (Figure 1). These excess charges can cause considerable damage, and the device response can range from temporary perturbations to permanent changes in the state or performance. These phenomena are called Single Event Effects (SEE).

Before use in space flight applications, electronic parts need to be qualified and tested for performance and radiation sensitivity. Typically, their susceptibility to SEE is tested by exposure to an ion beam from a particle accelerator. At such facilities, the device under test (DUT) is irradiated with large beams so there's no fine resolution to find particular regions of interest on the parts. This type of test can be very costly and time consuming.

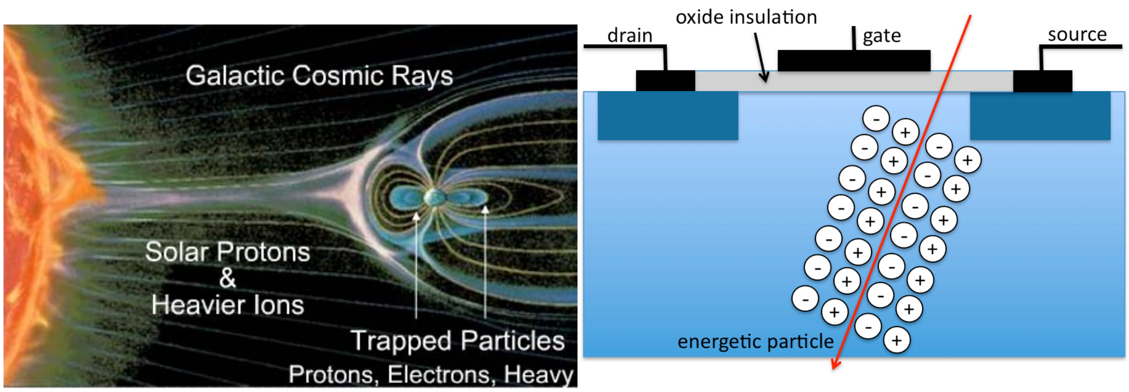


Figure 1. Left is an artist rendition of the radiation environment around Earth. An energetic particle can pass straight through a device and produce an ionization track (right). This single-event effect (SEE) can cause temporary or permanent changes in the state or performance of the device.

Laser-based Heavy Ion Simulation

Pulsed laser light can be utilized to simulate radiation effects with the advantage of being able to localize the sensitive region of an integrated microelectronic circuit. Generally, a focused laser beam of approximately picosecond pulse duration is used to generate carrier density in the semiconductor device and simulate the effect of a heavy ion. During irradiation, the laser pulse is absorbed by the electronic medium with a wavelength selected accordingly (Figure 2) by the user, and the laser energy can ionize and simulate SEE as would occur in space. With a tightly focused near infrared (NIR) laser beam, a

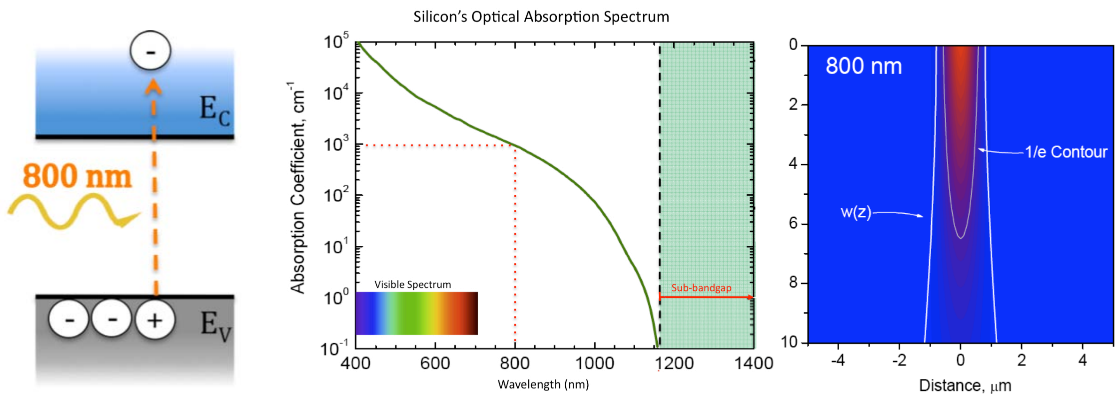


Figure 2. Single photon absorption by the silicon medium creates an electron-hole pair (left). The optical absorption spectrum of silicon (middle) shows sub-bandgap for wavelengths over 1200 nm. The calculated penetration depth (right) in silicon for a focused 800 nm beam (Courtesy of Pouget et al., 2009).

spot of about 1 μm can be achieved, and additional scanning techniques are able to yield sub-micron resolution. This advantageous feature allows us to map all of the sensitive regions of the studied device with fine resolution, unlike heavy ion experiments. The problematic regions can be precisely identified and it provides a considerable amount of information about the circuit.

Description of Facility

We have built a pulsed laser system (Figure 3 and 4) with a mode-locked Ti:Sapphire cavity pumped by a 5W Diode Pumped Solid State laser at 532 nm. A laser beam with about 2 picoseconds pulse-width is tightly focused through a microscope objective onto the device under test (DUT).

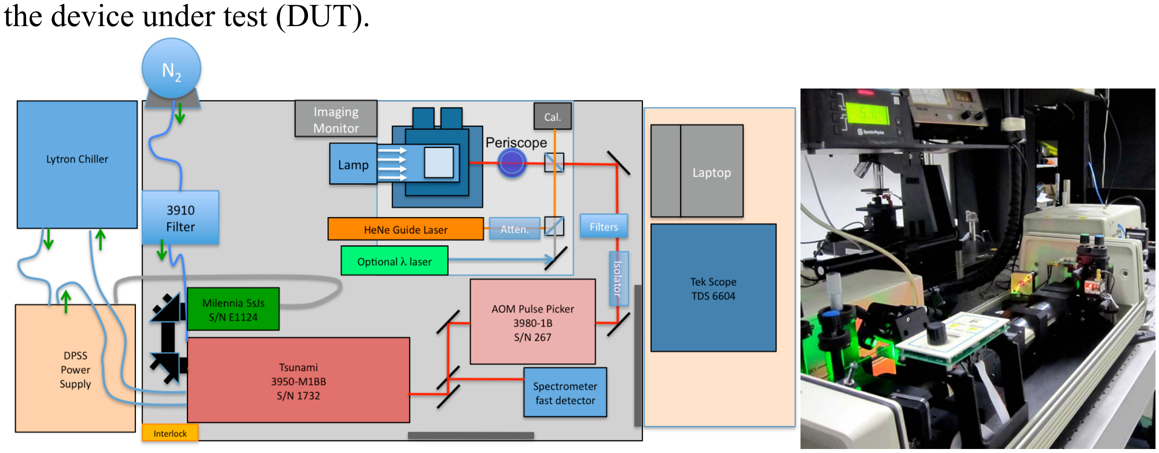
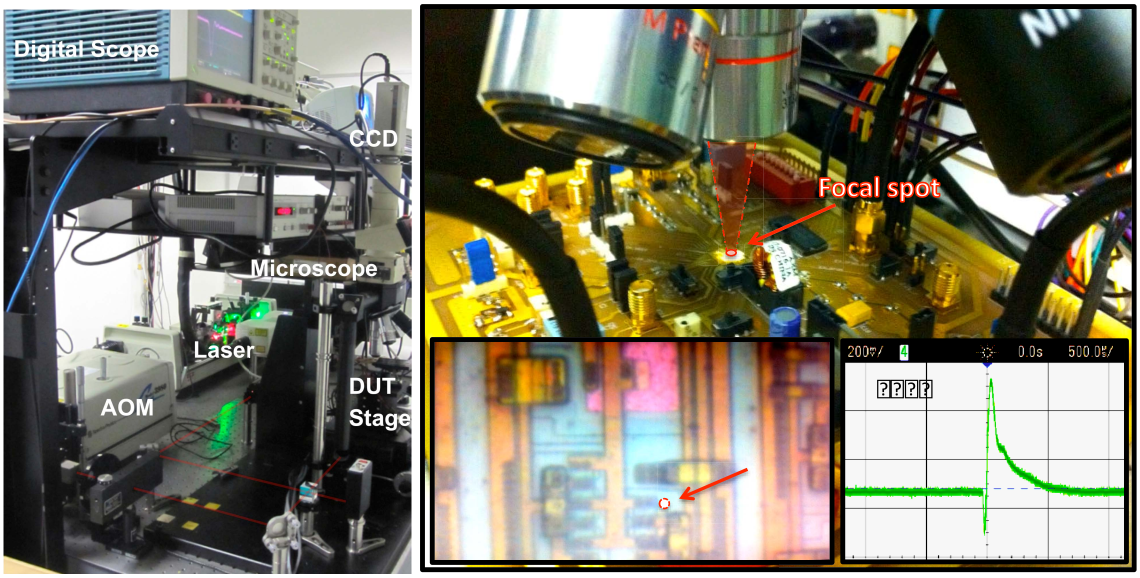


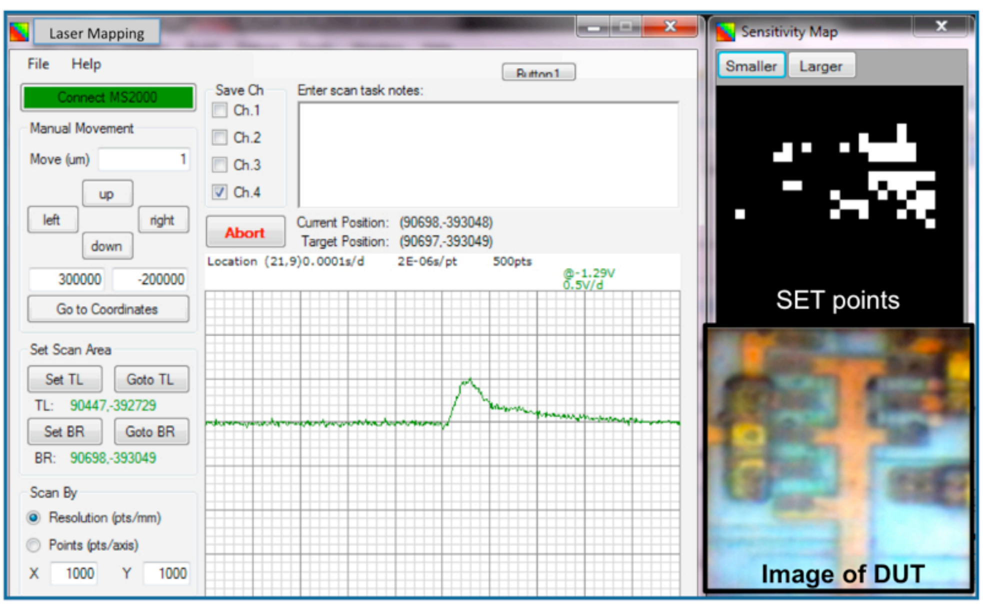
Figure 3. System layout (left), and photo (right) of opened mode-locked Ti:Sapphire cavity pumped by 5W of 532 nm laser light from DPSS. Microscope and translation stage can be seen in background.

The Ti:Sapphire has a wavelength range of 720-850 nm, and average power of 500 mW up to 1 W. The cavity outputs an 80-MHz rate of pulses, which are precisely selected by an acoustic-optical modulator (AOM). The beam power can be attenuated to deliver calibrated energy to the DUT, typically chosen in the range of 1 to 500 pJ. When focused to a micron waist, the electromagnetic radiation intensity ionizes the silicon medium to a penetration depth determined by the wavelength (see Figure 2) and induces single-event effects (SEE) within the device medium, simulating a heavy ion penetrating into the part.



laser system (left) delivers light to the DUT Stage. The objective lens of the microscope focuses the pulsed laser light onto the DUT (right) while a CCD camera images the circuit (lower left inset). A digital scope records the voltage transients (lower right inset) while the device position is precisely moved by a computer controlled 2-axis translation stage.

This laser system utilizes the tunable pulsed source along with a HeNe laser continuous wave source at 635 nm for alignment guidance. The system incorporates a motorized 2-axis stage to move the DUT and scan the area with resolution down to 100 nm. With automated computer control of the pulses, stage, and digital oscilloscope, the system can record the voltage transient responses, and generate a functional map of the device sensitivity with extremely fine resolution (Figure 5).



Relevance to NASA

Because of exposure to harsh environments, certain space flight qualifications require that electronic devices be tested for performance and radiation sensitivity. Currently, the parts are tested at other facilities at high cost, and all equipment must be transported. The laser-based radiation simulation facility allows faster turn-around times and is far less costly. While it cannot fully replace heavy ion testing, it serves as a necessary complementary tool that helps the radiation hardness assurance flow when qualifying electronics for space applications. It also offers high resolution imaging of the device sensitivity to localize problematic areas of the integrated circuits under test. It could also allow parts to be analyzed and issues diagnosed for research and development, leading to more robust and better performing electronics for space applications.