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Effect of UV radiation surface damage on silicon position sensitive photodetector

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ABSTRACT

As a result of the ever increasing energetic UV radiation doses and the need for more radiation hard devices, damage and degradation testing of optical sensors have become very imperative. In this report, results describing the effect of prolonged UV beam irradiation on the performance of a $p^{+}n$ duo-lateral position sensitive detector (*l*PSD) are reported. The results include the use of a simple method to visualize in 3-dimensional graphs, the effect of radiation damage on the *l*PSD sensitivity and position detection deviation over the entire active area. The results also show that the ionization damage effects at the Silicon-Silicon oxide interface result in decrease in sensitivity, increase in position detection deviation, and increase in leakage and shot noise current.

1. Introduction

One type of optical device that has become increasingly popular is the position sensitive detector (PSD) which is a type of optical position sensor that can measure the position of a light spot in one or two-dimensions on a sensor active area. Although other optical sensors like charged-couple devices (CCDs) can also be used for position measurement, the advantage of PSDs over these sensors is that the costs for design and additional operational electronics are much lower. The simplicity in design and operation are also other huge advantages of PSDs.

For applications involving low energy electrons, deep ultraviolet (DUV) spectroscopy, photolithography and laser radiation, PSDs are also reliable alternatives over typical CCD sensors. This is because CCDs have been known to have very poor responsivity as a result of strong absorption of UV photons in the polysilicon layers deposited on the active area of the detectors [1,2]. But like every other conventional photodetector, PSDs are vulnerable to degradation and instability due to radiation damage from continuous exposure to high energy photons (such as blue light and light with wavelength less than 350 nm). For photons continuously absorbed just a few (hundred) nanometers in the bulk silicon, oxide trapped charges and new interface states are generated near the vicinity of the Silicon–Silicon oxide (Si–SiO_2) interface [3]. An increase in the build-up of these fast interface states and holes trappings at the Si–SiO_2 interface as shown in Fig. 1, can result in increased interface recombination velocity. Other consequences include significant shift in depletion voltage and reduction in charge collection efficiency [4]. As a result of the various valid ramifications of radiation damage on the performance of optical sensors, numerous studies on characterization methods and techniques to reduce to the barest minimum, the resultant effects on semiconductor photodevices have been conducted [5–7].

Notwithstanding these studies, not much have been published on inexpensive and efficient techniques of characterizing radiation induced surface defects in optical sensors especially as it relates to the effect of radiation damage on position sensitive detectors. Although, PSDs especially the duo-lateral types (*l*PSDs),[1] are known to be highly linear and of reliable position reading irrespective of the beam size, shape, intensity or profile [8], the impact of continuous absorption of high energy photons on their linearity, and position deviation has not been exhaustively studied. Therefore, this research is aimed at exploring an alternative technique of evaluating the effect of radiation damage on a duo-lateral PSD through the use of a simple 3-dimesional mapping/graphing method.

By using this method, the *l*PSD active area surface defect that manifest as degradation of sensitivity, responsivity and resultant position deviation or error can be characterized and visualized.

[1] Duo-lateral PSD is made of a single active element with no gaps or dead zones. It has two parallel electrodes on the top layer (contacts 1 and 2 in Fig. 2) and another two parallel electrodes at the back layer that are positioned 90° to the top electrodes (contacts 3 and 4 in Fig. 2). A typical PSD determine the position of an ionizing beam by charge sharing via resistive charge division onto sets of two laterally placed readout electrodes.

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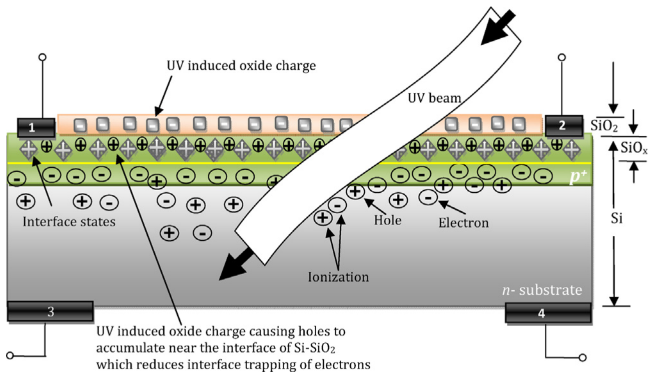

Fig. 1. A schematic illustration (not drawn to scale) of the UV-induced oxide charging effect in the vicinity of an interfacial layer (SiO_x) formed between the Si and SiO_2 layers of the *l*PSD from the continuous absorption of energetic UV photons.

2. Experimental technique

The photo-sensor used in the research is a commercially available p^+n *l*PSD from a popular manufacturer of photonic components. It is a detector with an active area of 0.0001 m^2 (10 mm × 10 mm), fabricated on a 480 μm thick wafer and with a passivation layer of approximately 7.5 nm thick SiO_2 film. The SiO_2 thickness was measured using reflectance spectroscopy with an Avantes AvaSpec-2048 spectrometer.

A transimpedance amplifier was constructed on each electrode (contacts 1–4 in Fig. 1) with low noise JFET-input operational amplifiers to convert the photon induced currents to voltage outputs. This was necessary because the photocurrents in/out of the electrodes of the *l*PSD are low-level and also because the ensuing analysis was in the voltage domain. Their use is also because they presents low impedance to the *l*PSD and isolates it from the output voltage of the operational amplifiers. In order to increase the response time/speed and attain highest possible linearity over the entire active area, the *l*PSD was reverse biased through the non-inverting inputs of the operational amplifiers at ±12 V bias voltage. More information about the circuit configuration can be found in Refs. [1,9].

To initiate radiation induced surface damage in the detector, a 253 nm UV beam of 1.09 mW/mm^2 irradiance was generated from an Energetiq EQ-1000 laser-driven light source (LDLS) and irradiated onto the detector (see Fig. 2a). The irradiance of the beam was measured using a calibrated Thorlabs S120VC power sensor coupled to a Thorlabs PM100D digital power meter console. The

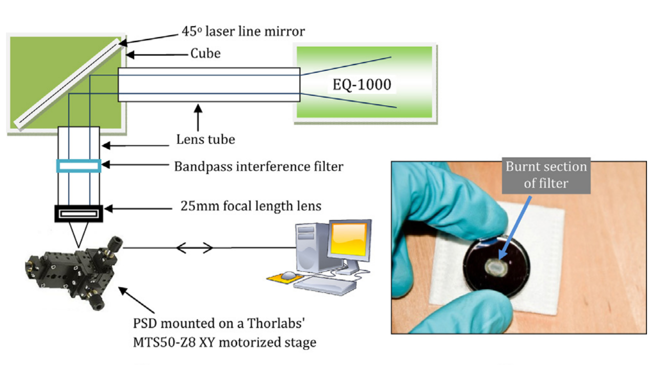

Fig. 2. (a) A schematic illustration of the measurement apparatus consisting of a laser-driven light source (LDLS), a laser line mirror, a filter, a lens and a motorized stage that were used to initiate radiation induced damage in the *l*PSD. For the 3-dimensions mapping and the position detection deviation measurement, a 100 μm spot size fiber optic cable and a beam profiler were used in place of the 25 mm focal length lens and bandpass interference filter. (b) Burnt section of an interference filter caused by placing it (the interference filter) directly after the laser source.

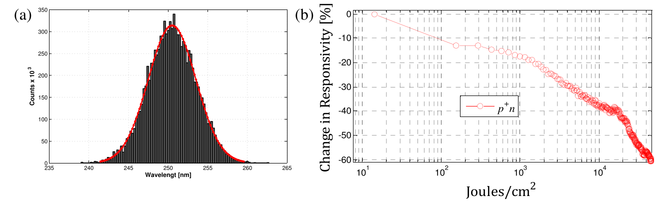

Fig. 3. (a) Transmittance spectrum of a bandpass interference filter placed after a 45° laser line mirror (b) The stability plots normalized to the peak response of the p^+n *l*PSD when exposed to 253 nm radiation.

beam (spectrum of 170–2100 nm) from the LDLS source was passed through a lens tube and a 45° laser line mirror that was used to reflect a narrower bandwidth beam in the region of 253 nm. But because the spectrum range and bandwidth of the reflected beam was broader than desired, a bandpass interference filter was placed after the mirror. Its importance was to transmit a narrower range of wavelength with peak wavelength of 253 nm (see Fig. 3a).

To minimize the risk of damage to the reflecting/focusing optics and ensure stability during the time of irradiation, the lens tubes and cube and their contents were used in a liquid nitrogen controlled environment and the intensity of the beam hitting the *l*PSD was continuously monitored using the calibrated sensor and power meter.

A 25 mm focal length lens was used to focus the beam of approximately 1 mm diameter on the detector which was stationed on a motorized XYZ stage. An attempt to increase the irradiance by bypassing the 45° laser line mirror and placing the bandpass interference filter directly between the LDLS source and the *l*PSD, resulted in the damage of the filter as can be seen in Fig. 2b. The optics coating was burnt off from the filter glass, thereby allowing no discrimination of wavelength through the optics.[2]

The experiment was performed in three stages. The first part involved mapping the sensitivity and the position deviation of the entire active area of the device as well as measuring the leakage currents (I_d) of the detector before irradiation. The next stage was irradiating the detector over a period of 183 h to cause ionization damage and degradation on the *l*PSD under constant UV beam radiation. In order to determine the induced radiation damage, position deviation and shift in leakage currents of the device caused by radiation damage, stage three was performed by repeating the steps in stage 1. All three stages were performed using the same beam wavelength and the setup shown in Fig. 2a. The only difference was that for stages 1 and 3 (involving 3-dimensions mapping and position detection deviation measurement), a 100 μm spot size fiber optic cable and a beam profiler were used in place of the 25 mm focal length lens and bandpass interference filter.

3. Results

Due to the reason that the photon energy irradiated on the detector (253 nm = ∼4.9 eV) is greater than the bandgap of silicon (∼1.1 eV), and the energy required for the creation of electron-hole pairs (∼3.66 eV [10]) in silicon, photocurrent will occur by carrier injection. The recorded photocurrent at any point in time of irradiation is a measure of responsivity of the detector which is a ratio of the electrical output to every absorbed UV photon. A measure of the ionization damage from prolonged irradiation was calculated in the form of the change in the responsivity of the *l*PSD as shown in Fig. 3b.

It is seen that after the absorption ∼0.5 × 10^5 J/cm^2 of UV photons, the detector loses about 62% of its original responsivity. The

[2] No result from the use of the burnt filter is shown in this paper.