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Radiation Tolerance for a Large Pixel Detector for XFEL

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Abstract

This work investigates the possible damage to the LPD (Large Pixel Detector) from the expected irradiation levels at XFEL. MOS capacitors were designed and fabricated in the same material to be used for the final detector. A range of samples were subsequently irradiated at the DORIS III beamline at DESY to various fluences up to 100MGray. IV-CV measurements were performed pre and post irradiation to give an indication to how such fluences will affect the sensor material used for the LPD at XFEL

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1 Introduction

In 2013, the XFEL (X-ray Free Electron Laser) will switch on at DESY, Hamburg. Its peak brilliance will be billions times higher than that of conventional X-ray light sources, emitting light pulses with a duration ¡100 femtoseconds, and covering a range from 0.02-1.46keV. It will open up areas of experimentation in wide-ranging fields such as structural biology, plasma technology and materials science [1]. The brilliance of the XFEL will set new standards. Its peak brilliance will be billions of times higher than that of conventional X-ray light sources, and its average brilliance will still be 10,000 times higher. The duration of the light pulses will be less than 100 fs. This time resolution will even make it possible to film chemical reactions that occur much too rapidly to be captured by other methods. It will be possible to vary the wavelength of the X-ray laser flashes from 0.085 to 6 nm, making it possible to recognize details even at the atomic level. The X-ray laser flashes will display the properties of laser light, thereby making it possible to record three-dimensional images of the nanoworld. The light will be generated using the SASE principle [2]. SASE stands for ”Self-Amplified Spontaneous Emission”. With SASE, the electrons interact with the radiation that they (or their neighbours) emit. As a result, the electrons organize themselves into extremely small bunches, so that the spontaneously emitted X-ray flashes are amplified like laser light.

2 LPD

The bunch structures and intensity of the X-rays have created demanding requirements for the pixel detector needed for such experiments. The Large Pixel Detector (LPD) [3,4] will be designed and built by Rutherford Appleton Laboratory (RAL) and Glasgow for the experiment as the detection system for the Pump-probe, Coherent X-ray diffraction imaging and small molecule imaging stations.

Performance Parameters	Max Value	Units
No of Pixels	20k x 20k	pixels
Radiation Hardness	$2x10^{16}$	ph/pixel
Dark Current	< 1	Eq. photon
Read Noise	< 1	Eq. photon
Quantum Efficiency	80	%
Linearity	1	%
Timing	5	MHz

Table 1: Proposed performance parameters required for the LPD at XFEL

3 Ideal MOS Diode

An important consideration for the LPD consortium is the effect of X-ray irradiation on the Si detectors. In an early fabrication run, MOS diodes (1x1mm, 2x2mm, 3x3mm & 5x5mm) were designed and placed at the outer edges of the wafer as drop test structures. (Fig 1)

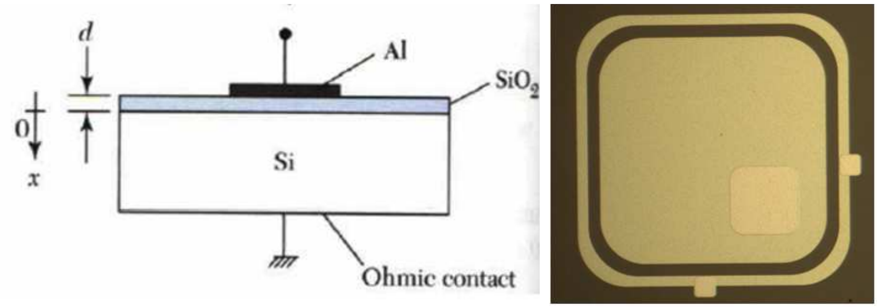

Figure 1: a- schematic of ideal MOS stack; 1b - image of fabricated 1x1mm MOS diode

The total capacitance, C, of a MOS diode is described as

$$C = \frac{C_o C_j}{C_o + C_j} Fcm^{-2} \tag{1}$$

Where C_o is the oxide capacitance and C_j is the semiconductor depletion layer capacitance [5]. With irradiation of the MOS diodes, we expect to see an increase in the density of traps and charged states, which could prove detrimental to the operation of the detector. The effects of such increases in defects/traps can be identified through the C-V characteristics of the irradiated MOS diodes. An illustration of the effects can be seen below in Fig 2 (note this is for a p-mos device) [5]

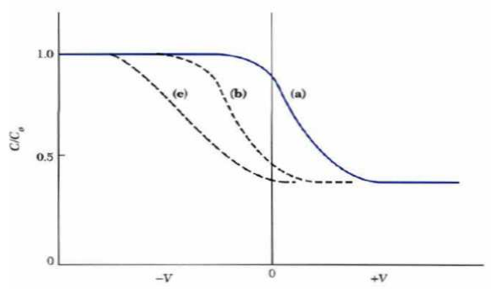

Figure 2: Effect of irradiation of the C-V curve of an ideal MOS diode

a)The C-V characteristics of an ideal MOS diode

b)Shows the parallel shifts of the C-V curve caused by non zero fixed oxide charge, mobile ionic charge and/or oxide trapped charge

c) Large amounts of interface traps varying the surface potential causes both a distortion and shifting of the ideal C-V curve

4 Irradiations at DESY

Irradiations were performed at the DORIS III synchrotron radiation source facility at DESY. Synchrotron radiation is produced in the accelerator ring, through the use of insertion devices (wigglers, undulators, and bending magnets). The spectrum of DORIS III ranges from infrared radiation to hard X-rays, and is extremely intense, particularly in the X-ray range [6]. The absorbed dose was measured using a calibrated diamond detector, and was calculated to be $33.37MGrayh^{-1}$ for the defined $0.5mm^2$ beam spot (the largest homogenous area achievable). Therefore, the irradiation rate for our $1mm^2$ devices (using a raster method) was $8MGrayh^{-1}$. The samples were attached to a ceramic holder, and inserted in a CLCC84 chip socket. This was positioned in front of the beam using an automated stage. A series of samples were then irradiated to the following fluences:

Hrs	Dose/ Quad (MGray)	Diode Dose (MGray)
0	0	0
1	33.37	8.34
3	100.11	25.0275
6	200.22	50.055
12	400.44	100.11

Table 2: Proposed performance parameters required for the LPD at XFEL

5 CV tests

C-V measurements were performed using a HP LCR meter and Keithley 237 voltage source controlled by LabVIEW software. The C-V of the unirradiated diode behaves like an ideal MOS diode (Fig 3).

Using

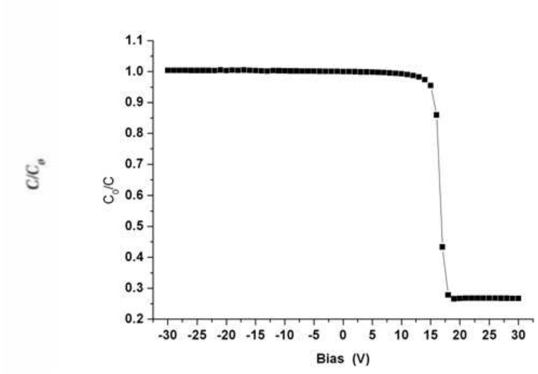

Figure 3: Measured C-V characteristic of un-irradiated diode

$$C = \frac{Q_{SC}}{C_o} + 2\psi_B \tag{2}$$

and

$$C_o = \frac{\epsilon_{ox}}{d} \tag{3}$$

(where V_T= Threshold Voltage, Q_{SC}=space charge in the semiconductor, psi_B=difference between the Fermi level and intrinsic level, ϵ_{ox}=oxide permittivity, d=oxide thickness) we find a measured value of V_T = -21V and a predicted V_T=17.5V, and a measured value of $C_o = 2.09x10^{-11}$ Fcm^{-2} with a predicted value of $6.21x10^{-10}Fcm^{-2}$. With irradiations, we can see evidence of both an increase in fixed charged states and an increase in interface traps causing distortion and shifting of the C-V curve. Initial testing shows these effects saturate by 25 MGray. (Fig 4)

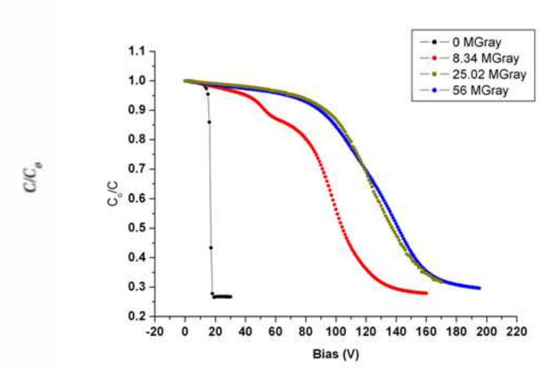

Figure 4: Measured C-V characteristic of irradiated diodes

6 Future Work and Conclusions

This work has detailed the investigation of the effect of X-ray irradiation on the detecting material to be use for the LPD at XFEL. MOS diodes were designed and included on early fabrication runs. An analysis of C-V characteristics shows that the un-irradiated diodes behave as expected, and that there is evidence of an increase in both charge trapping and interface states with irradiation. Initial results show that these effects saturate at $\sim$ 25MGray. Further irradiations will take place in late 2009 to examine both the exact saturation point for the irradiation effects in the material and to identify the trap energy levels.