The Version of Record of this manuscript has been published and is available in
Journal of Instrumentation, Volume 10, March 2015 C. Cruz et al 2015 JINST 10 C03005
DOI 10.1088/1748-0221/10/03/C03005
https://iopscience.iop.org/article/10.1088/1748-0221/10/03/C03005

10μm thin transmissive photodiode produced by ALBA Synchrotron and IMB-CNM-CSIC

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ABSTRACT: Thin silicon photodiodes are common X-ray beam diagnosis devices at synchrotron facilities. Here we present a new device featuring an extremely thin layer that allows X-ray transmission over 90% for energies above 10 keV. The diode has a radiation-hard silicon junction with silicon dioxide passivation and a protective entrance window. These outstanding features make this device suited for diagnostic applications in X-ray synchrotron beamlines. Hereby preliminary results of X-ray transmission, responsivity and uniformity are presented.

KEYWORDS: Beam-line instrumentation (beam position and profile monitors; beam-intensity monitors; bunch length monitors); X-ray detectors; Solid state detectors

doi:10.1088/1748-0221/10/03/C03005

Contents

1 Motivation

Transmissive silicon photodiodes are X-ray beam diagnosis devices extensively used in synchrotron beamlines as they allow the monitoring of the beam intensity while performing the experiment (figure 1). Due to Si absorption, devices thinner than 10 μm are needed to achieve transmission over 90% for energies above 10 keV. Such devices, to our knowledge, are currently not avail- able commercially in standard catalogues, arising the need to manufacture them in-house. With the aim of producing a 10x10 mm^2 10 μm thick transmissive photodiode, CELLS-ALBA and IMB-CNM-CSIC have produced the first prototype of thin photodiode and hereby we present our preliminary results.

2 Fabrication

The fabrication process is based on a technique developed at the Max Planck Institute to process large area thin detectors [1]. The first step of the process is to implant the back-side of a standard high resistivity Float Zone silicon wafer. Top and handle wafers are bounded (figure 2a) and then top wafer is thinned and polished to the desired thickness (figure 2b). Diodes are processed with conventional equipment on top wafer (figure 2c) and finally the bulk of handle wafer is removed by deep anisotropic etching, resulting in a thin diode (figure 2d). The area of the handle wafer not etched away works as a frame that provides mechanical stiffness for the ensemble.

The mask design includes eighteen DDS1-1010 diodes and eighteen DDS1-1005 diodes (figure 3), plus several test structures. DDS1-1010 and DDS1-1005 diodes have an active area of 8.3×8.3 mm^2 and 5.3×5.3 mm^2 respectively. The thinned wafers are diced to single chips at IMB-CNM-CSIC and mounted on PCB or ceramic support. The support has a window of 8.5 mm in diameter.

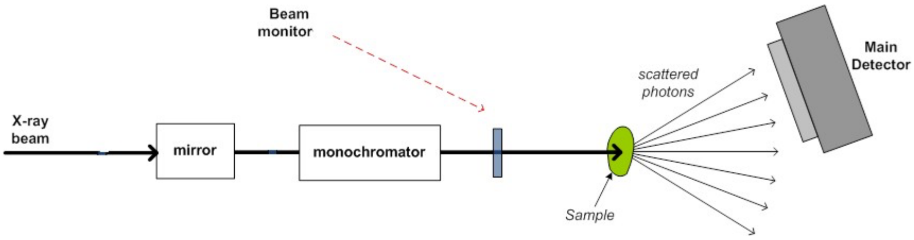

Figure 1. Example of beam monitor setup in a beamline.

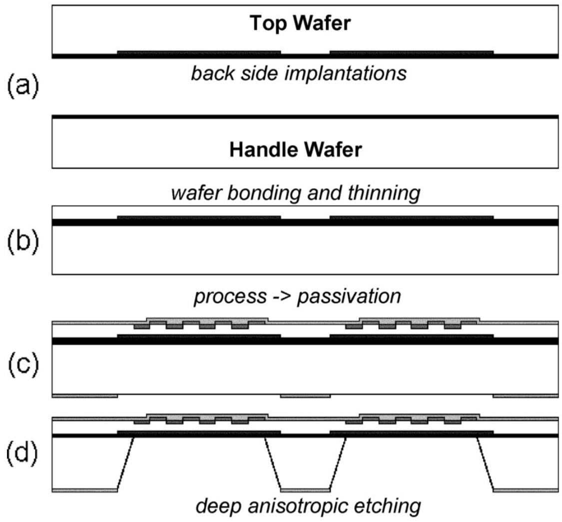

Figure 2. Fabrication process.

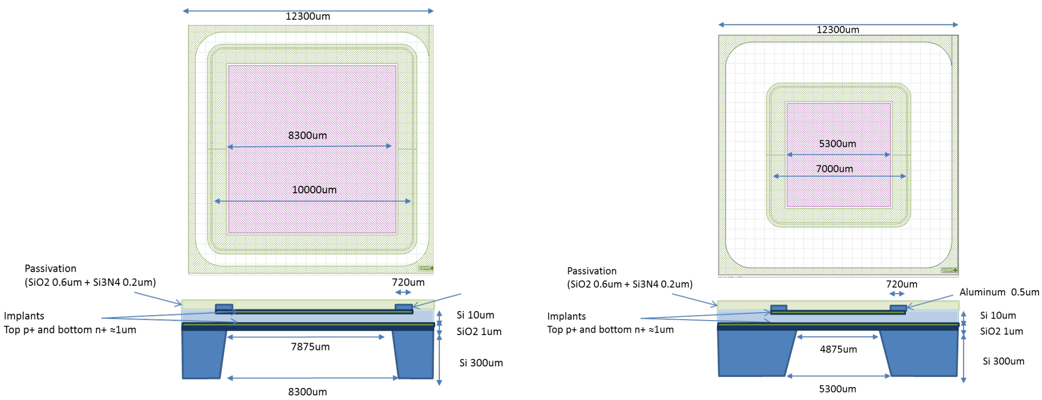

Figure 3. Layout of DDS1-1010 (left) and DDS1-1005 (right) diodes.

3 Characterization

An initial generic photodiode characterization has been performed at ALBA electronics lab to measure the device main parameters (section 3.1). The photodiode was later measured at ESRF detector's laboratory using an external Genix Cu X-ray generator at 8 keV and a flux up to $4 \cdot 10^8$ ph/s. The final tests using synchrotron beam have been done at BM05 beamline at the ESRF and at BL13-XALOC at ALBA [3]. The measurements have been done with the diodes mounted on

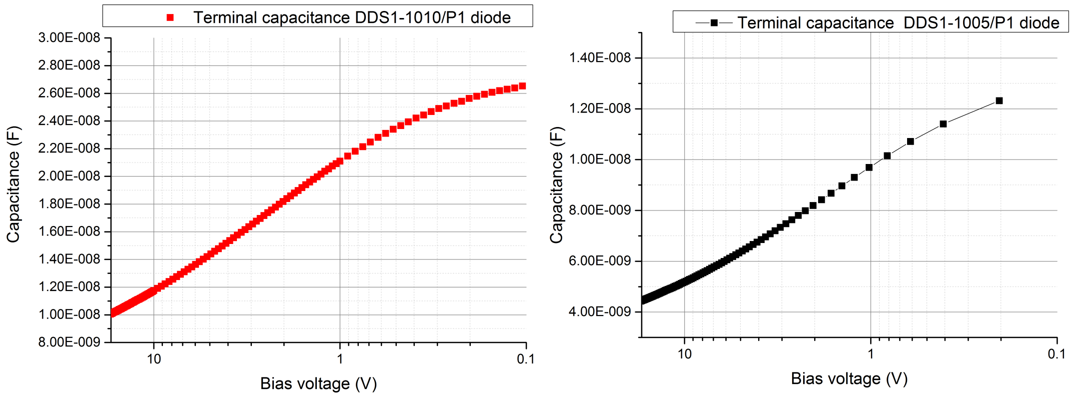

Figure 4. Terminal capacitance.

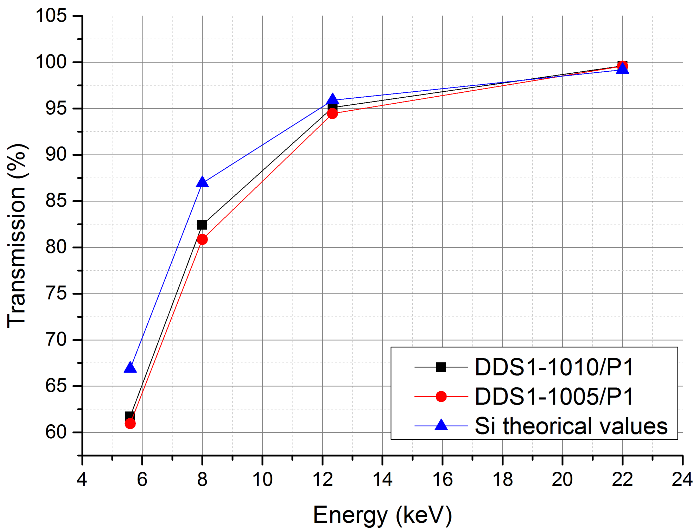

Figure 5. Dependence of the transmission of the diode upon X-ray energy.

PCB support and cased in a dedicated box with Kapton film windows that copes with the device mechanical inherent fragility. Cased diodes are identified adding /P1 in the coded name.

3.1 Main electrical characteristics

A complete I-V characterization has been done for determining the maximum reverse voltage operation of the diode, defined as the one generating 1μA reverse current, thus allowing a safe operation margin before exceeding the breakdown voltage threshold. The maximum reverse voltage recommended operation for DDS1-1010/P1 and DDS1-1005/P1 are 16.7V and 14.6V respectively.

The shunt resistance has been characterized over a range of ±10mV obtaining a value of 230MΩ for DDS1-1010/P1 diode and 420MΩ in DDS1-1005/P1 case.

The junction capacitance is the major factor for the response speed in photodiode application. It can be measured directly by measuring the terminal capacitance. In our case the terminal capacitance was measured from 0 to -10V reverse voltage, feeding a signal of 1MHz of frequency and 10mV of amplitude over the bias (figure 4). The capacitance obtained at 0V biasing was 0.275 nF for DDS1-1010/P1 and 0.123 nF for DDS1-1005/P1.

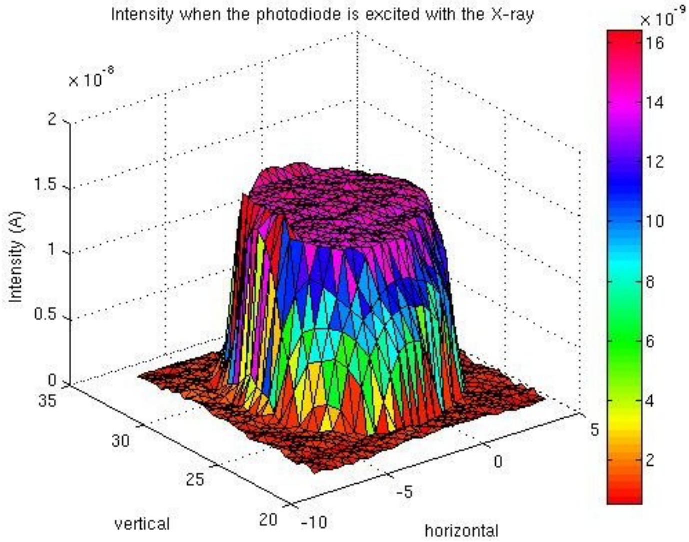

Figure 6. Spatial uniformity of the DDS1-1010 diode current exposed to 8 keV photons.

3.2 Characterization under the X-ray beam

The X-ray transmission of the DDS1-1010/P1 and DDS1-1005/P1 photodiodes were measured in BL13 beamline at ALBA Synchrotron using a commercial reference diode (AXUV36, IRD, CA, U.S.A.). The current of the reference diode was measured with direct X-ray beam and interposing the diode. The ratio of the two measurements at different X-ray beam energies determines the X-ray transmission curve of both diodes (figure 5).

The current of DDS1-1010/P1 diode was referenced to a calibrated diode to obtain the absolute responsivity, resulting in a responsivity of 0.035 A/W at 8 keV. Uniformity of the responsivity was measured with a scan of 30×30 steps of 0.4mm in each direction. The responsivity is high and uniform in a circular area of 8mm diameter at diode center (figure 6), with a maximum deviation of the responsivity of 4% with respect to the mean value. The responsivity is very low near the corners of the diode. The area where the DDS1-1010/P1 responsivity is uniform is the area coincident with the PCB hole and with the geometry of the diode.

Radiation hardness tests were performed by exposing the diode to synchrotron X-ray beam. The test at the ESRF was carried out in beamline BM05 using a beam of an energy of 15 keV and a flux of $4.22 \cdot 10^{12}$ ph/sec. The test at ALBA was performed in BL13-XALOC using a beam of an energy of 8 keV and a flux of $1.2 \cdot 10^{12}$ ph/s on a beam spot of $52 \times 6 \mu m^2$ (FWHM, h×v). The response was always stable and following the course of the incoming flux to the diode during exposures longer than eight hours (figures 7, 8). A full study on radiation hardness will be held in the future.

4 Conclusions

The newly designed transmission photodiodes presented here are well suited as a monitor detectors for synchrotron X-ray beams with energies above 5 keV. The results show a transmission of 81.6%

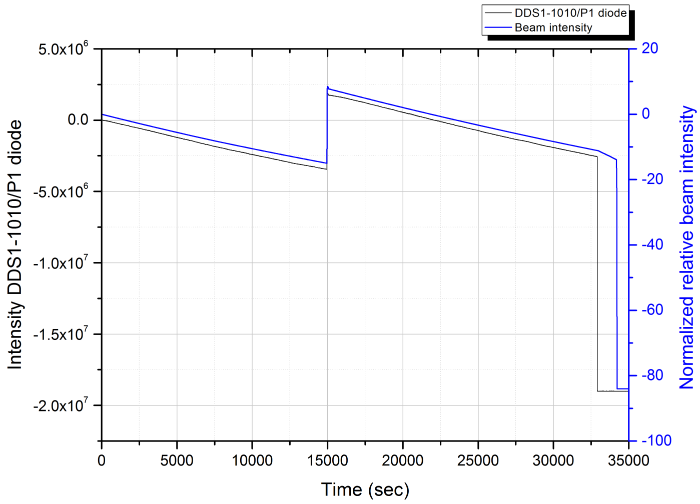

Figure 7. Evolution of the current of the DDS1-1010/P1 diode over 10 hours (black curve). The current follows the ESRF beam current (blue curve).

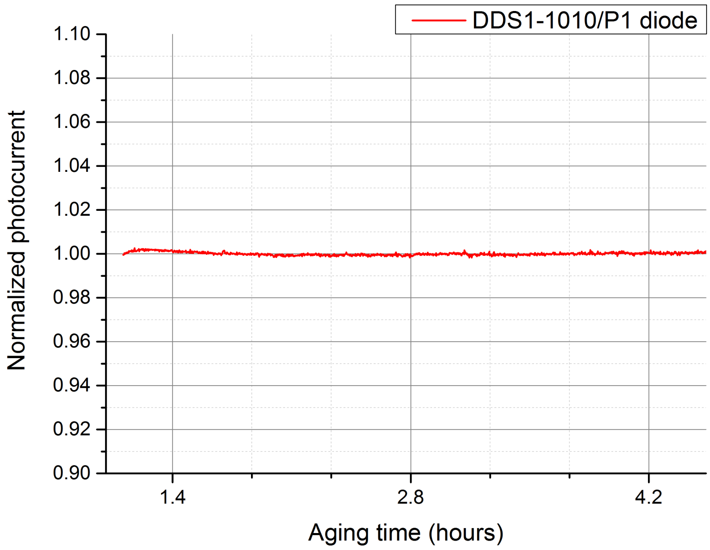

Figure 8. Evolution of the current of the DDS1-1010/P1 diode normalized with respect to the electron beam current on the ALBA storage ring.

at 8 keV and 94.15% at 12.338 keV as well as a uniform responsivity with a tolerance below 5% over a circular area of 8mm diameter.

Further test are planned to be done in BL13 beamline at ALBA synchrotron in the near future. Some samples has been sent to PTB [4] laboratory for further characterization on transmission and responsivity. In addition, a funded program is being developed under the EDI program of FCRi [5] to promote the availability of these devices to external institutes.

Acknowledgments

We want to thank Thierry Martin from ESRF detector unit for their help and collaboration.

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