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Use of active-edge silicon detectors as X-ray beam monitors

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Abstract

Silicon detectors have been developed which are active to within several microns of the physical edge of the detector. These active-edge devices can be placed near an intense X-ray beam to accurately measure the X-ray beam properties. In addition, they can be fabricated in a variety of geometries that will be useful for monitoring the intensity, profile, and position of synchrotron X-ray beams. One shape is a detector with a through hole surrounded by four active elements. The hole allows the intense X-ray beam to go through the center while the four elements can detect any change in the position or dispersion of the beam. Another shape is a rectangular 5 mm long × 0.5 mm wide device with a set of four elements that are 100 μm wide. These devices could be mounted on the upstream side of the jaws of an *x–y* collimating slit to measure the intensity profile of the beam that each jaw of the slit is stopping. Small detectors could also be mounted in a cylindrical beam stop to give on-line beam intensity measurements. A variety of different geometries were tested at beamline 10.3.1 of the Advanced Light Source using a 12.5 keV X-ray beam. They have wide dynamic range, excellent position sensitivity and low sensitivity to radiation damage.

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1. Introduction

The availability of X-ray beams of very high intensity and small beam spot size are enabling experiments that would have been considered impossible only a few years ago. However, to make optimum use of these beams it is necessary to measure in real time both the intensity and position with high accuracy. For example, focused X-ray beams are now available with a spot diameter of less than 0.5 μm and an intensity of more than $10^{12}\,s^{-1}$ to do XAFS experiments on heterogeneous samples where the beam spot dimensions must be stable to less than 1 μm for about 1 hour as the energy of the beam is scanned by 300 eV across the absorption edge. There are many critical components on a synchrotron beamline that can vary with thermal loading and mechanical motion that can produce significant drifts in beam position and intensity. Ion chambers are routinely used to measure the intensity of X-ray beams but they are difficult to make small and can become non-linear at high intensity because of space charge effects. Conventional planar silicon diodes and avalanche photo-diodes have a large dead area around the edges of the device. This limits their use as beam position monitors since they cannot be placed near the edges of the beam. The dead area also limits how small they can be made so they are difficult to use in electronic beam stop devices. The techniques used to fabricate active-edge sensors have been described in a previous publication [1]. The sensors are fabricated at the Stanford Nanofabrication Facility.

2. Detector geometries

Three of the most promising applications of active-edge detectors as beam monitors are as position monitors, beam profile sensors, and as active beam stop monitors. Firstly,

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for experiments with small diameter beams, it is important to monitor the position of the beam. One method of measuring the beam position is to fabricate a device with a hole in the center, which the main beam goes through. Active-edge devices are useful for this application since they can be relatively easily made to have a central hole that is 100 μm in diameter. If the device is not segmented, then the current in the device is proportional to the beam halo. If the beam moves, then the signal in the device will increase significantly since part of the main beam is entering the device. The device can also be fabricated with either two or four sections so that the direction of the beam motion can be measured. Another application of through-hole devices is in experiments using Fresnel zone plates as focusing elements. An active-edge detector could be placed between the zone plate and the sample to measure the harmonic component of the beam without reducing the flux of the primary beam.

Secondly, for experiments where experimental conditions are changed regularly, a collimating slit that contains active-edge devices on each jaw can provide a flexible way to optimize the beam conditions. Each jaw of the device has a rectangular detector where the active-edge device is mounted on the upstream edge of the collimating slit with only a few microns from the edge of the detector to the edge of the slit. Each device is 3 mm long $\times$ 0.5 mm wide $\times$ 0.2 mm thick with 3150 μm wide stripes per device. Scanning one jaw of the system through the beam would provide a one-dimensional profile of the beam and scanning one of the jaws of the perpendicular slit would then give the orthogonal profile. Using simple current measuring electronics on each element would provide an easy way to verify the position and flux of an X-ray beam. If the flux in the four elements nearest the edges of the slits is measured during the experiment, any change in beam conditions could be reliably detected.

Lastly, for some experiments it is useful to measure the total flux in the beam downstream of the sample without obscuring very much of the scattering area. Protein crystallography experiments are an example of this where the beam area at the sample is less than 200 μm^2 and a large-area CCD is mounted downstream of the sample to measure all the scattered X-rays. It is important to measure the scattered X-rays that are within several millimeters of the intense unscattered beam. Active-edge devices have been fabricated that have a total area of 0.22 mm $\times$ 0.22 mm and could be installed in a cylindrical beam stop to provide an accurate measurement of the beam flux for each CCD picture of the crystal.

3. Detector performance

A torus detector was fabricated and tested that had a central hole of 200 μm diameter. The left part of Fig. 1 shows a photograph of a similar, four-electrode torus and the right image shows the response of the single-electrode, 200 micron hole torus to 12.5 keV X-rays. The experiment was done at beamline 10.3.1 at the Advanced Light Source of Lawrence Berkeley National Laboratory. Even with no bias voltage on the sensor, it has excellent performance.

A series of long rectangular devices were also fabricated. Fig. 2 shows a photograph of a part of a sensor. A 5 mm long device with three electrodes on a 150 μm pitch was tested at various places along the length of the device. The device performance was excellent everywhere along the edge. The dead area at the edge of the device was measured with a 2μm $\times$ 4 μm, 12.5 keV beam and it was found to be less than 3 μm wide. In the top part of Fig. 2 the two interior pads were also tested and found to have linear response.

A variety of beam stops were also fabricated. Fig. 3 shows a photograph of a three-segment beam stop. The size

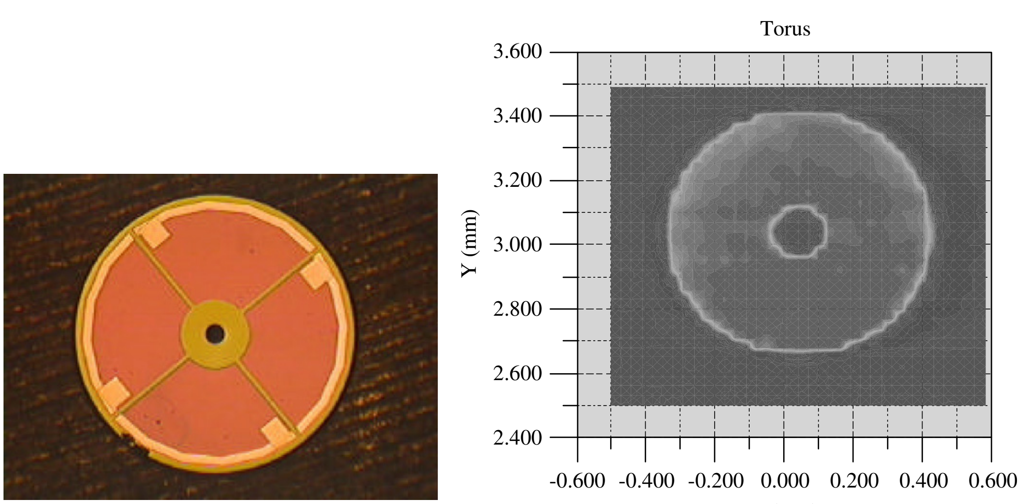

Fig. 1. Picture of a torus with 100 micron central hole divided into quadrants on the left; X-ray beam scan of a circular active-edge detector with a 200 μm central hole. The electrical output is linear over the whole device including the edge of the hole.