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Active Beam Attenuators for Synchrotron Radiation

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***Abstract*– Attenuating materials are employed on synchrotron beamlines to achieve photon flux modulation as well as beam hardening of the x-ray spectrum. In some experiments it is desirable to maintain the intensity of the beam on the sample at a constant value as the current in the synchrotron decays during a fill cycle. This is often done by attenuating the incident beam with a set of discrete, thin foils. To change the amount of material in the beam path typically involves inserting or redrawing a number of foils. The use of discrete foils imposes practical limits on the number of thickness values available as well as the smallest thickness increment. Micro-machined attenuators can avoid these restrictions by offering either continuous variation of the material thickness or through the implementation of a large number of small thickness steps. Through a combination of photolithography and appropriate device geometry sub-micron thickness increments can be fabricated. Device geometries such as staircase, low-angle triangle, and overlapping triangles will be described. Fabrication of these devices by direct micro-machining of materials such as silicon as well as micro-molding of various polymers can be done relatively easily. In addition, by manufacturing a silicon diode into the attenuator the absorbed fraction of the beam can be continuously monitored. By using a feedback loop where the attenuator thickness is varied based on a downstream beam monitor, it should be possible to maintain the photon flux on a sample to vary by less than 0.5 %. The performance of a variety of these devices at the Advanced Light Source is presented.**

Keywords: synchrotron, x-ray, attenuator, beam monitor, active edge
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I. INTRODUCTION

Attenuators are routinely used at many synchrotron beamlines to optimize the x-ray flux. For best results the flux should be matched to the specific sample, measurement technique, and instrumentation. Often experimenters need to use the highest flux possible without introducing significant dead time in the data-acquisition stream [1]. Sometimes flux should be reduced to avoid operating in a state where electronics or detectors are non-linear [2]. Particular samples or detectors maybe extra sensitive to radiation damage and thus require a lower flux [3]. At most synchrotron facilities the electron current in the main ring decays over time and some experiments benefit from having a constant flux during the measurement [4]. Different samples, or even different regions of the same sample, may be thicker than others and so have dissimilar optimal fluxes.

Several methods are currently used to control the x-ray flux with the insertion of foils of various thicknesses into the photon flight path being the most common. This works well, but is cumbersome and limited to a relatively small set of fixed attenuation values [5,6]. A rare technique is the use of a gas filled chamber, where the gas pressure and composition is varied to change the fraction of x rays absorbed [7]. Changing the separation of collimating slits can affect the total number of photons, which is done by modifying the beam area, while leaving the photon flux constant.

As part of this study triangular devices, which provide a continuous variation of the attenuation factor over a wide range from unobstructed to complete absorption, are made and tested. Use of polyimide and other low-atomic number materials can allow such designs to function down to photon energies of 3 keV [8]. The use of overlapping triangles would eliminate the variation in attenuation across the width of the beam, which occurs when using a single triangle. With micro-machining a staircase design with a large number of discrete thickness steps, each having at least the width of the beam, can be made. A single diode or a set of diodes can be incorporated into silicon triangles or staircases and provide not only the total absorbed flux, but also some information on the beam shape and location.

Attenuators with any cross-sectional form can be created and so the attenuation versus position can follow any single-valued, well-behaved function. The attenuation factor can also be designed to vary in two perpendicular directions with some constraints.

II. FABRICATION

A variety of techniques can be used to manufacture these attenuator designs. The simplest method is to use a precision saw with a diamond resin blade to cut a substrate into triangles as was done in this work for silicon and fused silica. Use of a mold to form triangles, staircases and other shapes allows low-atomic number materials to be used. Direct patterning of some substances such as SU-8 [9] and polyimide is possible with

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photolithography. Plasma etching and photolithography is an alternative technique to cut the substrate instead of using a normal saw. Perhaps the most complex process is to form p-i-n diodes using active-edge fabrication [10,11]. A chemical etchant, such as potassium hydroxide (KOH) or Tetramethylammonium hydroxide (TMAH), can be employed to form atomically-precise structures in silicon, which could incorporate sensitive diodes if desired.

III. RESULTS

Triangular pieces of silicon and fused silica, which were cut with a wafer saw, were mounted on a stage and used to attenuate a 100-µm-wide, 12 keV x-ray beam. An image of the silicon triangle is shown in Fig. 1. A long scan, using a downstream ion chamber to record the transmitted beam, across most of the sloped part of the triangle is shown in Fig. 2 demonstrating the large range in attenuation that is possible. Fig. 3 shows an expanded part of the attenuation curve with the continuity and smoothness of the curve illustrating the fine control of the beam flux that is achievable with this method.

Fig. 1. Diagram of two overlapping triangles (left), drawing of a staircase design (right).

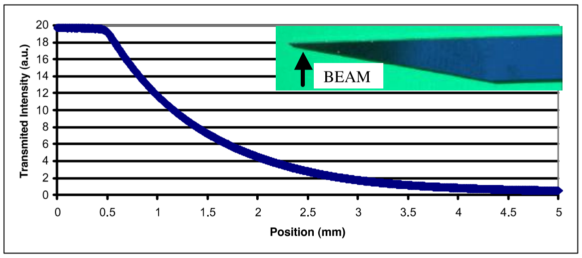

Fig. 2. Transmitted flux versus position of the beam relative to the silicon triangle (inset photograph) in one thousand, 5 µm steps.

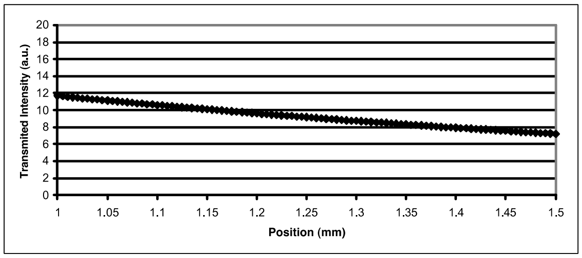

Fig. 3. Subsection of the curve in Fig. 1, showing 100, 5-µm step and high precision attenuation at the few parts per thousand level.

A photograph of an active-edge silicon diode subdivided into sixteen strips, with strips 1,2,3, and 16 read out and the intermediate strips floating, forms Fig. 4.

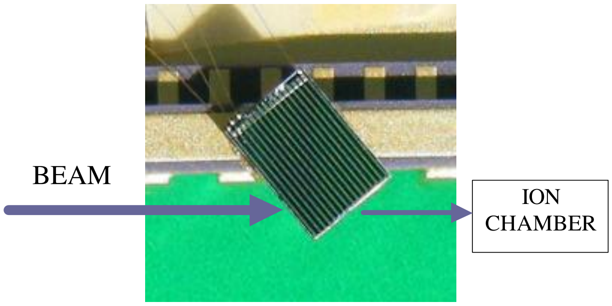

Fig. 4. Image of silicon p-i-n diode device used as an active attenuator.

The current from this provides a measure of the absorbed beam. In a diode with strip electrodes parallel to the beam axis, currents from the individual strips could provide information on beam position and shape. Fig. 5 shows the signal from the active-edge diode attenuator, the downstream ion chamber, and the normalized sum of the diode and ion detectors. The absorbed and transmitted signals are complements of each other. The slight dip in the summed signal is the result of charge carrier recombination in the middle of the device, where the strip electrodes were floating. The non-exponential character of the absorption curve is caused by a misalignment between the diode and the translation stage axis of motion.

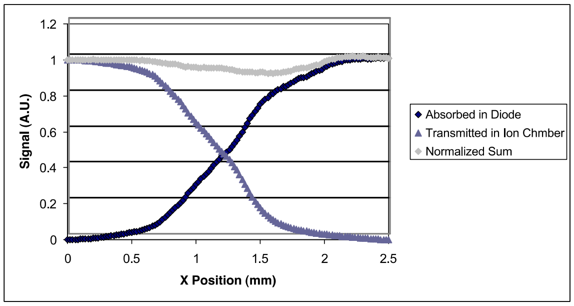

Fig. 5. Absorbed flux recorded by the angled, silicon diode shown in Fig. 4 and the transmitted flux observed in a downstream ion chamber, along with the normalized sum, as the beam was scanned across the angled silicon diode attenuator in 20 µm steps.

Another fabrication process is the etching silicon with a crystal-plane selective chemistry. KOH was used to form the structure with a triangular cross section depicted in Fig. 6. The transmission curve, using a 25 µm-wide-beam, for this device is plotted in the same Figure.

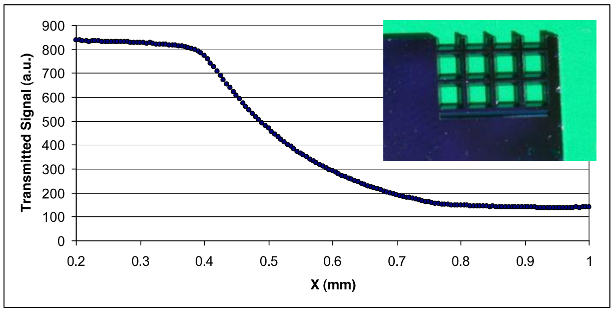

Fig. 6. Transmitted beam recorded by the downstream ion chamber as the beam is scanned across the KOH-etched, angled silicon (inset) in 5 μm steps.

IV. CONCLUSION

A plasma-diced, active-edge, silicon sensor has been demonstrated that can provide a real-time, in situ measurement of the beam flux, while simultaneously acting as a wide dynamic range attenuator. Triangular structures with low slopes, cut with a conventional wafer saw, made of both silicon and fused silica, have been used to attenuate a 12 keV photon beam with minimum attenuation steps of one part in a thousand. Another silicon device formed using a crystal-plane-selective, KOH etch was also used to precisely attenuate an x-ray beam. Use of a single, low-slope triangle on a translation stage provides an inexpensive, easy to use, continuous, and very-high precision attenuator. Other geometries such as overlapping triangles to eliminate variation across the beam and staircase layouts with a large set of discrete steps are being fabricated as diodes. In general one can make structures, which provide almost arbitrary attenuation functions in two perpendicular dimensions.

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