Silicon pore optics for high-energy optical systems

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SUMMARY

This thesis examines silicon pore optics (SPO) by studying its manufacturing process, applications, and prospects. SPO uses spin-in technology developed for decades by the semiconductor industry, which have massively invested in the fabrication and processing of silicon wafers. In essence, patterned coated silicon substrates are assembled into high-performance, self standing X-ray optics by direct bonding them on top of each other. Direct silicon bonding is key to controlling the paraboloid and hyperboloid shapes of Wolter-type telescope design. Moreover, the combination of thin film metallic coatings and direct silicon bonding is essential to increase the effective area of SPO-based X-ray telescopes that will survive launch and space flight conditions, and therefore extend the breadth and scope of future astrophysical observations. For instance, high-sensitivity observations in the X-ray band are needed to improve the understanding of high-energy phenomena of all classes of astrophysical objects, from large-scale hot gas structures to compact objects such as black holes.

SPO technology has become very mature thanks to the continuous development efforts to prepare the industrial production of Athena, the largest X-ray optics yet to be launched into space. In effect, SPO is not only an enabling technology for large spaceborne X-ray telescopes such as Athena, it is also a versatile technology that can be further developed for a wide range of applications. The technique of replication of a mandrel in self-standing stacks of mirror plates can be used for any medium to large series manufacturing of mirrors with potentially any figure. SPO-based Laue lenses, also known as silicon Laue components (SiLC), are being actively developed to create advanced gamma-ray focusing elements via the use of diffraction in the volume of the crystalline plates. Self-standing single or double-curvature stacks of plates can be used as Laue lens elements providing improved focusing capability compared to other methods.

For instance, we have designed and modeled a novel optical system composed of a Laue lens coupled to an X-ray tube that produces a focused beam in an energy range near 100 keV. One application of this system is radiation therapy as it plays an essential role in the treatment of cancer. However, it is not currently possible to deliver low-energy irradiation in the clinical setting without unacceptable toxicity to the skin and normal tissue. SPO-based Laue lenses are a potential solution as they can produce a high focus-to-skin ratio with a small, sharp focus and relatively low dose rate. Yet, several hurdles, such as the dose rate, need to be overcome before this could be translated into a meaningful clinical device.

Ultimately, the silicon pore optics technology is a maturing solution for high-energy optical systems. With further advances, this technology can enable more applications that require imaging and focusing of high-energy radiation.