Lithium x-ray refractive lenses

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I. INTRODUCTION

Re-evaluation of the possible use of refraction for x-ray optics[1,2] a decade ago, followed by a detailed comparison[3] of refractive x-ray optics with alternative techniques such as zone plates and glancing incidence mirrors, reinforced the long-standing belief that refractive x-ray lenses did not seem promising. However, once the first third generation synchrotron came online a few years later, useful refractive focusing of x-rays was achieved[4] with many refractive x-ray lenses in series that together form a compound refractive lens (CRL). Their first lens focused only in one dimension, but later they managed to focus x-rays in two dimensions with an ideal parabolic CRL.[6] While their original lenses were made from aluminum, they also made one-dimensional lenses from beryllium:[5] recently they may have constructed two-dimensional x-ray lenses from beryllium.[7] Since the first demonstration of CRLs, other groups have also made refractive lenses for x-rays.[8,9]

The lens material is typically chosen for its ease of manufacturing and low cost, such as aluminum or plastic. Silicon has also been used because it allows the fabrication of very small, intricate structures: the lens' focal length is proportional to its radius of curvature and the number of lenses in series.[10,11] The traditional best material for x-ray work, beryllium, has of course also been tried, with varying success.

We are the first to make x-ray refractive lenses from lithium metal, recognized as the best material for such an application. For refractive x-ray lens materials, the figure of merit N_0 is the phase shift per absorption length:[3] for beryllium N_0 is 2.5 times less than for lithium. Since lens characteristics such as the maximum gain are proportional to ${N_0}^2$, a lens from lithium might be 6 times better than a lens from any other material (except hydrogen).

II. METHODS AND MATERIALS

Lithium is rarely used in x-ray work because lithium is thought of as a difficult material with which to work. In actual fact, this bad reputation is only partly deserved: electrochemists that develop lithium batteries have long since figured out how to deal with lithium safely, and we have followed their protocols. The main difficulty with lithium is its rapid corrosion in open air, especially when the air is humid. The simple solution is to keep the lithium in an inert environment such as vacuum or a dry gas (nitrogen, argon or helium, for example). Lithium's special handling needs are thus quite compatible with techniques that are already standard for x-ray work: our lithium lenses are kept under vacuum, where they maintain their performance for over a year's time.

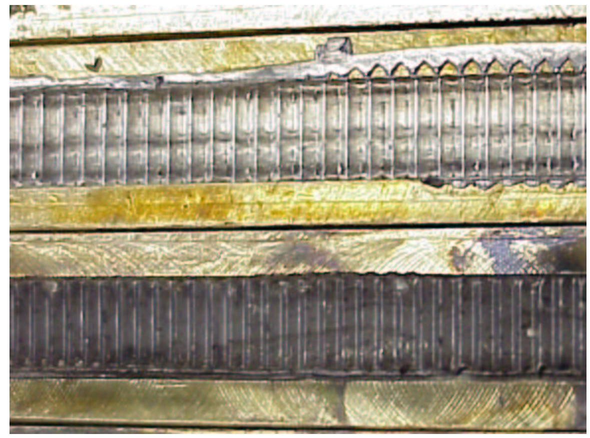

FIG. 1: Two lithium lens jaws with different tooth sizes.

For ease of manufacturing, we make our prototype lithium refractive x-ray lenses with Cederstrom's convenient alligator lens geometry.[12] This one-dimensional parabolic lens consists of a series of prisms under an angle with the x-ray beam. Manufacturing convenience strongly favors 90 degrees for the prism's top angle. A tooth of height h is then separated from its neighbor by $2h$. All our lenses are $L = 111$ mm long and have $N = L/2h$ teeth. Lens prototypes are all are 6.3 mm wide and have different tooth heights h, ranging between 0.15 and 1.5 mm.

Figure 1 shows two lenses with different tooth sizes. Each consists of a brass strip with a 6.3 mm wide channel for the lithium in its center. The teeth are made by pressing a machined mold into the lithium set in the channel. As with any malleable material, the mold's profile is faithfully reproduced in the lithium provided that the two separate cleanly on retracting the mold.

III. RESULTS

Figure 2 shows the intensity of the x-ray beam with and without the lens. The unfocused beam has wings caused by penumbra, and a profile that approximates a centered cut of a Gaussian beam. The peak intensity in the focused beam is 2.5 times larger than the unfocused

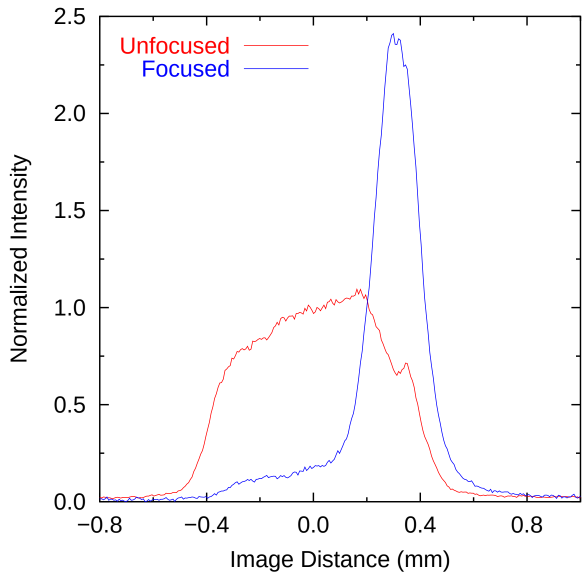

FIG. 2: Focusing by one jaw of a lithium lens.

beam. The gain is roughly 60 % less than estimated for an ideal lens, probably due to surface imperfections or scattering from impurities in the lithium. Next year we should be able to test lenses with better surfaces and less contamination.

The technical details have been published in Applied Physics Letters,[13] Review of Scientific Instruments,[14] and the Proceedings of SPIE.[15] These papers can be downloaded from our web sites.[16] To the best of our knowledge, this is the first refractive x-ray lens that uses lithium metal, and the papers may be the first ones that describe lithium's application in x-ray optics.[17] Perhaps because of this novelty, the lithium lenses have been highlighted in two widely read trade publications, SPIE OEMagazine[18] and Photonics Spectra.[19]

Acknowledgments

Operation of the MHATT-CAT Sector 7 beamlines at the Advanced Photon Source is supported by DOE Grant No. DE-FG02-99ER45743. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38. This work is supported in part by a Phase I SBIR award from the Missile Defense Agency.

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[16] See www.ecopulse.com or www.mhatt.aps.anl.gov .

[17] We will be extremely grateful to more knowledgeable readers pointing out publications on lithium for x-ray applications that contradict our statement, in email to pereira@ecopulse.com .

[18] SPIE OEMagazine, March 2002, pg. 10.

[19] Photonics Spectra, March 2002, pg. 20.