Lithium X-ray Refractive Lenses

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Introduction

A reevaluation of the possible use of refraction for x-ray optics that was done a decade ago [1, 2], followed by a detailed study comparing refractive x-ray optics with alternative techniques such as zone plates and glancing incidence mirrors [3], reinforced the long-standing belief that refractive x-ray lenses were not promising. However, once the first third-generation synchrotron came on line a few years later, useful refractive focusing of x-rays was achieved with many refractive x-ray lenses in series; together, these form a compound refractive lens (CRL) [4]. The first lens focused in only one dimension, but later an ideal parabolic CRL managed to focus the x-rays in two dimensions [5]. The original lenses were made from aluminum, but 1-D lenses were also made from beryllium [6]. Recently, researchers may have constructed 2-D x-ray lenses from beryllium [7]. Since CRLs were first demonstrated, other groups have also made refractive lenses for x-rays [8].

The lens material, such as aluminum or plastic, is typically chosen for its ease of manufacturing and low cost. Silicon has also been used because it allows the fabrication of very small, intricate structures; the focal length of the lens 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 it is for lithium. Since lens characteristics such as the maximum gain are proportional to N_0^2, a lens from lithium might be six times better than a lens from any other material (except hydrogen).

Methods and Materials

Lithium is rarely used in x-ray work because it is thought to be a difficult material to work with. In fact, this bad reputation is only partly deserved. Electrochemists that develop lithium batteries figured out how to deal with lithium safely a long time ago, and we have followed their protocols. The main difficulty with regard to lithium is that it rapidly corrodes in open air, especially when the air is humid. The simple solution is to keep the lithium in an inert environment, such as a 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.

For ease of manufacturing, we make our prototype lithium refractive x-ray lenses with Cederstrom's convenient alligator lens geometry [12]. This 1-D parabolic lens consists of a series of prisms under an angle with the x-ray beam. Manufacturing convenience strongly favors 90° for the prism's top angle. A tooth of height h is then separated from its neighbor by 2h. All our lenses have a length (L) of 111 mm and have a number of teeth (N) equal to L/2h. All lens prototypes are 6.3 mm wide, but they have different tooth heights ranging from 0.15 to 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 is the case for any malleable material, the mold's profile is faithfully reproduced in the lithium, provided that the two separate cleanly when the mold is retracted.

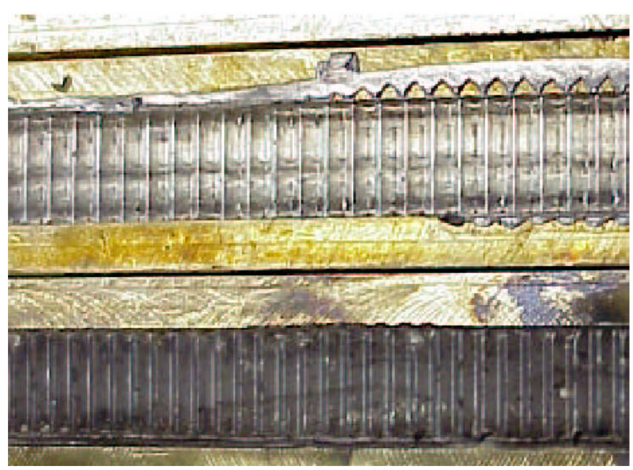

FIG. 1. Two lithium lens jaws with different tooth sizes.

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 it has a profile that approximates a centered cut of a Gaussian beam. The peak intensity is 2.5 times larger in the focused beam than in the unfocused beam. The gain is roughly 60% less than estimated for an ideal lens, probably as a result of 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 the Society of Photo-optical Instrumentation Engineers (SPIE) [15]. These papers can be downloaded from our web sites [16]. To the best of our knowledge, this refractive x-ray lens is the first to use lithium metal, and the papers may be the first ones to 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's *oemagazine* [18] and *Photonics Spectra* [19].

Acknowledgments

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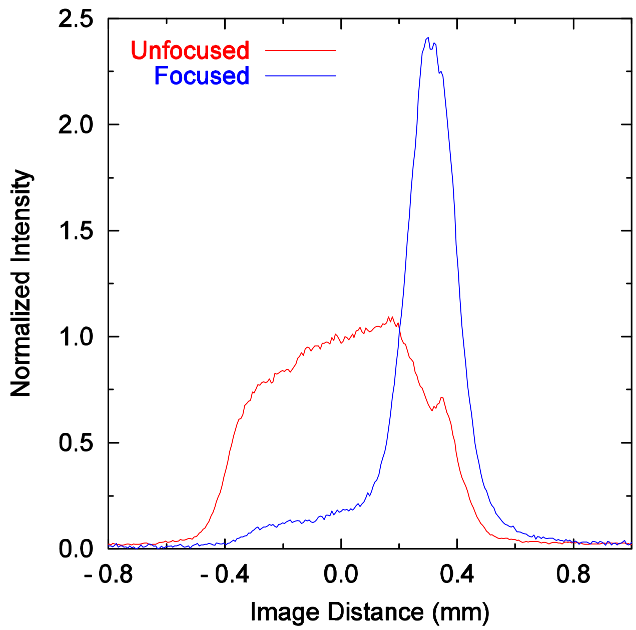

FIG. 2. Focusing by one jaw of a lithium lens.

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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 who point out publications on lithium for x-ray applications that contradict our statement, in email to pereira@ecopulse.com.

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