DOI : https://doi.org/10.56452/7-785

ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

*International Journal of Mechanical Engineering*

# Long-distance X-ray communication by diffractive and/or refractive optics

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## Abstract:

When returning space carriers to Earth, there is a communication blackout that must be overcome. The approach relies on the unique refractive - diffractive regime in which crystal optics operate. Lightweight, rigid, and an easy-to-align design are only a few of the benefits of the crystal arrangement compared to previously proposed approaches. All of these characteristics are crucial for optics in outer space. Several options are shown and built upon, demonstrating the unique X-ray space collimator's wide range of performance.

Keywords: refractive – diffractive, Lightweight, X-ray space collimator's

## Introduction

Beginning in the 1920s and 1930s, X-ray diffraction imaging (later called X-ray topography) was used to reveal the internal makeup of individual Laue spots. Optical microscopes were used to expose and examine fine grain photographic emulsions; due to its higher resolution, this technique is frequently referred to by the term X-ray microscopy [1]. Defect mapping in almost perfect single crystals [2] and stress mapping in cold-worked alloys of metals [3] were both accomplished using this method.

It was believed that each dot on the film or detector corresponded to a tiny hole in the reflecting crystal. The film has to be as close to the sample as possible, and the incoming X-ray beam needs to be accurately collimated, all in the name of good old-fashioned geometrical optics. Therefore, the detector's resolution limits the resolution to 500 nm [4], albeit in fact, it's closer to 1 m. Recent years have seen an explosion of writing on the topic of "communication blackout" [1, 2, 3, 4]. Spacecraft re-entering Earth's atmosphere are likely to blame for the current communication blackout. When a carrier body emits plasma, it disrupts Earth-to-spacecraft radio communications. X-rays with energy about 10keV[5-8] are a potential alternative to radio frequencies to communicate during this liminal period. There are several perspectives from which to investigate this matter. The most important aspect is long-distance X-ray photon transmission from the spaceship to ground control. There are two primary causes for the decrease in intensity.

Two things happen: first, the X-ray beam extends out because of air digestion, and second, its X-ray beam itself diverges. The problem of absorbance may be solved if an adequate energy range is used. The divergence problem may be addressed by collimating the radiation.

The purpose of this research is to examine the processes involved in developing a crystal collimator for X-ray space communications. Recent research has introduced total reflection optics and multilayer coated optics for usage in various optical communication systems. These guidelines result in systems that are cumbersome to manufacture because of their bulk, complexity, or all three. This article discusses the possibility of constructing an X-ray collimator using diffractive-refractive optics (DR optics) [9, 11].

The theory of X-ray DR optics is based on diffraction from a properly shaped (not curved) crystal. The interaction between diffraction and refraction processes may result in modifications to the diffracted light, such as focusing or collimation. It has been done earlier to sagittally concentrate synchrotron radiation by the application of diffraction on a longitudinal parabolic groove by slicing perfect crystals symmetrically or asymmetrically. The phenomenon of tilted diffraction is crucial in this scenario. The electro-optic modulator has been the subject of extensive research for quite some time. Many researchers in fields including fiber optics, coherent light transmission, and data processing are interested in optical signals because of their wide range of potential applications [12]. They are contemplating switching from using electrical/electronic communications to optical ones as a means of enhancing the present system of communication.There are now several distinct varieties of optical communication systems under development. If light beams were utilized instead of electronics, the number of conceivable communication networks would increase dramatically..

The improved usefulness of today's communication technology has contributed to its meteoric ascent to popularity in recent times. Communication technologies have advanced in tandem with the expansion of the electronic industry. Conventional electronic communication has made great strides thanks to the miniaturization of electrical components to the nanoscale. This means that electrons may potentially travel long distances in a short period of time, allowing for faster computations [13]. Every new technical development aims first and foremost to make devices faster, more efficient, and less reliant on power. This working speed is limited by the speed of the electron and the rising complexity of microchips, which need more and more connections between electronic gates. As a result, the maximum data rate that can be processed by even a highly fast electrical system is just a few Giga bytes (Gb) per second. All-optical circuits must replace the traditional electrical ones to increase the efficiency of a communication and computation system. UV and x-ray microscopy have gained in popularity during the last decade. Beams from third-generation synchrotron radiation sources [1] are suited for these applications due to their high brightness, minimal divergence, and almost homogeneous spectrum at an energy that can be tuned over a range of several keV. When an electromagnetic source is powerful enough (i.e., point-like and monochromatic), the optical instrument designer and the greater community of experimentalists and theorists have access to unexplored ground. This is in part due to the advancement of both the lensed microscope and x-ray microscope [2,3]. Third-generation sources have sufficient time and space coherence for exploiting x-ray diffractive optics approaching the diffraction limit, but innovative optical device design has not advanced beyond basic focusing optics. Zone plates (ZPs) have been around for a while as a method of focussing x-rays, but their commercial application has just begun within the past two decades [4,5]. That's because, although being invented over a century ago, implementing them has been a slow process due to technological difficulties.

## Literature Review

**Limin Jin et.al.,(2021)** X-ray communication has been shown to be an important method for interstellar communication and can also be used when a spacecraft passes through the plasma sheath it encounters during its high-frequency descent into Earth's atmosphere. It is suggested that the emission efficiency may be improved over the on/off control approach by using X-ray frequency modulation instead. In the present study, an X-ray communication system was assembled using a magnetically modulated two-target

**H. N. Chapman et.al.,(2021)** Both refractive lens and diffractive lens focusing solutions for hard X-rays are examined. Wide refraction glasses, including complex refractive lenses or waveguide gradients index refractive lenses, have focal length and primary plane variations with wavelength, which we account for in a novel method in our study. A combination of such a thick refractive lens and a multilayer Laue lens yields an achromatic system with a focusing precision of around 3 nm throughout a relative bandwidth of about 1%. The separation of the optical and diffractive lenses allows for the discovery of apochromatic systems that function at relative bandwidths greater than 10%. Without creating delays that exceed a few attoseconds, these configurations may be utilized to focus short bursts of energy. Such apparatuses allow for both high-flux scanning microscopy plus the production of powerful an X-ray pulses in the attosecond range.

**Jaromír Hrdy et.al.,(2019)** With longitudinal parabolic grooves manufactured on its diffraction surface, the Bartel monochromator serves as the basis for the diffractive-refractive optics X-ray crystal monochromator (IDL—inclined diffraction lens) that focuses in the sagittal plane. It is recommended to adjust the groove profile such that it consists of two parabolic surfaces that are laterally offset from one another. This monochromator produces two focused beams, one forward and one slightly offset to the side. We also talk about how these optics may be used to lengthen pulses.

## Proposed Work

We provide a space-saving method for performing diffraction imaging in which X-ray refractive lenses are positioned in front of both the specimen and the detector. Transmission X-ray microscopy using a comparable lens has been used to record a wavelength of 300 nm [12], and this might be accomplished by introducing a refractive lens into the scattered beam. The lens may also be able to correct for the progressive blurring created by the wavefront as it travels from the sample's surface to the detector. This would result in the instantaneous mapping of changes in strength on the detector to changes in reflectivity on the sample being restored. The dynamical diffraction processes that occur inside a crystal place a cap on the theoretical maximum picture resolution that may be achieved there. Fresnel zone plates have recently been put to use in X-ray reflect microscopy [13] to image monomolecular steps on a solid surface. These plates have also been put to use in scanning X-ray topography of stretched silicon oxide structures [14]. One of the benefits of CRLs is the efficient focusing they provide at photon energy E greater than 10 keV. Because regular KB mirrors do not satisfy the Abbe-sine criterion, they are incompatible with use in imaging systems. However, in order to circumvent this geometry-based transmission constraint, more complex multi-mirror configurations are now being researched and developed..

## Methodology

The European Synchrotron Radiation Facility's ID06 beamline swayed throughout our investigation. A liquid-nitrogen-cooled Si (111) monochromator, a 32-mm conventional in-air undulator, and an 18-mm cryogenically-cooled permanent-magnetic in-vacuum undulator generated 11 keV photons. The high-purity Beryllium (Be) condenser focused photons onto the sample at 67.9 m from the source (electron beam waist position in the middle of the two undulators). The enhanced flux on the imaged sample region boosted system optical efficiency (X-ray attenuation inside the condenser-CRLs was only 6%). The photon beam's divergence is barely impacted by the condenser CRL's one-to-one magnification. Photons strike the specimen at 2 x 1012. Six-circle diffractometers evaluated the material. The scattering plane and horizontal were perpendicular.

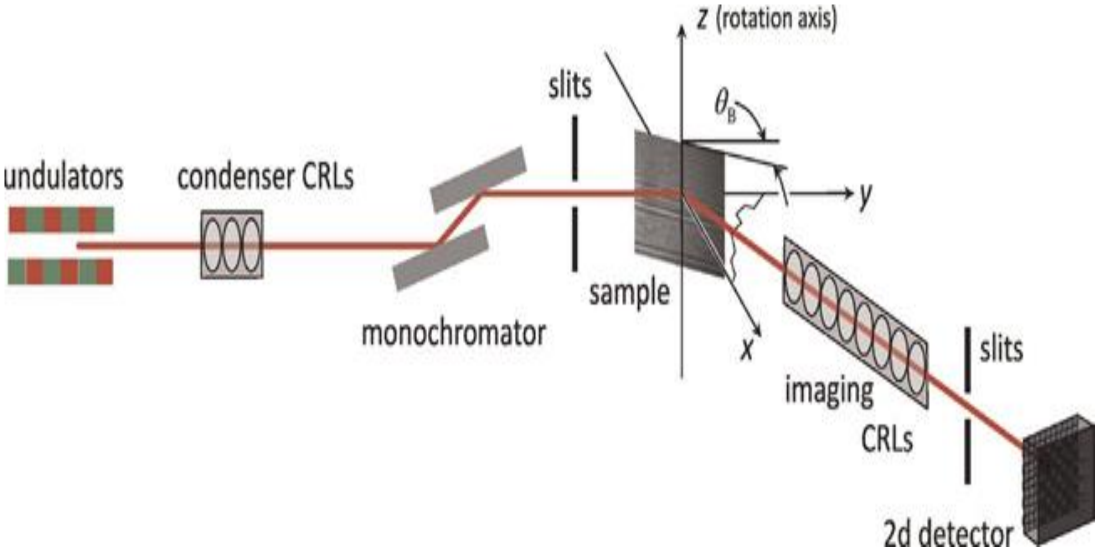

Figure. 1. Experimental setup for Bragg diffraction microscopy. 11 keV X-rays impinge on the sample

To ensure that the little sagittal divergence of the beam created by the left side of the collimator is entirely balanced by the right side, the crystal arrangement seems to need to be symmetrical. As the beam's sagittal divergence reduces from the first crystal to the last, however, the individual rays eventually arrive at slightly different locations along the parabola after being diffracted. The issue may be fixed by making a little adjustment to the parabola's a parameter for each diffraction surface. The system is not totally symmetrical from the perspective of grooves, even though it is symmetrical from the perspective of crystals. The spacing between adjacent diffracted surfaces might be adjusted, but the grooves could be left unaltered. Alternatively, we may try elevating the value of K. With the right selection of diffracting planes (H, K, L), we can carve out a groove at a precise angle in the crystal's surface. For the diffraction (at the groove's base) to be asymmetric, the diffracting planes must be positioned in a certain way. Significant advancements have been achieved in the area of X-ray refractive optics since since the first proven [1] performance achieved by an X-ray composite refractive glass (XCRL) for focusing a synchrotron radiation beams from a third-generation source. In addition Numerous low-Z materials, including aluminum [2-9], beryllium [2,5,7,9], silicon [10-12], and organic substances [2,5,13-14], have been subjected to experimental testing. Due to the lens's cross-shaped cylindrical hole drilling, it is possible for it to focus in two orthogonal planes [2-4,15]. An attractive strategy [10, 12] is to use a planar refractive lens with a single or many concentric parabolic profiles. Several advantages [6,8,9] may be gained by utilizing a prism with a parabolic shape and symmetrical rotation around its optical axis for micro-imaging and two-plane focusing. The development of refractive optics has been aided by a number of approaches, each with varying degrees of success.

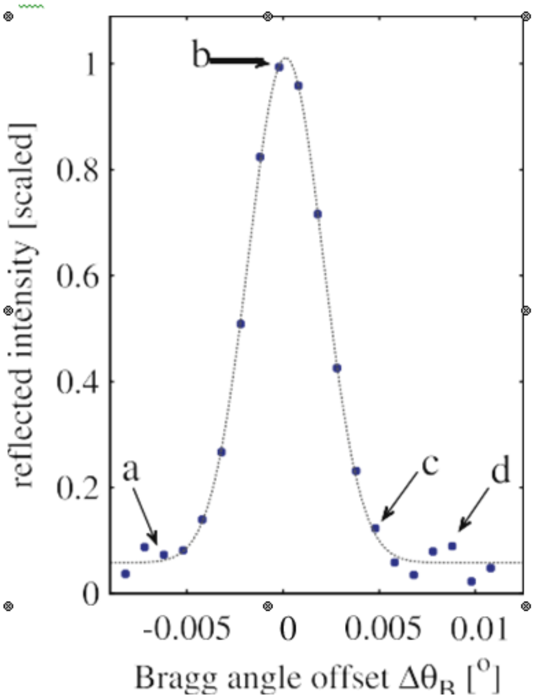

Figure 2 Rocking curve as measured by a photo diode, indicating also the angle positions

**Conclusion:** In the paraxial approximation, we construct a diffraction theory for the creation of the picture using parabolic X-ray composite refractive lenses. To shed light on the XCRL's imaging and focussing abilities, we derive an analytical formula for the image propagator. For reasonably long XCRLs of longitudinal dimension L, we create the improved thin lens approximation by factoring in linear in L/F adjustments. The lens formula is satisfied, and transparent things at the image distance become visible due to phase or edges enhanced imaging effects. These edge-enhanced pictures, we discovered, are linked to the object-induced local phase gradient in the X-ray wave field. These pictures also care about the direction of the phase difference. Since XCRL-based imaging is not the same as the standard in-line phase contrast method, this distinction needs to be made. This creates a brand-new avenue for microimaging of otherwise light-transmitting objects.

References

1. Jin, L., Jia, W., Hei, D., Zhao, L., & Cheng, C. (2021). Feasibility study of the high frequency X-ray communication using selective characteristic X-rays. Optics Communications, 484, 126697. https://doi.org/10.1016/j.optcom.2020.126697
2. Chapman, H. N., & Bajt, S. (2021). High-resolution achromatic X-ray optical systems for broad-band imaging and for focusing attosecond pulses. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 477(2251). https://doi.org/10.1098/rspa.2021.0334
3. Berujon, S., Cojocaru, R., Piault, P., Celestre, R., Roth, T., Barrett, R., & Ziegler, E. (2020). X-ray optics and beam characterization using random modulation: theory. Journal of Synchrotron Radiation, 27(2), 284–292. https://doi.org/10.1107/s1600577520000491
4. Hrdý, J. (2019). Diffractive–refractive optics: X-ray focusing splitter. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 925, 106–108. https://doi.org/10.1016/j.nima.2019.02.008

5. Hippke, M. (2019). Interstellar communication. I. Maximized data rate for lightweight space-probes. International Journal of Astrobiology, 18(3), 267–279. http://doi.org/10.1017/S1473550417000507
6. Kagias, M., Wang, Z., Birkbak, M. E., Lauridsen, E., Abis, M., Lovric, G., Jefimovs, K., & Stampanoni, M. (2019). Diffractive small angle X-ray scattering imaging for anisotropic structures. Nature Communications, 10(1). https://doi.org/10.1038/s41467-019-12635
7. Freund, H. P., & van der Slot, P. J. M. (2018). Studies of a terawatt x-ray free-electron laser. New Journal of Physics, 20(7), 073017. https://doi.org/10.1088/1367-2630/aacf7e
8. Seiboth, F., Schropp, A., Scholz, M., Wittwer, F., Rödel, C., Wünsche, M., Ullsperger, T., Nolte, S., Rahomäki, J., Parfeniukas, K., Giakoumidis, S., Vogt, U., Wagner, U., Rau, C., Boesenberg, U., Garrevoet, J., Falkenberg, G., Galtier, E. C., Ja Lee, H., & Nagler, B. (2017). Perfect X-ray focusing via fitting corrective glasses to aberrated optics. Nature Communications, 8(1), 14623. https://doi.org/10.1038/ncomms14623
9. Hémonnot, C. Y. J., & Köster, S. (2017). Imaging of Biological Materials and Cells by X-ray Scattering and Diffraction. ACS Nano, 11(9), 8542–8559. https://doi.org/10.1021/acsnano.7b03447
10. Kuriakose, T., Baudet, E., Halenkovič, T., Elsawy, M. M. R., Němec, P., Nazabal, V., Renversez, G., & Chauvet, M. (2017). Measurement of ultrafast optical Kerr effect of Ge–Sb–Se chalcogenide slab waveguides by the beam self-trapping technique. Optics Communications, 403, 352–357. https://doi.org/10.1016/j.optcom.2017.07.061
11. Roth, T., Detlefs, C., Snigireva, I., & Snigirev, A. (2015). X-ray diffraction microscopy based on refractive optics. Optics Communications, 340, 33–38. https://doi.org/10.1016/j.optcom.2014.11.094
12. Tanyag, R. M. P., Bernando, C., Jones, C. F., Bacellar, C., Ferguson, K. R., Anielski, D., Boll, R., Carron, S., Cryan, J. P., Englert, L., Epp, S. W., Erk, B., Foucar, L., Gomez, L. F., Hartmann, R., Neumark, D. M., Rolles, D., Rudek, B., Rudenko, A., & Siefermann, K. R. (2015). Communication: X-ray coherent diffractive imaging by immersion in nanodroplets. Structural Dynamics, 2(5), 051102. https://doi.org/10.1063/1.4933297
13. Antipov, S., Baryshev, S. V., Butler, J. E., Antipova, O., Liu, Z., & Stoupin, S. (2016). Single-crystal diamond refractive lens for focusing X-rays in two dimensions. Journal of Synchrotron Radiation, 23(1), 163–168. https://doi.org/10.1107/s1600577515020639
14. Midgley, S. (2007). Angular resolution in magnification radiography and the observation of x-ray wave interaction signatures. Physics in Medicine and Biology, 52(17), 5173–5186. https://doi.org/10.1088/0031-9155/52/17/005