Scientific Research Publishing

Journal of High Energy Physics, Gravitation and Cosmology, 2024, 10, 1359-1366
https://www.scirp.org/journal/jhepgc
ISSN Online: 2380-4335
ISSN Print: 2380-4327

Hybrid Prisms: Revolutionizing Optical Systems across Spectral Ranges

Friedrich Björn Grimm

RES Institute, Stuttgart, Germany
Email: grimmf04@gmail.com, friedrich.grimm@t-online.de

How to cite this paper: Grimm, F.B. (2024) Hybrid Prisms: Revolutionizing Optical Systems across Spectral Ranges. *Journal of High Energy Physics, Gravitation and Cosmology*, **10**, 1359-1366.
https://doi.org/10.4236/jhepgc.2024.104075

Received: March 7, 2024
Accepted: August 25, 2024
Published: August 28, 2024

Abstract

This research article introduces and explores the concept of a hybrid prism, which combines the properties of a lens and a reflective prism, designed for optical systems that operate in different spectral ranges of electromagnetic waves. The hybrid prism allows for precise focusing of light rays in a glass body and X-rays in a vacuum, enabling it to serve as an objective in various optical systems for imaging objects. The article delves into the structure and working principles of the hybrid prism, discussing its potential applications, including as an intraocular prism for macular degeneration, a lidar system for vehicle navigation, and objectives for cameras, telescopes, microscopes, X-ray devices, and X-ray microscopes. The revolutionary hybrid prism unlocks precise imaging of light and X-rays, reshaping optical systems and enabling groundbreaking applications.

Keywords

Imaging Technology, Electromagnetic Waves, X-Rays, Light, Lenses

1. Introduction

The evolution of optics from its beginning to the contemporary era has been marked by remarkable milestones and discoveries. From the rudimentary convex lenses of ancient times to the revolutionary insights of Galileo Galilei, Johannes Kepler, and Isaac Newton, the journey of optics has been one of continual refinement and innovation. The advent of X-rays by Conrad Roentgen ushered in a new epoch of imaging possibilities, further propelling the trajectory of optical advancements. Within this dynamic landscape, our research embarks on exploring the transformative potential of hybrid prisms, bridging the realms of lenses and prisms to redefine imaging capabilities across a spectrum of electromagnetic waves.

2. Description of the Hybrid Prism

The hybrid prism, an innovative optical lens that combines the properties of a lens and a reflective prism, features a rotational body shaped like a rhomboid. This body consists either of a denser glass for visible light or a vacuum for X-rays, surrounded by an optically thinner cladding to facilitate precise object imaging through linked ray paths. While the input and output of light can be refractive or diffractive, the hybrid prism's two internal totally reflective surfaces cancel out chromatic aberration. For X-rays, with a refractive index less than 1, the vacuum is optically denser than the surrounding material, making refractive lenses typically plano-concave or biconcave. The numerical aperture, representing the lens's light-gathering ability and resolution, is determined by the ratio of its radius to focal length [1]-[3].

The invention leverages the combination of a lens and a reflective prism to achieve superior imaging performance across different spectral ranges of electromagnetic waves. A conventional prism refracts light at its boundaries and can cause total internal reflection, changing the light's direction. In contrast, a lens refracts light rays to converge or diverge, forming images. The hybrid prism surpasses these limitations by utilizing a rotation rhomboid as its core, composed of an optically denser glass for visible light and a vacuum enclosed by glass or metal or for X-ray radiation. This core, with four interfaces to an optically thinner envelope, directs rays along a linked path to form clear images [4].

The rotationally symmetric body of the hybrid prism is designed for X-rays within the wavelength range of 0.1 - 5 nm. It includes a vacuum interfacing with an optically thinner, dual-part structure: a spindle arranged concentrically and coaxially with the optical axis, and a sleeve positioned radially apart. The spindle's generating curve comprises straight longitudinal sections with constant inclination angles and, in at least one section, a hyperbola or parabola. The sleeve's generating curve also consists of straight longitudinal sections with constant inclination angles, incorporating a parabola or ellipse in at least one section. The body's front and rear boundary surfaces, formed by refractive and/or diffractive correction lenses, deflect X-rays away from the optical axis at the front lens and towards the optical axis at the rear lens, causing total reflection four times at each of the spindle and sleeve boundary surfaces [1] [5].

This configuration allows the integration of the condenser and imaging optics of an X-ray microscope into a hybrid collecting prism. It precisely focuses X-rays from a synchrotron with an undulator, forming a brilliant monochromatic parallel beam on a focal point of 0.1 mm or smaller. The hybrid condenser prism acts as an objective for slightly divergent X-rays from a synchrotron, focusing them to a spot of 0.1 mm or less and producing a microscopic image on a CCD sensor [4] [6] [7].

The hybrid prism's design extends beyond optical properties, offering durability, reliability, and ease of integration. Unlike conventional optical components, which are prone to wear and degradation, hybrid prisms withstand extended use in diverse environments. Their robust construction and stable performance make them ideal for applications like space exploration, medical imaging, and industrial inspection. Their compact size and lightweight nature also suit integration into portable devices, broadening their application scope.

3. Applications of the Hybrid Prism

The study presents a range of applications for the hybrid prism, showcasing its versatility and potential impact in various fields of optics and imaging technology.

These detailed descriptions of the applications demonstrate how the hybrid prism, through converging cavity lenses, can significantly enhance the capabilities of X-ray imaging for various fields, including microscopy, chip production, and medical imaging.

3.1. Focusing Hard X-Rays by a Converging Cavity Lens

The longitudinal section below (**Figure 1**) shows a parallel bundle of hard X-rays that has been homologized by a synchrotron and an undulator to form a parallel bundle with a diameter in the range of 1 to 10 mm. The cavity lens is able to precisely focus a converged X-ray beam onto a focal point (Fd). The parallel X-ray beam, which is represented by the beams (A, B), undergoes a fourfold total reflection before it is precisely focused at the focal point (Fd). The mirror symmetry of the cavity lens enables achromatic imaging by double correction of chromatic aberrations. With hard X-rays, structural geometries smaller than 5 nm are accessible, which opens up new possibilities for microscopy and also for chip production. Critical angles of 0.07 degrees are required for hard X-rays in order to achieve total reflection. If absorption losses are accepted, X-ray imaging is also possible within larger critical angles. The cavity is sealed off from the atmosphere by four optical surfaces (a, b, c, d), whereby a and d can be either refractive or defractive correction lenses in order to homogenize the interlinked beam passage [6]-[8].

3.2. Soft X-Rays Focused by a Converging Cavity Lens

Cavity lenses, capable of focusing radiation across the entire spectrum from infrared to X-rays, form a cavity between an outer rotationally symmetrical body and an inner spindle around an optical axis. For X-rays, the cavity is optically denser than the surrounding matter, giving the refractive index a value just below 1. Soft X-rays, emanating from an X-ray tube as a deflected beam, are focused by the cavity lens. The lens consists of an outer shell and an inner spindle, which is attached to the shell with fastening elements or contactlessly with electromagnets. In the first longitudinal section of the cavity lens, beams A and B are totally reflected at a hyperbolic surface of the spindle, then again at a rotational paraboloid, forming a parallel bundle. This bundle undergoes total reflection at another rotational paraboloid before being focused at the focal point. This interlinked beam path enables a tenfold magnification of the X-ray image on film. Soft X-rays, in combination with a platinum coating, are totally reflected with a critical angle of about 0.25 degree, allowing for a total cavity lens length of only 200 mm in medical X-ray devices [4]-[8].

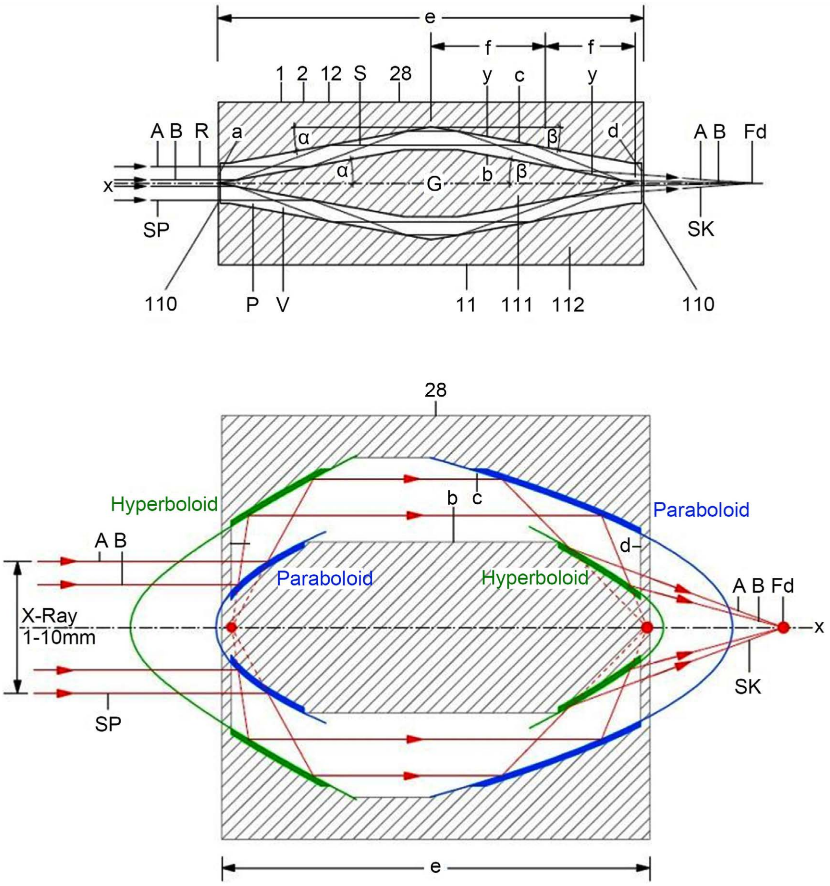

Figure 1. How to focus a diversion bundle of soft X-rays for enlarged X-ray imaging.

3.3. Intraocular Prism for Macular Degeneration

An innovative application of the hybrid prism is its use as an intraocular prism for individuals suffering from macular degeneration. Macular degeneration is a prevalent cause of severe visual impairment, affecting a significant portion of the elderly population. The macula, responsible for central vision, may become damaged, leading to a loss of sharp, central vision. Current treatment options have limited success in advanced cases of macular degeneration.

The hybrid intraocular prism addresses this issue by redirecting linked rays within the human eye around the macula. The prism consists of at least two ring-shaped glass bodies arranged concentrically and coaxially with respect to the optical axis. By positioning the focus of the hybrid intraocular prism within the eye at a distance from the retina, a ring-shaped image field is created around the macula. This allows rays of the linked path to bypass the macula on the inner side of the eye and project a complete image onto the healthy retina surrounding the macula. The hybrid intraocular prism can restore vision and improve the quality of life for individuals with macular degeneration [4] [5] [9] [10].

3.4. Lidar Systems for Vehicle Navigation

In recent years, lidar systems have gained prominence in the automotive industry, playing a vital role in autonomous vehicle navigation. Lidar, an acronym for "light detection and ranging," uses laser beams to detect objects and measure distances, enabling vehicles to perceive their surroundings and make real-time decisions for safe navigation.

The hybrid prism can be integrated into lidar systems as a spotlight and receiver unit for real-time object detection. The transmitter unit of the lidar system includes a radiation source for a pulsed light laser, a filter element for generating white light, and the hybrid collecting prism with a glass body designed as a spotlight. This spotlight converts the parallel beam of the laser into a converging beam and focuses it within the glass body, illuminating the area in front of the vehicle with a divergent beam. The receiver unit, comprising a camera with multiple ring-shaped rotational rhomboids arranged concentrically and coaxially with the hybrid collecting prism, detects the pulsed light reflected from objects and projects it onto a ring-shaped lidar sensor. This integrated approach allows lidar systems to detect and recognize objects in real-time, providing valuable information for safe navigation and collision avoidance [1] [3] [11].

3.5. Objectives for Optical Systems

The hybrid prism's design and focusing capabilities make it highly suitable as an objective in various optical systems, including cameras, telescopes, and microscopes. The hybrid prism can be tailored to serve as either a converging prism or a diverging prism, providing precise imaging with minimal aberrations [6] [7] [11].

In cameras, the hybrid prism can function as a lens, enabling clear and sharp images to be captured. Its ability to correct chromatic aberrations by twofold total reflection ensures that light rays of different colors converge at a single focal point, resulting in high-quality photographs and videos. Similarly, the hybrid prism can serve as an objective in telescopes, enhancing the visibility of distant celestial objects [3] [4] [11].

3.6. Different Kinds of X-Ray Devices

In medical X-ray devices, the radiation source is formed by an X-ray tube with a point-shaped radiation source which emits a divergent radiation beam with a useful aperture angle of less than or equal to 10 degrees as soft X-rays in the range from 10 keV to 20 keV. Inside the X-ray tube there is an objective for the X-rays, which is designed as a hybrid condenser prism, the front focus of which is arranged congruently with the radiation source of the X-ray tube, which is assumed to be punctiform. The condenser prism is designed to homogenise the X-rays by means of the front correcting lens and to concentrate them at the boundary surfaces of the rotationally symmetric body in an interlinked beam path with quadruple total reflection onto a rear focus of the rear correcting lens. An object formed by a body or part of a body is then X-rayed. The X-ray apparatus can be designed, for example, as a tomograph that rotates around the object so that sharp tomographic images of the object can be obtained on a cylindrical imaging surface by means of a cell detector [1] [4] [5].

For X-ray microscopes, the optical system has a hybrid collecting prism and is designed to concentrate the monochromatic parallel beam with a beam diameter of 1.0 mm to 10 mm, which is coupled out at a synchrotron with an undulator, as hard X-rays in the range of 10 keV to 125 keV through an objective formed by the hybrid collecting prism onto a focus of the rotationally symmetric body associated with the rear boundary surface. A divergent beam is then projected onto an image surface to obtain a microscopic image of the object irradiated by the parallel beam of X-rays using a CCD sensor of a CCD camera. Alternatively, the optical system of the X-ray microscope can have a hybrid condenser prism. The condenser prism combines the function of a condenser and an imaging objective, whereby the divergent X-ray beam emitted by a synchrotron in the range of 10 keV to 125 keV is first concentrated on a focus of the rotationally symmetric body assigned to the rear boundary surface, in order to subsequently obtain a microscopic image of the object transmitted by the divergent X-ray beam on an image surface by means of the CCD sensor of a CCD camera [1] [3]-[7].

In a terrestrial or satellite-based X-ray telescope, the hybrid collecting prism has a diameter of at least 1 m and is designed to image X-rays in the range 0.1 keV to 2.0 keV emitted by known and unknown radiation sources by means of a CCD camera. The totally reflecting interfaces of the hybrid collecting prism are formed by a spindle arranged coaxially and concentrically to the optical axis and a sleeve concentrically surrounding the spindle at a radial distance, which define the vacuum with internal interfaces. The spindle and the sleeve each have a generating curve for the rotationally symmetric body in a longitudinal section of their length. At the inner boundary surfaces of the rotationally symmetric body, the X-rays are each totally reflected four times in an interlinked beam path and concentrated in a rear focus, so that an image of the radiation source can then be recorded on the image surface of the optical system using the CCD sensor of a CCD camera [1] [4]-[7] [11].

4. Future Directions and Challenges

4.1. Advancements in Hybrid Prism Technology

The future of hybrid prism technology holds exciting opportunities for further innovation and discovery. Continued research and development efforts are expected to provide new insights into the design, fabrication and performance of hybrid prisms, enabling even greater precision and efficiency in light manipulation. Emerging technologies such as metamaterials and photonic crystals may offer new ways to enhance the optical properties of hybrid prisms and open up new applications in areas such as quantum computing and photonics.

Researchers are also exploring novel materials and fabrication techniques for hybrid prisms to achieve even greater precision and efficiency. By harnessing the power of advanced computational algorithms and nanofabrication techniques, scientists can push the boundaries of optical engineering and unlock new possibilities for hybrid prism-based systems. The integration of hybrid prisms with emerging technologies such as artificial intelligence and nanotechnology holds immense potential for expanding their capabilities and applications. By leveraging these synergies, researchers can develop hybrid prism-based systems that are more intelligent, adaptive, and versatile, paving the way for new discoveries and innovations in science and technology.

4.2. Addressing Technological Challenges

Despite their numerous advantages, hybrid prisms also face certain technological challenges that must be addressed to realize their full potential. These challenges include manufacturing complexity, cost considerations, and performance optimization in extreme environments. Overcoming these hurdles will require interdisciplinary collaboration and ongoing research efforts to refine fabrication techniques, reduce production costs, and enhance the robustness of hybrid prism-based systems. By addressing these challenges head-on, researchers can unlock new opportunities for advancing optical engineering and harnessing the full potential of hybrid prism technology.

5. Conclusions

The hybrid prism represents a groundbreaking development in optics, offering a versatile and efficient solution for precise imaging of electromagnetic waves in different spectral ranges. Its unique properties, such as the combination of lens and prism functionalities and the ability to focus light and X-rays, make it highly valuable for a wide range of applications. The research article concludes with a discussion on the potential impact of the hybrid prism on the field of optics and its prospects for future research and development.

In conclusion, the hybrid prism has the potential to revolutionize optical systems, providing new possibilities for imaging and enhancing various applications. Its ability to focus both light and X-rays opens doors to improved imaging technologies in medicine, research, and various industries. Further research and development in this area are likely to lead to even more exciting advancements and applications for the hybrid prism in the future. As the field of optics continues to evolve, the hybrid prism's contributions are expected to play a pivotal role in shaping the future of imaging technology and beyond.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Grimm, F. (2021) Hybridprisma als Bauelement für Optische Systeme. German Patent

No. DE 10 2020 001 448 B3.

[2] Alcon MFG Ltd., Hong, X., Vannoy, S.J. and Zhang, X. (2007) Pseudo-Accomodative IOL Having Diffractive Zones with Varying Areas. International Patent No. WO 2007/092949 A1.

[3] Schmahl, G., Rudolph, D., Lengeler, B. and Schroer, C. (2001) Röntgenlinsen, Linsen für harte und weiche Röntgenstrahlung erlauben den Bau von Röntgenmikroskopen und Mikrosonden. In: *Physikalische Blätter*, **57**, Wiley-VCH Verlag GmbH.

[4] Niemann, B. (1997) Condenser Monochromator Arrangement for X-Rays. German Patent No. DE 197 00 615 A1.

[5] Grimm, F. (2021) Optical Component Comprising a Hybrid Prism. International Patent No. WO 2021/175910 A1.

[6] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH and Schneider, G. (2013) Röntgenmikroskop mit Kondensor-Monochromator-Anordnung hoher spektraler Auflösung. German Patent No. DE 10 2005 056 404 B4.

[7] Xradia Inc., Wang, Y. and Yun, W. (2004) Phase Contrast Microscope for Short Wavelength Radiation and Imaging Method. US Patent No. US 2004/0125442 A1.

[8] Pareschi, G., Spiga, D. and Pelliciari, C. (2021) X-Ray Telescopes Based on Wolter-I Optics. In: Burrows, D.N., Ed., *The WSPC Handbook of Astronomical Instrumentation*, World Scientific, 3-31. https://doi.org/10.1142/9789811203800_0001

[9] Advanced Medical Optics Inc., Lang, A.J. and Zhao, H. (2008) Multi-Zonal Monofocal Intraocular Lens for Correcting Optical Aberrations. US Patent No. US 7 381 221 B2.

[10] Apollo Optical Systems LLC, Buralli, D.A., Federico, R.J. and Morris, G.M. (2004) Diffractive Lenses for Vision Correction. US Patent No. US 7156516 B2.

[11] Grimm, F. (2020) Kameramoduleinheit für Digitalaufnahmen. German Patent No. DE 10 2017 011 352 B4.