What are Fresnel Zone Plates?

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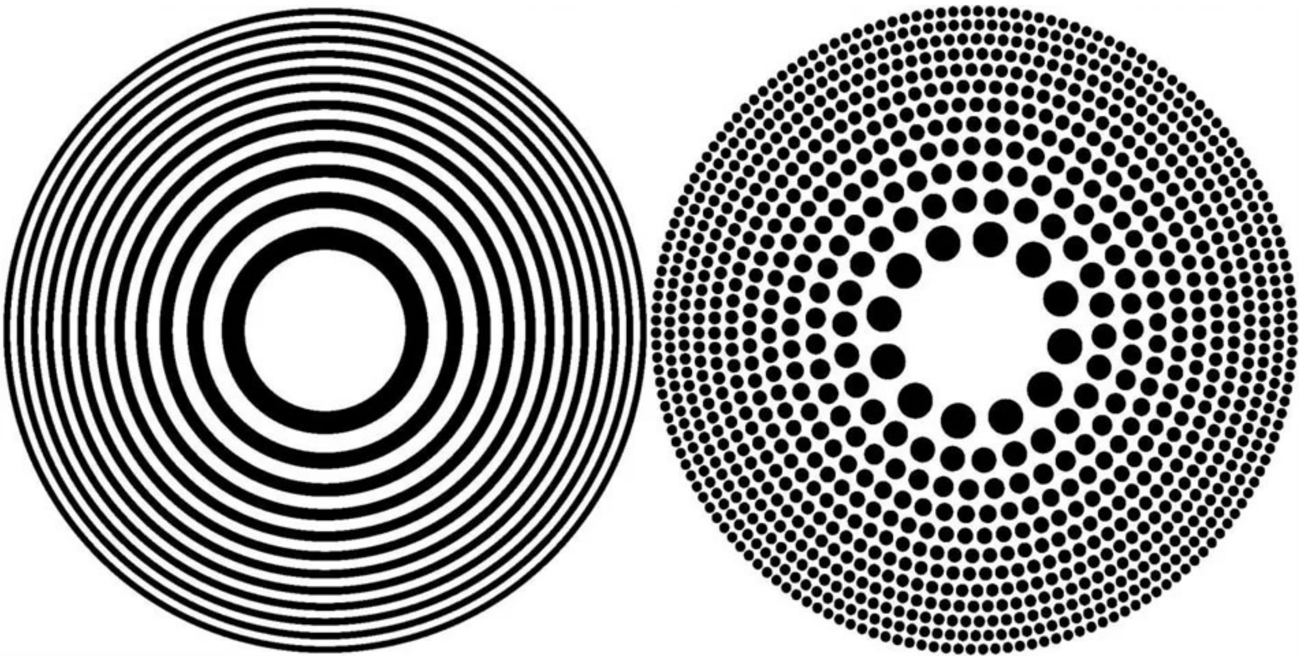
Feb 14 2023

Fresnel zone plates are extensively used in magnifying and focusing optical devices, offering high resolution. They consist of circular gratings with a radially increasing line density. Fresnel zone plates use diffraction instead of reflection or refraction, as in lenses or curved mirrors.



This drawing shows the differences between Fresnel zone plates and the photon sieve. The latter is dotted with millions of precisely machined holes. Image Credit: NASA

A set of concentric rings alternates between transparent and opaque, where the light hitting the transparent ring is transmitted, whereas the light hitting the opaque ring is diffracted. The spacing between the rings determines the interference of diffracted light at the desired focus, resulting in image formation.

The Purpose of Fresnel Zone Plates

Normal lenses are not transparent to X-rays. Hence, Fresnel zone plates are used as alternatives to normal lenses to focus X-rays on a point. In addition, various spectroscopy-based tasks require a high local sensitivity, which can be achieved using these plates.

Enhanced sensitivity enables the retrieval of information regarding the spatial distribution and oxidation state of a chemical element, which otherwise cannot be obtained using electron microscopy.

How do Fresnel Zone Plates Work?

The Fresnel zone plate is ridged on one side and flat on the other. The operation of Fresnel zone plates is based on either phase-shift modulation or amplitude. In the case of the amplitude-based mechanism, light infringing on the opaque zones is suppressed. Thus, the light passing through the transparent zones interferes at the focus point. In the phase-shift mechanism, diffraction is based on phase modulation rather than on suppressing part of the incident radiation with the wrong phase.

Applications of Fresnel Zone Plates

Physics

Traditional lens materials, such as glass, are not transparent at many wavelengths of light outside the visible region of the electromagnetic spectrum, making lenses more challenging to make. Similarly, for many wavelengths, no materials exist that have a refractive index noticeably greater than one.

Fresnel zone plates do not require transparent, refractive, or simple-to-manufacture materials for each spectral region. Because the same zone plate concentrates light from various wavelengths to various foci, they can also be used to block undesirable wavelengths while concentrating the light of interest.

Photography

In photography, zone plates are used in place of a lens or pinhole to create a glowing, soft-focus image. In addition to the unusual fuzzy effect obtained with zone plates, one advantage of zone plates over pinholes is that the visible region is greater. Consequently, the exposure period is shortened, and the effective focal number of the zone plate is smaller than that of the corresponding pinhole.

Telescope

On a deep-space spacecraft propelled by solar sails, a Fresnel zone plate lens constructed from solar sail material serves as the primary optic for a very large-aperture telescope. This type of lens might be useful as a solar concentrator and for laser communication.

Nuclear Medicine

The Fresnel zone plate aperture enables the recording of a gamma-ray image in coded form, similar to a hologram. Doctors can make use of this advantage to either shorten the time it takes to produce an image or to provide a lower dose of radiopharmaceuticals.

Recent Developments in Fresnel Zone Plates

A recent article published in *Ultrasonics* used Fresnel zone plate lenses for underwater sound focusing at approximately 5 MHz. In this work, the authors achieved a focusing spot's stable subwavelength full width at half maximum (FWHM) and observed a quasi-linear relationship between the diameter of the lens and focal length, which was validated numerically, theoretically, and experimentally.

Another work published in *Scientific Reports* reported the development of a phase-reversal Fresnel zone plate using a commercial three-dimensional (3D) printer from polylactic acid (PLA) and proposed it as an efficient and magnetic resonance imaging (MRI) compatible alternative to Soret Fresnel zone plate. The authors mentioned that the phase-reversal Fresnel zone plate leverages the incident energy and adds phase-compensation regions. Compared to the Soret Fresnel zone plate, the fabricated phase-reversal Fresnel zone plate achieved a focal gain of 4.0 dB.

A *Nanophotonics* article recently reported the fabrication of ultrathin Fresnel zone plates on metal films using holographic femtosecond lasers. Femtosecond pulses were used to split Fresnel zone plates into a series of element patterns. The prepared Fresnel zone plates were spliced using printed element structures without any size limitations.

Similarly, the fabrication of a two-dimensional (2D) semiconductor material, molybdenum sulfide (MoS_2)-based atomic thin Fresnel zone plate device, utilizing a femtosecond laser scribing technique was discussed in a study published in *Opto-Electronic Engineering*. In addition to the bandgap properties of MoS_2, the authors anticipate that this fabrication method may be useful for integrated optical systems.

Conclusion

Overall, Fresnel zone plates are interesting optical devices that resemble lenses but use diffraction rather than refraction to produce the desired result. The unique pattern of Fresnel zone plates helps to focus the incoming energy to a point, resulting in the formation of high-resolution magnified images that are useful in a wide range of applications.

References and Further Reading

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Bhavna Kaveti is a science writer based in Hyderabad, India. She has a Masters in Pharmaceutical Chemistry from Vellore Institute of Technology, India, and a Ph.D. in Organic and Medicinal Chemistry from Universidad de Guanajuato, Mexico. Her research work involved designing and synthesizing heterocycle-based bioactive molecules, where she had exposure to both multistep and multicomponent synthesis. During her doctoral studies, she worked on synthesizing various linked and fused heterocycle-based peptidomimetic molecules that are anticipated to have a bioactive potential for further functionalization. While working on her thesis and research papers, she explored her passion for scientific writing and communications.