

Application of Metalens

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Introduction

As the size of technological components approach to nanoscopic level, a new type of optical component called metalens was created to deal with the need for focusing light on a smaller scale. Metalens utilizes metasurface, an artificial interface that contains structures of subwavelength size, to focus light. This report will explore the basic structure and fabrication method of them, the application of metasurface optics like metalens, and their comparisons and advantages over conventional diffractive lens.

Basics of Optics

What is Optics?

Optics, a field that studies how light interacts with objects, plays an important role in our daily lives. A prism that disperses a beam of white light into different colors is an image people regularly see on a physics textbook that involves basic optical phenomena. However, this report will focus on a more specific type of optics: lens that focuses incident light. One of the simplest examples would be a pair of glasses that people wear to adjust their far-sighted visions. Such pair of glasses would usually have two convex lenses that help eye lens to focus light on the retina and thus form an image. A far-sighted eye is caused by eye lens focusing the image behind the retina, so a focusing convex lens is used to focus the light before it passes the eye lens to form the image on the retina. To help better understand a lens, there are some properties that are used to describe the lens shown in Figure 1.

Structure of a Lens

Other than the things labeled in Figure 1, there is refractive index, one of the most important

properties of an optical material. Refractive index is the ratio of the velocity of light in vacuum to the velocity of light in the material. This is most commonly shown when a half-submerged pencil seems to be disjointed in a glass of water. For a lens, the light will have to enter the lens structure and come out from the other side. This makes refractive index important when evaluating the focusing efficiency and focal distance of the lens. The physical parameter of the lens such as the radius, thickness and height of the lens can also influence its numerical aperture, focal length and point (6).

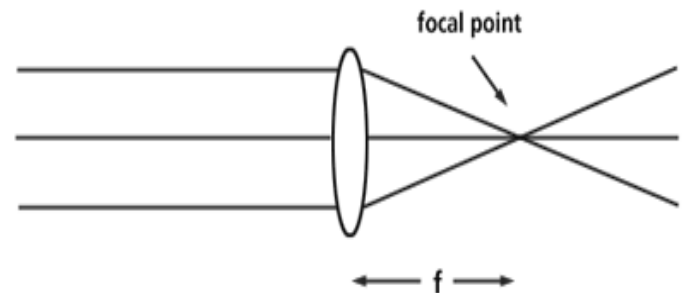


Figure 1. Basic Structure of a Focusing Convex Lens. The letter “f” stands for the focal length (9)

Fundamentals of Metalens

Structure of Metalens

As shown in Figure 1, conventional focusing lenses tend to have a convex shape and they can use their refractive properties to bend the light going through them. However, for metasurface optics, most of them tend to have a flat surface. For example, Figure 2 shows a comparison between a conventional lens and a metalens.

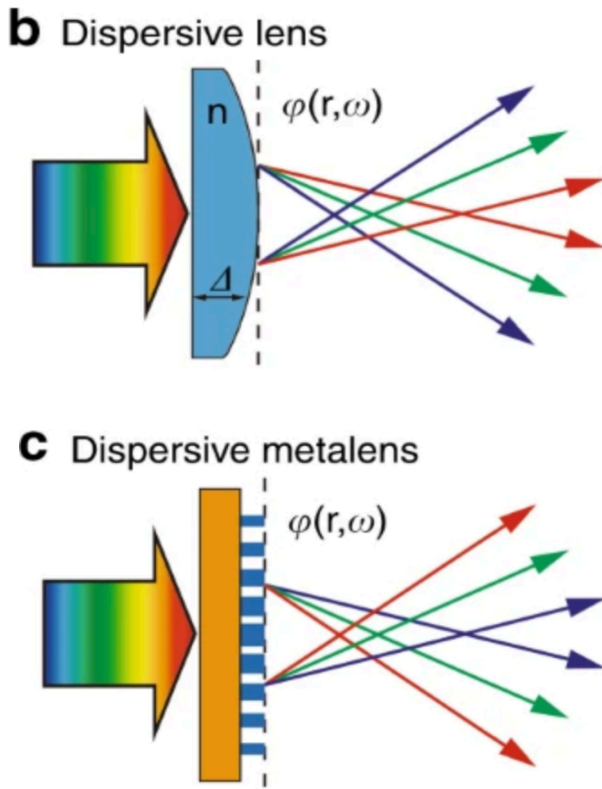


Figure 2. Conventional Lens vs. Metalens (8)

Metalenses use their unique structures to create a phase delay on the incoming light. There are three main ways to create such phase delay and each of them require different structures on the metasurface: geometrical phase, truncated waveguide, and resonant nanoantennas (2).

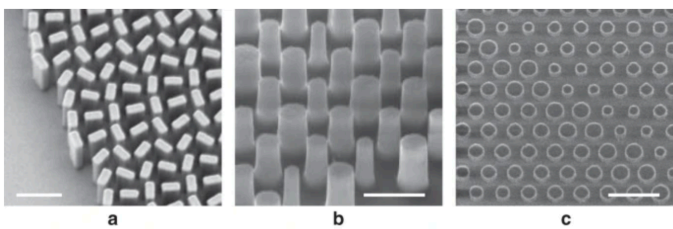


Figure 3a: Geometrical phase implementation. 3b: Truncated waveguide implementation. 3c: Resonant nanoantennas. (2)

In Figure 3a, the nanostructures on the surface are rotated which would induce a phase change on the light through these structures. Figure 3b shows nanostructures with different radii which act as truncate waveguides which can phase shift the

incident light. Figure 3c shows resonant nanoantennas that are similar to geometric phase but use the polarization of light to produce the phase shift. All of these nanostructures on the surface are generally made of materials with high refractive index such as SiN and HfO₂ (2).

Fabrication Process

In order to produce these nanostructures, one of the most common methods used to etch these structures on a substrate is called lithography. This process basically involves in depositing the materials on the substrate and then depositing a layer of resist on the desired area on the material layer. Depending on the nature of the resist material, the etch process will either remove the part covered with resist (positive resist) or vice versa (negative resist). This way the lens design can be fabricated through repeatedly depositing resist and etching the materials into a desired pattern (4).

Application of Metasurface Optics

Some of the most prominent applications of metasurface optics are the aforementioned metalenses, meta-holograms, and polarization optics. Metalenses are primarily used in place of conventional diffractive lenses. Due to their flat surfaces, they can be installed on small systems where bulky diffractive lenses cannot fit. Because of their relatively thin structure, they are commonly used for microscopy and imaging where space is limited. The thickness of conventional diffractive lenses would require a different material or reduce the height of the lens which might cause efficiency and focal distance to drop. Metalenses also solve the chromatic aberrations that diffractive lenses face. Chromatic aberrations are usually caused by light at different frequency to be focused on a different focal length. An image under chromatic aberrations would be blurry with fringes of different colors on the edge. Metalens could avoid chromatic aberrations entirely by arranging the structure of all the nano antennas on the metalens to impose a different shift according to the incoming wavelength of the light (1).

Holograms are used to create a 3D reconstruction of a light field that results in an image with depth. Meta-holograms are different approaches to creating holograms that normally require multiple bulky lenses to create a complex phase distribution. Earlier hologram methods were mostly amplitude modulated which produced low efficiency. Modern holographic method using spatial light modulator yielded phased modulated hologram but was limited above wavelength size. Using meta-holograms would produce a higher efficiency while limiting the product hologram to be limited to one color. To create a multi-color hologram, multiple meta-holograms would be needed (3).

Because metasurfaces allow for each nanostructure to be tuned individually, this enables the creation of light beams of complex polarizations. The customizability of metasurface can fit multiple structures with high refractive index to create a powerful artificial birefringence, an optical property that indicate the dependence of refractive index on the polarization and propagation of light. Therefore, metasurface optics can produce a highly polarized light that can be useful when attempting to create focused laser or reduce the glare effect in imaging process (2).

Comparison and Advantages

While the development of metasurface optics has been significant, it is important to realize that metasurface optics are still not enough to entirely replace conventional lenses. One of the most common competitors is multilevel diffractive lens (MDL). An MDL is a lens with levels of different heights on the surface. A visual comparison of both is shown in Figure 4. There have been arguments over which one is better overall. While to the customers, both lenses can be ultra-thin without significant differences, from the manufacturer's perspective, there is no clear comparisons on which one is easier to fabricate (5).

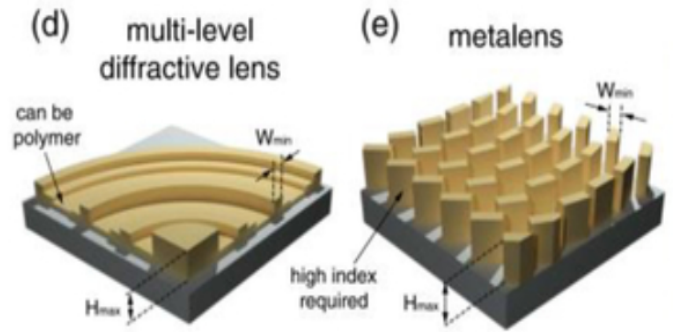


Figure 4: Comparison of MDL and Metalens (7)

One definitive advantage of metasurface optics, however, is the previously mentioned ability to avoid chromatic aberrations. While chromatic correction, the operation to fix chromatic aberrations, is achieved by increasing the diffraction order of conventional lenses which will adjust the angle of diffraction for different wavelengths. Nevertheless, this way sacrifices thinness of the lens which would contribute even more to the bulkiness of the lens. Since metalens is flat and one can easily design the metalens to impose a desired phase shift on the incoming light, chromatic aberrations could be easily avoided (2).

There are still some more fields that need to be tested and explored since metasurface optics are still relatively new. For example, since each nanostructure on the surface can be tuned specifically, this sometimes contribute to a more complex fabrication method and therefore raise the production cost. A fixed structure also means it is used under a specific condition. While there are ways to mechanically stretch the surface to alter some of its properties, the same technics can also be applied to some of the conventional lenses. Therefore, there are still much to explore about the tunability of these new technologies. (1)

Conclusion

Metasurface optics are not replacements of conventional lenses, rather, to expand the scope of them. In the future, more research will be conducted to see how to improve metasurface including potential of active metasurfaces and quantum metasurfaces.

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