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Polarization Sensitive Metasurface for Holography

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Abstract: *Metasurfaces for polarisation sensitive holography is suggested here which is combination of holography and nanotechnology. Metasurface holograms are nanoscale structures fabricated on firm substrates. A polarization sensitive recording material consists of silicon nanostructured patterns on a glass substrate, which act as superpixels. These superpixels respond to a certain polarization state of the incident light. Huge data can be recorded in the hologram by scheming and positioning the nanofins to respond differently to the chirality of the polarized incident light.These nanofins can also pave the way to practical applications including polarization manipulation, beam steering, novel lenses, and holographic displays.*
Keywords -*Dielectric ridge waveguides (DRWs), Metasurface,Holography*

I. INTRODUCTION

Holography, a revolutionary 3-D imaging technique, has been developed for recording and recovering the amplitude and phase of light scattered by objects.Optical security is a technology with great scope in Research & development and isextensively used because of the parallel and high speed processing capabilities. Holograms were widely used as one of the most reliable tools for brand authentication and document security. Holographic storage offers higher data density, faster transfer rates and better safety of stored data.

Holograms belong to the class of Diffractive Optically Variable Image Devices (DOVIDs). Holograms were widely used as one of the most trusted tools for product authentication and security. Even though it is believed that holograms are difficult to be counterfeited, with the advent of latest computerized technology it is now easy to counterfeit the holograms. So in order to exploit the advantage of holograms in optical security effort must be taken to develop more secure holograms. Apart from the advanced technology that is required, the uniqueness of a 3D object presents a significant additional threshold for the counterfeiter of such security holograms. DOVIDs are used consisting of predominantly flat diffractive artwork as a security feature. In these cases first line security is often found in unique optical effects that present a significant difficulty for would be counterfeiters.

Holograms using metasurfaces have been of interest for past few years which can efficiently control light, representing a potential new technology for advanced sensors,HD displays and optical data processing.Under development for about 15 years, meta-materials owe their unusual potential to precision design on the scale of nanometers. Researchers have developed optical nanophotonic circuits which utilizes the surface plasmons to manipulate and control the routing of light in devices too tiny for conventional lasers.It is possible to control the intensity and phase, or timing, of laser light as it passes through the nano structures.Surface Plasmon resonance can also be used for full colour Holograms which is promising for High resolution display holograms.

This Paper proposes polarization Sensitive Metasurface which will enhance the security of holograms by making the holograms dependent on the polarization of light. This will be a combination of holography and nanotechnology with use ofNano-scale patterned structures that are sensitive to polarization (the direction in which light vibrates) to produce different images depending on the polarization of incident light. This advancement, which works across the spectrum of light, improves anti-fraud holograms as well as those used in High resolution displays.

II. RECORDING MATERIAL– METASURFACE

Polarization is the path along which light vibrates.There are several states of polarization. In plane polarized light the direction of vibration remains confined in a single plane while in circularly polarized light it rotates clockwise or counterclockwise. The direction of rotation of light is called as the chirality of the beam.

The photosensitivity of some organic and inorganic materials depends on the polarization of the optical field, and anisotropy is induced by the illumination of polarized light. Polarization holography has been demonstrated using such polarization-sensitive materials. There are several kinds of polarization holographic materials. The origin of photoanisotropy is different for different kinds of materials. Photoisomerization, polarizationdependent, photodissociation, and the photoinduced reorientation of linear molecules are typical origins of photoanisotropy.

Metasurfaces are ultra-thin artificial materials made of individual structures, called meta-atoms. These meta-atoms dictate the optical properties of the resulting metamaterial with their specific shape, size, orientation, and arrangement. Metasurfaces are essentially planar and thus simpler to fabricate, with significant consequences for practical applications. One of the prominent features of Metasurfaces is that they permit to control the phase and amplitude of impinging light over scales much smaller than its wavelength. Thus, it is possible to design with extremely complex behavior. Some recent examples include the generalization of Snell's law, flat lensing, ultra-broadband coherent perfect absorption, beam steering, and ultrathin vortex wave plates for applications in optical tweezers and optical communication systems, and wide angle filters. The optical response of Metasurfaces can be tuned, by varying geometrical or physical parameters for various applications like polarization manipulation, tunable absorption, laser steering and optical signal modulation. The capability to engineer the phase of an optical beam with high accuracy and spatial resolution is perfectly suited for holographic applications. This has been exploited to demonstrate several applications in security, displays and the storage and manipulation of information. Metasurface allow for pixel by pixel modification of the phase profile of the hologram, allowing for highly efficient designs compared to amplitude only holograms. Holographicmetasurface use the 2D arrangement of meta-atoms to produce an image from the scattered incident light.

In this paper we do not investigate details of such materials but discuss the polarization-sensitive response based on a simple model. Suppose that a polarization sensitive recording material consists of silicon nanostructured patterns on a glass substrate, which act as superpixels. The superpixel responds to a certain polarization state of the incident light. Large volume of information can be encoded in the hologram by designing and arranging the nanofins to respond differently to the chirality of the polarized incident light.

In this design, the apertures are replaced by effective apertures (pixels) with a polarization functionality provided bythe specifically incorporated meta-element. For the first study, the metaelementconsists of three dielectric ridge waveguides (DRWs), made ofamorphous silicon, on a glass substrate. A diffraction conditionwhere most of the transmitted light is funneled into the first orders (±1)is achieved by adjusting the DRW design parameters (width, height,and separation) and the lateral dimension L of the meta-element.In the

design, each pixel of dimension 2L consists of two of such metaelements,that is, six amorphous silicon ridges The transmitted power from each pixel is nearly completely split betweenthe +1 order and the −1 order in a broad wavelength range (1100 to1800 nm), whereas unwanted orders are suppressed. The dispersive responseof the pixel is designed with finite-difference time domain simulationsto closely satisfy the relation q =sin−1(l/L), toachieve awavelength-independent phase shift Dφ.

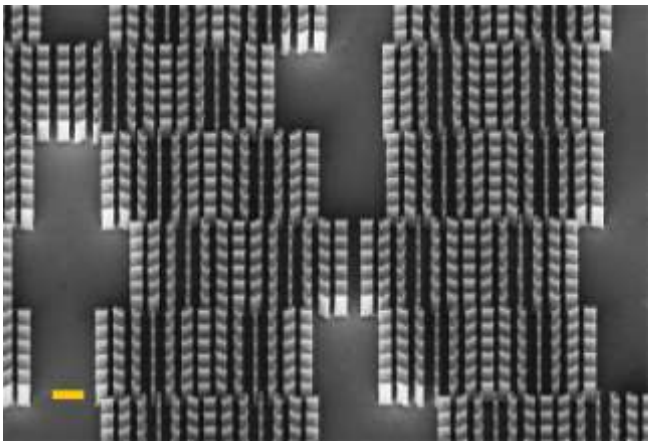

Fig.1. SEM image of the hologram generated by the chiral hologram under different incident polarizations at l = 1350 nm.

Previous research from the Capasso lab used nanostructures or metasurface made of titanium dioxide, a widely available material, consisting of an array of polarization-sensitive pillars—also called nanofins—that redirect the incident light.Being sensitive to polarizationtwo different images could encoded in the metasurface. However, those images were dependent on one another, meaning both were created but only one appeared in the field of vision.The novelty of this type of metasurface is that two vastly different images could be recorded and projected independently using arbitrary states of polarization.

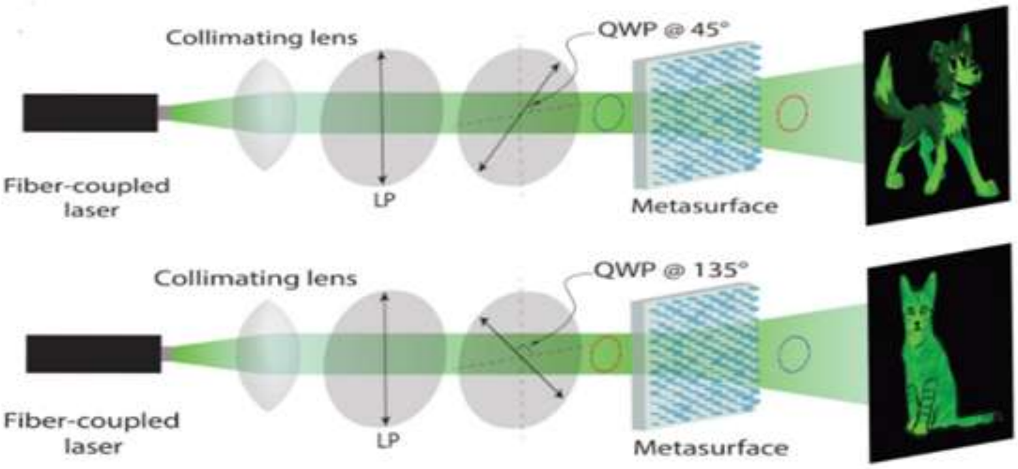

Fig. 2 Single metasurface encodes two separate holograms when illuminated with light of different polarizaion

III. METASURFACE IN HOLOGRAPHY EXPERIMENTAL ANALYSIS

By design, the hologram provides thesame image quality for all the wavelengths in the range from 1100 to 1800nm. This feature results from the dispersionless phase realization approach.

The efficiency is measured as the ratio of the optical power inthe holographic image to the incident power. High Efficiency of about 75% can be achieved. This value is close to the theoretical value (81%) of abinary phase grating optimized for a specific wavelength. Although the metasurface is designed as a phase-only hologram, the use of sub wavelength diffractive elementsmakes it possible to create imageswith high efficiency in the first orders only. The wavelengthdependence of the efficiency can be interpreted in terms of the angulardistribution of the diffracted power.

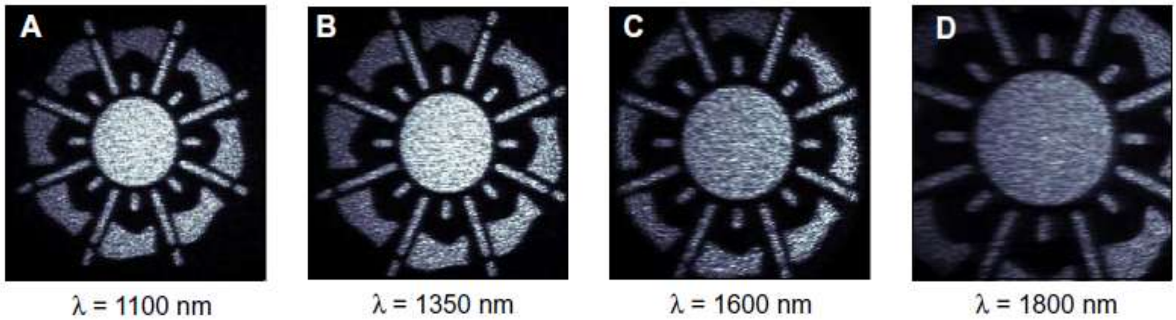

Fig.3 Images generated when the hologram is illuminated with NIR light.

The hologram (based on its dispersionless design) maintainsits functionality even for visible light, althoughthe transmittance of the device drops toward shorter wavelengths as aresult of absorption from the silicon ridges. The interaction of the DRWs with the incident light is highly polarizationdependentbecause of the DRWs' deep-subwavelength width and asymmetriccross section (the length is much larger than the width). In other words,only light that is linearly polarized along the length of the DRWs (y axis)is efficiently diffracted, whereas light that is polarized along the width(x axis) is transmitted nearly nondiffracted, As a result of thepolarization sensitivity of each pixel, our device is characterized by a highextinction ratio (ER) between orthogonal polarizations, within a broad wavelength range. ER is defined as the ratio of normalized intensitiesin the images for two different polarizations [along the y and xaxes for the IYL hologram and circularly left- and right-polarized forthe chiral hologram (to be discussed later in the paper)].This straightforward and reliable phase shift realization provides anopportunity for designing multifunctional devices. This moves thereconstruction plane 2 cm forward in the light propagation direction.Image blurring and correctfocusing are evident. It is worth noting that light focusing by the Fresnelhologram occurs along the diffraction direction (q = 30° at l = 1350 nm).Projection at large angles is a longstandingchallenge (known as the shadow effect) that is overcome by ourdesign. This opens the possibility of designing flat and compact opticalcomponents for imaging at a wide range of angles.

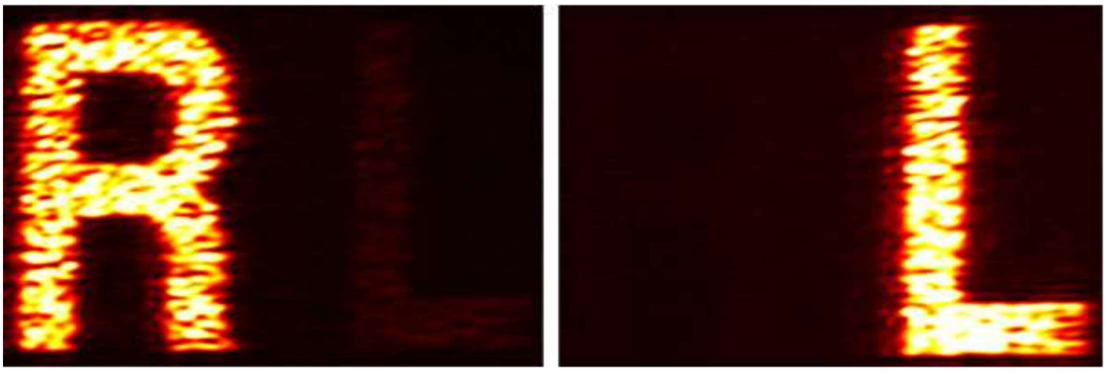

Fig.4 The same hologram illuminated with different polarizations displays two vastly different images

As further proof of the versatility of our approach, we designed achiral hologram whose functionality depends on the handedness ofthe reference beam. For this task, the meta-element consists of nanofins

similar to those in the studies of Khorasaninejad and Crozierand Lin et al. . When circularly polarized light passes through thesestructures, it is diffracted along a principal direction according toits handedness. Changing the light handedness results in the switchingof the direction from q to −q analogously to other chiral subwavelengthstructured surfaces. According to what has been discussedso far, a phased array of such subwavelength structured pixels wouldresult in the appearance of the designed intensity distribution along aparticular direction only for circularly polarized light with the properhandedness. However, in the fabricated device, we divided each pixelinto two parts (along the y-axis direction) and coupled half of it to onehandedness and the other half to the opposite handedness. The rotated nanofins in our design introduce a geometric phasesimilar to the rotated apertures of Shitrit et al., known as the Berry-Pancharatman phase. Thus, image displayed in the field of viewof the optical system depends on the light handedness. Figure 3 shows that a light intensity distribution corresponding to the letter "R"appears for right circular polarization, whereas it changes into the letter"L" for left circular polarization. For linearpolarization, both letters appear. In addition, this device demonstrateshigh values of absolute efficiency and ER, as well as a broadband functionality.

IV. CONCLUSION

In conclusion, metasurfaces can be used for phased pixels in flat and compact dielectric holograms with a broadband response. Depending on the subwavelength structured building blocks, different responses to light polarization states can be encoded for scalable polarimetric devices. In this workdielectric material is used instead of metals which allows transmission scheme with a transparent substrate while minimizing optical losses. Furthermore, lens-like optical elements working off-axis can be implemented for wearable devices, where lightness, compactness, and image quality are mandatory. In fact, although dynamic diffractive optical components, such as spatial light modulators, typically have a broadband response, they have a large footprint with respect to our devices. A new hologram with chiral imaging functionality has been demonstrated which enables a single hologram to record different images depending on the polarization of light. Alternative fabrication methods, such as deep ultraviolet lithography and nanoimprinting, can facilitate the mass production of the metasurface.

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