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# Controlling Circular Polarized Localized Surface Plasmon Resonance in Nanorod Based Metasurface

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**Abstract**

**In this study, a plasmonic gold nanorod based chiral metasurface was studied to operate different circular polarized state of light. The chiral metasurface achieve controllable circular dichroism from –10% to +10% through manipulating the asymmetric coupling between nanorods which could benefit to chip-scale integrate circuits and bio-sensing.**

## 1. Introduction

It is critical to control the circularly polarized (CP) states of light for their various applications from bio-sensing to optical communication.[1] The distinct behaviors in the absorption of left-handed circularly polarized (LCP) and right-handed circularly polarized (RCP) lights are known as the optical chirality, or called “circular dichroism” (CD). In other words, the CP states of light can be controlled by the manipulation of CD.

One means of controlling the CD of light is to apply a chiral plasmonic metasurface. Owing to the confinement of the localized surface plasmon resonance (LSPR) modes in metallic nanostructures, plasmonic metasurfaces with chiral building blocks exhibit strong optical chirality and has been achieved in various reports.[2] In addition, the ultrathin dimension of metasurfaces are beneficial to reduce the sizes of practical devices.

In this work, we demonstrate a plasmon Au nanorod based chiral metasurface to achieve controllable CD. The LSPR properties of Au nanorods have been widely studied[3] bring us an appropriate building block to construct the chiral metasurface. The optical chirality of the nanorod based chiral metasurface was investigated from simulation and the controllable CD was experimentally characterized.

## 2. Experiment

Fig. 1(a) illustrates the schematic diagram of the Au nanorod-based chiral metasurface, shift dimer nanorods (SDNRs), on silica substrate. The devices were fabricated by electron-beam lithography(EBL) to define pattern and metal deposition followed by lift-off process. The deposited metal layer was 50 nm of Au with 30 nm of Ti as adhesive layer.

The SDNRs consist of two neighboring, identical Au nanorods with length of L= 150 nm and width of W= 80nm. The two nanorods arranged in parallel separated by G= 40nm with a lateral shift of S along their long axis. Accordingly, the SDNRs are divided into the achiral type $D_0$ and two chiral counterparts type $D_+$ and $D_-$ as shown in Fig. 1(b)–(d). The chirality of these types of structures has been demonstrated by Meinzer et al. and Cotufo et al.[4, 5]

In order to characterize the chirality of these chiral metasurfaces, we measured the corresponding circularly polarization resolved extinction of the SDNRs array. Non-polarized white light from a tungsten-halogen source was back-side-focused on the metasurfaces by a 10x objective lens. The transmission light is collect by the other 10x objective lens and a fiber-based spectrometer recorded the spectra. For chirality characterization, a broad−band quarter wave plate and a linear polarizer were set before the spectrometer to resolve the circular polarization information of the SDNRs.

## 3. Results and Discussion

The nanorod-based design of the metasurface provides the resonance along the long axis of each single rod, and the nanogap between the SDNR enables the resonant coupling. In addition, if the two nanorods are aligned with a finite lateral shift ($D_+$ and $D_-$ types), the resonant coupling occurs in different phases and produces a variable coupling strength along the long axis. It deforms the electric field and induces the coupled resonant modes with near-field optical chirality.

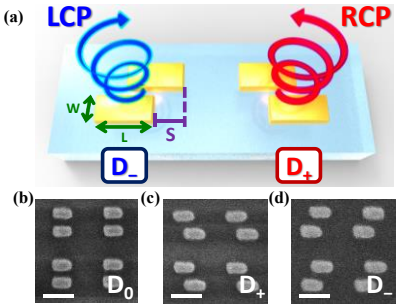


Fig. 1 (a) Schematics of the nanorod based chiral metasurface. (b) Scanning-electron-microscopy images of the (b) achiral $D_0$, (c) chiral $D_+$, and (d) $D_-$ SDNR arrays. Scale bar is 200nm.

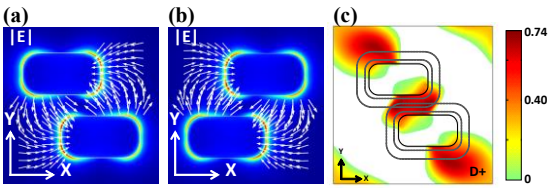


Fig. 2 The 3D-FEM calculated electric field profiles of (a)$D_+$ and $D_-$ type SDNRs at resonance. (c)The local CD distribution around $D_+$ SDNR.

The asymmetric coupling can be confirmed by the three dimensional finite-element method (3D-FEM) calculated electric field profiles of $D_+$ and $D_-$ SDNRs on resonance shown in figure 2(a) and (b). Furthermore, the directions of electric fields indicate opposite optical chiralities between $D_+$ and $D_-$ SDNRs.

To investigate the details of circular polarization states in the SDNRs, unpolarized dipole emitters were set in the region between two nanorods and around the nanorods corners. The calculated circular dichroism value (CD) distribution around the $D_+$ SDNR is expressed as Fig. 2(c), the CD value is defined as $(I_R-I_L)/(I_R+I_L)$, where $I_R$ and $I_L$ are the RCP and LCP intensities respectively. It can be observed that for $D_+$ type SDNR, the asymmetric coupling resonant mode tend to generate stronger $I_R$ than $I_L$ leading positive CD. Moreover, the maxima CD is located in the center between two nanorods due to the strongest asymmetric coupling occur.

The simulations discussed above indicated the fabricated devices would exhibit optical chirality in far-field. Fig. 3(a) shows the RCPextinction spectra $EXT_R$ and LCP counterpart $EXT_L$ of the $D_+$ and $D_-$ SDNRs. As LSPR occur, photons with specific wavelength coupled to the SDNRs induced significant light extinction and a peak in the extinction spectra. The CP component that better matched the polarization of resonant modes would trigger the stronger extinction. The degree of optical chirality can be quantify by the CD of extinction as $CD_{EXT} = (EXT_R - EXT_L)/(EXT'_R - EXT'_L) \times 100\%$, where $EXT'_R$ and $EXT'_L$ are the RCP and LCP peak extinction. Therefore, the $D_+$ ($D_-$) SDNR interacted more with the RCP (LCP) component of incident beam, caused the more substantial RCP extinction peak in spectrum and positive (negative) $CD_{EXT}$ values.

Due to the intrinsic optical chirality of the SDNRs originated from the asymmetric coupling between two nanorods, it indicates we can manipulate this coupling to achieve different CP states in the SDNRs. A series of SDNRs with varying S denoted as $D_{\pm n}$ were fabricated to control the asymmetric coupling in structure. The number n is proportional to the S of nanorods from 25% to 75% of L. Following the same measurement and analysis above, we convert the CP extinction spectra to the $CD_{EXT}$ spectra of corresponding SDNRs shown in Fig. 3(b). For achiral SDNRs ($D_0$), no preference of circular polarization lead $CD_{EXT}$ values remain almost 0 at any wavelength. On the other hand, chiral $D_+$ ($D_-$) type SDNRs express positive (negative) $CD_{EXT}$ values with one peak (dip) at the same wavelength in the spectra which reflect the intrinsic RCP (LCP) light coupling preference chiral feature. The peak (dip) $|CD_{EXT}|$ values vary with different $D_{+n}$ ($D_{-n}$) type SDNRs are displayed in Fig. 3(c). In general, the

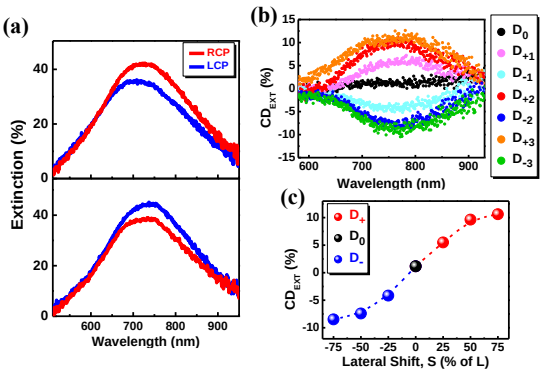


Fig. 3 (a) The circularly polarized extinction spectra of (a) chiral $D_+$ and $D_-$ SDNRs. (b) The $CD_{EXT}$ spectra of $D_0$ and $D_{\pm n}$ SDNRs. (c) The peak (dip) $CD_{EXT}$ of $D_{\pm n}$ SDNRs varying as a function of the lateral shift, S, of nanorods.

$|CD_{EXT}|$ increase with S due to enhance the asymmetric coupling between two nanorods. Therefore, a controllable CD from –10% to +10% can be obtained. We also noticed the $|CD_{EXT}|$ increments are saturated after S exceed 50% of L which is due to the reciprocal relationship between coupling strength and phase difference when increasing S.

## 4. Conclusions

In conclusion, a CD controllable Au nanorod based metasurface, SDNR, was demonstrated through manipulating the asymmetric coupling between nanorods. The optical chirality in the SDNRs has been confirmed by the 3D-FEM simulation and fabricated devices demonstration. Controllable CD from –10% to +10% were achieved in a series of SDNRs with different lateral shift between two nanorods. The resonant modes in SDNRs are evolved from the LSPR of nanorods means the optical chirality properties can be shift to other wavelength through changing the geometries of the composed nanorods. This work provides an ultrathin platform to manipulate the circular polarized state of light which could be applied in practical applications such as chip-scale bio-sensing and optical information processing.


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