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Full Stokes Mid-Wavelength Infrared Polarization Photodetector Based on the Chiral Dielectric Metasurface

Bo Cheng ¹, Yuxiao Zou ²  and Guofeng Song ^{1,*}
¹ Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China; chengbo9610@semi.ac.cn

² Kunming Institute of Physics, Kunming 650223, China; yuxiaozou@foxmail.com

* Correspondence: sgf@semi.ac.cn

Abstract: Conventional imaging techniques can only record the intensity of light while polarization imaging can record the polarization of light, thus obtaining a higher dimension of image information. We use the COMSOL software to numerically propose a circular polarization photodetector composed of the dislocated 2-hole Si chiral metasurfaces controlling the circular polarization lights and the HgCdTe (MCT) photodetector chip to detect the intensity of light signals. The chiral metasurfaces can be equated to a significant radiation source of the Z-type current density under the right circularly polarized incidence conditions, which explains the large circular dichroism (CD) of absorption of 95% in chiral photodetectors. In addition, the linear dichroism (LD) of the linear polarization pixel is 0.62, and the extinction ratio (ER) is 21 dB. The full Stokes pixel using the six-image-element technique can almost measure arbitrary polarization information of light at 4 μm operation wavelength. Our results highlight the potential of circular dichroic metasurfaces as photonic manipulation platforms for miniaturized polarization detectors.

Keywords: chiral dielectric metasurface; polarization; circular dichroism

1. Introduction

Polarization imaging is a new optoelectronic detection system that can obtain one more dimension of scene information compared with traditional imaging, and it has important applications in industrial inspection, biomedicine, remote sensing of the earth, aviation, and marine fields [1–7]. In general, the polarization camera concepts are divided into three categories: the division of amplitude, the division of the aperture [8], and the division of the focal plane [9–11]. The division of the focal plane, where the full Stokes grating capable of modulating the polarization information and the photodetector are directly integrated together, has the advantages of real-time operation and optical system stability, so it has quickly become a strongly tracked research direction.

Metasurfaces can flexibly and precisely modulate the phase and polarization information of light by encoding subwavelength geometric unit cells [12–19]. The design of circular dichroic wave plates (CDWP) using metasurfaces has been reported in some cases, and the geometry of their unit cell can be either the two-dimensional Archimedean helix [20,21], fish-line metal nanoparticles [22,23], Z-shaped plasmonic particles [24], Z-shaped silicon wafers [25,26], etc., or the three-dimensional helical structure [27]. In addition, combining a quarter-wave plate (QWP) [28] and the linear polarizer to sense the circularly polarized light is also a booming direction. In 2018, Bai [29] constructed excellent circular polarization metasurfaces with a pair of cross-shaped metallic QWPs and a 45-degree linearly polarized grating, but the high ohmic loss of the ultrathin QWP resulted in the CD of the chiral device being less than 20%. In the next year, Basiri [30] proposed an a-Si dielectric QWP without the thermal loss instead of the metallic QWP, and the optical efficiency of the circular dichroic metasurfaces improved to 80%. In 2022, Liu [31] placed the geometrically phased metasurfaces in the Fourier optical spin splitting microscope (FOSSM) system, which can



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form two images with different displacements on the imaging plane for the LCP and RCP. In 2024, Yang [32] proposed and experimentally demonstrated an extremely compact imaging system using the metalens with spatially and polarization-multiplexed point spread functions (PSFs) to record LCP and RCP optical interference patterns using the commercially available polarization camera. However, only a few research results on polarization photodetectors that have already integrated the CDWP have been reported in the past ten years, which severely limits the rapid development of miniaturized polarization-integrated detectors. In 2012, Afshinmanesh [33] proposed a Si-based photodetector integrating two-dimensional spiral microstructures. At a working wavelength of 830 nm, the ER of the linearly polarized and circularly polarized light are 25 and 1.13:1, respectively. In 2015, Li [34] prepared a miniaturized circularly polarized Schottky photodetector with quantum efficiency and circularly polarization extinction ratio of 0.2% and 3.4:1, respectively. In 2023, Yao [35] developed a high-performance polarization camera for the visible wavelength band, in which the circular polarization filter is a combination of the typical quarter-wave plate metasurface and the linearly polarized metasurface, and the chiral metasurface, and the CCD in this camera are aligned by the UV adhesive.

In this article, we numerically analyze the dislocated 2-hole Si metasurfaces with the CaF₂ substrate, which can make the transmission to the left circularly polarized incident light much larger than to the right circularly polarized light. Moreover, the CD and ER of transmission at 4 μ m operation wavelengths are 0.68 and 22 dB, respectively. The excellent CD performance is illustrated by the interaction of the dominant magnetic dipole. The combination of this chiral metasurface and the MCT probe chip is expected to provide direct sensing of the polarization properties of light in space.

2. Materials and Methods

2.1. Structure and Optimization

It is shown in Figure 1a that the 3D geometric information of the six proposed HgCdTe (MCT) detectors integrating the Si full Stokes grating controlling specific polarization is specified accordingly. The full Stokes polarization device contains six subpixels arranged in a 2×3 array. The P1, P2, P3, P4, P5, and P6 correspond to the 0-degree, 90-degree, -45-degree, and 45-degree polarized grating, and the left and right circular dichroic pixels, respectively. The HgCdTe detector chip belongs to a typical n-on-p structure, consisting of the n-doped region, a 7 μ m thick p-type HgCdTe absorption layer, and the CdZnTe substrate (removal of the CdZnTe substrate before hybridization). The chiral metasurface consisting of two identical square-shaped holes displaced in opposite directions can be prepared using standard silicon-based processes. Meanwhile, the circularly polarized detectors can be formed by aligning the HgCdTe chip and the chiral dislocated two-hole metasurfaces using an indium column interconnect process, which is similar to the flip chip interconnection process of readout circuits, including the under bump metallurgy deposition, photolithography, indium film deposition, lift-off, and solder reflow [36]. Figure 1b shows the front view of the 0-degree polarization detector showing thickness and material information. The light irradiates the photodetector from the +z boundary to the -z boundary. Figure 1c shows the top view of the chiral Si/CaF₂ metasurface. The refractive index of the HgCdTe photodetector is derived from Ref. [37], and the refractive indices of the silicon (Si) and CaF₂ are derived from Refs. [38] and [39], respectively. The commercial software COMSOL physics is employed to analyze the optical properties of these metasurfaces. In the COMSOL model, the boundary conditions that truncate the electromagnetic far field in the Z-axis direction are the perfectly matched layer (PML) and the waveguide mode ports. In addition, periodic boundary conditions are imposed along the surrounding boundaries. The phase information of the transmitting and reflecting ports is derived from the S-parameters of the waveguide mode ports. We obtain the reflected (transmitted) light intensity R(T) by integrating the Poynting vector over the reflected (transmitted) waveguide port. Finally, the absorption of the polarized photodetector can be expressed as $1-R-T$.

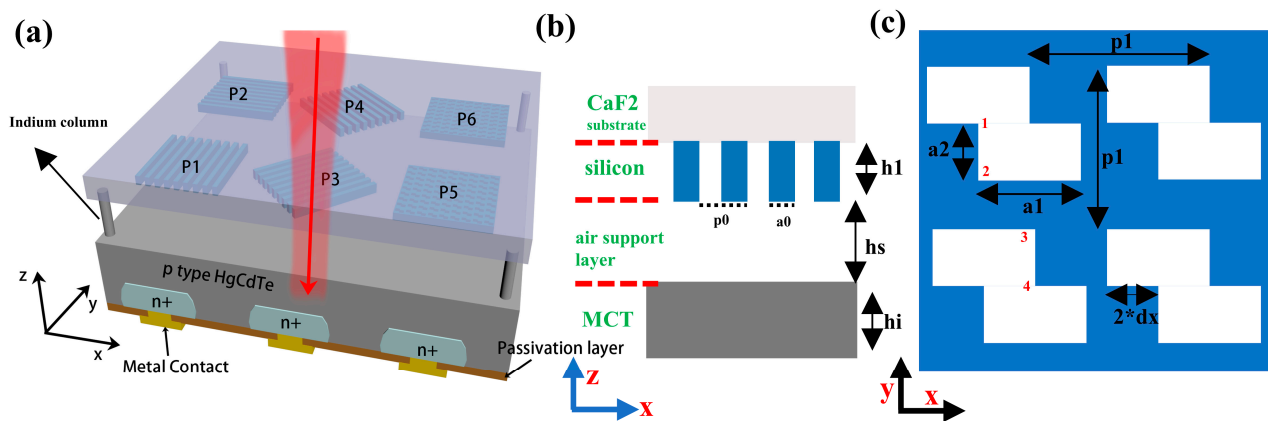


Figure 1. Mid-wavelength infrared (MWIR) full Stokes polarization detection. (a) The 3D structural diagram of six small pixel unit cells. The P1, P2, P3, P4, P5, and P6 are 0-degree, 90-degree, -45 -degree, and 45 -degree polarized grating, and the left and the right circular polarization metasurfaces, respectively. The P5 is transformed into the P6 by the mirror image transformation operation on the YZ cross section. The pixel P1 is rotated by 90° , -45° , and 45° to get qualified pixels P2, P3, and P4. The red arrow is the direction of the incident beam. (b) Front view of the 0-degree polarization detector showing thickness and material information, $p_0 = 1.9 \mu\text{m}$, $a_0 = 950 \text{ nm}$, $h_1 = 0.84 \mu\text{m}$, $h_s = 6.4 \mu\text{m}$, $h_i = 7 \mu\text{m}$. (c) The top view of the chiral Si metasurface of the circular polarization detector, $p_1 = 2.08 \mu\text{m}$, $dx = 240 \text{ nm}$, $a_1 = 905 \text{ nm}$, $a_2 = 860 \text{ nm}$. The blue color represents silicon material.

The design optimization of the polarized image element by scaling up or down the dimensions is particularly significant to note. The impacts of different geometrical parameters of metasurfaces on the performance of different circular polarizations (CP) in the wavelength range of $3 \mu\text{m}$ – $5 \mu\text{m}$ is investigated. For the transmittance of a dislocated 2-hole Si chiral metasurface with the CaF2 substrate, the CD of the transmittance is $T_{LCP} - T_{RCP}$, and the transmissive extinction ratio (ER) is $10 \times \log \left(\frac{T_{LCP}}{T_{RCP}} \right)$. Here, T_{RCP} and T_{LCP} are the transmission of the chiral metasurface in the case of the right circularly polarized (RCP) and left circularly polarized light (LCP) incidence, respectively. The quality factor, $CD \times ER$, is a composite metric that can be aptly evaluated for chiral device performance. Figure 2a shows the impacts of the period of the chiral Si metasurface on the transmission of the CP incidences. It is seen that the quality factor (QF) spectrum moves very drastically and the largest peak corresponds to the period of $2.08 \mu\text{m}$ is 13.5 dB. Moreover, the peak of the QF spectrum is dramatically redshifted with increasing period and it spans $3.4 \mu\text{m}$ – $4.7 \mu\text{m}$. On the contrary, the change in the QF peaks in Figure 2b seems to be irregular. Figure 2c shows that the wavelength of the QE peak does not change with the displacement length dx . However, the intensity of the peak fluctuates a little, and the maximum value corresponds to the case of $dx = 240 \text{ nm}$. Figure 2d shows that the QE peak undergoes a weak redshift as the length a_1 of the chiral Si grating increases. Figure 2e is similar to Figure 2d. The robustness, brought about by the fact that the device performance does not vary with the size of geometry, is very exciting news for the fabrication process. The qualified polarization photodetector should possess the high response to the specific polarization mode but the lowest response to the orthogonal polarization modes in order to ensure a large circular polarization ER. Finally, an optimal chiral miniaturized device whose p_1 , a_1 , a_2 , h_1 , and dx are $2.08 \mu\text{m}$, 905 nm , 860 nm , 840 nm , 240 nm , respectively, is achieved. As shown in Figure 2f, the transmissive CD and ER of the optimized circularly polarized transmissive metasurface are about 0.68 and 22 dB at the $4 \mu\text{m}$ operation wavelength, respectively.

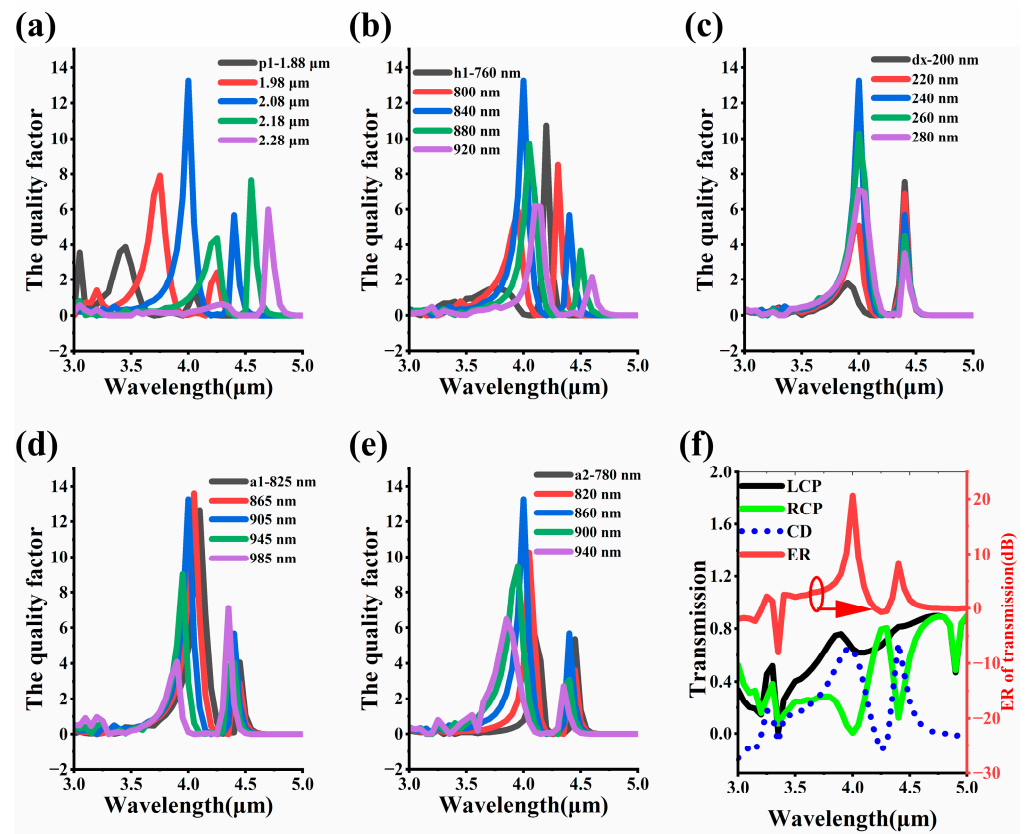


Figure 2. Effect of different structural parameters on the chiral Si metasurfaces with the CaF2 substrate: (a) period p_1 ; (b) thickness h_1 ; (c) length of the displacement dx ; (d) length a_1 ; (e) width a_2 ; (f) transmission and ER spectrum of the optimized chiral devices.

2.2. Optical Mode and Analysis

Displacing two identical rectangular holes in opposite directions can break the geometrical symmetry of the unit cell, completing the breakthrough from the C2 symmetry corresponding to $dx = 0$ nm to the chiral symmetry. Figure 3a shows the effect of the length of the displacement dx on the QF spectrum of the dislocated 2-hole Si transmissive metasurface with the CaF2 substrate. In the vicinity of the $4 \mu\text{m}$ operating wavelength, the QF peak blueshifted with increasing the length of the displacement dx , and the highest QF peak was about 13.5 dB ($\lambda_0 = 4 \mu\text{m}$). Figure 3b shows the energy-localized quantity in the Si material region of the dislocated 2-hole chiral metasurface for different circular polarization incidences at the $4 \mu\text{m}$ operation wavelength. The energy-localized quantity Q can be expressed as $\int |E| dV / \int |E_0| dV$. Here, the integral volume is the Si material region and E_0 is the electric field of the incident light. It is clear that the largest difference in Q between RCP and LCP occurs at $dx = 240$ nm. In addition, the underlying reason for the exceedingly large gap in the transmittance of the chiral dislocated 2-hole silicon metasurfaces, motivated by orthogonal chiral incidence modes, can be traced by observing the near-field profiles. Figure 3c,d shows the direction of electric current in the cross section of 2×2 unit-cells of the Si chiral metasurfaces in the case of the CP incidence. In the case of RCP incidence, the direction of the Z-type current in the silicon medium flows along the endpoints 1, 2, 3, and 4, which is mainly pooled in the narrow tunnel that exists between two neighboring unit cells in the y-direction. The current intensity in Figure 3d has been scaled up by a factor of 50. In the case of LCP incidence, the current accumulates mainly in the tunnel existing between two neighboring unit cells in the x-direction, but the current intensity is negligible compared with Figure 3c. In addition, the multipole moment expansion method is also one of the powerful means to analyze the optical resonance information of optical metasurfaces. It investigates the far-field properties by equating the optical device with

a series of radiant power sources. In the calculation of the multipolar decomposition, the total scattering power mode can be expressed as

$$I = \frac{\omega^4}{C^3}|P|^2 + \frac{\omega^4}{C^3}|M|^2 + \frac{\omega^6}{5C^5}Q_{\alpha\beta}Q_{\alpha\beta} + \frac{\omega^6}{20C^5}M_{\alpha\beta}M_{\alpha\beta} \quad (1)$$

$$P = \frac{1}{i\omega} \int j dv \quad (2)$$

$$M = \frac{1}{2C} \int (r \times j) dv \quad (3)$$

$$Q_{\alpha\beta} = \frac{1}{i\omega} \int \left[r_{\alpha} j_{\beta} + r_{\beta} j_{\alpha} - \frac{2}{3}(r \cdot j) \right] dv \quad (4)$$

$$M_{\alpha\beta} = \frac{1}{3c} \int \left[(r \times j)_{\alpha} r_{\beta} + (r \times j)_{\beta} r_{\alpha} \right] dv \quad (5)$$

Here, P , M , $Q_{\alpha\beta}$, and $M_{\alpha\beta}$ represent the scattering from the electric dipole (ED), magnetic dipole (MD), electric quadrupole (EQ), and magnetic quadrupole (MQ), respectively. The j is the current density in the unit cell of the Si metasurface, c is light speed, and α and β represent any two of the three mutually orthogonal projection directions. Figure 3e shows the multipole expansion of the Si chiral device in the case of RCP incidence, and the chiral device may also be manipulated by a combination of the dominant MQ and the small amount of MD at the 4 μm operation wavelength. In circularly polarized photodetector, a destructive interfering optical cavity mode is likely to have a significantly detrimental effect on the QF of absorption due to the air domains existing between the Si chiral metasurface and MCT photodetector; therefore, a careful parametric scan for the height of the air domain seems to be indispensable. Here, the QF of absorption is the product of CD of absorption and ER of absorption: CD of absorption is $A_{LCP} - A_{RCP}$, ER of absorption is $10 \times \log(A_{LCP}/A_{RCP})$, and A_{LCP} and A_{RCP} are the absorption of LCP and RCP for the left circular dichroic device named the pixel P5, respectively. The maximum QF of absorption corresponds to an optimal air domain thickness of 6.4 μm , as shown in Figure 3f. Figure 3g shows the absorption and ER spectrum of the pixel P5, CD of absorption is 0.95, and ER of absorption is about 21 dB at the 4 μm operation wavelength. Figure 3h shows the electric field intensity distribution in the xz and yz cross sections of the pixel P5 for CP incidence. In the case of RCP incidence, it is very clear that almost no photon energy can reach the MCT through the Si metasurface. However, in the case of LCP incidence, there are standing waves in the air domain caused by the FP cavity resonance between the Si metasurface and MCT, which may be the main reason for the increase in CD of transmission (0.6) on the Si chiral metasurface to CD of absorption (0.95) on the pixel P5.

The polarization response characteristic of the linear polarization photodetector is dependent on the linear polarized Si grating with the CaF2 substrate placed in front of the image element of the MCT. Figure 4a shows the linear dichroism (LD) and ER spectrum of the Si linear polarized grating with the CaF2 substrate in the pixel P1. Here, the LD of the transmittance is $T_{TE} - T_{TM}$, and the ER of the transmittance is $10 \times \log(\frac{T_{TE}}{T_{TM}})$. The T_{TE} and T_{TM} are the transmission of the linear polarized metasurface in the case of the TE and TM incidence, respectively. The TM and TE modes correspond to the cases where the direction of the electric field of the incident light is along the y- and x-axis, respectively. In addition, a peak and a valley appear in the TM transmission spectrum, and the transmission spectrum of the TE mode has two peaks, and the maximum value of ER of the transmissive Si linear grating is about 28 dB, as shown in Figure 4a. The optical properties of the linear grating extending infinitely in the y-direction can be accurately evaluated in terms of the light field components in the y-direction. Figure 4b illustrates the magnetic field distribution of the linear Si grating at two specific TM wavelengths. For valley d of the TM mode, the photon energy is converged in silicon, and a large amount of light energy is reflected back into the CaF2 medium by the silicon grating. For the peak c of the TM mode, the light

energy in the CaF₂ medium, which represents the reflective domain, is still much larger than that in the air medium, which represents the transmissive domain, but the leakage field present at the interface between the Si grating and air medium makes the transmitted light no longer negligible. Moreover, the light energy in the transmission domain mainly permeates through the air slits between neighboring silicon bars in the grating in the case of the TE peaks, as shown in Figure 4c. Figure 4d shows the absorption and ER spectrum of the 0-degree polarization MCT photodetector named the pixel P1 with 6.4 μm thickness of the air layer between the linear grating and MCT. Here, LD of absorption is $A_{TE} - A_{TM}$, ER of absorption is $10 \times \log(A_{TE}/A_{TM})$, and A_{TE} and A_{TM} are the absorption of the TE and TM by the pixel P1, respectively. LD of absorption is 0.62 and ER of absorption is about 22 dB at the 4 μm operation wavelength.

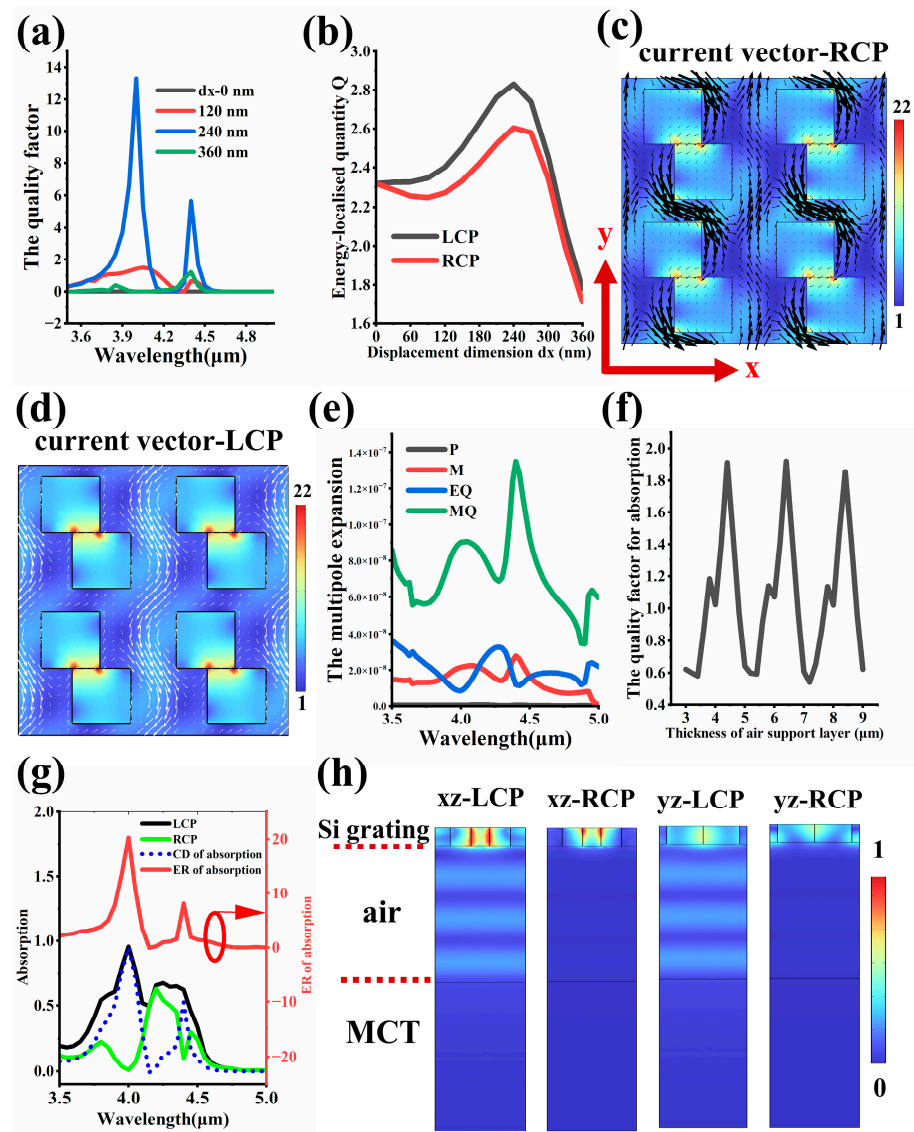


Figure 3. (a) The effect of the length of the displacement dx on the QF spectrum of the dislocated 2-hole Si metasurfaces with the CaF₂ substrate. (b) The impact of the size of the displacement dx on the energy-localized quantity of the Si chiral transmissive metasurfaces. (c,d) The current vectors in the cross section of 2×2 unit cells of the Si chiral metasurfaces for the CP incidence. The current intensity in (d) has been scaled up by a factor of 50. The color legends in (c,d) are the same. (e) The multipole expansion of the RCP. (f) The effect of the thickness of the air support layer on the QF of absorption. (g) Absorption and ER spectrum of the left circular dichroic device named the pixel P5. (h) Distribution of electric field intensity of the pixel P5.

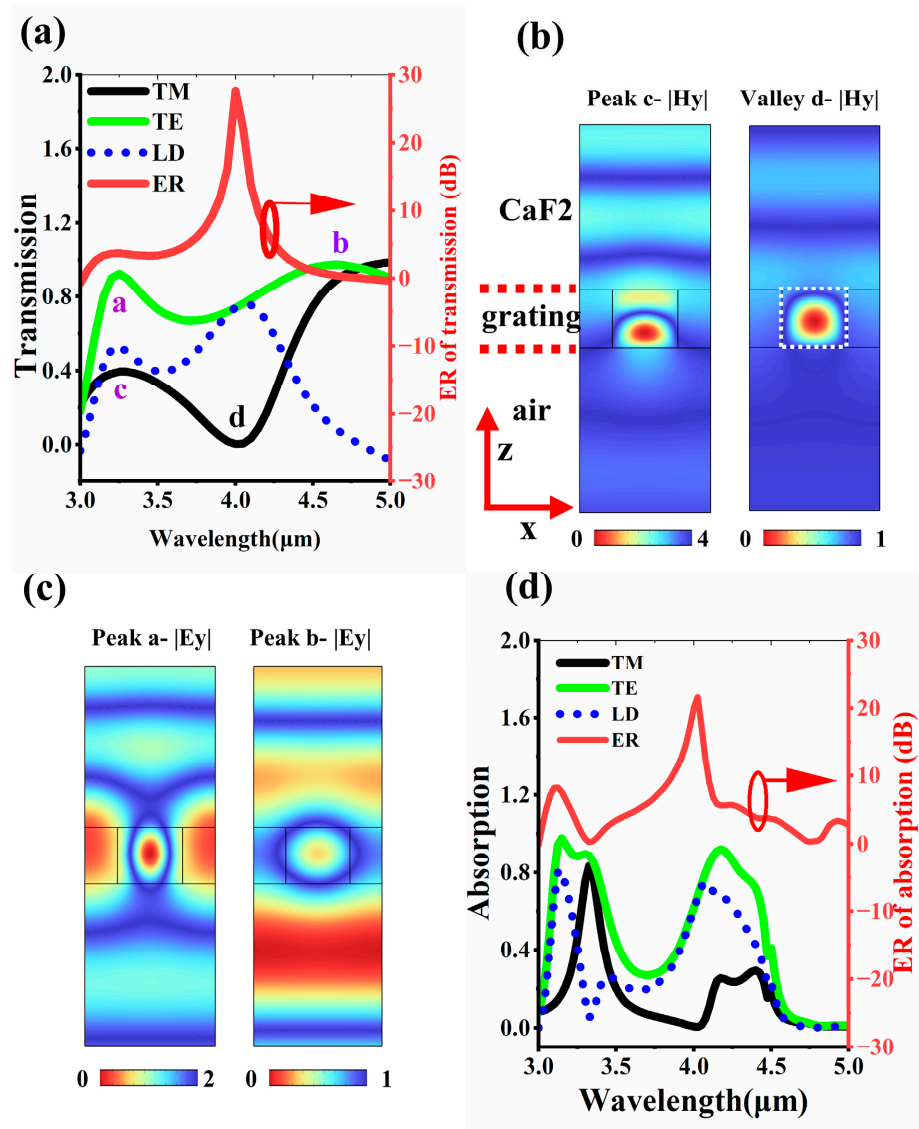


Figure 4. (a) Transmission and ER spectrum of the Si linear grating with the CaF2 substrate in the pixel P1. (b) Magnetic field distribution in TM mode @ peak c and valley d. The white dashed box corresponds to the boundary of the silicon material. (c) Electric field distribution in TE mode @ peak a and peak b. (d) Absorption and ER spectrum of the 90-degree polarization MCT detector called the pixel P1. The red arrow in (a,d) represents the curve corresponding to the right y-axis.

3. Results

In the previous section, we introduced a miniaturized MWIR full Stokes polarization detector chip with six subpixels; we also traced the chiral evolution of the high circular dichroism of the chiral silicon metasurface and analyzed the whole process of symmetry breaking of the unit cell. In this chapter, we prefer to consider the errors introduced during the actual experiments. We use the errors in the degree of linear polarization (Dolp) and circular polarization (Docp) to evaluate the performance of the miniaturized MWIR full Stokes polarization detector chip. Errors for the Dolp and Docp are defined as $10 \times \log \left(\left| \sqrt{S_1^2 + S_2^2} / S_0 - \sqrt{D_1^2 + D_2^2} / D_0 \right| \right)$ and $10 \times \log \left(\left| S_3 / S_0 - D_3 / D_0 \right| \right)$, respectively. Here, $|x|$ is an operator that performs an absolute value operation on the element x . The (D_0, D_1, D_2, D_3) is the theoretical Stokes parameter corresponding to the incident light, e.g., for the RCP: the theoretical Stokes parameter (D_0, D_1, D_2, D_3) is $(1, 0, 0, 1)$. The (S_0, S_1, S_2, S_3)

represent the simulated values of the Stokes parameter obtained by the COMSOL, and the four components of the Stokes parameter [40] (S_0, S_1, S_2, S_3) can be defined as:

$$S_0 = (A_0 + A_{90})/\alpha_{TE} \quad (6)$$

$$S_1 = (A_{90} - A_0)/\alpha_{TE} \quad (7)$$

$$S_2 = (A_{-45} - A_{45})/\alpha_{TE} \quad (8)$$

$$S_3 = (A_{RCP} - A_{LCP})/\alpha_{LCP} \quad (9)$$

$$A_\gamma = I_{\gamma,inc} * (1 - R_{\gamma,inc} - T_{\gamma,inc}) \quad (10)$$

Here, $A_0, A_{90}, A_{45}, A_{-45}, A_{RCP}$ and A_{LCP} , the optical powers absorbed by six different polarization detectors, are in the case where γ corresponds to 0, 90, 45, -45 , RCP, and LCP, respectively. The α_{TE} is the optical absorption of the 0-degree linear polarization photodetectors for the TE incidence, and α_{LCP} represents the optical absorption of the left circular polarization device for the LCP incidence. The other subscript “inc” in Equation (10) represents the incident mode with different polarization characteristics, and $I_{\gamma,inc}$, $R_{\gamma,inc}$ and $T_{\gamma,inc}$ are the intensity of the incident light, the reflected light, and the transmitted light for the specific polarization incidence, respectively. In addition, θ and Θ can represent the polarization diversity of the incident light illuminating the six small pixels. Table 1 shows that the D_3 and S_3 are very close due to the high circular dichroism possessed by the silicon metasurface, which indicates the high-quality tracking effect of Equation (9) for the circularly polarized incident light. As shown in Figure 5a,b, the error of Dolp is less than -17 dB at $4 \mu\text{m}$ operation wavelength and the minimum value of the error of Dolp corresponds to the case where θ is $\pm 90^\circ$. Meanwhile, the average error in the Docp exhibits a small value, which is -15 dB. In practice, the linear grating usually has a small deviation in the etching angle after the dry etching, which is not the ideal, perfect 90° vertical etching angle. Figure 5c shows the impact of the etching vertical angle on a 0-degree linear polarizer (the pixel P1). In the range of the vertical etching angles from 75° to 90° , the ER of the pixel P1 only weakly fluctuates. Moreover, the impact of the mesh density on the performance of the CD photodetector is shown in Figure 5d. The QF of the pixel P5 converges to a specific value as the grid size of the silicon and air media becomes smaller. In addition, we must also not lose sight of the fact that some minor inconsistencies in published databases on the optical refractive index for optical material may introduce errors in the performance of the chiral device. Figure 5e demonstrates the effect of different refractive index databases of the Si and CaF2 on the QF of the pixel P5. The refractive index set in the COMSOL model is $n_0 + \Delta n$, n_0 is 3.5 and 1.4 for Si and CaF2, respectively. The error in the refractive index Δn is ± 0.2 . When Δn is within the range of ± 0.05 , the performance of the device remains uncompromising. In addition, in the practical etching processing process, the eight right-angle vertices of the dislocated 2-hole in the chiral device will be more likely to become circles with a small radius, so it is necessary to estimate the effect of the size of the circle radius on the performance. Endpoints 1 and 4 of the eight endpoints belong to the inner endpoints, and the other endpoints are outer endpoints. Figure 5f shows the QF of the pixel P5 remains a good 16 dB when the fillet radius is less than 100 nm.

Table 1. Comparison of theoretical and simulated values of Stokes parameters for CP incidence.

Incidence	D_3	S_3
LCP	-1	-0.9809
RCP	1	0.9802

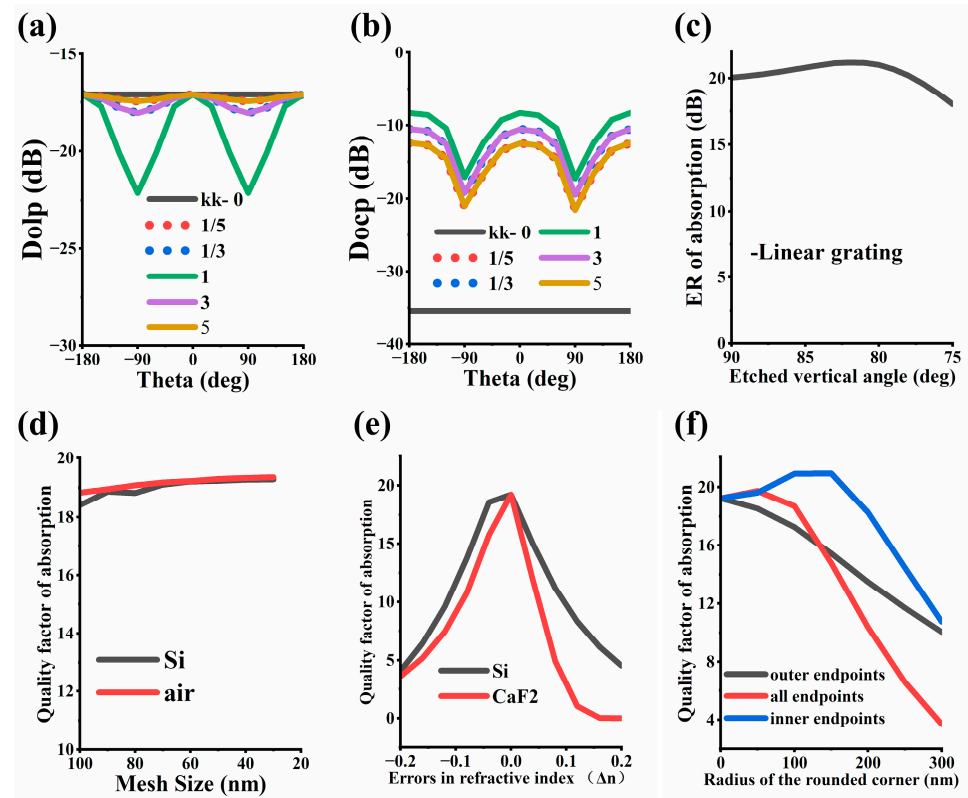


Figure 5. (a,b) The error for Dolp and Docp at 4 μm operation wavelength: kk: 0, 1/5, 1/3, 1, 3, 5. Here, kk corresponds to the quotient of the amplitude of the incident light in the x- and y-directions, and θ is the phase difference of the electric field between the x-axis and y-axis directions. (c) Impact of the etched vertical angle of the Si linear grating on the pixel P1. (d) The maximum value of mesh size of the material in COMSOL software on the pixel P5. (e) The errors in refractive index. (f) The radius of the rounded corner.

When arranging different patterns on the same detector, several things may need to be considered/mentioned. Tracking the minimum period of the pixel is critical for evaluating the performance of the photodetector. We use COMSOL to study the effect of the number of unit cells of metasurfaces on device performance, and we use PML to truncate the electromagnetic field at the upper and lower boundaries and impose the scattering boundary conditions in the lateral direction. The upper limit on the number of unit cells for circularly dichroic metasurfaces and linearly polarized metasurfaces is limited by the computational power of the server. The black solid line in Figure 6a, the transmissive CD in the 3D optical model, shows that the CD value of the metasurface becomes larger as the number of unit cells increases. The red dashed line is a linearly extrapolated function of the transmissive CD. The CD of the circular dichroic metasurfaces approaches the theoretical value when the number of unit cells is 18. The LD based on the 2D optical model approaches the theoretical value of the linearly polarized metasurfaces when the number of unit cells is about 21, as shown in Figure 6a. Figure 6b shows the influence of the pixel pitch on the cross-talk between the linearly polarized pixels in the case of the TE mode incidence. The illustration in Figure 6b shows the schematic of the model for the optical crosstalk where the light beam is incident perpendicularly on pixel b, and then, the light absorption of pixels a, b, and c is extracted by the monitor in COMSOL, respectively. The optical cross-talk between the pixels is defined as $(I_a + I_c) / (2 \times I_b)$, and I_a , I_b and I_c are the light absorption of pixels a, b, and c, respectively. The optical cross-talk is attenuated to 0.9% when the pixel pitch is 30 μm .

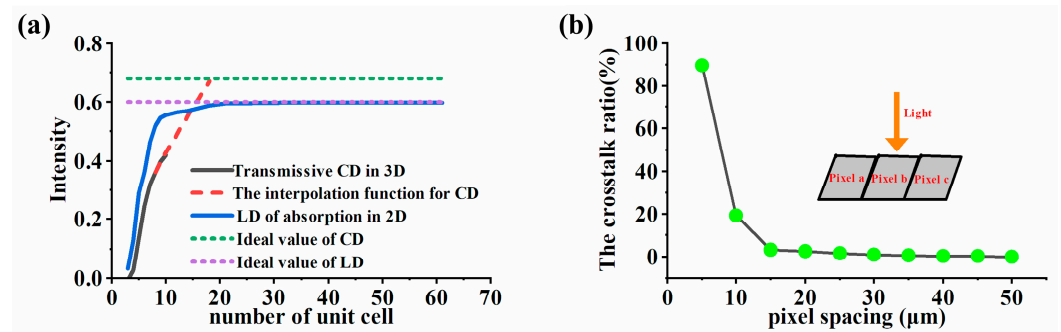


Figure 6. (a,b) Influence of the number of the unit cells of metasurfaces and the pixel pitch on the device performance. The green dots are the ideal value of CD corresponding to periodic boundary conditions.

4. Discussion

On-chip full Stokes polarimeters that can simultaneously achieve efficient linear and circular polarization responsivity on the same detection material chip with high ER are eagerly pursued based on the trend of miniaturization and integration. Full Stokes detectors typically integrate miniature polarizers at the top of the detector array at the imaging focal plane, which is similar to the idea of a filter. The performance of the miniature circularly polarized grating directly affects the application range of the polarization detector. However, chiral metasurfaces with high extinction ratios are usually made of double-layer grating stacks, which greatly increases the difficulty of fabrication.

In this paper, we have simulated a monolayer of the silicon chiral metasurfaces to realize large circular dichroism using translational motions to increase the chiral geometric factors. We have optimized and analyzed the CD values for circularly polarized detectors as numerically realizable chiral MWIR full Stokes polarization configurations are composed of the MCT and the dislocated 2-hole Si chiral metasurfaces with the CaF₂ substrate. The ER and CD of absorption of the full Stokes polarization photodetector we designed are 21 dB and 0.95, respectively. The excellent ER of the MWIR chiral photodetector is caused by the significant Z-type current density under the RCP incidence conditions. Moreover, the LD of the LP pixel based on the Si grating is 0.62, and the ER is 22 dB. Meanwhile, due to the excellent Dolp (−17 dB) and Docp (−15 dB), the full Stokes photodetector consisting of six small pixels can almost accurately reproduce the polarization information of light at 4 μm operation wavelength. Our work may offer another promising strategy for designing the miniaturized full Stokes polarization MWIR photodetector.

Author Contributions: Conceptualization, B.C.; methodology, B.C. and Y.Z.; software, B.C.; validation, G.S., B.C. and Y.Z.; formal analysis, B.C.; investigation, Y.Z.; resources, B.C.; data curation, B.C.; writing—original draft preparation, B.C.; writing—review and editing, B.C.; visualization, Y.Z.; supervision, Y.Z.; project administration, Y.Z.; funding acquisition, G.S. All authors have read and agreed to the published version of the manuscript.

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