DEPARTMENT OF PHYSICS & ASTRONOMY

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Infrared Polarization Rotation and Ellipticity in Coupled Surface Plasmon–Phonon Polaritons

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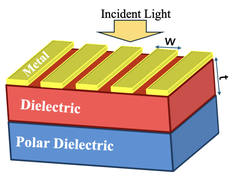
ABSTRACT

Controlling the phase and polarization of infrared light is essential for wavefront shaping and polarization conversion yet achieving such control across the mid- and far-infrared (MIR–FIR) remains challenging: natural anisotropic optical materials are scarce in this range, and lossy plasmon polaritons alone offer limited control at longer infrared wavelengths. Here, we demonstrate infrared waveplates based on Au gratings on VO_2/SiC (MIR) and SiO_2/GaAs (FIR), in which coupled surface plasmon and phonon polaritons produce an anisotropic optical response. We characterize their polarization response with polarizer–analyzer reflection measurements and compare the results with numerical calculations. A Jones-calculus analysis relates the measured reflected intensities to the Stokes parameters, enabling direct extraction of the polarization-axis rotation and ellipticity spectra. Both spectra show resonant features that originate from Fabry–Pérot cavity resonances of the coupled polariton mode. Fitting a single-resonance Lorentzian response function yields maximum polarization rotations and ellipticities of 7.6° and 4.1° near 840 cm^{-1} for the SiC-based waveplate, and 2.8° and 1.4° near 276 cm^{-1} for the GaAs-based waveplate. These results demonstrate that hybrid plasmon–phonon resonances can enable compact waveplates, polarization converters, and wavefront-control devices throughout the infrared.

SCIENTIFIC MOTIVATION AND EXPERIMENTAL APPROACH

- Surface plasmon polariton -light interacts with free electrons- metal-dielectric interface.
- Surface phonon polaritons - light interacts with lattice vibrations- dielectric-polar dielectric interface.
- Both polaritons coupled- coupled guided polaritonic mode with propagation constant β.
- Gold gratings with width w forms Fabry Perot resonance cavity to trap coupled guided mode.

1[a]



1[b]

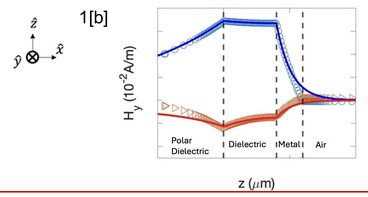
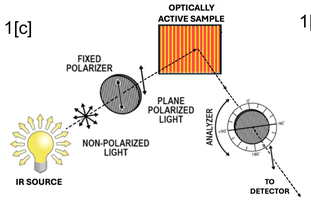


Figure 1[a] Schematic of hybrid plasmon-phonon polaritonic metasurfaces. 1[b] Field profile in device resulting into coupling of surface plasmon-phonon modes inside dielectric spacer layer.

1[c]



1[d]

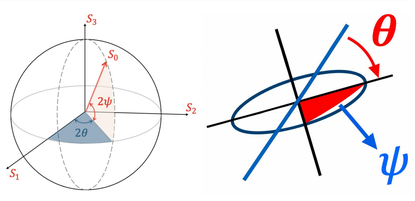
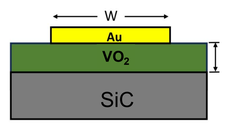


Figure 1[c]Schematic of FTIR reflectance experimental setup with polarizer and analyzer of IR polarimetry of device. 1[d] Poincare sphere representation and 2D representation of polarization state evolution, illustrating polarization rotation θ and ellipticity ψ .

MID IR POLARIZATION RESPONSE

2[a]



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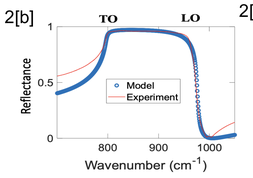

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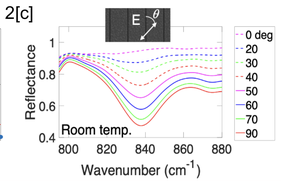
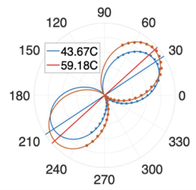
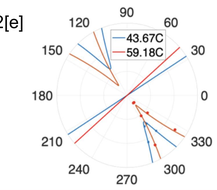


Figure 2[a] Schematic of Mid IR device with SiC as a substrate and vanadium dioxide as spacer layer. 2[b] Reststrahlen Band of SiC bounded by TO and LO phonon modes between 797 $cm^{-1}$and 970 cm^{-1} and 2[c] Experimental reflectance spectrum showing resonance around 840 cm^{-1} in response to rotating polarizer.

2[d]



2[e]



2[f]

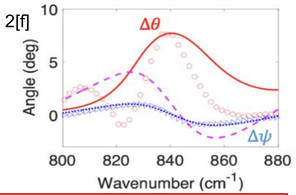


Figure 2[d]Polar plotting illustrating the polarization rotation induced by our hybrid nanocavity. 2[e] Non zero extinction response demonstrating creation of phase among two orthogonal field components.

2[g]

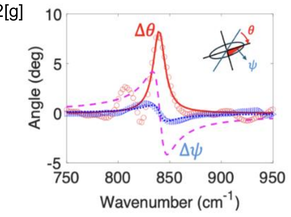
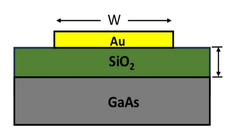


Figure 2[f] Comparison of experimentally measured and simulated polarization rotation and ellipticity. 2[g] Experimental polarization rotation and ellipticity using a Lorentzian resonance model where rotation and ellipticity are defined by real and imaginary part of Lorentzian function respectively.

$$L(\omega) = \frac{A}{\gamma + i(\omega - \omega_0)}$$

FAR IR POLARIZATION RESPONSE

3[a]



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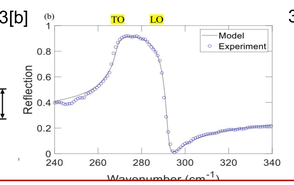


3[c]

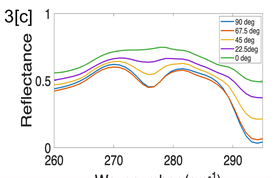
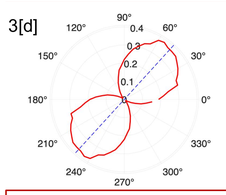
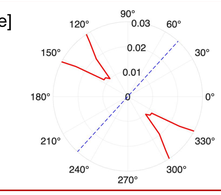


Figure 3[a] Schematic of Far IR device with GaAs as a substrate and silicon dioxide as spacer layer. 3[b] Reststrahlen Band of GaAs bounded by TO and LO phonon modes between 265cm^{-1} to 290 cm^{-1} 3[c] Experimental reflectance spectrum showing resonance around 276 cm^{-1} in response to rotating polarizer..

3[d]



3[e]



3[f]

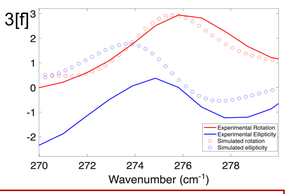


Figure 3[d]Polar plotting illustrating the polarization rotation induced by our hybrid nanocavity. 3[e] Non zero extinction response demonstrating creation of phase among two orthogonal field components.

3[g,h]

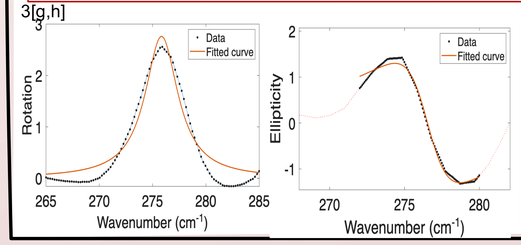


Figure 3[f] Comparison of experimentally measured and simulated polarization rotation and ellipticity. 3[g,h] Experimental polarization rotation and ellipticity using a Lorentzian resonance model where rotation and ellipticity are defined by real and imaginary part of Lorentzian function respectively.

KEY FINDINGS AND CONCLUSION

- Hybrid polaritonic resonances enabled simultaneous modulation of polarization rotation and phase modulation.
- Mid-IR performance- Rotation= 7.6 degrees; ellipticity= 4.1 degrees.
- Far-IR performance- Rotation= 2.8 degrees; ellipticity= 1.4 degrees.
- Simulations captured the overall experimental trends, with quantitative deviations.
- The close agreement between Lorentzian fit parameters for both rotation and ellipticity responses indicates that they are originating from single source of resonance from the device accounting for surface plasmon-phonon polaritonic resonance.

FUTURE RESEARCH AND APPLICATIONS

- Active Tunability- Modulate carrier concentration in GaAs and using vanadium dioxide phase transition driven optical changes to tune the resonant response in IR
- Wavefront engineering- Develop gradient metasurfaces for customized phase profiles, steering beam and can also generate optical vertex generation (beams carrying orbital angular momentum.

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