Dual-polarization control of nonreciprocal thermal radiation

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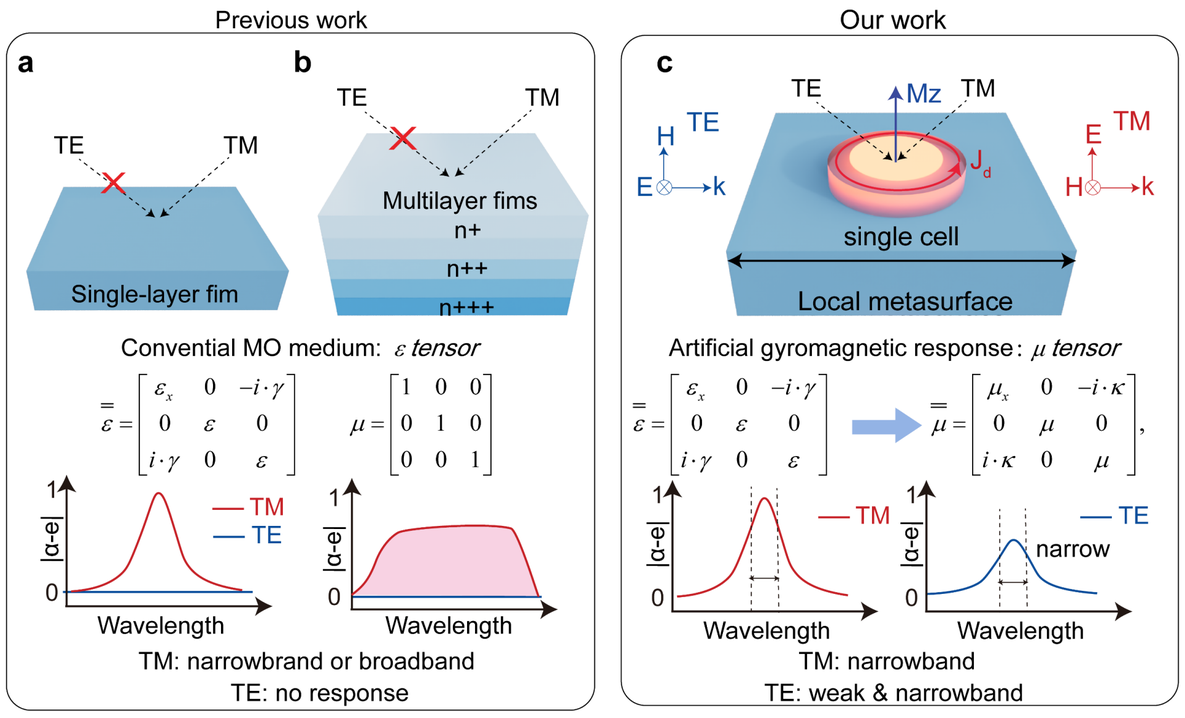
Introduction



- Kirchhoff's law of thermal radiation can be violated in nonreciprocal systems : $\alpha(\lambda,\theta,\varphi) \neq e(\lambda,\theta,\varphi)$
- However, previous work generally confines nonreciprocity to transverse-magnetic (TM) polarization, which originates from the inherent gyroelectric property of natural magneto-optical materials

Mechanism of breaking the polarization constraint

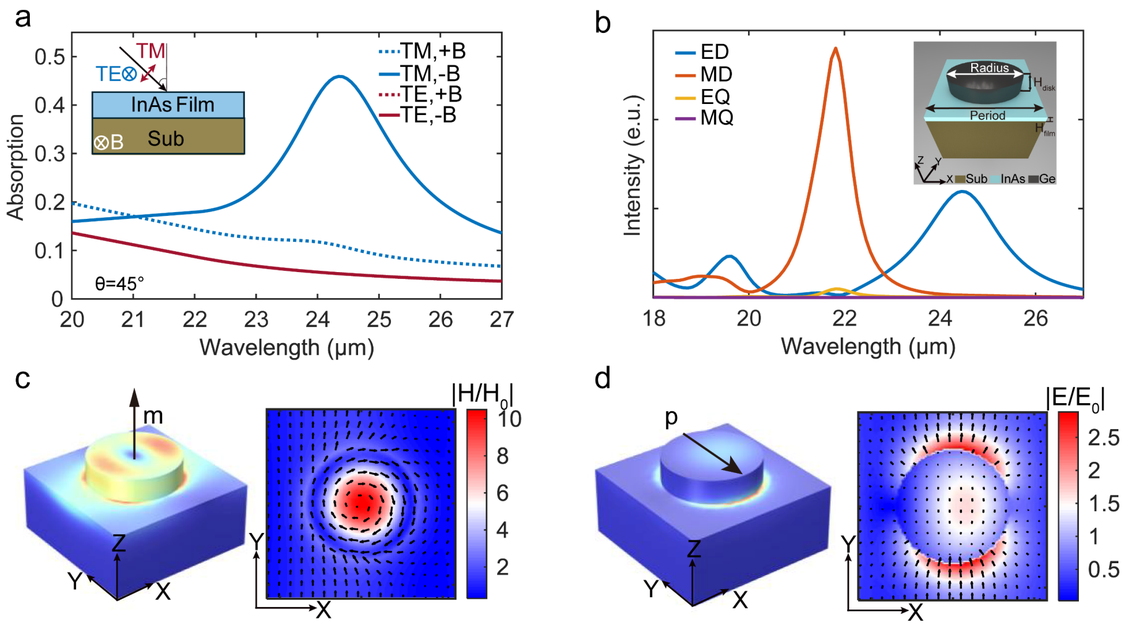


Figure 1. Mechanism of breaking polarization constraint in local thermal metasurface.

$$C_{\text{ext}} = -\frac{\pi}{k^2}\sum_{l=1}^{\infty}\sum_{m=-1,+1}(2l+1)\,\text{Re}[m a_{\text{E}}(l,m) + a_{\text{M}}(l,m)]$$

$$C_{\text{sca}} = \frac{\pi}{k^2}\sum_{l=1}^{\infty}\sum_{m=-l}^{l}(2l+1)\,[|a_{\text{E}}(l,m)|^2 + |a_{\text{M}}(l,m)|^2]$$

Electric dipole (ED) mode: electric field oscillating along the y- direction

Magnetic dipole (MD) mode: circulating electric-field vector in the x-y plane

- MD resonance reconfigures the local field distribution and introduces an additional Ex component that is absent in the bare film, enabling effective interaction with MO medium under TE polarization

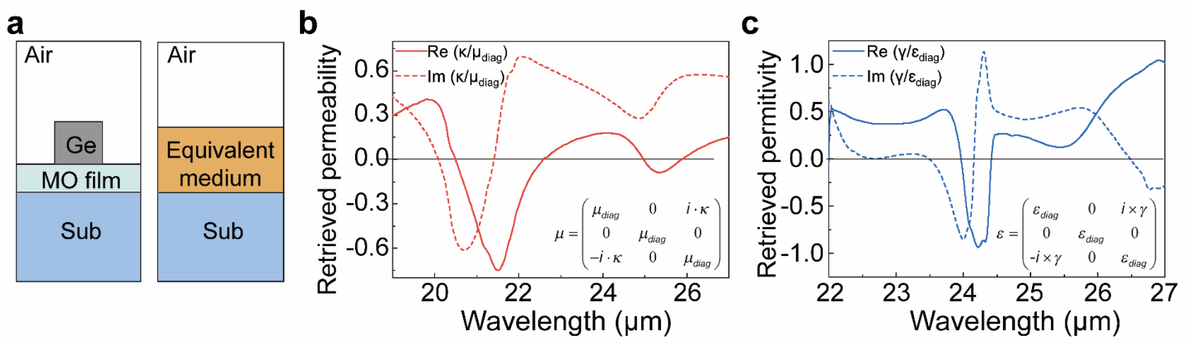


Figure 2. The schematic diagram of resonant structure and its related equivalent material.

$$\begin{vmatrix} \varepsilon_x & \frac{k}{k_0}\cos\phi & \frac{k}{k_0}\sin\phi \\ \frac{k}{k_0}\cos\phi & \mu & -i\cdot\kappa \\ \frac{k}{k_0}\sin\phi & i\cdot\kappa & \mu \end{vmatrix} = 0\ (TE), \quad \begin{vmatrix} \mu_x & -\frac{k}{k_0}\cos\phi & -\frac{k}{k_0}\sin\phi \\ -\frac{k}{k_0}\cos\phi & \varepsilon & -i\cdot\gamma \\ -\frac{k}{k_0}\sin\phi & i\cdot\gamma & \varepsilon \end{vmatrix} = 0\ (TM)$$

$$n^2_{TE} = \varepsilon_x\mu\left(1-Q^2_m\right),\ Q_m = \kappa/\mu$$

$$n^2_{TM} = \varepsilon\mu_x\left(1-Q^2\right),\ Q = \gamma/\varepsilon$$

TE-polarized : governed by the off-diagonal permeability coefficient κ.
TM polarization : governed by the off-diagonal permittivity coefficient γ.

- Retrieved effective permittivity and permeability tensors demonstrate an artificial gyromagnetic response under TE polarization

Experimental Results

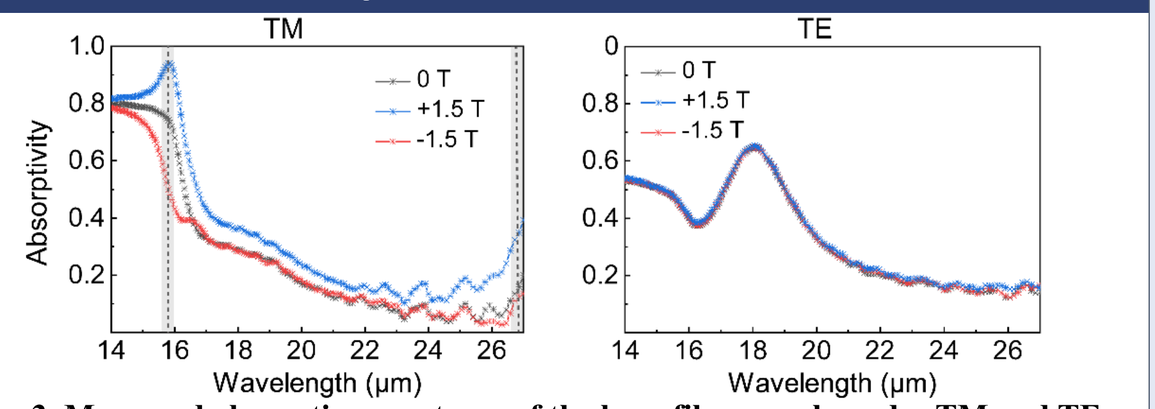


Fig. 3. Measured absorption spectrum of the bare film sample under TM and TE polarized incident light..

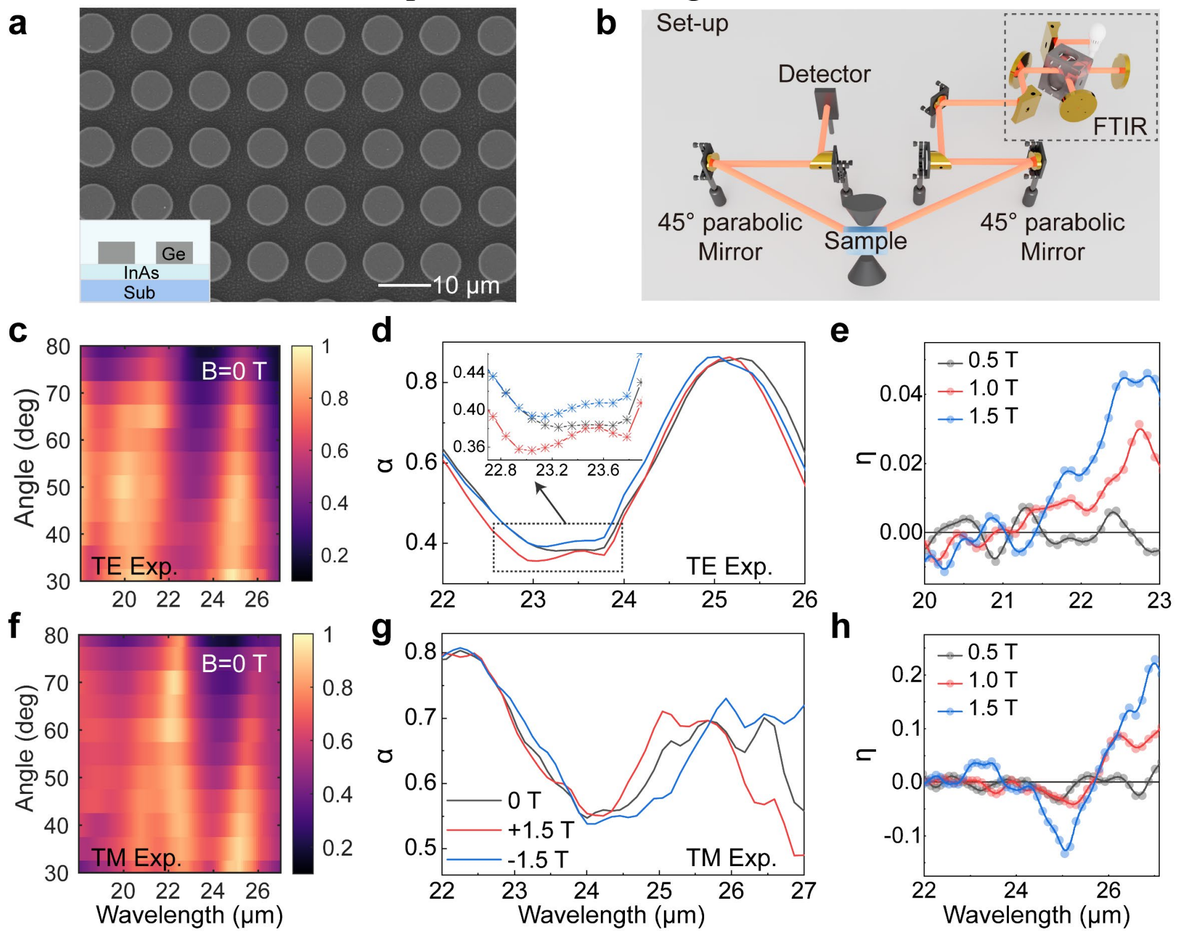


Fig. 4. Experimental demonstration of nonreciprocal absorption under dual polarization.

- No discernible nonreciprocal absorption contrast is observed over the entire spectral range under TE polarization for natural MO material
- Clear absorptivity contrast is resolved in the local thermal metasurface, but only in the vicinity of the MD resonance

Conclusion

- The strong MD mode reconfigures the local electric field orientation and enable artificial gyromagnetic response , which is absent in conventional platforms.
- Experimentally demonstrate that the polarization limitation in nonreciprocal thermal radiation can be overcome in our proposed metasurface