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Low Dissipation Spectral Filtering at Long Infrared Wavelengths using a Field-Effect Tunable III-V Hybrid Metasurface

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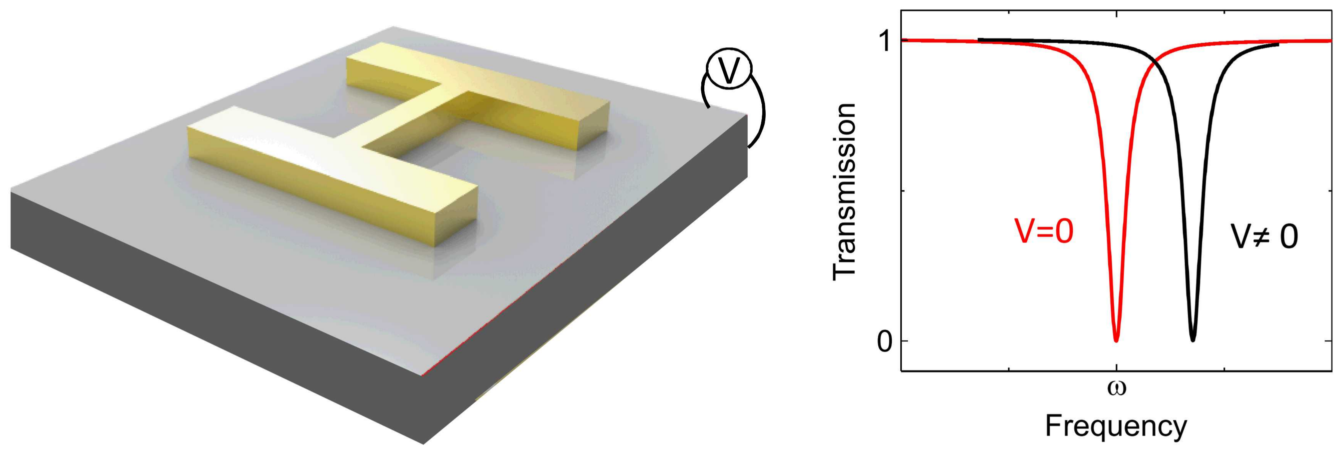
Introduction

Metasurfaces are optically thin arrays of subwavelength sized and subwavelength spaced resonators. Collectively the resonators generate a spectral response dictated by the shape and size of the individual resonators. Ability to modulate the spectral response of the metasurface using an external stimulus creates the possibility of realizing an ultrathin tunable filter[1,2].

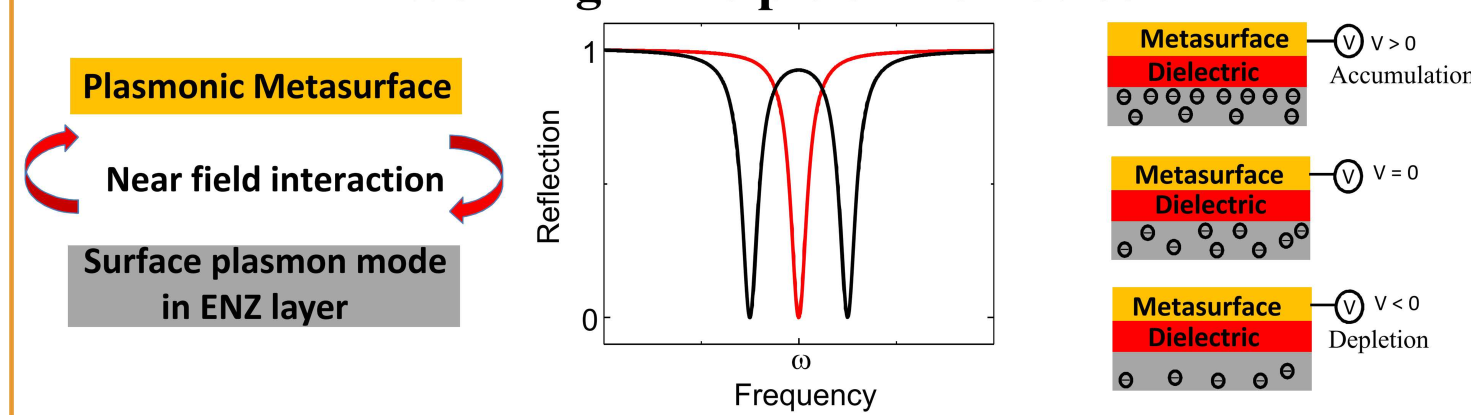


An ultrathin voltage tunable filter using a III-V Hybrid Metasurface

In this work, we demonstrate a monolithically integrable, low dissipation, field-effect tunable, III-V hybrid metasurface operating at long-wave-infrared spectral bands. Our device relies on strong light-matter coupling between epsilon-near-zero (ENZ) modes of an ultrathin InGaAs layer and the dipole resonances of a plasmonic metasurface. The tuning mechanism is based on field-effect modulation, where we modulate the strong coupling by modifying carrier density in the ENZ layer using an external bias voltage.

Working Principle and Device Structure

Working Principle of the Device

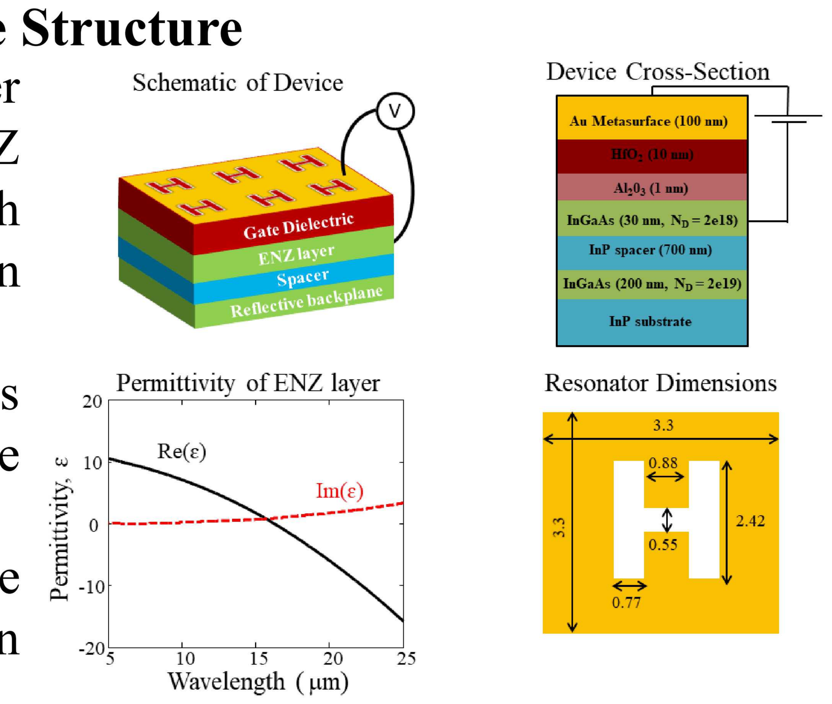


Working Principle of the Tunable Metasurface.

The resonances of the metasurface strongly couple to the ENZ mode when placed in near field[1]. The strong coupling leads to spectral splitting of the resonance which can be controlled by a bias voltage[1,3].

Device Structure

- 30 nm doped InGaAs layer which supports an ENZ mode at long-IR wavelength of ~ 15.5 µm was grown on an InP substrate.
- 10 nm HfO_2 layer was deposited to act as gate dielectric.
- A metasurface with dogbone resonators was fabricated on top of the Hafnia.

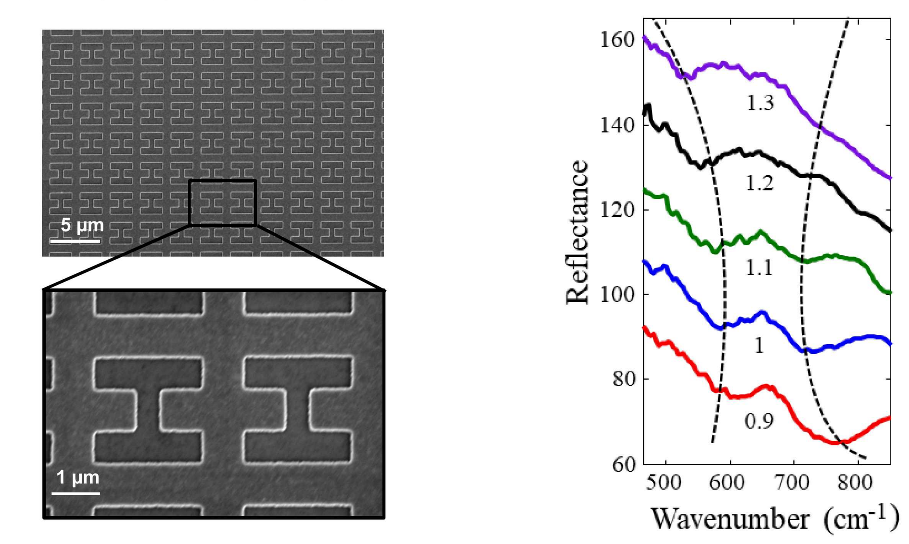


Cross Section and Device Structure

Optical and Electrical Characterization

Optical Characterization of Strong Coupling

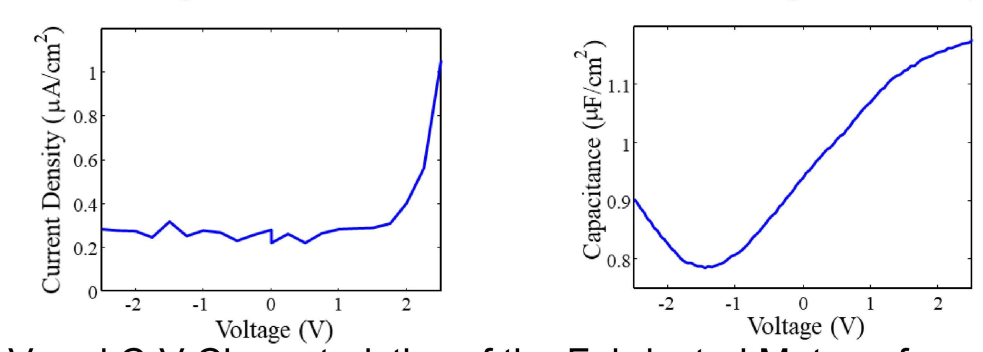
- Metasurfaces of different scale factors were fabricated and reflectance was measured using a FTIR microscope.
- Strong coupling was confirmed by looking at the anti-crossing of the two polariton branches.



FTIR Reflectance Measurement of Strongly Coupled Metasurfaces

Electrical Characterization of the Device

- The device exhibits low leakage currents.
- Capacitance changes due to modulation of charge density.



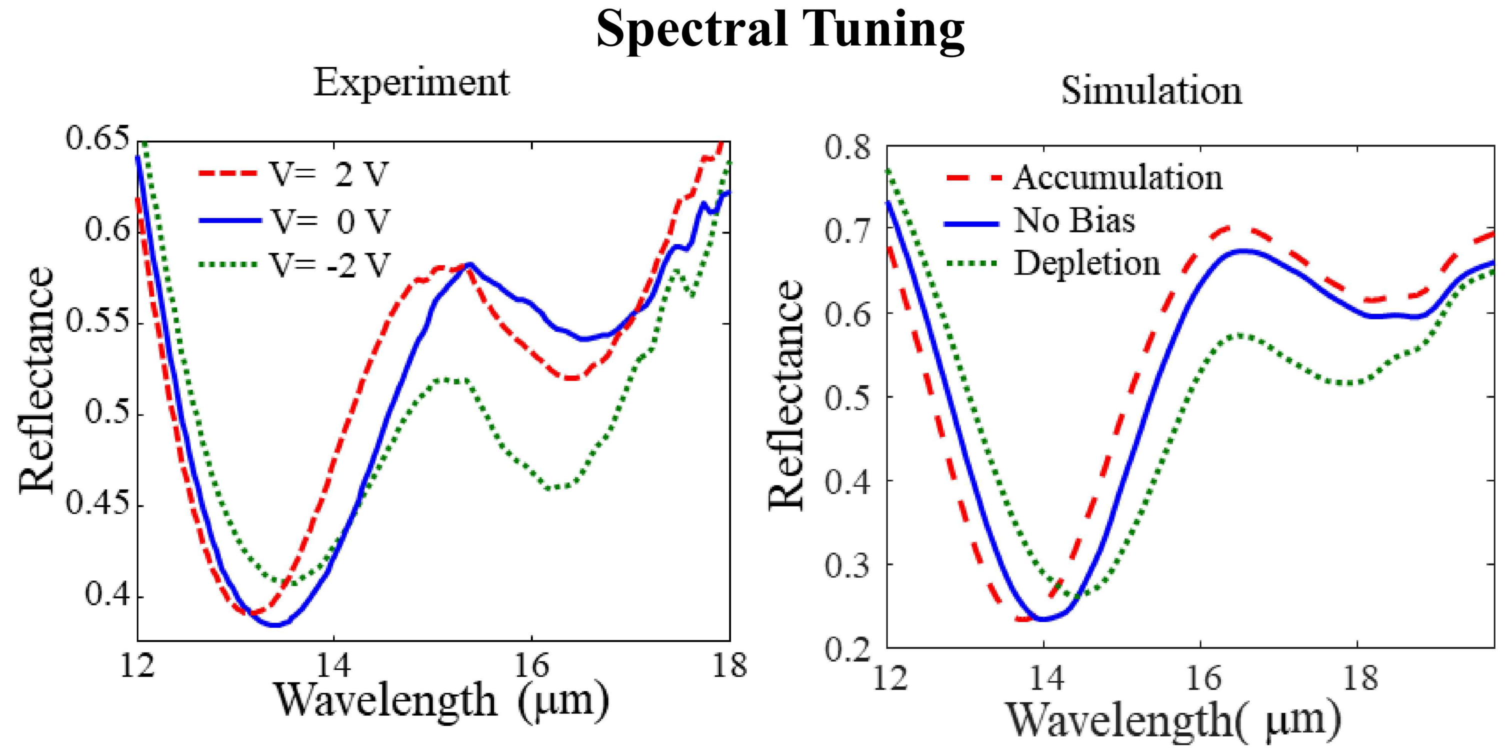
I-V and C-V Characteristics of the Fabricated Metasurface

Spectral Tuning and Amplitude Modulation

We performed the voltage tuning experiment, where we measured the reflectance of one of the strongly coupled metasurfaces as a function of bias voltage.

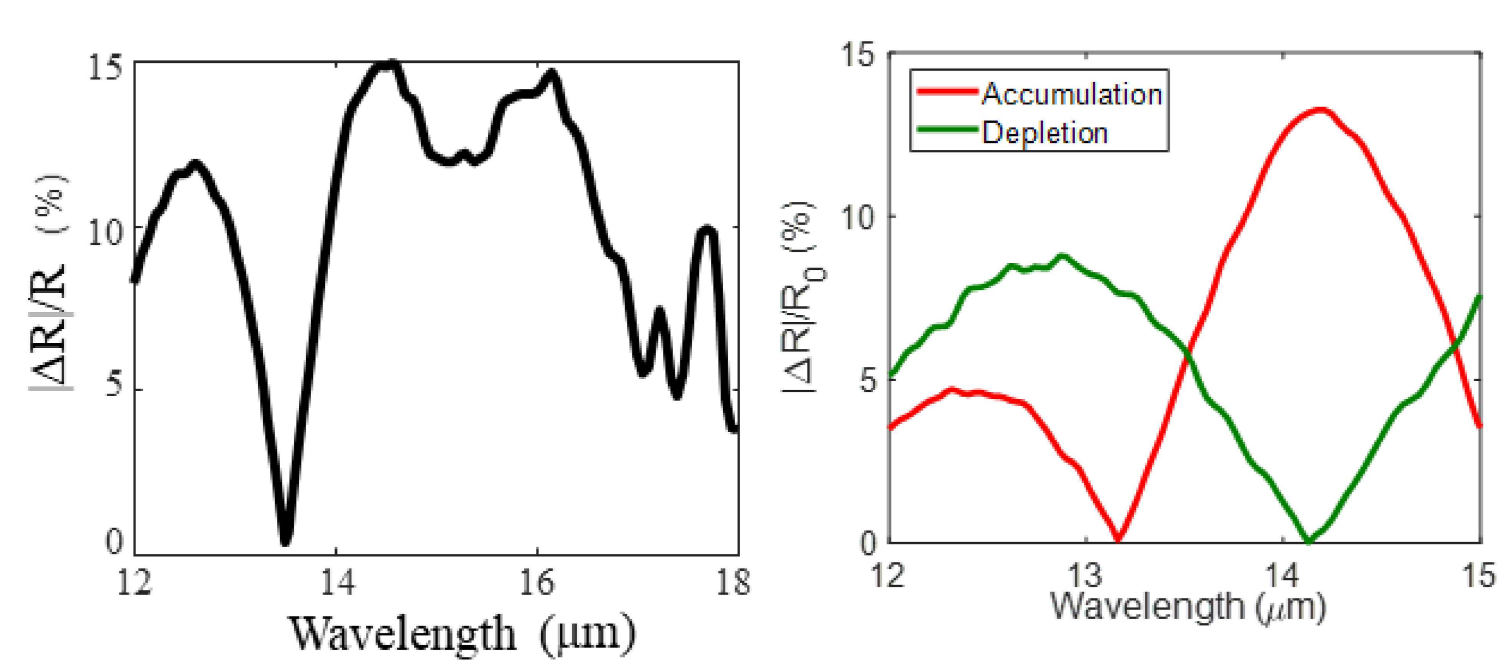
- We observed both spectral tuning and amplitude modulation.
- The spectral tuning is dominant for the upper polariton branch at $\lambda \sim 13\mu m$ as it is more "resonator like" . The lower polariton branch at $\lambda \sim 16\mu m$ is more " matter like" and mostly shows an amplitude modulation.
- The maximum spectral tuning observed was ~ 480 nm and maximum amplitude modulation observed was ~ 15 %[4]. We also performed Finite Difference Time Domain simulations and simulations agree well to the experimental results [4].

Spectral Tuning



Experimentally Measured Spectral Tuning and Comparison to Simulations

Amplitude Modulation



Experimentally Measured Amplitude Modulation of Reflectance

Summary and References

- We demonstrated a low dissipation field-effect tunable III-V hybrid metasurface at long infrared wavelengths.
- We observed spectral tuning of ~ 480 nm and amplitude modulation of ~ 15 % with leakage currents less than $1\mu A/cm^2$ at maximum operating voltage of ± 2V.
- The presented device achieves SWaP gains and is monolithically integrable. The approach is also wavelength scalable.
- We are currently investigating new resonator designs with higher quality factors for enhancing the device performance.

References

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[2] A. Benz et al., Appl. Phys. Lett. 103, 263116 (2013).
[3] J. Park et al., Sci. Reports 5, 15754 (2015).
[4] R. Sarma et al., Appl. Phys. Lett. 113, 061108 (2018).

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