Searching for narrow band thermal emission in mid-infrared from phonon polaritonic metasurfaces

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Abstract

Metasurfaces, artificial optical devices, which consist of an array of two-dimensional optical antennas with subwavelength thickness and separation, can be tailored to produce gradient optical responses and shape the wave fronts of scattered light. The polaritonic metasurfaces used in this work, are comprised of polar dielectrics and metal-dielectric multilayers patterns. The excitation of surface phonon polariton modes in the mid-infrared are confined metal-dielectric nanostructures and shows a very strong resonance with low optical power loss. The purpose of the study is to investigate a well-defined and narrow-band thermal emission from surface phonon polaritonic metasurfaces in the optical phonon band of silicon carbide (SiC) in the mid-infrared wavelength of 10–12 microns. Recently, we obtained single, controllable, and strong localized polariton resonances of these optical devices. We expect to observe thermal emission according to Kirchhoff's law stating that a good absorber is a good emitter in thermal equilibrium. We built a home-made thermal emission measurement setup. A thermoelectric pad used to heat the metasurface device. To maximize the collection of thermal radiation from metasurface device, we used ZnSe objective lens and thermal emission data is taken by using a Fourier Transform Infrared Spectrometer. The thermal emission device will be used to construct novel thermal metasurfaces.

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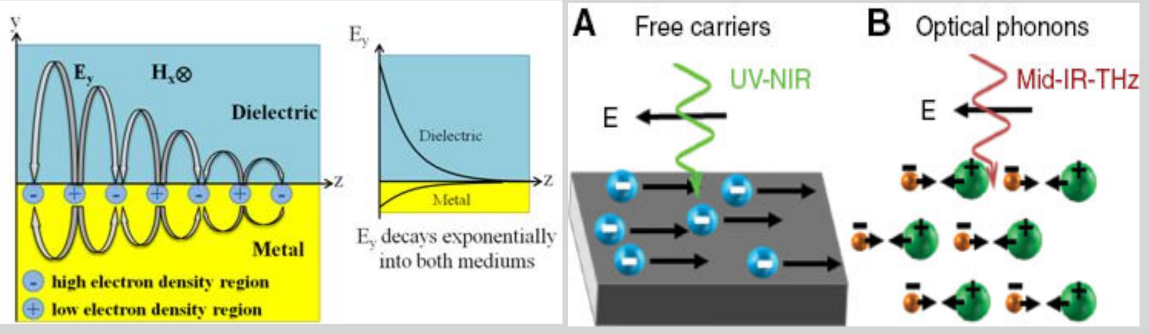
Introduction

Metasurfaces are a type of metamaterial, or artificial optical device, whose central purpose is to control or confine the flow of light. Metasurfaces consists of a 2-D periodic array of structures (such as antennas or spherical particles) with subwavelength separation and thickness. Their design can spatially vary the optical responses of light, such as enhancing the amplitude, changing the polarization, and/or phase of an electromagnetic wave. Realizing Metasurfaces in the IR/Thz range is beneficial for creating innovative applications in data storage and transmission, biomedical sensing devices, photodetectors, thermal emitters and many others. Up to this point previous research in thermal emitting devices has been unsuccessful because of high optical losses and existing light emitters only operate at bandwidth's and frequencies similar to the molecules' properties, but by heating the metasurface and engineering its size, shape, and material, one can achieve a narrowband thermal emitter in the infrared spectrum.

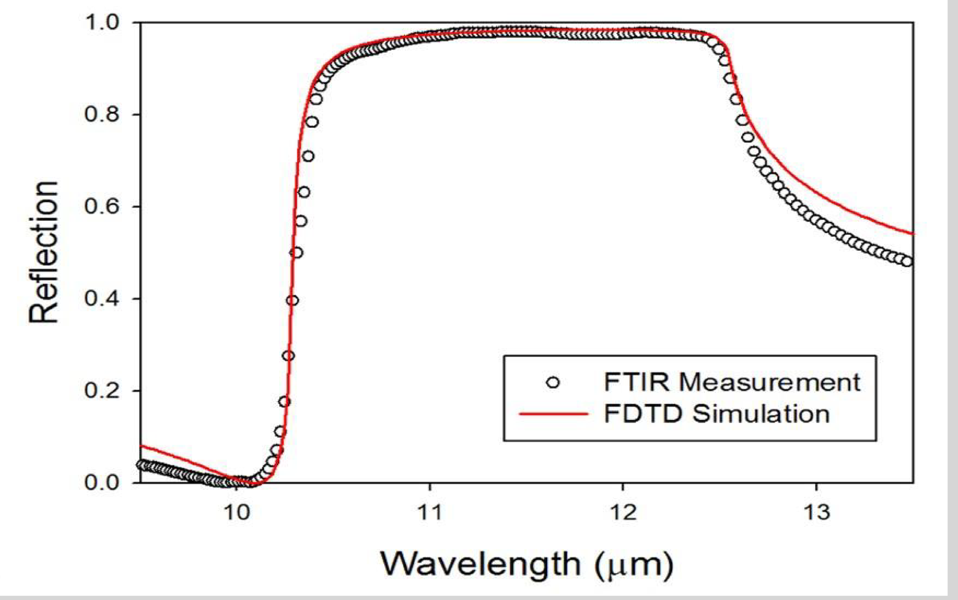
Materials and Methods

SURFACE POLARITONS: The resonant interaction between surface charge oscillations(surface atomic lattice vibrations) and the electromagnetic field of light constitute surface plasmons(phonons) polaritons, which occur between the metal/dielectric interfaces of materials and give rise to their unique properties.



Materials and Methods

- Silicon Carbide (SiC) is a polar dielectric crystal that was chosen for its high thermal conductivity and active phonon band in the mid-infrared region of the electromagnetic spectrum.
- The Reststrahlen band is a wavelength region of high reflectivity and strong absorption that lies between the transverse, TO, and longitudinal, LO, optical phonon energies of a polar dielectric.



•Optical measurements were performed using a Fourier-Transform Infrared Spectrometer

•In order to obtain a good measurement of each SiC Gold metasurface pattern, a compound microscope was built in order to obtain a good resolution and correct alignment of the SiC sample. Heating was first done conventionally and then by electric resistance.

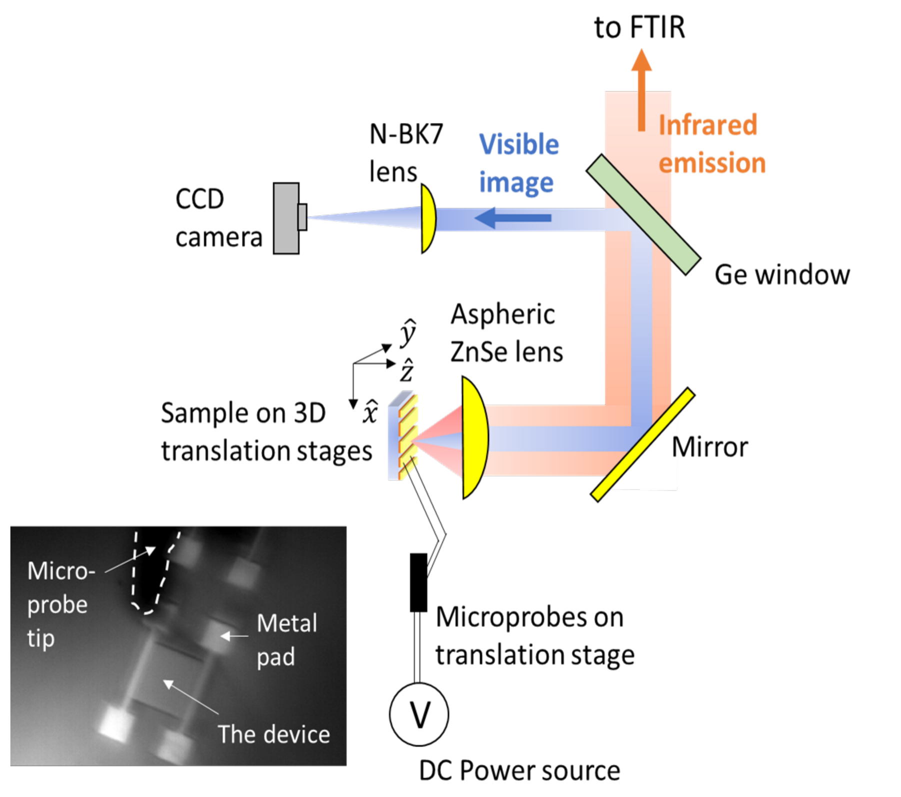


Fig 1. Optical Schematic

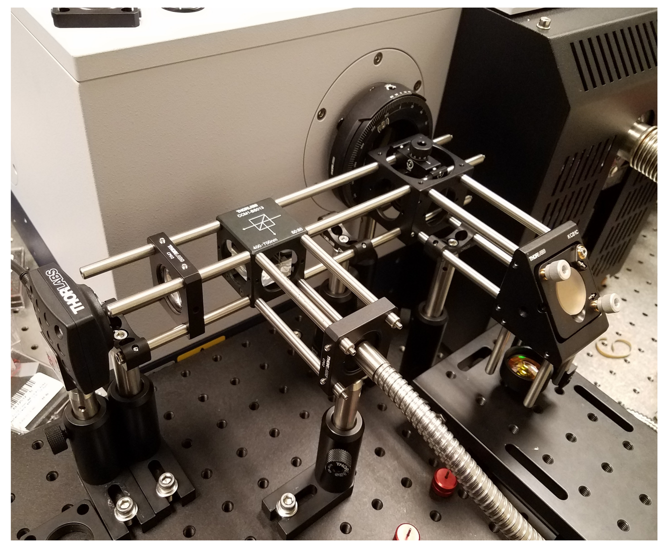


Fig 2. Compound Microscope Setup

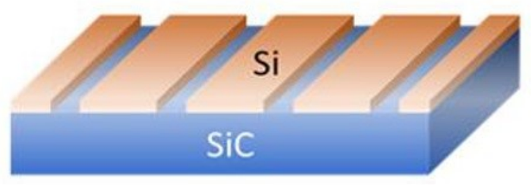


Fig 3. A schematic of surface phonon polaritonic metasurfaces

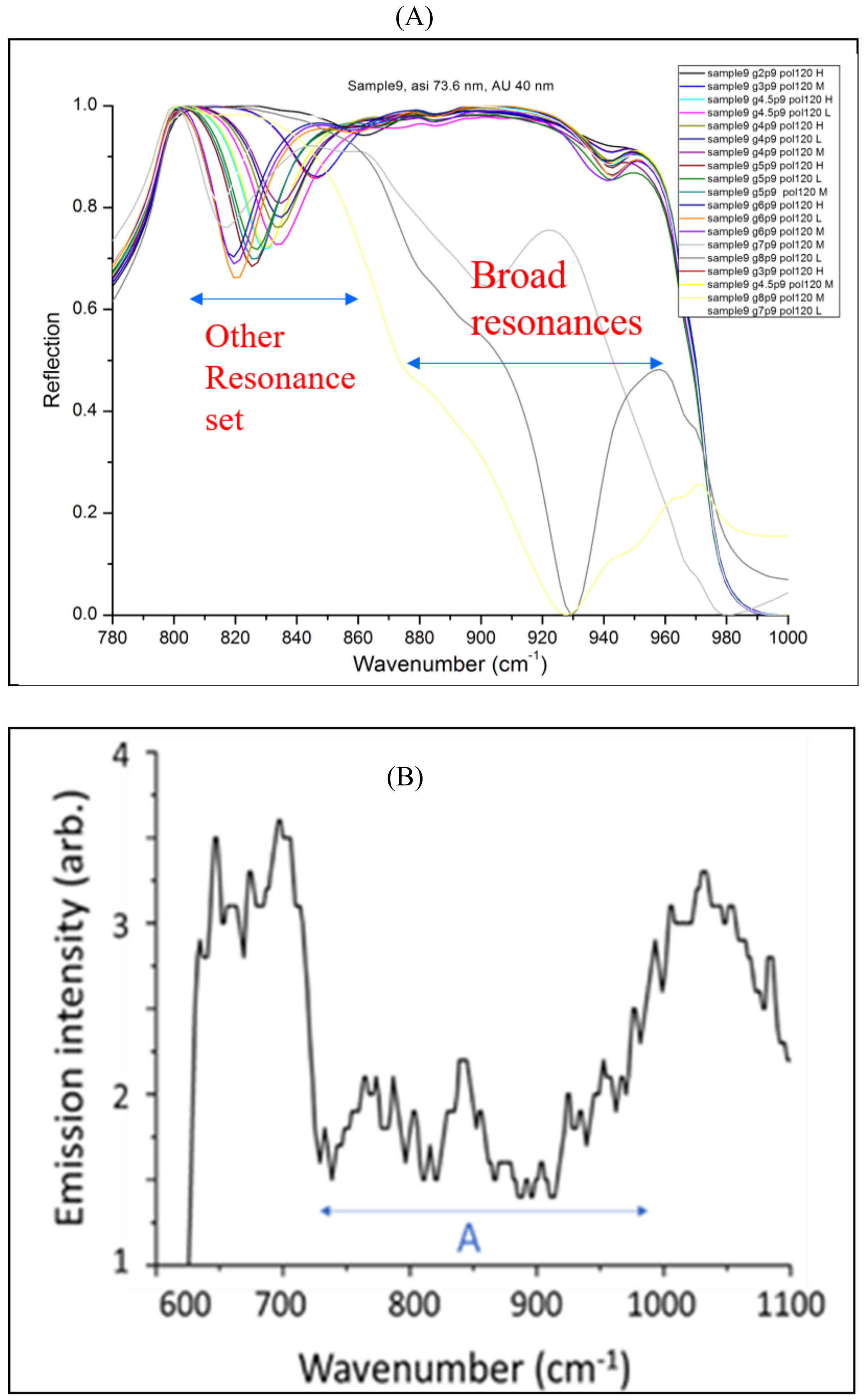


Fig. 4 Sample #9 spectral features. (A) Reflectivity spectrum and (B) Thermal Emissivity spectrum are compared next to each other.. Broad resonances are spread from 880 cm^{-1} to 960 cm^{-1}. Another resonance set from 820 cm^{-1} to 850 cm^{-1}

Results

Based on thermal emission measurements taken with the FTIR, the data showed two broad emission resonance peaks from about 820 cm^{-1} – 960 cm^{-1}. The measurements showed some polarization dependence between 0 and 90 degrees, but after studying the SiC background polarization measurements it is unclear if it is from thermal emission. Low intensities and arbitrary spectral changes between measurements of different parts of the SiC sample that was studied showed the signals to be unclear.

Conclusion

•This experiment demonstrated that this novel type of metasurface device works at mid-infrared spectral ranges.

•Measurements yielded a broad emission spectrum, and smaller emission intensities than what was expected.

•Thermal emissions could be a mix of both the SiC substrate and the Gold/SiC metasurface pattern.

Future work

•Our initial focused on this project to obtaining a clear emission signal, but due to low resolution of the nanostructure patterns and the heating element used proved to be an obstacle for the desired results.

• We improved the current research by adding ZnSe objective lens in the optical setup and a thermoelectric pad to heat the metasurface device. First, we try to see the emission from SiC device in mid infrared region. Furthermore, we are expecting a direct resonant emission signal from only one pattern rather than by multiple patterns to realize thermal emitters.

Fig 5. New test setup with ZnSe objective lens

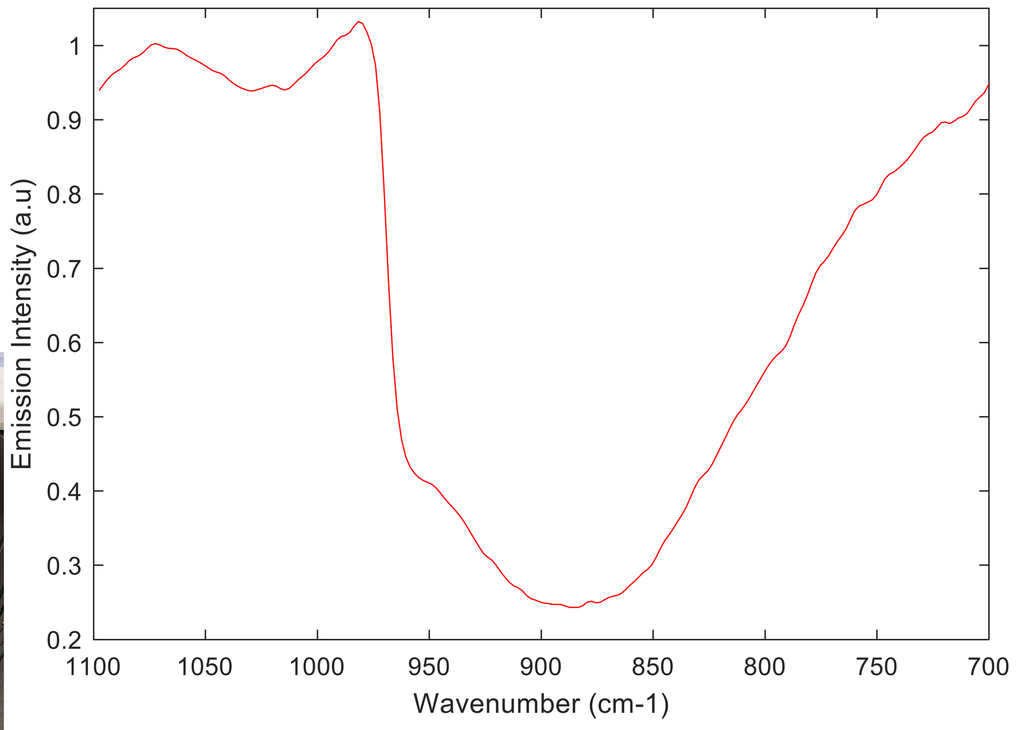


Fig 6. SiC emission spectra

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