Broadband Polarization-independent and Wide-angle Metasurface for Radar Cross Section Reduction

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Introduction: The goal of this work is to use COMSOL Multiphysics RF Module to simulate and analyze metamaterial perfect absorbers (MPA) based on heavily-doped silicon microstructures in the terahertz regime. In this work, periodic arrays of tapered cylindrical heavily-doped silicon structures and substrate are employed to realize an ultra-broadband and polarization independent THz perfect absorber for a wide-angle response.

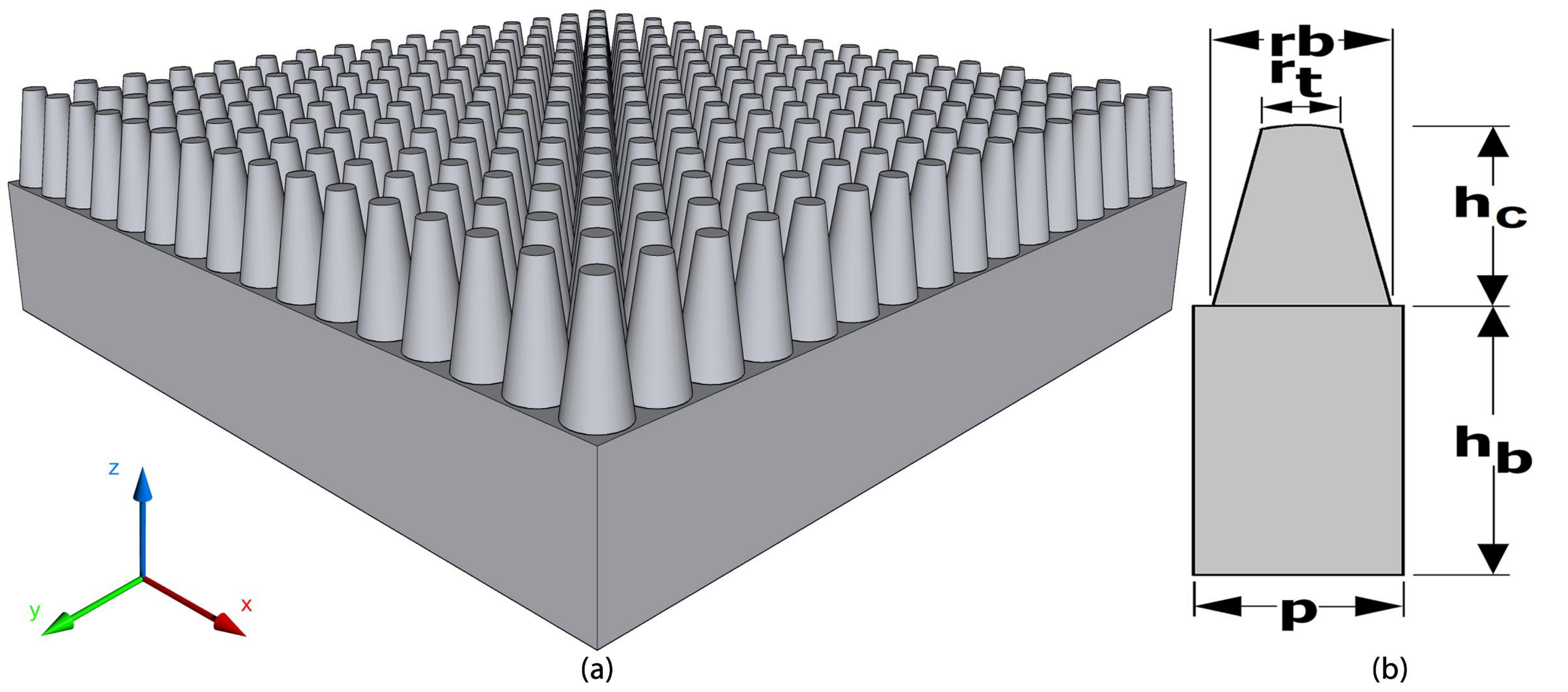

Figure 1. (a) Doped silicon based perfect absorber (b) Unit cell of THz doped silicon perfect absorber p=100 μm, h_b=200 μm, h_c=140 μm, r_b=45μm, r_t=20 μm

Computational Methods: The unit cell of silicon based MPA is modeled with the Floquet boundary conditions for the side faces, excitation port with diffraction orders for the top face, and output port for the bottom face. The doped-silicon (entire structure) is modeled using the Drude model (**ε**) and the frequency dependent transmittance, T(ω), reflectance R(ω), and absorbance A(ω) is calculated using the S_{11} and S_{21} parameters for transverse electric (TE) and transverse magnetic (TM) incident waves (frequency range from 0.1 to 5.0 THz for an incidence angle of 0 to 75 degrees.

$$\varepsilon = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\gamma\omega};\ \varepsilon_\infty = 11.7,\ \omega_p = 2\pi\times5.22\text{ THz},\ \gamma = 2\pi\times1.32\text{ THz}$$

$$T(\omega) = \left|S_{21}(\omega)\right|^2,\ R(\omega) = \left|S_{11}(\omega)\right|^2,\ A(\omega) = 1-T(\omega)-R(\omega)$$

Results: The absorption spectra (Figure 2) of doped silicon MPA structure under normal and oblique incidence for both TE and TM incident waves reveals that MPA structure supports a near-unity absorbance for a frequency spectrum of 1.6 to 3.8 THz along with polarization independent and wide-angle response up to 60° of incident angle. The magnetic field distribution and power loss density reveals the underlying mechanisms to be a combination of air-cavity mode, mode-matching resonance, and Fabry-Perot resonance (Figure 3). Also, the tapered cylindrical periodic structures provide impedance matched surface to the air allowing efficient coupling with the metasurface and the lossy doped silicon also aids in efficient absorption along the propagation.

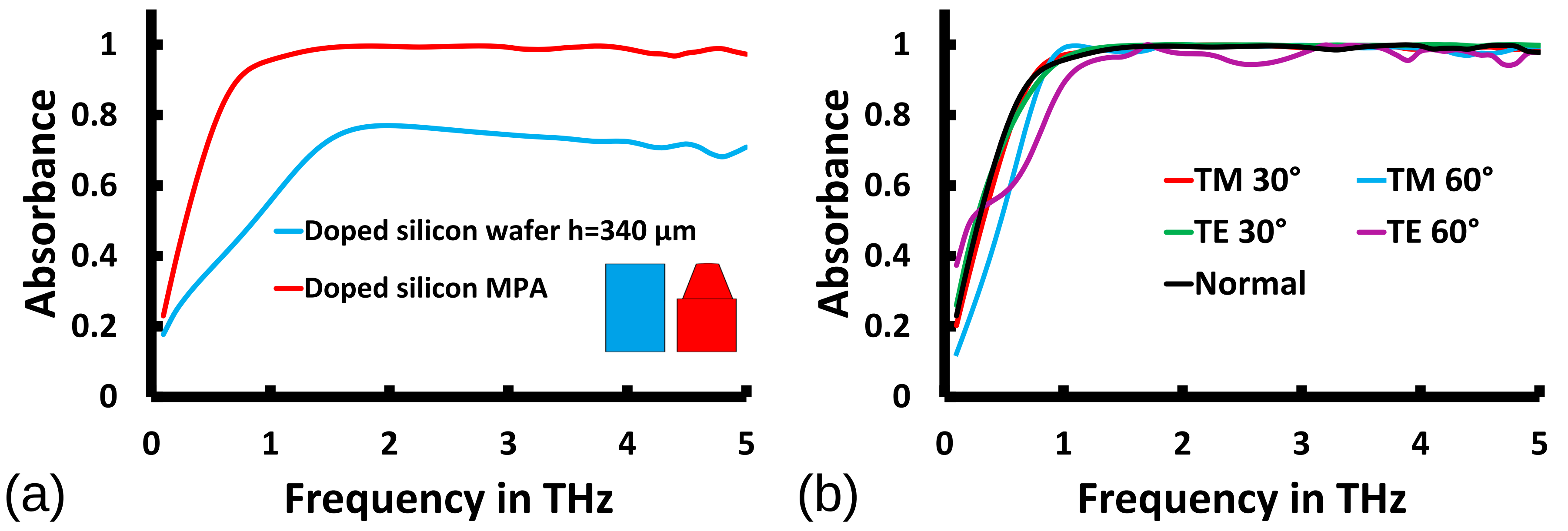

Figure 2. (a) Absorbance for normal incidence in doped silicon MPA and doped silicon wafer (thickness 340 μm) and (b) absorbance in doped silicon MPA for TE and TM incident waves at oblique angles.

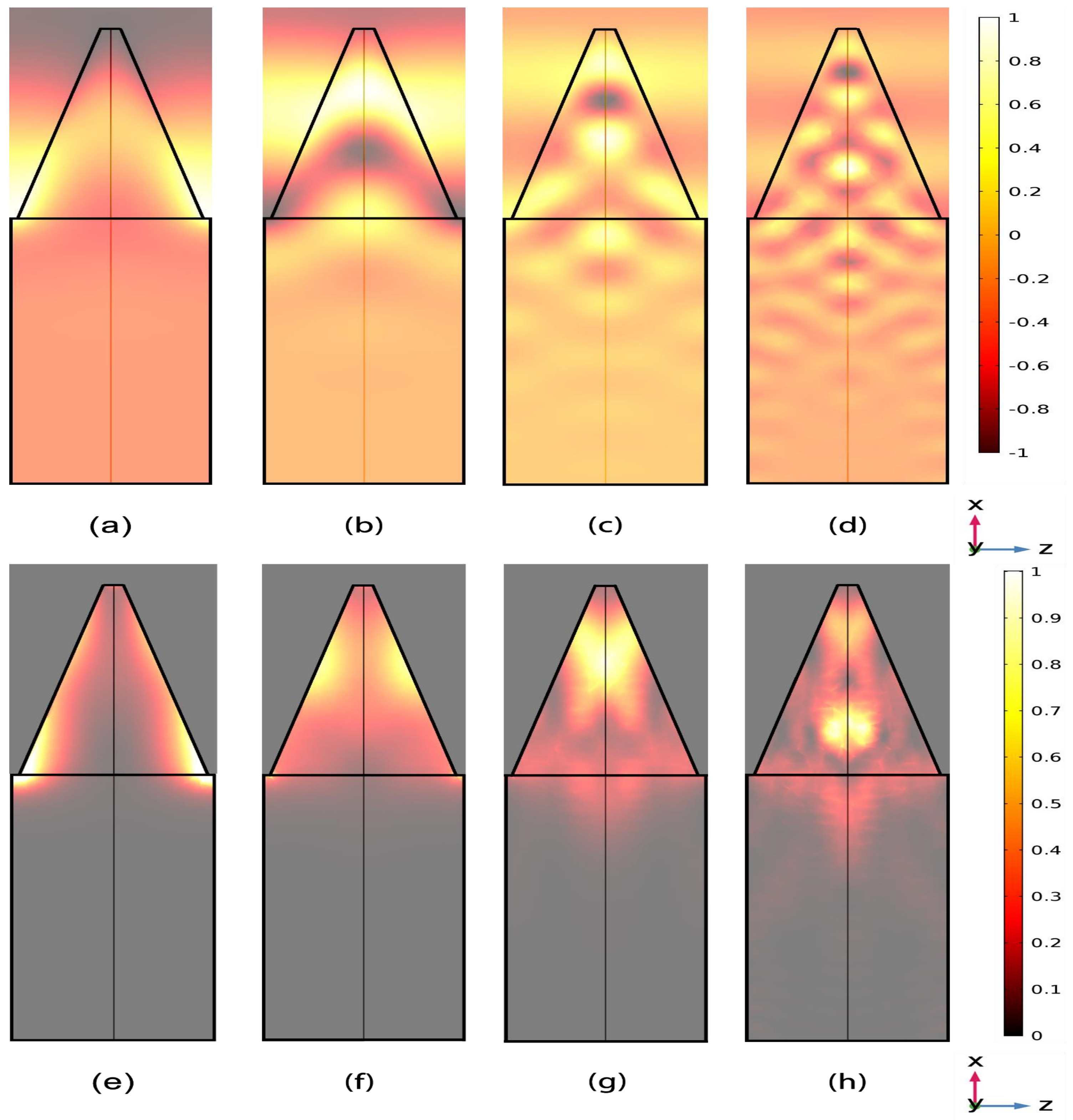

Figure 3. Magnetic field distribution (a-d), H_y, and power loss density (e-h) at resonant frequencies: 1.0 THz, 1.8 THz, 2.7 THz, and 3.7 THz

Conclusions: A high-performance broadband, wide-angle, and polarization independent perfect absorber is designed using doped silicon to operate in the spectrum of 1.0 – 5.0 THz. This MPA structure can be easily fabricated and scaled with current microfabrication technology, and it can be readily integrated with applications in THz imaging systems, sensors, and anti-radar cloaking. This MPA structure can significantly reduce the radar cross section over a wide spectral range in the terahertz region by efficiently absorbing the incident radar waves of any polarization and incident angle.

References:

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