Tapered hyperbolic metamaterials for broadband absorption

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Improving fabrication technologies and methods have allowed for highly subwavelength features to be created and approximated as "meta-atoms" in a metamaterial with unique optical properties. While zero and negative refractive index structures have received a lot of attention in previous works, hyperbolic metamaterials (HMMs) have led to many interesting studies due to their broad range of operation and relatively low loss, making them interesting candidates for sub-diffraction limit imaging applications [1].

Multi-layer metal-insulator stacks can be approximated as an effective medium with uniaxial anisotropic permittivity and low loss along the axis perpendicular to the layers. It is interesting that tapered nanostructures fabricated from these stacks can be used as a strong absorber over a broad range of wavelengths [2]. Due to their anisotropic permittivity, these materials can generate a hyperbolic dispersion over a broad range of wavelengths as opposed to typical spherical dispersion in isotropic media. Previous work has shown that this property can be utilized to create nano-scale cavities with ultrahigh optical indices and unique resonance properties [3].

When analyzing COMSOL Multiphysics field profile simulations of tapered hyperbolic metamaterials similar to those presented in Ref. [2], one can see that light propagates in the surrounding medium (assumed $n = 1$) until a certain depth where power flow shows that light is effectively coupled into the tapered structure where it then propagates according to the hyperbolic dispersion of the material. Figure 1 (left) shows the normalized magnetic field profile with the strongest field enhancement and power coupling occurring at distinct width dependent on the wavelength, similar to the so-called "light funneling" effect of metal-insulator-metal structures observed in previous work [4].

Once the light enters the structure, it can be shown that phase propagation continues in the +z direction, but time averaged power flows (arrows in Figure 1 (left) and profile in (right)) in the –z direction, showing opposite phase and power flow which occurs in hyperbolic metamaterial structures. The broad absorption range can be explained through the increased confinement and higher optical indices present in HMM structures. A fabricated structure is shown in Figure 2 along with simulated and experimental absorption spectra. Through further experimentation, it could be demonstrated that the absorption peaks seen in the simulated spectrum can be explained by cavity resonances in HMMs, similar to Ref. [3].

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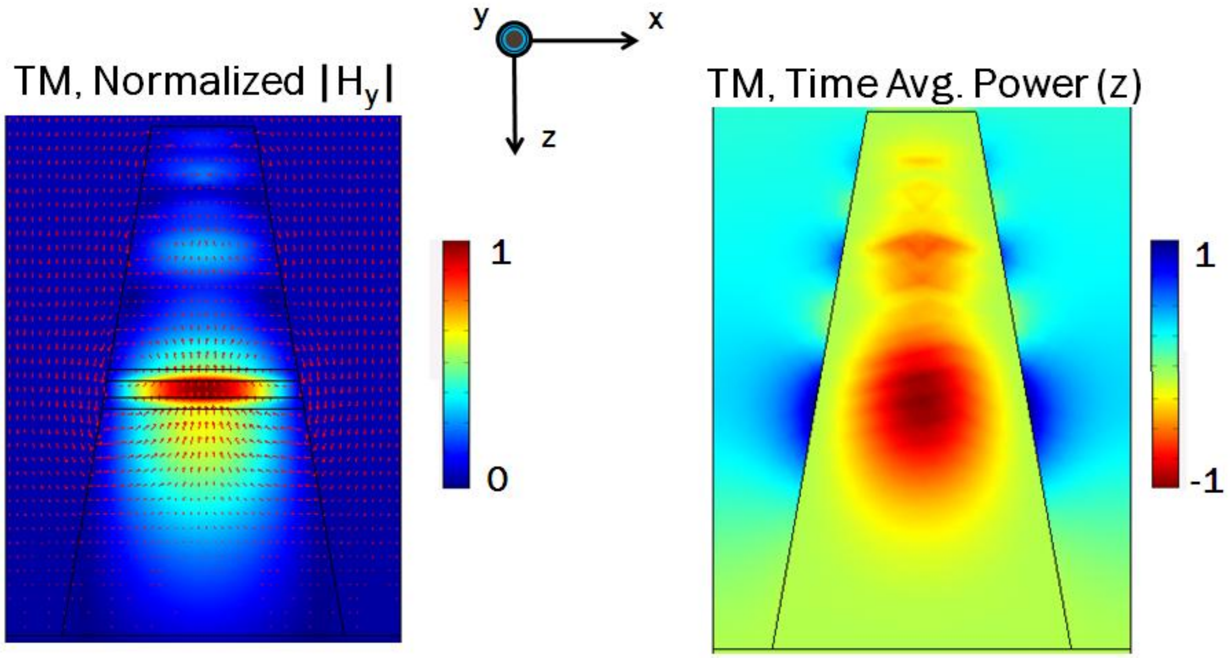

Figure 1: (Left) Normalized magnetic field profile (colored) and time averaged power flow (arrows) for TM polarized light (H in y-direction). A single metal-insulator-metal stack is shown within the metamaterial to demonstrate the localized absorption. **(Right)** A color profile showing the time averaged power flow in the z-direction.

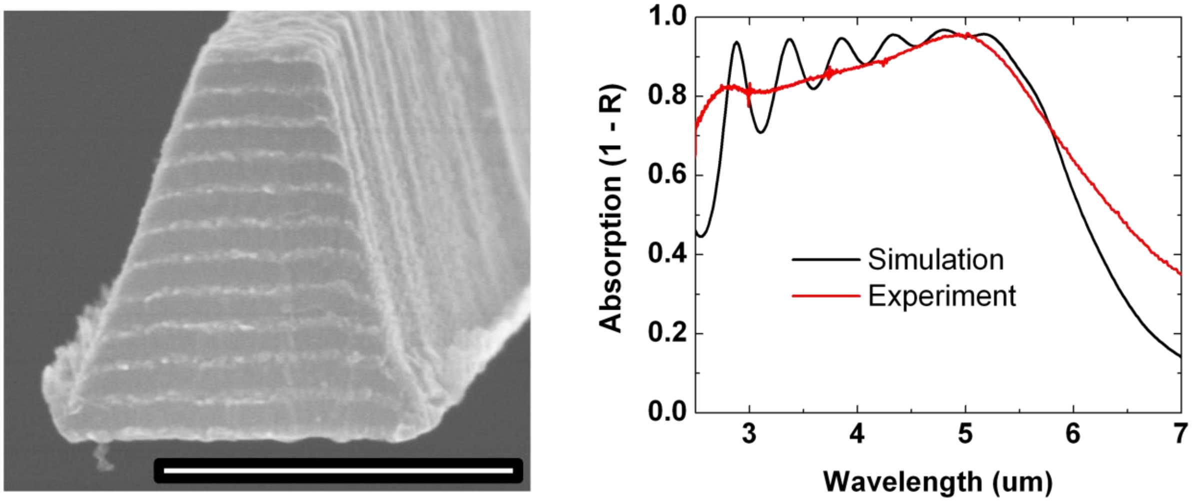

Figure 2: (Left) SEM image of Au-Ge stack structure lifted from metal substrate. **(Right)** Simulated and experimental absorption spectra (1 – Reflection). Measurements were taken with TM-polarized light.