Low-Loss Infrared Ultrawide Type II Hyperbolic Metamaterials based on III-V Semiconductors

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While polar dielectric materials provide natural low-loss infrared hyperbolic resonances through the excitation of phonon polaritons, the operational bandwidth of these materials is limited to a few hundred wavenumbers (cm^{-1}) or tenths of electronvolts. Also, integrating these materials with large-scale infrared optoelectronic devices presents many challenges. In this work, we implemented an ultrawide low-loss Type I hyperbolic metamaterial covering a spectral bandwidth of 2000 cm^{-1} for wavelengths above 4.7 μm. We produced the hyperbolic metamaterial with a stack of intercalated heavily-doped InAs and undoped InAs epilayers grown by molecular beam epitaxy. The InAs epilayer was heavily doped with Tellurium to obtain electron concentrations of $\sim 8\times10^{19}$ cm^{-3}. The Type II hyperbolicity of these stacks was determined through infrared ellipsometry obtaining effective optical constants for the stacks. These materials were then dry etched to form one-dimensional (1D) square gratings with periods and linewidths ranging from 1 to 5 μm. The measured effective optical constants measured through ellipsometry were used to model the grating's optical response by finite element electromagnetic calculations (COMSOL). The models agree with measurements, showing the formation of hyperbolic plasmon polaritons at the same frequencies where experimental features were observed. This work demonstrates that high subdiffractional light confinement can be achieved with a III-V metamaterial that can be integrated with III-V semiconductor infrared devices such as photodetectors and emitters at a large scale.

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