NDnano Summer Undergraduate Research 2016 Project Summary

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Faculty mentor: Dr. Anthony Hoffman
Project title: Designing hyperbolic metamaterials using polar III-nitride semiconductors

Skills Developed

Designing the hyperbolic metamaterial involved creating a theoretical model to simulate the optical response of the metamaterial. The design process greatly improved my ability to gather information from a wide range of sources to create a theoretical model. I ran simulations produced from the developed model using MATLAB. Therefore, my computer programming, in general, improved while simultaneously becoming more nuanced, specifically, with the MATLAB language.

Research Summary

Optical hyperbolic metamaterials (HMMs) have unusual optical properties that enable phenomena rarely found in natural materials such as negative refraction, and the materials are driving the development of applications such as sub-diffraction confinement and imaging. The unique optical dispersion of these metamaterials is realized by alternately stacking sub-wavelength layers of isotropic materials with positive and negative permittivity. During the summer, I designed and modeled a new class of low-loss HMMs in the Restrstrahlen band of III-nitride polar semiconductors. In the Reststrahlen band—energies between the longitudinal and transverse optical phonons—the permittivity is negative. The model I developed uses thin layers (~20 nm) of gallium nitride (GaN) and aluminum nitride (AlN), materials with different Reststrahlen bands, to design HMMs in the mid-infrared with optical losses that are lower than existing materials.

Figure 1: metamaterial structure

The permittivity of the individual layers is modeled using isotropic permittivity functions that include a Lorentz oscillator with the optical phonon energies. The AlN and GaN permittivities are used in two different transfer matrix codes to calculate the reflection and transmission for the HMM: (i) anisotropic effective medium and (ii) isotropic multi-layer. For some of the simulations, a polarization charge is introduced into the model as a thin layer of free-carriers at each AlN/GaN interface. The addition of free-carriers into the simulations produces noticeable differences between the simulations with charge and without charge. The designed samples are being grown by molecular beam epitaxy, and measurements will be compared to the developed models.

The figures below show reflectance simulations of the metamaterial with a 2 micron thickness. The metamaterial only possesses hyperbolic dispersion in the regions outlined in red. Figure 2: anisotropic transfer matrix reflectance simulation. Figure 3: isotropic transfer matrix reflectance simulation. Figure 4: isotropic transfer matrix simulation with free-carriers at each AlN/GaN interface.

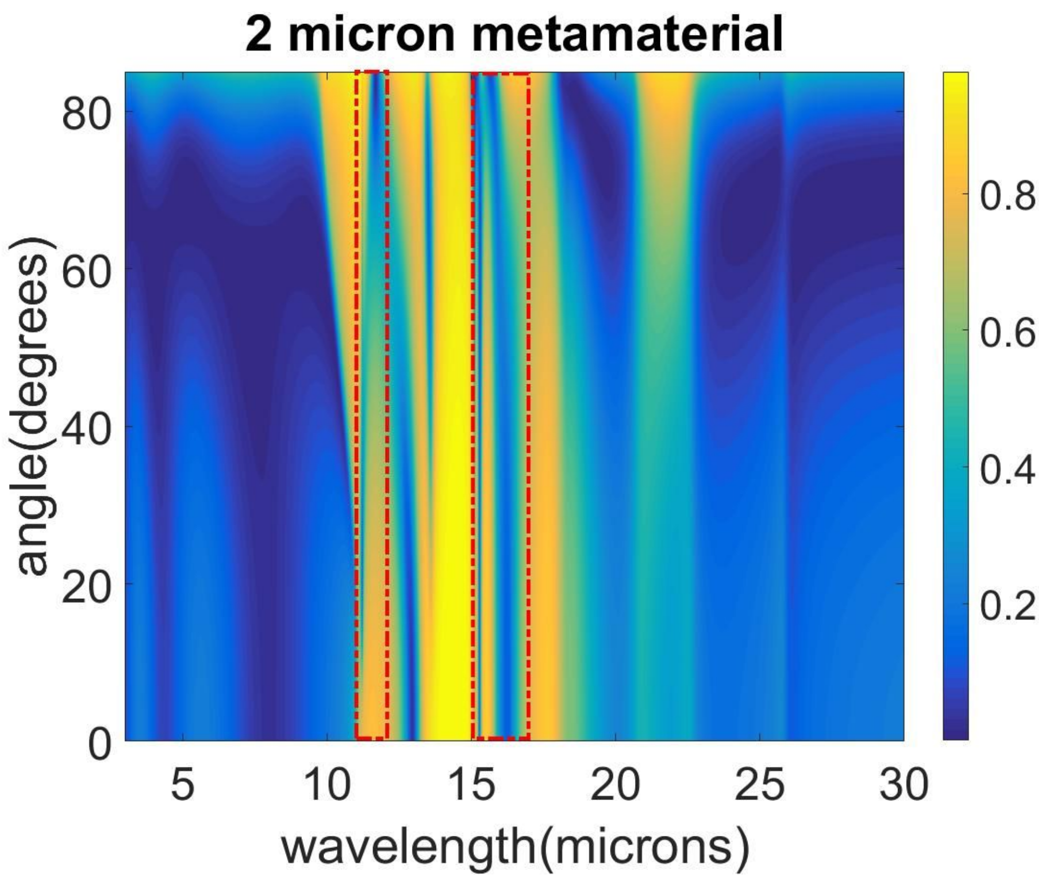

Figure 2

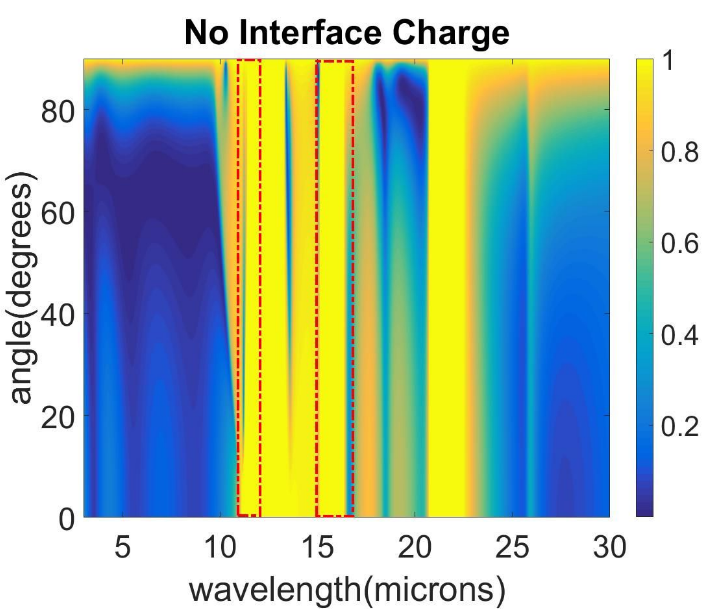

Figure 3

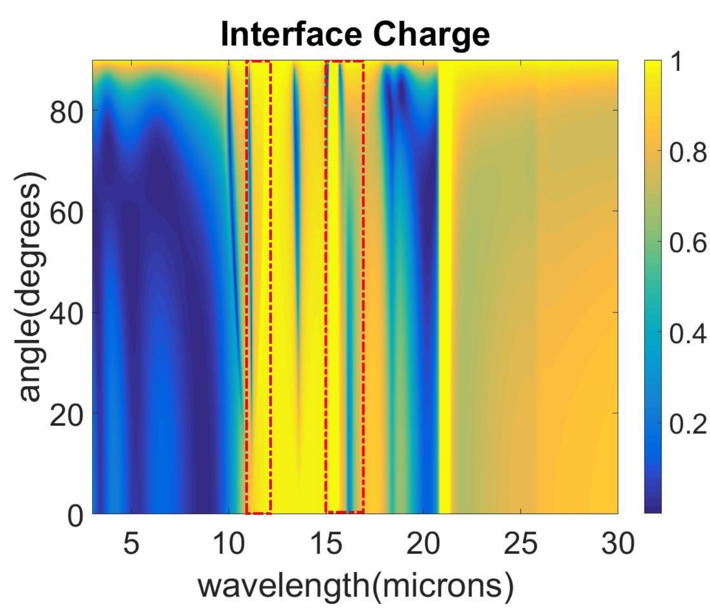

Figure 4

The work here was presented at an end of summer presentation session for NDnano Undergraduate Research Fellowship recipients.