

High-Resolution Transmission Measurements of Left-Handed Metamaterials

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Left-handed metamaterials are promising in their potential for high-resolution mid-infrared (mid-IR) imaging and planar lens design [1]. Metamaterials' sub-wavelength features determine their macroscopic electromagnetic properties; left-handed metamaterials have negative indices of refraction for certain wavelengths of light. With an ultimate goal of using left-handed metamaterials in applications such as planar lenses for infrared cameras, left-handed metamaterials' reflection, transmission, and absorption must be characterized and compared to theoretical predictions based on metamaterial design.

To measure sample transmission spectra we used a Fourier Transform Infrared Spectrometer (FTIR), which transmits a beam of IR light through a sample and measures the intensity of the beam on the other side using a liquid nitrogen-cooled mercury-cadmium-telluride detector. To control both the incident angle of the beam on the sample and the position of the detector, we used a custom-built, external apparatus called the Bi-Axial Rotation Device (BARD), as seen in Fig. 1A. This computer-controlled setup precisely rotates the sample and the detector independently about a common vertical axis.

We investigated a 20 μm thick metamaterial composed of alternating 80 nm layers of uniformly-doped InGaAs with a free-electron density of $7.5 \times 10^{18} \text{ cm}^{-3}$, and intrinsic InAlAs mounted on an InP substrate. We varied the incident angle from 0° to 70° in 10° increments, and at each incident angle varied the detector position from -10° to 10° , advancing in 1° increments; transmission in the mid-IR range (wavelengths from 2.5-25 μm) was measured for each position. We paired each sample measurement with a background measurement using the same detector position but no sample to compensate for signal loss in the air. A polarizer was also used to isolate the transverse electric and transverse magnetic components of the infrared beam, and we compared each component's interactions with the sample. Figure 1B shows a set of data from the InGaAs/InAlAs sample.

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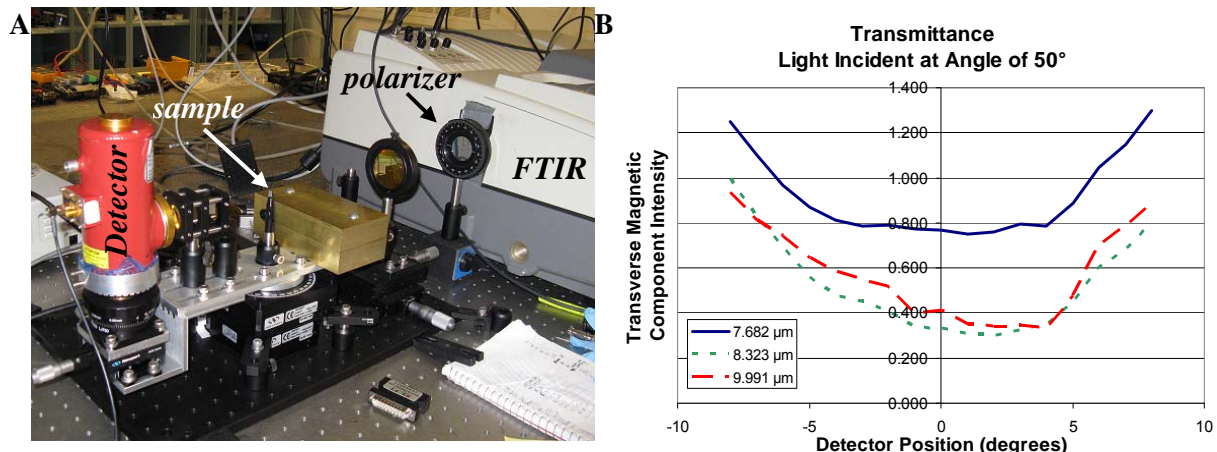


Figure 1: A) The experimental setup, with the BARD on the left and the FTIR on the right.

B) Transmitted intensity at varying detector angles with the sample at 50° .

- [1] Anthony J. Hoffman, Leonid Alekseyev, Scott S. Howard, Kale J. Franz, Dan Wasserman, Viktor A. Podolskiy, Evgenii E. Narimanov, Deborah L. Sivco, and Claire Gmachl, "Negative Refraction in Semiconductor Metamaterials," *Nature Materials*. **6**, 946-949 (2007).