Transmission and Reflection Measurements of Mid-Infrared Left-handed Metamaterials

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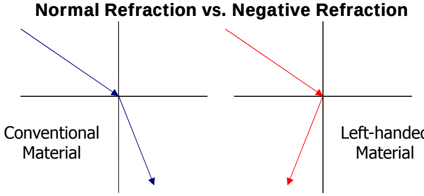
Left-Handed Metamaterials

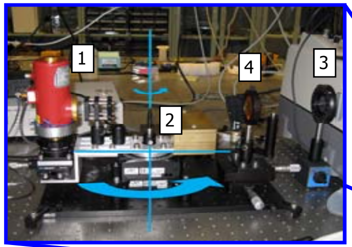
In 1967, Russian physicist Victor Veselago coined the term "left-handed materials" to describe materials with negative permittivity and permeability. He predicted the fabrication of new materials that could exhibit negative refraction or bend light in the opposite direction of the usual forward energy flow. Negative-index materials were first produced in 1999 and are a relatively new development. Today we are working with more advanced materials than those first created in 1999. In order to further understand these materials, we characterized them through transmission and reflection measurements.

Normal Refraction vs. Negative Refraction

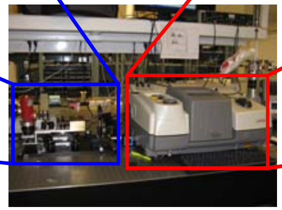


Equipment

In order to take our measurements we used a Fourier transform infrared (FTIR) spectrometer, mercury-cadmium-telluride (MCT) detector, a polarizer, and a bi-axial rotation device (BARD) setup.



1 MCT Detector
2 Mount for Sample
3 Polarizer
4 Focusing Lens
5 FTIR



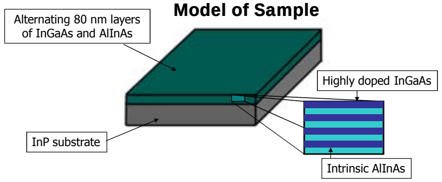
The BARD is a custom-made device that allows the sample and the detector to rotate independently of one another on a common axis. Arrows indicate path of rotation.

The FTIR is a machine that measures a sample's response to infrared radiation. Interferograms are produced by one of a series of mirrors, the moving mirror, in the machine. Those interferograms are converted to spectra by the machine and recorded as data.

Samples

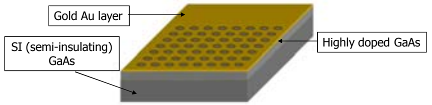
Sample A : 20 µm thick sample of alternating 80 nm highly-doped InGaAs and intrinsic AlInAs layers grown on InP substrate

Model of Sample



Sample B: Sample A with Au Grating

Model of Grating

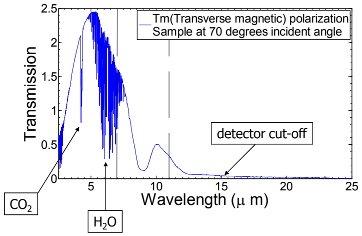


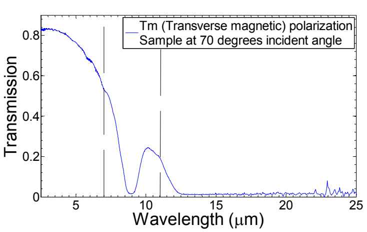
Grating affixed to left-handed material above (sample A)

Transmission

We took measurements by varying the angle at which the source hit the sample or incident angle from 0–90 degrees. A strong resonance appeared between angles 40-70 degrees.

Right: Raw data of Sample A transmission. The artifacts are primarily from CO_2 and water.



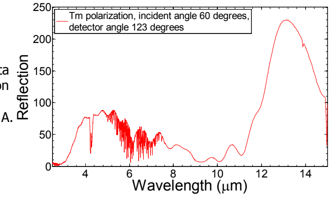


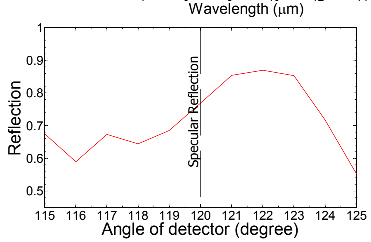
Left: Transmission of Sample A, showing resonance in between dashed lines, 7 – 11 µm (λ). Result of raw data ratioed over background or light source without the sample. Strong resonance indicates transition to negative refraction in the material.

High Resolution Reflection

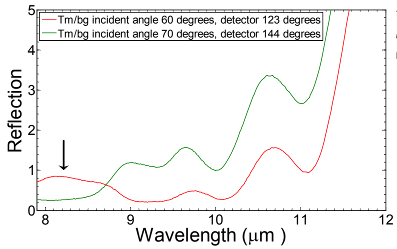
For our reflection measurements, we changed the angle at which the detector received the reflected light. According to the law of reflection, the angle at which light hits a reflective surface will equal the angle at which the light is reflected. Thus, following this law, the angle at which we set the detector was equal to double the incident angle of the sample. However, this did not imply that all samples would follow this law. But using the law of reflection as a standard, we tested the reflection of the light 5 degrees above and below double the incident angle moving the detector in 1 degree increments in between each measurement.

Right: Raw data reflection for Sample A.

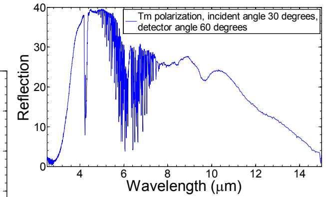




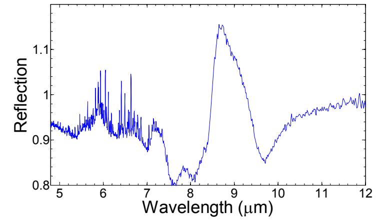
Above: Comparison of angle of detector vs. maximum height at switch from low to high reflectivity as shown by arrow in figure to the close right. Range of max wavelength was 8.0-8.2 µm. Incident angle of sample at 60 degrees, detector angle ranging from 115 – 125 degrees.



Above: Reflection of Sample A with transverse magnetic polarization ratioed over background. Figure depicting difference in high and low reflectivity at around 8.2 µm for two different incident angles, shown by the arrow. At 60 degrees reflectivity increases and at 70 degrees it decreases. Change in reflectivity indicates shift from positive to negative refractive index in the sample.



Left: Raw data reflection for Sample B.



Above: Unique feature found in the Tm (Transverse magnetic)/Te (Transverse electric) ratio of sample B. Incident angle of sample at 30 degrees, detector at 60 degrees.

Conclusion

Through our transmission and reflection measurements, we were able to successfully characterize left-handed metamaterials. The study of left-handed materials is a relatively new field of research with many opportunities for scientists. With our measurements we can further understand the waveguide properties of these materials. In the future, the data we collected may help scientists develop better left-handed metamaterals, which can be used for various applications including gas sensing, imaging, or the ability to produce lenses without resolution limits.

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