Terahertz Spectroscopy of Hyperbolic Metamaterial Based on CdTe/$Cd_{1-x}Mg_xTe$ Multiple Quantum Wells

J. Łusakowski[1,2], A. Frączak[1], E. Imos[1], A. Siemaszko[1], M. Zaremba[1], K. Karpierz[1], Z. Adamus[3,4], T. Słupiński[3,4], and T. Wojtowicz[4]

[1]*Faculty of Physics, University of Warsaw, ul. Pasteura 5, 02-093 Warsaw, Poland*
[2]*Centera Laboratories, Institute of High Pressure Physics, Polish Academy of Sciences, ul. Sokołowska 29, 01-142 Warsaw, Poland*
[3]*International Research Centre Mag Top, Institute of Physics, Polish Academy of Sciences, al. Lotników 32/46, 02-668 Warsaw, Poland*
[4]*Institute of Physics, Polish Academy of Sciences, al. Lotników 32/46, 02-668 Warsaw, Poland*

The tensor of the dielectric function of hyperbolic materials (HM) is defined by components which real parts are of opposite signs. Then, the surface of the constant frequency in the $\omega - k$ space is a hyperboloid which supports (theoretically) infinite number of wave vectors k for given value of ω. This drastically changes propagation of the electromagnetic wave, leading, e.g., to sub-diffraction imaging or negative refraction. Although some of naurally existing materials show such properties in a certain range of frequency (e.g., hexagonal Boron Nitride in the range 6.3 - 7.3 μm) HM are usually artificially constructed with the help of advanced growth or processing technology. One of such structures, falling into the category of artificial hyperbolic metamaterial (HMM), is an alternating sequence of conducting and isolating layers showing hyperbolic properties for a limited range of wavelenghts λ of electromagnetic radiation (under the condition $\lambda \gg d$, where d is the period of the structure). Then, HMM can be treated as a medium characterized by effective constants $\epsilon_{||}\epsilon_{\perp} < 0$, where $||$ and $\perp$ are defined with respect to the plane of the HMM and in such a HMM the hyperbolic properties are exhibited for the Tranverse Magnetic modes of radiation.

Samples of molecular-beam-epitaxy-grown modulation-doped multiple quantum wells can be considered as appropriate for such studies because alternating doped barriers and quantum wells supplied with free electrons consitite the required sequence of isolating and conducting layers. In the present work, we studied response of such structures, grown in the form of a series of ten CdTe quantum wells, modulation doped in each barrier separating the wells. The total electron concentration estimated by transport measurements was equal to about 10^{12} cm^{-2}. Measurements of transmission of linearly polarized THz radiation through the samples were carried out at 4.2 K (the sample was cooled with an exchange helium gas) as a function of magnetic field up to 9 T and as a function of the angle between the plane of the sample and the magnetic field. Tilting the sample allowed to generate TM modes of the radiation while the magnetic field allowed to tune the efective dielectric tensor of the structure.

We observed a rich response of investigated samples showing an interplay of the tilt, magnetic field and frequncy of radiation. These factors conributed both to the shape as well as to position of spectral features, typically built aroung the magnetic field of the cyclotron resonance. By studying the THz photoresistance we showed that investigated samples could be used as sensitive detectors of THz radiation in magnetic fields below 1 T when Shubnikov - de Haas oscillations become a dominant feature of spectra.

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