Ferromagnetic fluids based on semisynthetic oils at the THz frequency range

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***Abstract* — Possibility of application of ferromagnetic fluids based on semisynthetic oils as medium to control characteristics of terahertz quasioptical beams is shown. Influence of the external magnetic field on the cell with ferrofluid based on magnetite and semisynthetic oils is researched. Coefficients of transmission and permittivity for the plane cell with samples of magnetic fluids in the presence of external transverse and longitudinal magnetic fields in frequency range 130-250 GHz are obtained.**

I. Introduction

At the present time the short-wave part of gigahertz and terahertz frequencies range is intensively investigated. There are well-known terahertz applications in sensing, imaging, which need various terahertz functional devices, such as polarizers, filters, modulators, sensor, and isolators [1]. Magneto-optical devices are in the THz systems for polarization, transmission, and phase changing. Previous investigations have showed possibility of parameters control of electromagnetic waves by orientation of nanotubes in polymer at THz frequency range [2-3]. However, using of non-mechanical controlled materials in quasi-optical paths more preferably. For this purpose ferrofluid is supposed to be a medium controlled by the external magnetic field. Ferrofluid is a stable colloid suspension of magnetic nanoparticles (e.g. magnetite) in a liquid carrier [4-5]. Their properties depend on characteristics components and the presence of the external magnetic field. Ferrofluids have found a lot of applications including heat and mass transfer, for example, liquid-cooled loudspeakers and high power transformers, magnetophotonics (magnetically controlling backward and forward scattering), environmental cleaning through water purification, and some biomedical applications [6-7]. In the absence of the external magnetic field particles possess a random orientation and ferrofluid is isotropic [4-5]. But in the presence of the external magnetic field particles align in its direction. The particles are placed one after another to form thin linear chains, distributed throughout the sample and oriented in the direction of the applied magnetic field [6].

II. Results

We made ferrofluids from mixture of semisynthetic oils and magnetite nanoparticles by mechanical mixing. It should be mentioned that magnetite nanoparticles are coated by amorphous carbon, which also helps to prevent magnetic clumping. Five samples of ferrofluids with concentration of magnetite in semisynthetic oils from 35:65 to 20:80 were prepared for research (Table 1). An average diameter of magnetite particles was 5 microns.

Table 1. Concentrations of magnetite and semisynthetic oils, kinematic viscosity of samples at temperature 300K.

Sample	Semisynthetic oil (%)	Magnetite (%)	Kinematic viscosity (m^2/s)
1	65	35	1.33×10^{-5}
2	70	30	1.33×10^{-5}
3	80	20	1.33×10^{-5}
4	70	30	8.50×10^{-5}
5	70	30	4.00×10^{-6}

An experimental setup (Fig. 1) based on the Mach-Zehnder interferometer, a plane-parallel cell for measuring of the transmission coefficient and the phase shift were used. Interferometer consists of two arms: with investigated sample (working) and without sample (reference). Backward-wave oscillator with water cooling was used as a source of monochromatic polarized electromagnetic wave. Focusing of quasi-optical beam carried out with teflon lenses. As a detector of terahertz radiation was used optoacoustic converter (Golay cell). Amplitude modulation was set by chopper. The polarization of the radiation was set by grid splitter. Helmholtz coils were used for magnetizing of ferrofluid. Construction of Helmholtz coils allow to magnetize cell with ferromagnetic fluid in longitudinal and transverse respect to direction of propagation of electromagnetic wave. From obtained spectra of transmission coefficient and phase shift produced calculations of complex dielectric permittivity of ferromagnetic fluids.

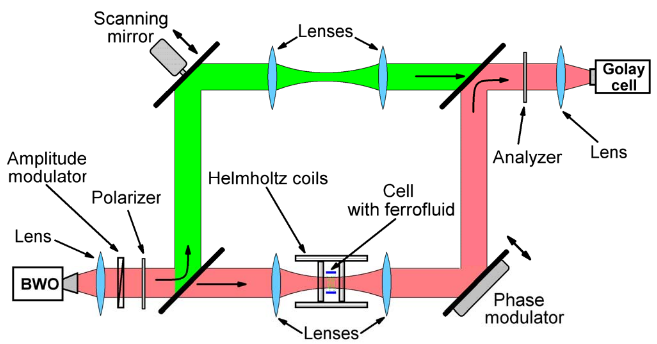

Fig.1. The experimental setup of the Mach-Zender interferometer for researching of the influence of the magnetic fields on ferrofluids at THz region.

Helmholtz coils (Fig. 2.) had a range of the magnetic field from 0 to 300 Oe. Maximum DC current supplied to the coil is 10 A. Power carried out by using laboratory power supply with resolution 0,1 A. Control of magnetic field inside magnetic system (Helmholtz coils) was provided with a precise magnetometer.

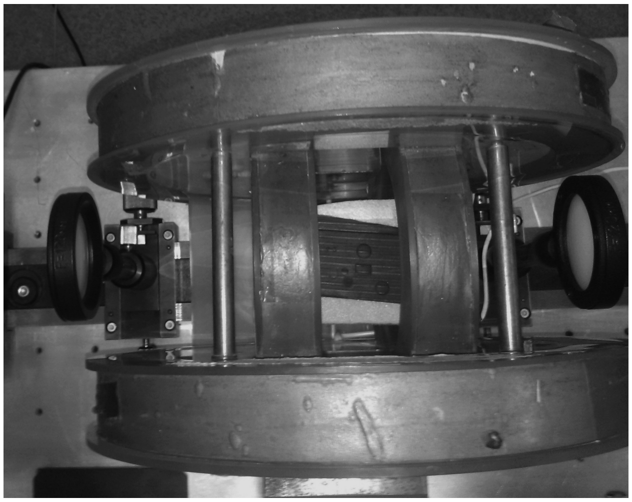

Fig.2. Helmholtz coils in quasioptical path of terahertz spectrometer

Investigated ferromagnetic fluid located in the special nonmagnetic cell with thickness of 9.92 mm. Windows of the cell had diameter of 30 mm and were made of teflon film (thickness of 60 microns). Maximal values of the changing of the dielectric constant under the influence of the transverse external magnetic field obtained at a ratio of concentrations of oil and magnetite 70:30 (sample № 2). Graph on Fig. 3 shows that to change value of the real part of the dielectric constant the external transverse magnetic field of 20 Oe is enough.

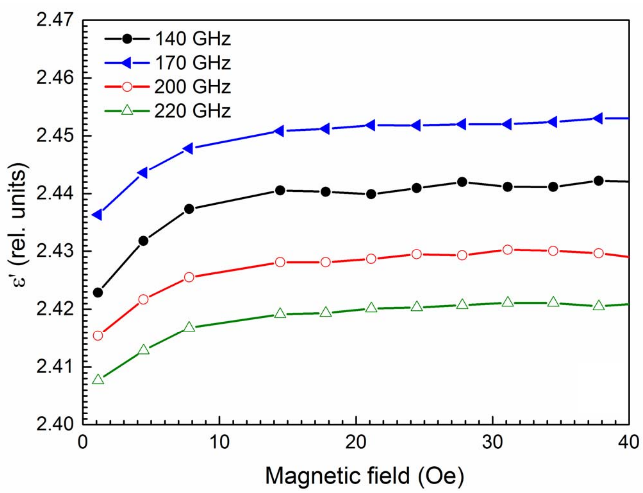

Fig.3. The dependence of real part of permittivity (sample № 2) on the external transverse magnetic field.

On Fig. 4 it is shown that real part of dielectric permittivity of ferrofluid (sample № 2) changes under the influence of the external transverse magnetic field (~ 100 Oe) in the frequency range 130-250 GHz at 1.5 %. Ordering takes place in magnetite particles agglomerate in the direction coinciding with the polarization of the incident electromagnetic wave.

Applying of external magnetic field relative to initial state of ferrofluid reduces real part of permittivity at 0.4%.

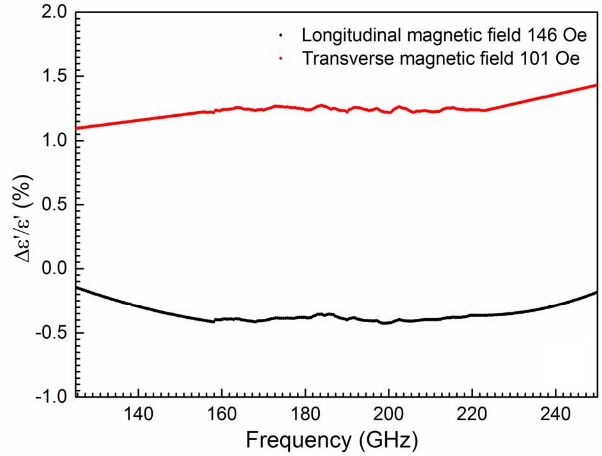

Fig.4. Frequency dependence of relative changes (in percent) of dielectric constant at the influence of longitudinal and transverse external magnetic fields.

It is caused by formation of agglomerates of magnetite particles along direction of electromagnetic wave propagation.

III. Summary

Thus, obtained results of anisotropy of electrophysical parameters of ferrofluids in the terahertz frequency range can be used to develop tunable elements of quasioptical tract of terahertz equipment.

IV. ACKNOWLEDGMENT

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