Variable THz attenuator based on 5BDSR microparticles in synthetic 80W-90 oil

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***Abstract*—We present a prototype of the variable THz attenuator based on magnetophoretic driven 0.5 wt% 5BDSR microparticles solution of highly viscous 80W-90 synthetic oil. Two pairs of Helmholtz coils are used as a source of an external magnetic field that possesses to drive the ferrofluid in a real-time. Dependence of the transmittance on particles orientation was studied in the range 0.2-2 THz using a custom made THz-TDS. Ferrofluid solution in a standard 1 cm length quartz cuvette possesses extinction ratio up to 20:1 at 1.4 THz. The prospects for their use for THz photonics are discussed.**

I. INTRODUCTION

USING ferrofluids is one of the possible approaches for making THz polarizers and attenuators. They could be used because they can form periodic structures that look similar to conventional wire-grid polarizers. Magnetophoretic formation of head-to-tail structures in polymer solutions gives them a high degree of conductivity anisotropy thus gives a cost-effective approach for THz attenuator fabrication [1]. By choosing the size and concentration of nanoparticles, the magnitude of the magnetic field, one can create THz polarizers with different spectral properties. For example, refractive indices strongly depend on particle concentration and external magnetic field amplitude due to Faraday and Voigt effects [2].

In this work, we demonstrate polarization modulators based on soft magnetic submicron particles of the 5BDSR alloy (analog of Hitachi nanocrystalline FINEMET® alloy) [3].

To characterize the fabricated device THz-TDS setup made in the Institute of Automation and Electrometry was used. This setup possesses a spectral range of 0.2-2.4 THz and equipped with a set of additional polarizers that offers extinction ratio more than 1000:1 over frequency range [4].

II. RESULTS

Powder with particles from several hundred nm to 2-3 μm was obtained, as a result of two-stage ball mill grinding of initial 35 μm thick 5BDSR alloy foil. At the first stage, isopropyl alcohol was used, at the second stage, grinding was performed in argon. SEM image of sieved powder is shown in Figure 1.

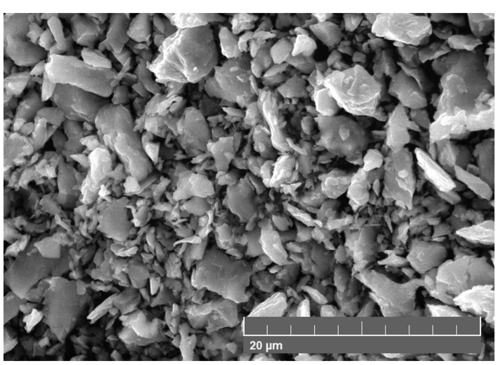

Fig. 1. SEM image of sieved 5BDSR powder, magnification is 5000x.

Obtained particles possess coercivity of only 18 Oe, residual magnetization of 1.4 emu/g, and relatively high magnetization saturation 140 emu/g [5]. These properties allow the orientation of particles under an external magnetic field of various amplitudes from tens to hundreds of mT.

Preliminarily, to select the optimal ferrofluid base THz spectra and viscosity of 5 different types of oils were investigated. Finally, dispersions of 0.1-5 wt% 5BDSR particles in 80W-90 synthetic oil were prepared. They were sonicated before putting in a quartz cuvette for further testing. Obtained ferrofluid in a 10 mm cuvette after magnetic saturation under ~3 mT external magnetic field is shown in Figure 2.

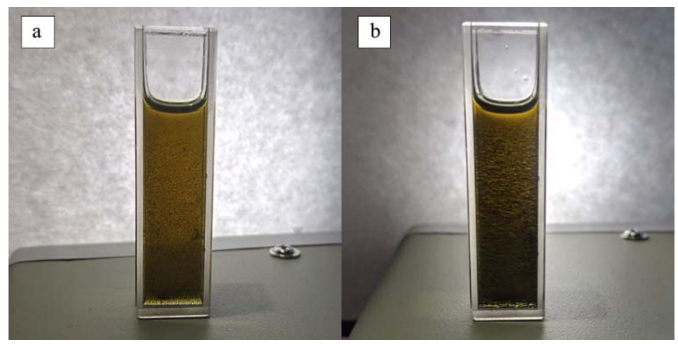

Fig. 2. 5BDSR 0.5 wt% dispersion after aligning under external magnetic field: a) magnetic lines are pointing inwards; b) lines are directed from right to left.

It tooks less than a minute to align homogeneous dispersion with an external magnetic field. Particles could remain in suspension for several days after ultrasonic mixing. However, after the magnetophoretic formation of grating-like structures, those clusters tend to settle to the bottom of the cuvette when an external magnetic field is turning off. After precipitate formation, dispersion could be resonicated and used again.

As a source of the external magnetic field, two crossed pairs of Helmholtz coils were used. The calculation of the parameters of the coils and the design was carried out. Inner pair of coils can be rotated relative to the outer pair. Using two pairs makes it possible to obtain high uniformity magnetic field. This field has the shape of an ellipsoid with two radiuses of ~0.3 R of each pair of coils radius. In our setup, we use vertical pair with 5 mm thick coils with an average radius of 70 mm, consists of 280 turns of 0.3 mm diameter coated Cu wires. Under voltage up to 15 V, current and temperature should not exceed 700 mA and 60°C respectively. The horizontal pair of coils have an average radius of 45 mm, a thickness of 5 mm, and each consists of 150 turns of the same wires as the vertical one. The current is not exceeds 500 mA with a 15 V. At the maximum applicable level of current for the pair of coils, the magnitude of the magnetic induction in the center of the system is 3.7 mT for the internal (vertical) pair of coils and 3.2 mT for the external (horizontal) pair. The colorized scheme of Helmholtz coils with a cuvette inside, and a photo of a fabricated and functioning THz attenuator, are shown in Figure 3.

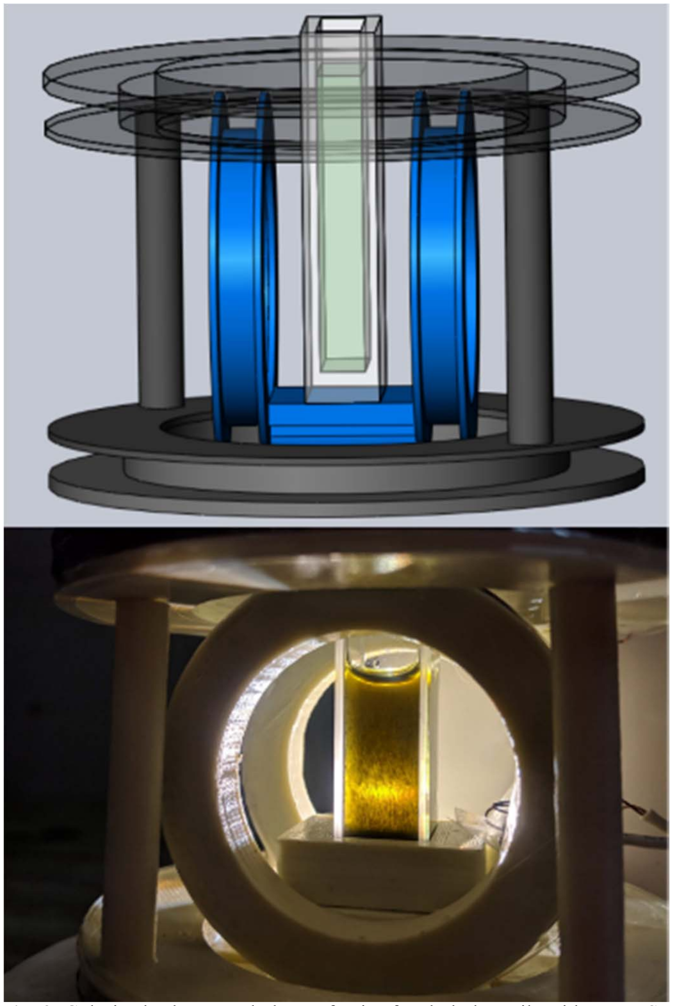

Fig. 3. Colorized scheme and photo of pair of Helmholtz coils with a 5BDSR particles dispersion.

On a photo an external magnetic field are created by a horizontal pair of coils. The region where the magnetic field created by Helmholtz coils is uniform exceeds the size of the cuvette. It is possible to adjust voltage and current on both pairs of coils simultaneously and, therefore, the amplitude of the external magnetic field. It allows us smooth rotation of the linear agglomerates in the dispersion.

In order to obtain THz spectra, crystal quartz cuvette with a 5BDSR solution was placed in a special holder in the center between pairs of crossed coils. This holder than was placed between a pair of focusing mirrors of THz-TDS.

Figure 4 shows the obtained transmission spectra and extinction ratio within a frequency range of 0.2-1.6 THz. The absorption of 0.5 wt% 5BDSR particles itself in the THz region of spectra is similar to that for Fe oxides [6].

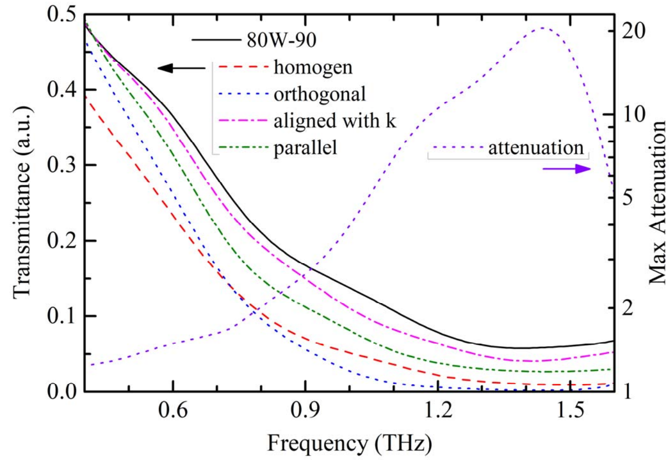

Fig. 4. Transmission spectra and extinction ratio (or a maximum attenuation) for 80W-90 oil and differently orientated solutions with 5BDSR particles.

The homogen spectrum represents no current applied. Parallel spectrum for current applied to vertical pair of coils, when the orientation of the magnetic induction is orthogonal to the ***k*** vector of incident THz beam and the magnetic particles agglomerates are parallel to E_{THz}. "Aligned with k" for same pair of coils, but now they facing mirrors of THz-TDS. Orthogonal for current applied to horizontal pair of coils and thus agglomerates are orientated orthogonal to E_{THz}.

III. Summary

When the particles are oriented along with ***k***, the maximum transmission is achieved. In this position, the transmittance of the attenuator is practically the same as pure oil. The pair of crossed coils allows the real-time smooth rotation of agglomerates in the two planes by just adjusting the current. saturation 140 emu/g. These properties allow the orientating of particles under an external magnetic field of various amplitudes. To improve properties of the designed attenuator, optimization of particle concentration and external field parameters is to be carried out.

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