DOI 10.1007/s11182-019-01726-8

Russian Physics Journal, Vol. 62, No. 3, July, 2019 (Russian Original No. 3, March, 2019)

ANALYSIS OF THE SPECTRAL CHARACTERISTICS OF PROMISING LIQUID CARRIERS IN THE TERAHERTZ SPECTRAL RANGE

D. O. Zyatkov,[1,2] Z. S. Kochnev,[2] A. I. Knyazkova,[2,3] and A. V. Borisov[2,3]

UDC 537.876.4

Results of analysis of the spectral characteristics of promising liquid carriers with different viscosities and natures at room temperature in the terahertz spectral range are given. The spectral absorption characteristics of the examined liquid layers with thickness of 3, 6, and 9 mm in the range from 0.3 to 2 THz are presented. It is shown that synthetic Toyota motor oil 5w40 is promising as a liquid carrier for synthesis and application of a magnetic liquid for the THz range regardless of the thickness of the layer of the examined sample.

Keywords: THz spectroscopy, liquid, magnetic liquid, viscosity, compound, silicone.

INTRODUCTION

The present work is devoted to the search for promising liquid carriers that can be used in the THz range as magnetic liquids. In recent years, research in the THz spectral range has been performed intensively. For example, in [1, 2], the possibility of control over the parameters of THz electromagnetic waves by orienting the nanotubes in a polymer was demonstrated. However, the use of magnetically or electrically controllable materials, for example, a magnetic liquid instead of materials controllable mechanically using quasi-optical paths is preferable. The magneto-optical properties of such liquids have been widely studied in the optical range, but in the THz range, these studies are difficult, since water-based liquids have a very strong absorption. The penetrating properties of THz radiation in the absence of the –OH hydroxyl group allow such radiation to be used for solving spectroscopy problems in communication infrastructure, medical diagnostic complexes, and various security systems. To increase the application efficiency of THz radiation, the elemental base design for the corresponding devices, including elements based on magnetic liquids, is urgent. Magnetic liquids are artificially prepared and specially structured media with unique electrical and magnetic properties. These properties are understood as special values of physical parameters of the medium: dielectric permittivity ε and magnetic permeability μ, spatial structuring depending on the size and shape of magnetic and dielectric particles, and the capability to control over the parameters of the medium under the action of external fields [3, 4]. The high mobility of magnetic particles in a liquid provides their strong sensitivity to weak magnetic fields and gives a significant advantage compared to solid-state analogs [5, 6]. Obviously, the use of magnetic liquids will allow passive elements of terahertz technology to be designed with tunable characteristics of the magnetic liquid itself, which can be controlled by switching on external magnetic and electric fields [7, 8].

For synthesis of magnetic liquids, various carrier liquids and stabilizers (surfactants), including organic solvents, water, hydrocarbons, and silicones are typically used. Magnetic liquids based on kerosene, perfluoropolyether, transformer oil, siloxane liquid, mineral hydrocarbon oil, synthetic hydrocarbon oil, oleic acid, oleic acid with addition of decalin, and cyclohexane are often used for investigations [5, 9]. However, most of these solutions cannot be used in

[1]JSC "Scientific Research Institute of Semiconductor Devices," Tomsk, Russia, e-mail: zyatkov.88@mail.ru; [2]National Research Tomsk State University, Tomsk, Russia, e-mail: kochnev_zakhar@mail.ru; borisov@phys.tsu.ru; [3]Siberian State Medical University, Tomsk, Russia, e-mail: a_knyazkova@bk.ru. Translated from Izvestiya Vysshikh Uchebnykh Zavedenii, Fizika, No. 3, pp. 15–20, March, 2019. Original article submitted November 21, 2018.

 1064-8887/19/6203-0400

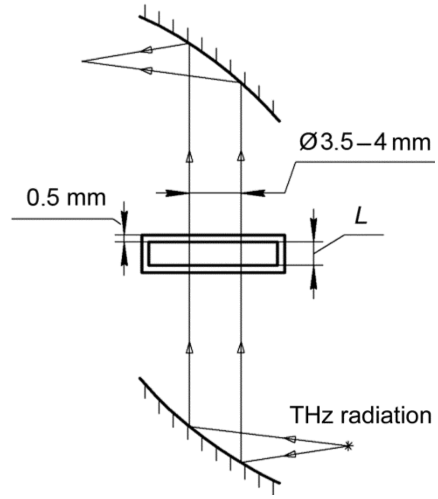

Fig. 1. Scheme of the experiment.

the THz range due to the presence of water and –OH hydroxyl group. For example, semi-synthetic oil is used for investigations in the THz range [10]. The search for liquid carriers intended for THz electronics is a promising direction of research aimed at the development of a class of THz modulators that can be integrated into other magnetic or non-magnetic systems, such as metamaterials and waveguides [11]. The purpose of the present work is to study the properties of promising liquid carriers in the THz range.

OBJECT AND METHOD OF RESEARCH

In the present work, liquid organosilicons, epoxy resins, and organic materials considered as magnetic liquid carriers promising for application in the THz range were used. Characteristics of the corresponding liquids are presented in Table 1. Stabilization of magnetic particles in a liquid carrier is a sufficiently difficult problem. Liquids with a wide range of viscosities and polymerizing liquids that can be used to develop elastomers with an internal chain structure from magnetic particles were chosen for investigation.

Let us consider the methodology of the experiment. Figure 1 shows the scheme of the experiment performed with a T-Spec THz spectrometer (EXPLA Technologies) with recording of signal from the liquid and reference signal. The signal from the liquid passed through the cell filled with the examined liquid. The cells were printed on a 3D printer from the Watson material with the distance between walls L = 3, 6, and 9 mm, a wall thickness of 0.5 mm, and cell length and height equal to 12 and 20 mm, respectively. The THz beam diameter was about 3.5–4 mm.

Every time, before recording the THz spectrum of the liquid, the empty cell was measured and then filled with a liquid sample without changing the cell position. The liquid spectra in the cell with a distance between the walls of 3 mm were first obtained. Then the liquids with the lowest THz-radiation absorption were selected, and measurements were performed with the cells having a distance between the walls of 6 and 9 mm, respectively.

RESULTS AND DISCUSSION

Figure 2 shows the THz spectra of the intensities of signals passed through the air in the spectrometer and through the empty cell and averaged over 20 points. Measurements were performed with 20 cells. From Fig. 2 it can be seen that the THz signal slightly changes its shape in the presence of the cell; therefore, the cell does not affect the shape of the absorption spectra of the examined liquids.