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## OPTOPHYSICAL MEASUREMENTS

# MEASUREMENTS OF THE TRANSMISSION COEFFICIENT OF SAMPLES OF NEW MATERIALS IN THE SUB-TERAHERTZ BAND OF FREQUENCIES

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*The propagation of radiation in the frequency range 0.2–0.3 THz through samples of composite materials is considered. The samples are in the form of a strip of carbon fibers stacked into tapes impregnated with epoxide resin on in the form of a block of randomly arranged quartz filaments bonded with borosilicate glass. It is shown that the results of measurements performed in the terahertz range of frequencies may be used to study the structural parameters and for the purpose of flaw detection in composite materials.*
***Keywords:*** *terahertz frequency range, transmission coefficient, composite materials, carbon fibers, quartz filaments, flaw detection.*

The importance of developing a technology that functions in the terahertz frequency range for high-speed information transmission and information processing systems, the identification of the composition of a substance and chemical analysis (in pharmacology and medical research), measurements of the properties of new construction materials, and nondestructive control of the quality and integrity of articles has been repeatedly emphasized in the scientific literature. Terahertz radiation is characterized by lengths of electromagnetic waves in the range 0.1–1 mm, which corresponds to the region between microwave and infrared radiation. This range of radiation requires new methods and new measurement techniques. Because of its physical properties, terahertz radiation is used to establish the nonhomogeneity of structural dielectrics that are opaque in the optical and ultraviolet ranges, in the study of the thermal insulating properties of new materials, and in the measurement of the degree of blackness of these materials. One new application involves the study of the radiophysical properties of metamaterials.

It is possible that reliable, compact, and sufficiently inexpensive devices for the terahertz range will be created in the near future, making it possible to solve these problems. There are two major roadblocks in the path towards the creation of this type of measurement technology. One entails the creation of powerful radiators in the selected frequency range. The other has to do with the development of a sensitive detector of radiation functioning in the same frequency range (the fact that this

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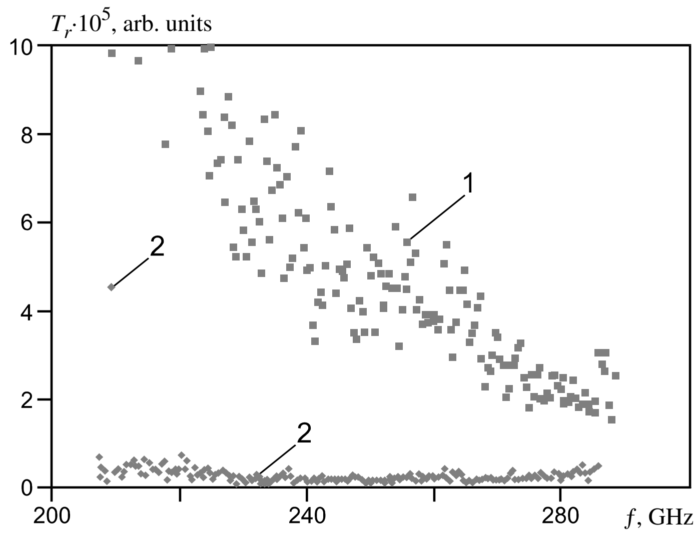


Fig. 1. Results of measurements of the relative transmission coefficient of sub-terahertz radiation of sample No. 1 of thickness 1 mm in the frequency range $f$ = 0.2–0.3 THz. Sets of points *1* and *2* correspond to the orientation of the vector of the electric field strength in orthogonal and parallel stacking of the fibers.

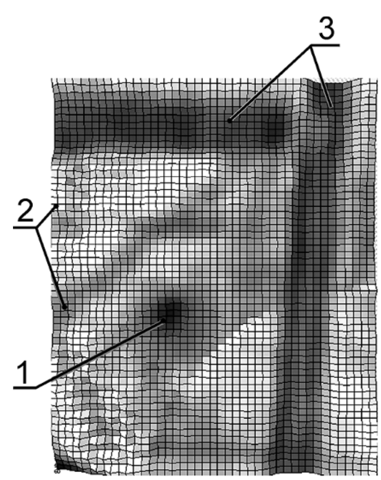


Fig. 2. Distribution of transmission coefficient of sample No. 2 at working frequency of 0.30 THz. Artificial inhomogeneities across the sample: *1*) hole 3 mm in diameter perpendicular to the plane of observation; *2*, *3*) holes of diameter 3 and 5 mm, respectively, in the plane of the sample.

range may be expanded is pointed out in [1, 2]). Even after a radiator–detector pair has been selected, it is still important to establish the working frequency range in which the measurements will be performed, since the presence of new materials absorption bands in a broad frequency range may be caused not only by the composition of the composite material, but also by its structure.

We carried out measurements of the transmission coefficient of samples of composite materials in the frequency range $f$ = 0.2–0.3 THz in connection with the development of diagnostic instrumentation in the terahertz range for the purpose of flaw detection of new construction materials:

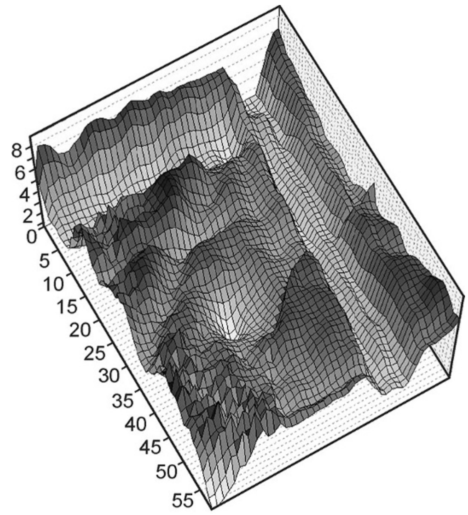


Fig. 3. 3D image of distribution presented in Fig. 2.

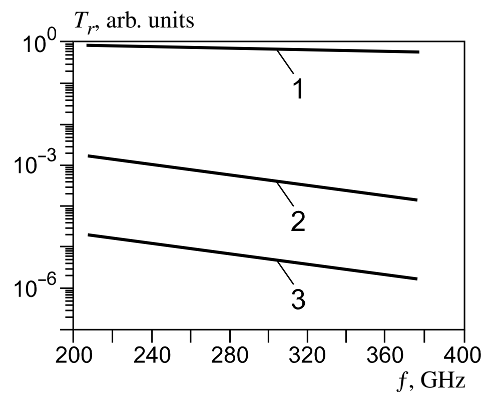


Fig. 4. Transmission spectra of sample No. 2 from fibers of fused quartz (curve *1*) and sample No. 1 of carbon fiber 0.7 mm in thickness for two polarizations of the vector of electromagnetic radiation incident on the sample (curves *2* and *3* propagating perpendicular to and along the fibers, respectively).

*Sample No. 1*, a strip 3.8 mm in thickness consisting of 10 layers of UKN-2.5 carbon filaments 5.6 μm in diameter stacked in the form of tapes with transverse bond of UOL-300 longitudinal filaments. The loosely stacked tapes were impregnated with EPS-I-108 epoxide resin. The orientation of the reinforcing fibers in the sample was varied gradually from layer to layer, 0–45–90°;

*Sample No. 2*, a 50 × 55 × 30 mm block made of TZMK-10 with reduced thermal conductivity. The fibers that are in the block are made of fused quartz 1–8 μm in diameter arranged randomly throughout the sample. Borosilicate glass forms the bundle of fibers. The mass density of the composite is in the range 140–150 kg/m$^3$.

Radiation at a frequency of 0.2–0.3 THz was directed at the samples. Measurements were performed on a STD-08 quasi-optical terahertz spectrometer with radiator based on a backward-wave tube in the range $f$ = 0.1–1.25 THz. A total of 400 measurements were carried out with orientation of the vector of the electric field strength orthogonal to the stacking of the fibers and the same number of measurements with orientation parallel to the stacking of the fibers. The results of the measurements are presented in Figs. 1 and 2. The dependences of the transmission coefficient on the polarization of incident radiation at a very high degree of absorption in sample No. 1 were unexpected. Thus, whereas the vector of the electromagnetic wave strength is perpendicular to the axis of the fiber, as the working frequency of the translucent radiation (210–290 GHz) is varied, the transmission coefficient decreases to one-fifth, while if the vector is directed along the fiber, absorption is practically absent throughout the entire frequency range (cf. Fig. 1, groups of points *1*, *2*).

In measurements with sample No. 2, a distribution of the transmission coefficient across the cross-sectional area of the sample with inhomogeneities amounting to 10–15% in the initial sample and up to 80% with artificial inhomogeneities across the thickness of the sample in the form of vertical and horizontal through holes 3 and 5 mm in diameter (cf. Figs. 2 and 3) was also obtained. The working frequency of the measurements was 0.30 THz. Drops in the translucency of the sample are apparent in the recovered 3D images.

The spectral dependences of the transmission coefficient of both samples are presented in Fig. 4, where the influence of the internal structure of the samples on the absorption coefficient is apparent. The exponential dependence of the transmission coefficient on frequency varies roughly by two orders of magnitude and depends on the orientation of the fibers relative to the field for sample No. 1. The scale of the variation was observed over the entire range of frequencies studied (208–378 GHz). In sample No. 2, the exponential dependence of the transmission coefficient on frequency is flatter, but its values are roughly one-thousand times greater, which may be explained by the greater thickness of the sample. No absorption bands or resonances were observed in either of the samples.

Thus, the measurements of the transmission coefficients that were carried out in the sub-terahertz frequency range of electromagnetic waves demonstrated that it is possible to use these waves to study the structural parameters and for the purpose of flaw detection of composite materials alongside already well-known acoustic, optical, and x-ray structural measurements as well as in the technology of magnetic, electrical, and microwave diagnostics.

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