Sub-THz absorbers based on BaTiO$_3$/Epoxy composites

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Abstract. The paper presents the results of studying electromagnetic response from polymer composite materials in the frequency range from 0.1 THz to 1.6 THz obtained using a BWO-based spectrometer and a time-domain spectrometer. The composites used were epoxy resin with the addition of barium titanate (BaTiO$_3$) with a mass concentration of 40% to 80%. Based on these data, the values of the complex permittivity of composite samples are calculated and analyzed, and the electromagnetic response from the samples is modeled. An assessment of the applicability of this material in the elements of the THz range technology is carried out.

1. Introduction

Today, the scientific community is striving to develop a promising area of the electromagnetic spectrum - the terahertz (THz) frequency range. This range has a number of advantages, THz radiation has established itself in medicine as a safe X-ray [1-3], in security systems [4, 5], the study of biological objects [6-8], connections of the new generation [9], medical diagnostics and therapy [10-12] and other areas of life. In connection with the transition of technologies to a higher frequency range, there is a need for materials that are necessary to harmonize and protect the components of the THz and sub-THz ranges. One of the options for the development of such materials is the creation of composite materials as absorbers of electromagnetic radiation [13]. During production, composites impart electrophysical and physicochemical properties unattainable for materials: flexibility, elasticity, high strength properties. Of great interest is the development of polymer composite materials, ferroelectric ceramics due to the ability to screen electromagnetic interference, weight, high dielectric constant, mechanical strength, strong bond with a polymer binder. On their basis, piezoelectric generators, capacitors, dielectric lenses [14] and antenna systems are being developed. All this emphasizes the possibilities of using ferroelectrics in the elemental base of THz technology. The purpose of this work is to investigate the ferroelectric-based composite for its shielding properties.

2. Experimental samples

For the research, composite samples were made from two components: a filler and a binder. The polymer base of the composite material was EDP-20 epoxy resin with polyethylene polyamine hardener. Ferroelectric powder BaTiO$_3$ with a particle size of 100 μm was used as a filler. At the first stage of sample production, the components were weighed on an electronic scale. By chemical treatment, the components were mixed on an ultrasonic apparatus with a power of 75 W for 10 minutes. This treatment is used to achieve greater uniformity, and also breaks down the agglomerates of the filler. After ultrasonic treatment the resulting mixture was fully polymerized at room temperature. The final stage is the mechanical processing of the samples with thickness $h$ and the desired diameter $D$. 
The processing is carried out using an engraving nozzle, which removes the excess and forms plane-parallel faces. Figure 1 contains a photo of the test samples.

![Figure 1](image_url)

**Figure 1.** Photo of the studied samples of a composite based on BaTiO₃.

In Table 1 characteristics of investigated samples are presented.

**Table 1.** Characteristics of composites.

| Sample | Epoxy resin (wt. %) | Hardener (wt. %) | BaTiO₃ (wt. %) | h (mm) | ε' (rel. units) | ε'' (rel. units) | ρ (g / cm³) |
|--------|---------------------|------------------|---------------|--------|----------------|------------------|------------|
| 1      | 51                  | 9                | 40            | 1.95   | 4.9            | 0.34            | 0.3591     |
| 2      | 34                  | 6                | 60            | 1.95   | 7.5            | 0.63            | 0.4532     |
| 3      | 17                  | 3                | 80            | 1.95   | 14.7           | 2.50            | 0.5102     |

3. **Measurement technique**

Time domain (TDs) and continuous wave (CW) spectroscopy methods were used to measure the electromagnetic response of BaTiO₃/Epoxy composites.

3.1 **Time-domain spectroscopy**

TDs spectrometer works in conjunction with two modules for reflection and transmission and has a wide spectral range up to 3.5 THz, data collection rate in real time, up to 10 spectra / s. The installation uses a femtosecond laser, a beam divider, lenses and prisms. The emitter and detector are photoconductive antennas based on GaBiAs. The design of the emitter and detector is based on two metal electrodes under an external voltage of the order of 40 V. When the gap between the electrodes is illuminated with a laser pulse, the concentration of free charge carriers increase, which are accelerated by the applied field. As a result, a short-term current pulse arises, which is a source of terahertz radiation. As a result, the signal and its fast Fourier transform are recorded using the software.

3.2 **Continuous wave spectroscopy**

The measurements were carried out on a terahertz spectrometer STD-21 by the open space method. The sample was placed in a path along the path of the radiation. The transmission coefficient was calculated as the ratio of the power received by the detector when passing through the sample and during calibration scanning (without the sample). As a radiation source, a generator based on backward wave oscillator (BWO), operating in the range of 115-258 GHz, was used. The detector is an opto-acoustic transducer (Golay cell) [15]. The received signal from the detector is recorded at fixed frequencies in
the selected interval and displayed on the screen of a personal computer using the T-scan software product.

4. Results
Figures 2, 3 shows the measured frequency dependence of the transmission and reflection coefficients of a composite based on BaTiO$_3$ at the range of 100 - 1600 GHz.

**Figure 2.** Frequency dependences of transmittance of a composite based on BaTiO$_3$. The lines in the graphs indicate the data obtained using a time-domain spectrometer (TDs) T-SPEC 1000, symbols - using the STD-21 BWO spectrometer.

**Figure 3.** Frequency dependences of reflection of a composite based on BaTiO$_3$. The lines in the graphs indicate the data obtained using a time-domain spectrometer (TDs) T-SPEC 1000, symbols - using the STD-21 BWO spectrometer.
The analysis of the graphs shows that the frequency dependences of the transmission and reflection coefficients obtained using the STD-21 BWO-spectrometer and the T-Spec 1000 pulse spectrometer are mutually correlated.

Figure 4, 5 shows the result of calculating the distribution of the transmission, reflection and absorption coefficients (T, R, A) on the frequency and layer thickness for a composite material containing 40 wt. % and 80 wt. % BaTiO$_3$.

![Figure 4](image1.png)  ![Figure 5](image2.png)

**Figure 4.** Distribution of T, R, A over frequency and layer thickness for a material containing 40 wt. % BaTiO$_3$.

**Figure 5.** Distribution of T, R, A over frequency and layer thickness for a material containing 80 wt. % BaTiO$_3$.

It can be seen from the graphs that a composite with 40 wt. % BaTiO$_3$ with a thickness of 2 mm at frequency of 220 GHz absorbs up to 70 % of radiation, and reflects more than 20 %. The maximum absorption from 80 to 90 % is observed at frequencies of ~ 250 GHz and a material thickness of 2.75 – 3 mm. For a composite sample with 80 wt. % BaTiO$_3$, the transmission coefficient is less than 10 % at frequencies of 120 - 260 GHz with a layer thickness of more than 1 mm. In this case, 60-70% of the radiation is absorbed, and the rest is reflected.

5. Conclusion
An analysis of the results obtained shows that a composite containing 40 wt. % BaTiO$_3$ is promising for creating an absorber in the THz frequency range. Varying the mass concentration of the matrix filler in the range of 40 - 80 wt. % allows one to change the real part of the dielectric constant of the composite in the range of 5 - 15 rel. units. In this case, the increase in the imaginary part of the dielectric constant reaches 2.4 rel. units, which is 5 times higher than the initial value (at 40 wt. %).

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