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Dmitry M. Ezhov, Dmitry M. Lubenko, Valery F. Losev, Yury M. Andreev, "Prospects of controlling the propagation of high-power THz radiation by passive optical elements including 3D printed," Proc. SPIE 12086, XV International Conference on Pulsed Lasers and Laser Applications, 1208625 (2 December 2021); doi: 10.1117/12.2614227

SPIE.

Event: XV International Conference on Pulsed Lasers and Laser Applications, 2021, Tomsk, Russian Federation

Prospects of controlling the propagation of high-power THz radiation by passive optical elements including 3D printed

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ABSTRACT

Optical properties of different commercial plastics for fused deposition modeling 3D printing are defined at room temperature in the spectral range 0.2-1.2 THz. We compare absorption coefficients and refractive index of ABS, PETG, and SBS printed 1-4 mm plates. Different types of optical elements for controlling high-power THz radiation are studied. A comparison is made of the efficiency of attenuation of linearly polarized THz radiation with homemade band-pass polarizers obtained by etching copper from a flexible polyimide substrate. Filters and polarizers created using 3D printing or by deposition of polymer matrix with magnetic particles under external field are cost-effective and can be easily changed or replaced. Comparison between plastic insets, filters based on magnetic particles, and polyimide film filters are made.

Keywords: fused deposition modeling, polystyrene co-polymers, THz polarizers, THz attenuation

1. INTRODUCTION

The unique properties of Terahertz (THz) radiation and advances in the improvement of methods of THz radiation generation, including "old-fashioned" nonlinear optical crystals[1], dipole antennas (including THz-TDS technology)[2], extremely powerful plasma sources[3], or even cutting-edge techniques that use spintronic devices[4] leads to problems with effective radiation modulation, in other words with a controlling of THz radiation.

Different fields like biomedical imaging[5], security imaging[6], and even cultural heritage research are applying THz technologies. Low-photon energy THz radiation makes it possible to conduct various non-destructive and non-invasive evaluations of, for example, forms of artworks[7].

In modern days, the THz industry seeks different efficient optics and quasi-optic devices for different spectral ranges. For example, composing ultrathin metallic films in a free-stand wire-grid configuration is one of the conventional THz attenuation methods. With fine-spaced wires, such systems possess broadband attenuation[8,9].

Nevertheless, the creation of simple inexpensive systems, with variable properties in the THz range, based on cheap and easily accessible materials like 3D printer filaments, is an attractive and actual task.

In principle, almost any kind of lenses or more complicated optics can be produced by 3D printing. Gratings with different periods made using fused deposition modeling (FDM) can act as a parallel-plate waveguide or a gradient-refractive index structure[10]. Almost all available types of plastics that could be considered as printing materials: PLA, ABS, HDPE, HIPS were already characterized in the THz range[11].

In this work, we make comprising research on the properties of several 3D filament polymers. Using ABS plastic as an already researched base, we found SBS (styrene-butadiene-styrene) as a cheap and transparent in THz range material for 3D printing. Additionally we propose specially printed insets made of SBS that combine the advantages of real-time magnetic fluid control properties [6] and dielectric regular structures that create spectral selectivity. We compare this approach with a filter made by drop-casting and further evaporation of ethylene-vinyl acetate (EVA) dispersion with magnetic particles.

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XV International Conference on Pulsed Lasers and Laser Applications, edited by Anton V. Klimkin, Maxim V. Trigub, Victor F. Tarasenko, Proc. of SPIE Vol. 12086, 1208625 · © 2021 SPIE · 0277-786X · doi: 10.1117/12.2614227

2. MATERIALS AND METHODOLOGY

Plastic slabs with a thickness of 1, 2, and 4 mm of acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), and styrene-butadiene-styrene (SBS) filaments were prepared using i3 Duplicator (Wanhao, China) FDM printer, with a 0.3 mm extruder nozzle. THz properties of prepared slabs were measured using Z3 (Zomega, USA) THz-TDS system.

A liquid THz filter driven by an external magnetic field was demonstrated earlier[12]. Further modification of the prototype led to an extinction ratio of up to 1000 with a power transmission of 0.4 after passing a 1 cm long filter. Using an external magnetic field allows us to control THz transmission in real-time. However, due to the irregular structure of oriented particles, these filters are fundamentally non-selective. We decide to modify such a non-selective but effective filter. To add spectral selectivity to the filter, we developed dielectric insets in the form of gratings with different periods. Using a cuvette with an inset filled with magnetic dispersion makes it possible to control the effective medium refractive index using an external magnetic field. Choosing the parameters of the inset additionally allows controlling the spectral and spatial properties of the radiation passing through the filter. 3D insets with various grating periods are shown in Fig. 1. These periodic structures could be inserted in a standard quartz cuvette.

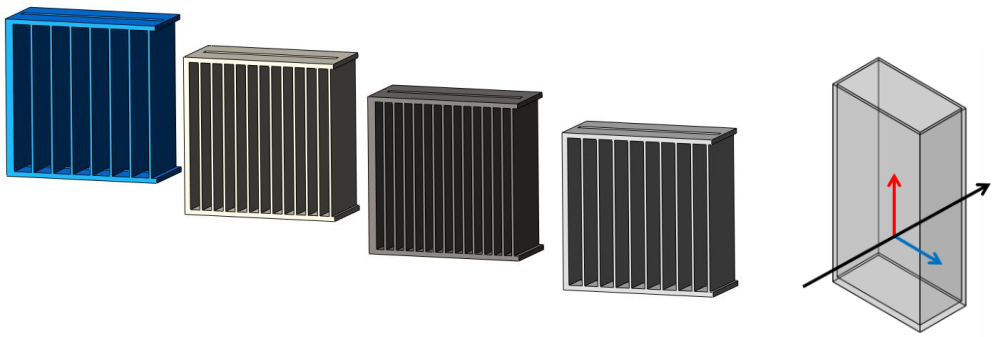

Figure 1. Scheme of a 3D printed insets and an overview of a cuvette with a polarization of THz radiation.

Transmittance spectra of produced SBS cuvette insets in Air and in cuvette filled with transmission oil 80W-90 were recorder using T-Spec 1000 (TeraVil, Lithuania) THz-TDS spectrometer.

Planar linear copper foiled polyimide gratings and EVA are shown in Figure 2.

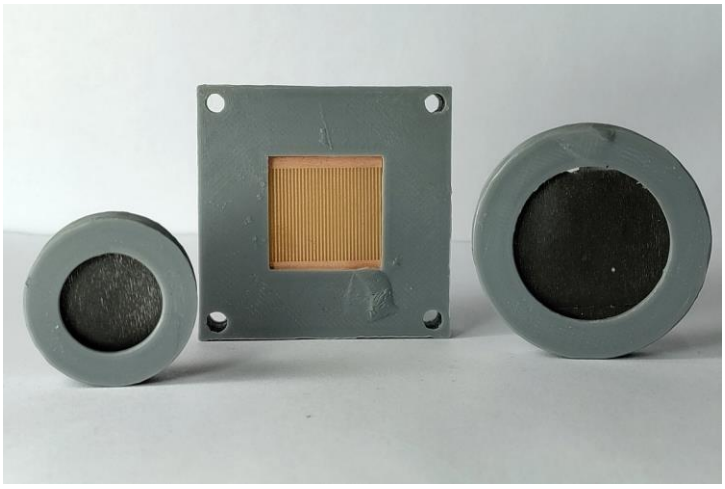

Figure 2. Film filters under test: drop-casted EVA (black), copper foiled polyimide – in the center.

It is well known conventional filters possess high polarization extinction ratio in certain frequencies due to Fabry-Perot interference[13]. Measured transmission spectra of copper filters with the different grating periods could be found elsewhere[14]

3. RESULTS AND DISCUSSION

Spectra of studied 3D printed slabs are shown in Fig. 3:

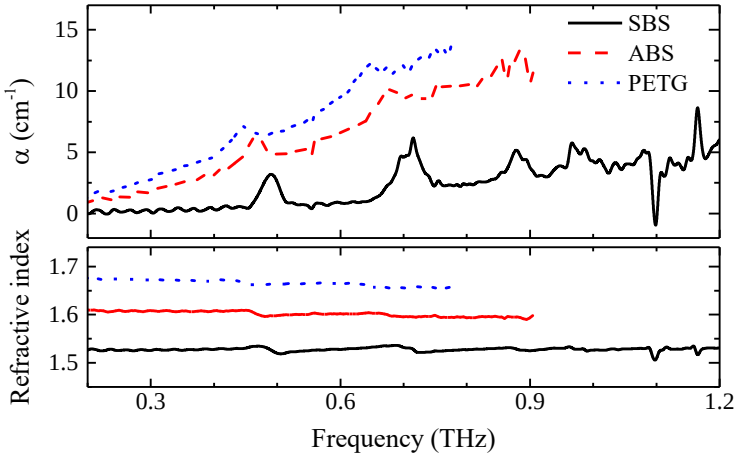

Figure 3. Calculated absorption coefficient and refractive indices of studied plastics.

We used plastic slabs of different thicknesses to ensure good SNR and a wide dynamic range. Fig. 3 shows spectra obtained from slabs of ~ 4 mm thick. It is clearly seen that the absorption of PETG and ABS samples is too high to be studied at frequencies higher than 0.8 THz or 0.9 THz. Among studied plastics, SBS shows both the lowest absorption coefficient and refractive index. The average refractive index for studied materials is 1.66, 1.6, and 1.52 for PETG, ABS, and SBS correspondingly. It is necessary to ensure the refractive index of plastic is as close as possible to filler liquid to neglect unnecessary reflection and refraction on a media interface.

Absorption spectra of a quartz cuvette filled with 80W-90 synthetic oil, with 3D printed insets with different grating spacing are shown in Fig.4.

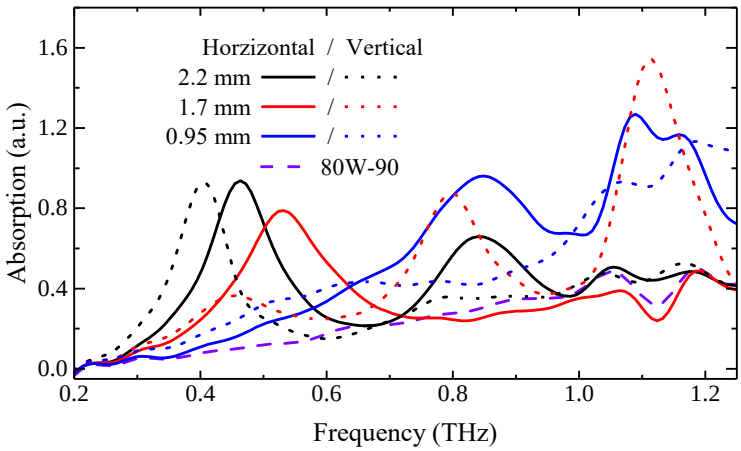

Figure 4. Absorption spectra of different orientated SBS insets in a 1 cm cuvette with 80W-90 oil.

Periodic structures act as selective filters; their properties depend on the grating period and relative orientation of incident THz radiation polarization. Different absorption pattern for each grating period is clearly seen. Moreover, with the 90° rotation of insets in a cuvette, absorption peaks are shifted to higher frequencies range from vertical orientation (when grating slits are parallel to E component of THz wave) to horizontal.

Transmittance spectra of composite thin filters are shown in Fig. 5. Clean EVA 0.3 mm thick film shows 0.9 transmittances in the full operating range of the used THz-TDS spectrometer.

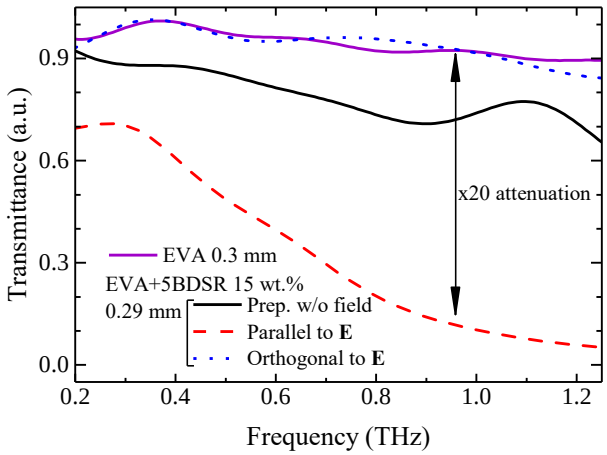

Figure 5. Transmittance spectra of composite EVA with a 15 wt% of 5BDSR particles films, depending on orientation.

Composite films with particles of 5BDSR 15 wt% exhibit up to 25 dB extinction ratio at 1 THz using only a 0.29 mm thin film. Due to the irregular structure of metal agglomerates in the EVA matrix formed by an external magnetic field, such filters attenuate polarized THz radiation in a wide range with various efficiency.

4. CONCLUSION

We demonstrate properties of different quasi-optic THz filters: obtained by the deposition of magnetic particles in the presence of an external magnetic field in a transparent polymer matrix; by 3D printed or obtained by etching copper from a flexible polyimide substrate. Filters and polarizers created using 3D printing or by evaporation of polymer matrix with magnetic particles under the presence of an external magnetic field are easily produced and cost-effective elements. 3D printed insets with different grating periods show similar properties to etched polyimide films. They can be used to create spectral selective filters or in structures with a gradient refractive index. Good mechanical and optical properties make SBS plastic perfectly suitable for use in THz photonics.

ACKNOWLEDGEMENTS

This study was supported by Russian Science Foundation (RSF) (project No. 19-19-00241).

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