



Flexible film broadband absorber based on diamond-graphite mixture and polyethylene



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ABSTRACT

Flexible film broadband absorber based on diamond-graphite mixture and polyethylene was fabricated by hot pressing. The film thickness of the absorber was 90 μm . We have measured angular reflectivity, diffusional reflectivity and transmittance in the range 85–8000 cm^{-1} (117–1.25 μm) in order to determine the absorption. It was shown that room temperature pressing of mesh print with 250 μm step significantly reduces reflectivity of the absorber. The absorption was over 0.85 in the range 85–320 cm^{-1} (117–31.25 μm) and >0.98 in the range 320–8000 cm^{-1} (31.25–1.25 μm). We believe that the designed and manufactured absorber might become a promising material for optical devices where high broadband absorption and flexibility are required.

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1. Introduction

At the present time, the interactions of photon radiation with materials have been actively studied [1–3]. This is due, on the one hand, to the fact that optical properties of materials are studied by using photon radiation [4–8]. On the other hand, characteristics of photon radiation are determined by using optical materials [9]. In many cases, the photon radiation is used to determine reflectivity, transmittance and absorption of new materials [10–14]. Reflectivity, transmittance and absorption of designed materials may be different for each wavelength range [13].

There are many optical high-quality materials, that have been used in different applications. These materials may be optical filters [15], optical waveguides [16], mirrors [17,18], selective mirrors [19], photodetectors [20,21], transparent conductive electrodes [6,13,22], absorbers [23,24] and so on. Among these materials, absorbers are unique materials. This is because the high-quality absorbers possess the smallest reflectivity and transmittance coefficients. Simultaneously, absorption is the largest. Ideally, a high-quality absorber supposed to be a black body where no light is transmitted or reflected. It should be noticed that the black body is a theoretical object that absorbs all photon radiation and the most

efficient thermal absorber and emitter [23]. In real life a black body does not exist.

Since the black body efficiently converts light to heat, it makes the black body valuable for many applications. As an example, absorbers like black body have been used in solar thermoelectric converters [25], solar steam generation [26], solar thermophotovoltaic device [27], infrared thermal detectors [28] and so on. There is also specific task of using the absorber like black body. That is a measurement of the absorption temperature dependence and highly reflective coatings emission [29].

There are many methods of manufacturing the absorbers and creating a black surface [30]. For example, it was shown that black surfaces can be obtained by chemical etching of Ni–P alloy [31,32]. The method for creating of absorption coating for solar water heating applications is known [33]. Recently developed metamaterial absorbers for the terahertz range are interesting and promising for to use [34–39]. Also, nanostructured materials can be used as high-quality absorbers [40]. However, most of the absorbers have a narrow absorption range that limits their application.

To expand the absorption range, it is necessary to use carbon materials due to their absorbing properties. However, absorption and emission of carbon materials are limited in 0.8–0.85 because of reflection at interface. Nanostructured carbon materials can be used to resolve this issue. In the study [23], it was shown that the high-quality absorber from vertically aligned single-walled carbon

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Fig. 1. A typical image of the film flexible absorber based on diamond-graphite mixture and polyethylene.

nanotubes absorbs light across a very wide spectral range 0.2–200 μm . However, most of absorbers based on nanostructured carbon materials that have been made on solid substrates with no have flexibility.

In this study, we have developed and fabricated a flexible film broadband absorber using diamond-graphite mixture and polyethylene. Angular reflectivity, diffusional reflectivity and transmittance of the absorber were investigated in the range 85–8000 cm^{-1} (117–1.25 μm).

2. Experimental

Diamond-graphite mixture and ultrahigh molecular polyethylene (UMP) were used to produce the flexible film absorber. The diamond-graphite mixture was obtained by the detonation synthesis. The method details can be found in references [41–43]. The diamond-graphite mixture contains up to 35% of nano-diamonds, 55–60% of non-diamond forms of carbon, and 5–10% of metal-containing impurities (mainly iron, its oxides and copper from explosive chamber material, detonators and wires). Here the weight percentages are implied. The ultrahigh molecular polyethylene was bought in Sigma-Aldrich. The diamond-graphite

mixture was mixed with the ultrahigh molecular polyethylene in an agate mortar. The weight percentage for the diamond-graphite mixture and UMP was 25% and 75%, respectively. During manufacturing process of a film absorber, we tried to maximize the weight content of diamond-graphite mixture. However, over 25% of diamond-graphite mixture content, the absorber was brittle and collapsed. Thus, 25% of diamond-graphite mixture was in optimal weight ratio.

Pressing of diamond-graphite mixture and UMP substances was produced by the Spekac Hydraulic laboratory press 15t (Germany) using a special shape and metal rings. The pressing temperature was 110°C. Obtained absorber film had thickness of ~90 μm and a good flexibility. A circle with a diameter of 9 mm was cut out from the absorber film. Mesh print with 250 μm step was made by using room temperature pressing to reduce reflectivity of the absorber. Press strengthening was 1000 kg.

To study the optical properties of obtained absorber film in near, middle and far infrared region, we used Bruker Vertex 80 Fourier-spectrometer (Germany) equipped with a variable angle reflection accessory A513 and diffuse reflectance accessory EasiDiff of PIKE Technologies (USA). Bruker optical microscope Hyperion 2000 was used to view the mesh print on the surface of the absorber film.

3. Results and discussion

Fig. 1 shows a typical film absorber obtained from diamond-graphite mixture and polyethylene.

To determine transmittance of the manufactured flexible film absorber, we have conducted measurement in range 85–8000 cm^{-1} (117–1.25 μm) as shown in **Fig. 2**.

As can be seen from **Fig. 2a**, the transmittance of the flexible film absorber strongly decreases while the wave number increases. The transmittance was 0.091 and 0.0036 at wave number of 85 and 670 cm^{-1} , respectively. In the range 400–8000 cm^{-1} , the transmittance continues decreasing up to 6000 cm^{-1} as shown in **Fig. 2b**. However, at the beginning from 6000 cm^{-1} the transmittance slightly increases. Generally, the transmittance of the flexible film absorber did not exceed 0.004 in this region. It might be noticed from **Fig. 2b** that there are three regions of a significant decrease in the transmittance (717, 1458 and 2890 cm^{-1}) which are related to

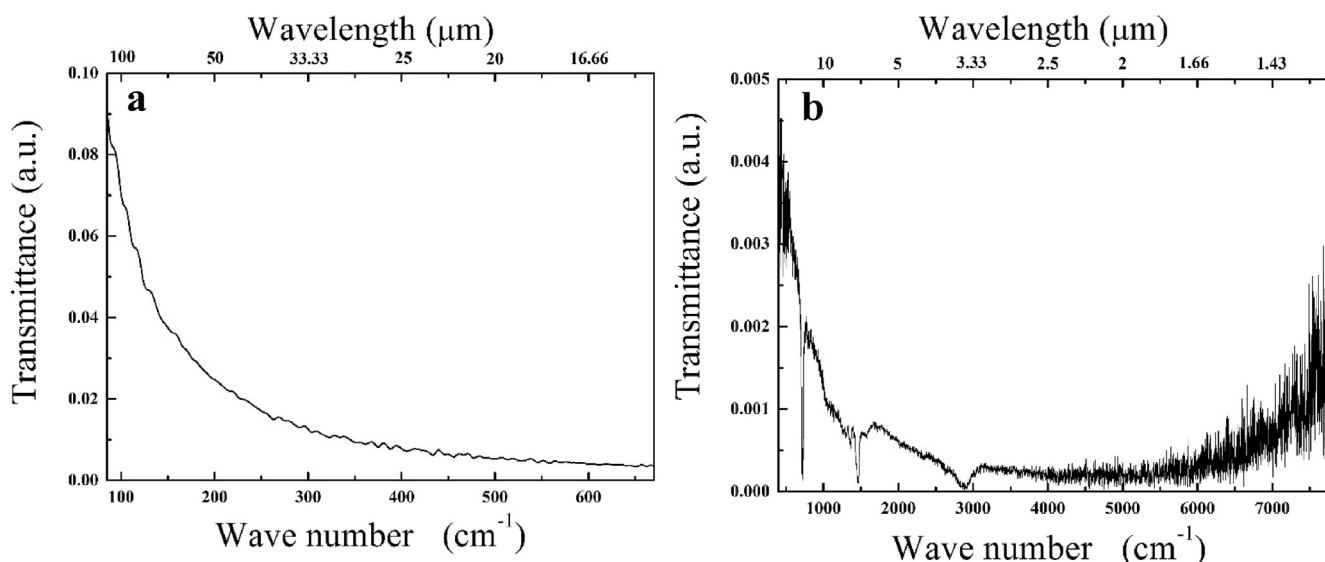


Fig. 2. The film absorber transmittance in range: (a) 85–670 cm^{-1} and 400–8000 cm^{-1} (b).

absorption of polyethylene [44–46].

We carried out measurements of diffuse reflectance in range $85\text{--}8000\text{ cm}^{-1}$ ($117\text{--}1.25\text{ }\mu\text{m}$). The diffusion mode of measurement was needed to collect all reflected light. Dependence of the diffuse reflectance on wave number is shown in Fig. 3a–b.

The mirror was used in accessory EasiDiff at measuring of diffuse reflectance. We installed the mirror first and then a sample (our thin absorber). Thus, if the thickness of our absorber is below a certain thickness, re-reflection from the mirror will occur. For this reason, we made a cone, which was installed instead of the mirror. This cone helps to avoid re-reflection. In addition, if the diffuse reflectance spectra measured by mirror and the cone match up (Fig. 3a) when the smallest possible thickness of the thin absorber is determined. Thus, we have obtained the optimal absorber thickness of $\sim 90\text{ }\mu\text{m}$.

As can be seen from Fig. 3a, reflectance of the thin absorber was near 0.11 at 85 cm^{-1} . With increasing wave number up to 200 cm^{-1} , the reflectance decreased. At this stage, the reflectance was 0.048 at 200 cm^{-1} . However, with a further increasing of wave number, the

reflectance was quasi-constant and did not exceed 0.06. The diffuse reflectance dependence on of the wave number in range $400\text{--}8000\text{ cm}^{-1}$ is shown in Fig. 3b. Fig. 3b shows that reflectance is practically constant, however there are some regions with appearance of a significant change. That might occur due to the polyethylene absorption. Moreover, these regions coincide with the transmittance spectra. The reflectance did not exceed 0.06 in range $400\text{--}8000\text{ cm}^{-1}$ excluding the regions. To reduce the reflectance, we made an impression on the film absorber surface. The surface is shown in Fig. 3c.

As can be seen from Fig. 3a–b, the reflectance was significantly reduced due to the impression. Initially, the reflectance does not exceed 0.02 in the range from 146 cm^{-1} to 8000 cm^{-1} .

To check whether all reflected light from the film absorber was recorded by diffuse mode, we carried out measurement of angular dependence of reflectance of the film absorber with imprint in range $85\text{--}670\text{ cm}^{-1}$ (Fig. 4). Fig. 4 shows that the main contribution in the reflectance were angles up to 20° . Thus, the diffuse mode collected all the reflected light from the film absorber.

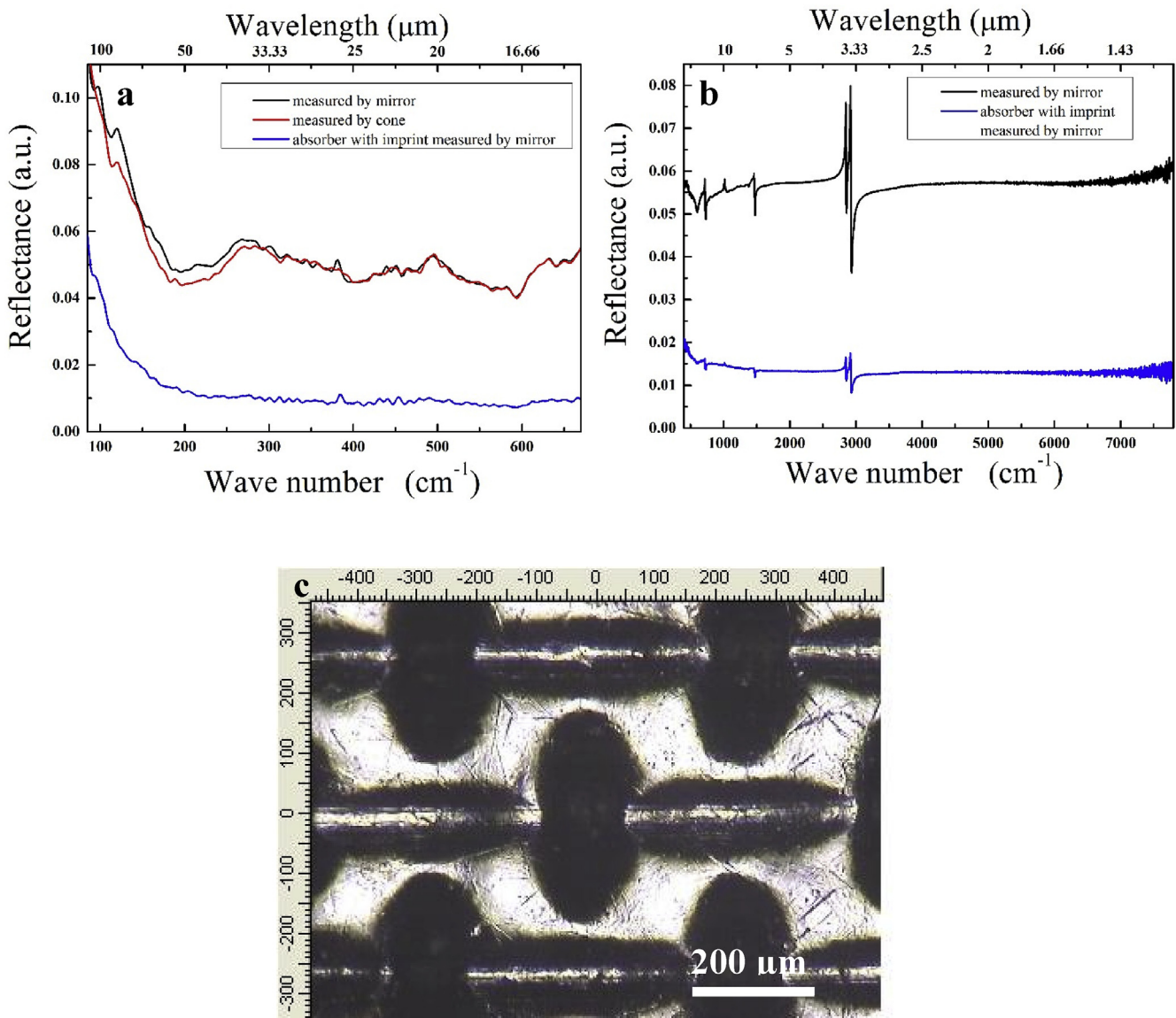


Fig. 3. The film absorber reflectance measured in diffuse mode: (a) $85\text{--}670\text{ cm}^{-1}$ and $400\text{--}8000\text{ cm}^{-1}$ (b), (c) image of absorber surface with impression.

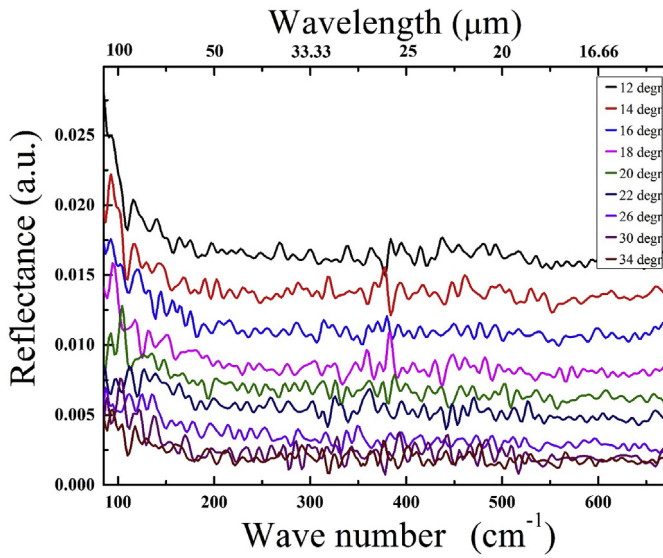


Fig. 4. Angular dependence of reflectance of the film absorber with imprint measured in 85–670 cm^{-1} .

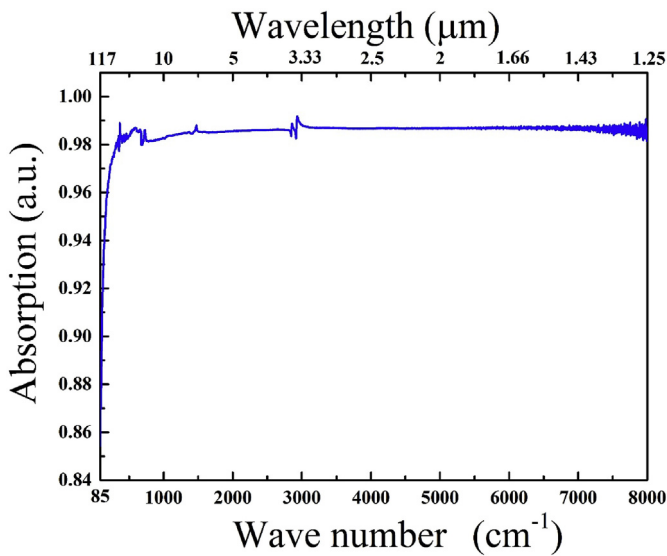


Fig. 5. The dependence of absorption of the flexible film absorber on the wave number in range 85–8000 cm^{-1} .

Using the measured transmittance and reflectance of the flexible film absorber in range 85–8000 cm^{-1} and using the equation [13]:

$$T + R + A = 1, \quad (1)$$

where T, R, and A denote transmittance, reflectance, and absorption, we have obtained the absorption dependence on the wave number as shown in Fig. 5.

Thus, as shown in Fig. 5, the absorption of the flexible film absorber is becoming more than 0.85 in the range 85–320 cm^{-1} and more than 0.98 in the range 320–8000 cm^{-1} .

High absorption of the developed flexible absorber in a wide range can be explained as following. The used diamond-graphite mixture is complex object of carbon allotropes [42]. Each carbon allotrope has its own electronic structure. Each electronic structure corresponds to an absorption spectrum. The electronic structure of carbon allotrope might be varied by structural changes in the diamond-graphite mixture. Thus, we have a sum of electronic structures of all carbon allotropes. Ultimately, there is a continuous absorption spectrum from a sum of electronic structures of all carbon allotropes. In addition, there is a phonon spectrum of diamond-graphite mixture. This spectrum is determined by analogy with the electronic structure. This phonon spectrum corresponds to the absorption spectrum. Thus, there is the absorption spectrum from the electron structure and the phonon spectrum.

It can be assumed that the absorption depends on the wavelength. To increase the absorption in the entire range, it is necessary to increase the content of diamond-graphite mixture as much as possible in the absorber. A good binder for diamond graphite mixture appeared to be polyethylene. The polyethylene maximizes content of diamond graphite mixture in film absorber. As a result, the absorption increases and is aligns over the entire spectrum. Additional absorption occurs when the incident wavelength is repeatedly reflected from a structured surface (see Fig. 3c). Ultimately, the broadband and uniform absorption spectrum is obtained.

To compare our manufactured flexible thin absorber with the other absorbers, we have collected important parameters of the absorbers in Table 1.

As can be seen from Table 1, basically, broadband absorbers are either carbon materials or nanostructured materials that have high absorption and do not have a flexibility. On the other hand, our fabricated absorber has absorption comparable in magnitude to the other absorbers and has sufficiently wide absorption range. Furthermore, one of the main advantages of the absorber is flexibility. Thus, the designed and manufactured absorber based on diamond-graphite mixture and polyethylene might become a

Table 1
The important parameters of different absorbers.

Absorption range ($\text{cm}^{-1}/\mu\text{m}$)	Absorption	Composition of absorber	Flexibility	Reference
85–8000/117–1.25	>0.98 (>320 cm^{-1})	Diamond-graphite mixture and polyethylene	Yes	Present study
50–50000/200–0.2	0.98–0.99	Vertically aligned single-walled carbon nanotubes	No	[23]
7143–25000/1.4–0.4	>0.968	Disordered nanostructured material based on Au nano-absorbers	No	[47]
833–40000/~12–0.25	>0.99	Biomimetic silicon nanotip	No	[48]
4000–10000/2.5–1	>0.95	Carbon nanotube and nanodiamond	–	[49]
667–25000/15–0.4	>0.99	Vertically aligned multiwall carbon nanotubes	No	[28]
6452–25000/1.55–0.4	>0.96	Laser textured titanium	No	[50]
2079–5650/4.81–1.77	>0.98	Nanostructured Pd and polyimide	No	[40]
714–3333/14–3	>0.99	Vertically aligned carbon nanotube	–	[51]
200–2000/50–5	>0.98	Vertically aligned carbon nanotube	No	[52]
1428–28571/7–0.35	>0.97	Vertically aligned multi-walled carbon nanotube	No	[53]
1000–25000/10–0.4	~0.99	Au nanoparticles and Al_2O_3 nanoporous template	No	[54]

promising material for optical devices where broadband absorption and flexibility are required.

4. Conclusion

We manufactured the flexible broadband absorber using diamond-graphite mixture and polyethylene. Angular reflectivity, diffusional reflectivity and transmittance were investigated in the range 85–8000 cm^{-1} (117–1.25 μm). These measurements were necessary to determine the absorption. It was shown that absorption has over 0.85 in the range 85–320 cm^{-1} (117–31.25 μm) and >0.98 in the range 320–8000 cm^{-1} (31.25–1.25 μm). We believe that designed and manufactured the absorber might become a promising material for optical devices where broadband absorption and flexibility are required.

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