Glass composite modified with silicon carbide and gallium arsenide, that absorbs electromagnetic radiation

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Abstract. The possibility of using waste of semiconductor manufacturing containing silicon carbide and gallium arsenide as an effective additive in radio absorbing material preparation was established as a result of research. The resulting material meets the requirements of effective porous electromagnetic radiation absorbers of extremely high frequency range: maximum absorption and minimum reflection of electromagnetic radiation, fire safety, the minimum allowable level of toxic and hazardous substances.

1. Introduction

The relevance of research on the porous glass composites creation due to the demand for radio absorbing materials with improved characteristics that differ from their counterparts in environmental and fire safety. The glass composite considered in this paper is a porous inorganic material consisting of a vitreous matrix and micro-sized particles of crystalline phase in the interporous septum. The particles of crystalline phase with high dielectric and magnetic permeability, give to material ability to absorb electromagnetic radiation. Such materials been used as radio absorbers of electromagnetic radiation of extremely high frequency range in various areas: shielding of premises, protection of mobile objects from detection, when detecting dangerous objects and substances. The requirements of functional properties for this material such as high absorption coefficient and low reflection coefficient of electromagnetic radiation, as well as reduced density and increased mechanical strength. Achieving these properties increases the material efficiency and has great prospects, but it is rather difficult to implement in practice, therefore it is of scientific interest for researchers.

Foam glass materials and composites obtained on the basis of glass microspheres are analogous to porous glass composite. Many foreign scientific publications contain the results of development and use of foamed glass materials in a wide variety of field. The use of foam glass as an absorber of electromagnetic radiation is a current new direction [1]. Broadband, efficient, lightweight, and relatively inexpensive radio absorbing materials are required in this area. Broadband is achieving due to the multi-layer structure, for example, sandwich panels, laminates and epoxy composites [2–5]. This approach greatly complicates the technology of radio absorbers and requires high-tech production. The material effectiveness is proving by the additional introduction of such absorbing additives as carbon nanotubes, carbon fibers, graphene, ferrites, magneto dielectrics [6, 7]. Carbon nonmaterial interacts with electromagnetic radiation and are effective modifiers, including the extremely high frequency range 53–73 GHz [8]. At the same time, the price of carbon nonmaterial is currently still quite high. Therefore, effective and relatively inexpensive additives are of practical interest.

Previously obtained experimental data showed that electronic manufacturing waste, consisting of silicon carbide and gallium arsenide, could be using as an effective modifier of porous silicate system [9]. Material safety is confirming by biotesting results and atomic emission spectroscopy of aqueous extract. According to the measurements, the amount of arsenic, transferred from the material to water, does not exceed the maximum permissible concentrations and amounts to 9.35 mg/l. This indicates the possibility of using this type of waste to obtain a safe material [10]. The waste transfer to safe state and its use as a component for production radio-absorbing material is an extremely important task. Gallium arsenide is supposed to improve the electrophysical properties of radio absorbent, since it has a number of structural features: a wide band gap (1.43 eV), high electron mobility (8500 $cm^2/(V \cdot s)$), direct interband transitions. Thus, without the use of expensive components, solved problems of environmental improvement and improvement functional properties of material.

The aim of the work is to develop a porous glass composite modified with silicon carbide and gallium arsenide at temperatures not exceeding 400 °C, which has a high radio absorbing ability in the extremely high frequency range (from 30 to 300 GHz).

Due to high permeability, electromagnetic waves of this range have great prospects and are using in such fields as medicine, safety systems, the study of fundamental characteristics of materials [11, 12].

2. Materiaks and experimental method

Liquid glass, perlite microspheres, hardener, semiconductor manufacturing waste containing silicon carbide and gallium arsenide using to obtain a radio absorbing material. Industrial sodium liquid glass with a silicate module 3 and a density of 1.36 g/cm^3 using in the work. Na_2SiF_6 with a content of sodium fluorosilicate of 98% been chosen as a hardener of the liquid glass composition. Perlite hollow microspheres with a bulk density of 150 kg/m^3 provide a lower material density. Perlite microspheres have the following chemical composition, wt. %: SiO_2 – 74.7; Na_2O – 5.3; CaO – 0.6; Fe_2O_3 – 1.2; K_2O – 5.1; Al_2O_3 – 12.8; MgO – 0.3. The phase composition of perlite microspheres is represented by orthoclase and glass phase. The average size of microspheres is 125 μm with a wall thickness of about 2 μm according to electron microscopy data (Figure 1), the shape is uneven, elongated, asymmetric. Figure 1 shows that microspheres have a polycameral cellular structure.

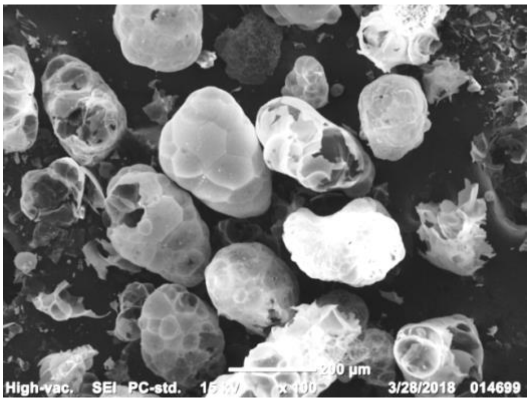

Figure 1. Electronic micrograph of perlite microspheres.

Waste of semiconductor manufacturing is forming in the process of cutting plates of gallium arsenide and polishing. The work investigated the sludge formed after polishing plates using silicon carbide. By particle size, waste refers to finely dispersed materials. The studied waste is 90% represented by particles with a size of less than 5 microns, and 30% of the grains have a size of less than 3 microns according to the results of laser diffraction (Figure 2). The bulk density of the waste powder, dried at room temperature, is 730–760 kg/m^3. The phase composition of waste is representing by silicon carbide and gallium arsenide. Reflexes corresponding to gallium arsenide are more pronounced and are consistent with the main established reflection maxima (d = 0.3263; 0.1998;

0.1708 nm). Less intense reflections correspond to silicon carbide (d = 2.5162; 2.5208; 2.6276 nm). The content of gallium arsenide is about 55%, and silicon carbide in pure form is 40% according to the results of a quantitative X-ray structural analysis carried out using the Match! Program. Less intense reflexes correspond to minor impurities in the form of gallium and boron carbide.

The radio absorbing properties were evaluating by measuring the reflection, transmission, and absorption coefficients using the “free space” method on a STD-21 terahertz spectrometer in the 120–260 GHz range. To study the electromagnetic response, flat samples with a size of 30×50 mm^2, of various thicknesses were using.

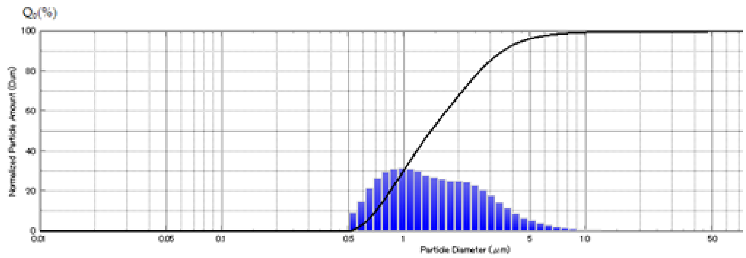

Figure 2. Electronic micrograph of perlite microspheres.

The absorption coefficient was calculated (1):

$$A = 1 - R - T \tag{1}$$

where R – reflection coefficient, T – transmission coefficient, rel. unit.

3. Results

Production of porous glass composite was caring out according to the developed technological scheme presented in Figure 3. The technology includes the stage of waste preparation, mixing of components and heat treatment of liquid glass composition to a solid state. Waste preparation involves drying, since the sludge formed after grinding plates has a moisture content of about 15%. Granulation was caring out with the addition of a solution of liquid glass, which leads to the coating of the granules with a strong film of sodium silicate and transfers the waste to a safe state. On the other hand, the contact of the granules with the liquid glass composition is improved. The use of liquid glass due to its ability to foam at a temperature of from 100 °C to 550 °C, which gives the material additional porosity and lightness. A hardener converts sodium silicate to an insoluble state. Perlite microspheres contribute to reducing mass of finished absorber, reacting with liquid glass and promoting its silicatization.

The temperature of the synthesis of the material does not exceed 400 °C. Gallium arsenide decomposes with arsenic starting with 600 °C.

It is knew that electro physical properties of porous material depend on its composition, structure and thickness. The presence in the material composition additives in the form of dispersed particles with high dielectric constant leads to increase absorption coefficient. In the case of waste, the role of such additives is performing by silicon carbide and gallium arsenide. The influence of waste amount on the efficiency of electromagnetic radiation absorption of the considered range was carried out on samples containing 10, 20 and 30 wt. % waste. A higher amount of waste leads to increase material density. The results of all experiments are giving for samples with a thickness of 1 cm.

Figure 4 shows the dependences the values of absorption, reflection and transmission coefficients of electromagnetic radiation for a sample with waste (10%) and without. The results show that the value of reflection coefficient is close to zero, including the material obtained without waste. This indicates that the mechanism for reducing intensity of electromagnetic radiation for these porous samples lies in the wave absorption and not in its reflection. When waste content at composite in the amount of 30%, the value of the absorption coefficient increases at a frequency of 22 GHz by 28 times, and at a frequency of 40 GHz by 4 times. The transmission coefficient in this case is regularly reducing by 2 times at 22 GHz and 5 times at a frequency of 40 GHz.

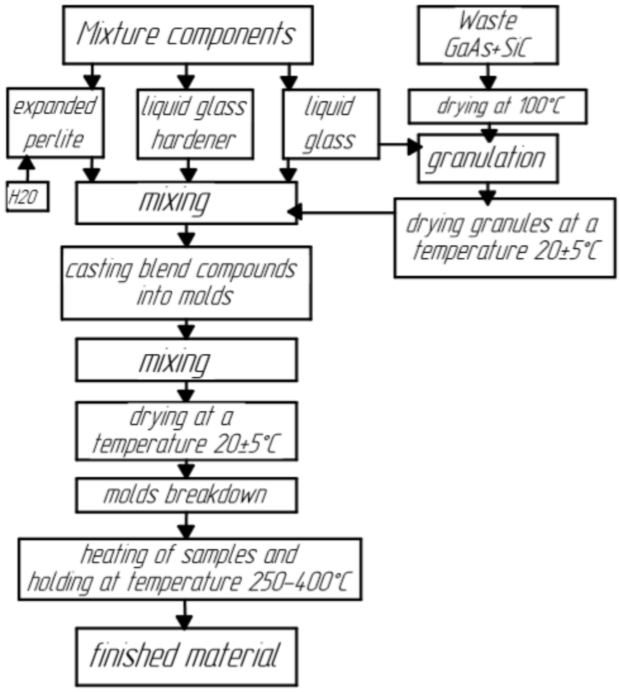

Figure 3. Technological scheme for obtaining electromagnetic radiation absorber with waste of semiconductor manufacturing.

The similarly situation in the high-frequency range of 120 – 260 GHz. The reflection coefficient is zero for all samples. With an increase the waste amount in the composite, the transmission coefficient decreases to zero when the waste content is 30%. The maximum value of absorption coefficient equal to 100% has a sample with a maximum content of waste at a frequency of 240 GHz (Figure 5). The value of the sample wave transmission coefficient with 30% waste compared to the sample without waste decreases at a frequency of 120 GHz by 15 times, and at a frequency of 240 GHz by 33 times.

For the obtained samples, the main physic mechanical properties were determined, the results of which are giving in table 1. The apparent density of the material increases, which also leads to an increase in the mechanical strength of the material with an increase waste content. Material corresponds to the class of heat-insulating structural materials according to the values of these indicators.

Table 1. Physical and mechanical properties of the composite.

The amount of waste in the composite, wt. %	Apparent density, kg /m^3	Compressive strength, MPa	The porosity of the composite,%
0	330	0.3	87
10	350	1.5	86
20	510	4.7	80
30	560	6.0	78

IOP Conf. Series: Materials Science and Engineering 1019 (2021) 012091 doi:10.1088/1757-899X/1019/1/012091

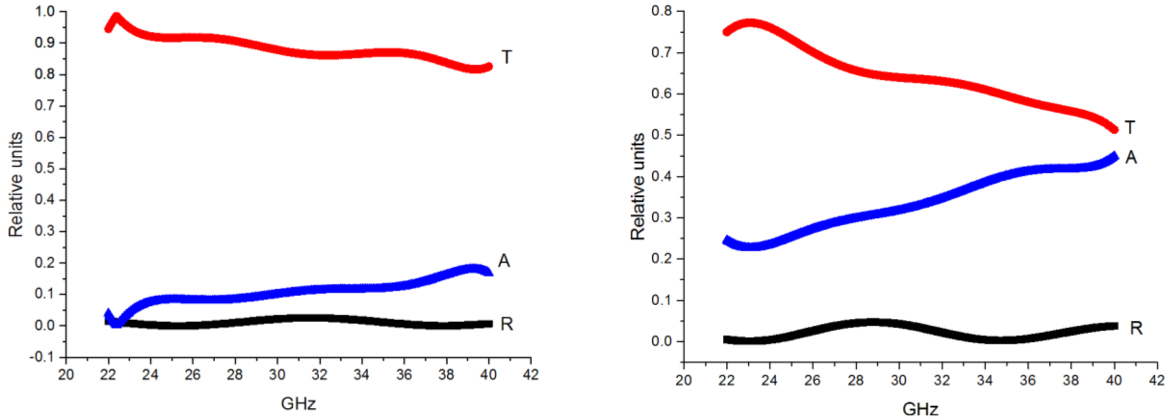

Figure 4. The dependence of absorption (A), reflection (R) and transmission (T) coefficients at a frequency of 20-40 GHz for a sample without waste (from the left) and with a waste of 10% (from the right).

Because of the research conducted, it was establishing that semiconductor production wastes could be using as an effective additive in obtaining a composite that absorbs electromagnetic radiation, including the extremely high frequency range.

4. Discussion

The developed mixture composition, comprising up to 30 wt.% of semiconductor manufacturing waste containing silicon carbide and gallium arsenide provides a composite that absorbs electromagnetic radiation in the extremely high frequency range of 30–300 GHz.

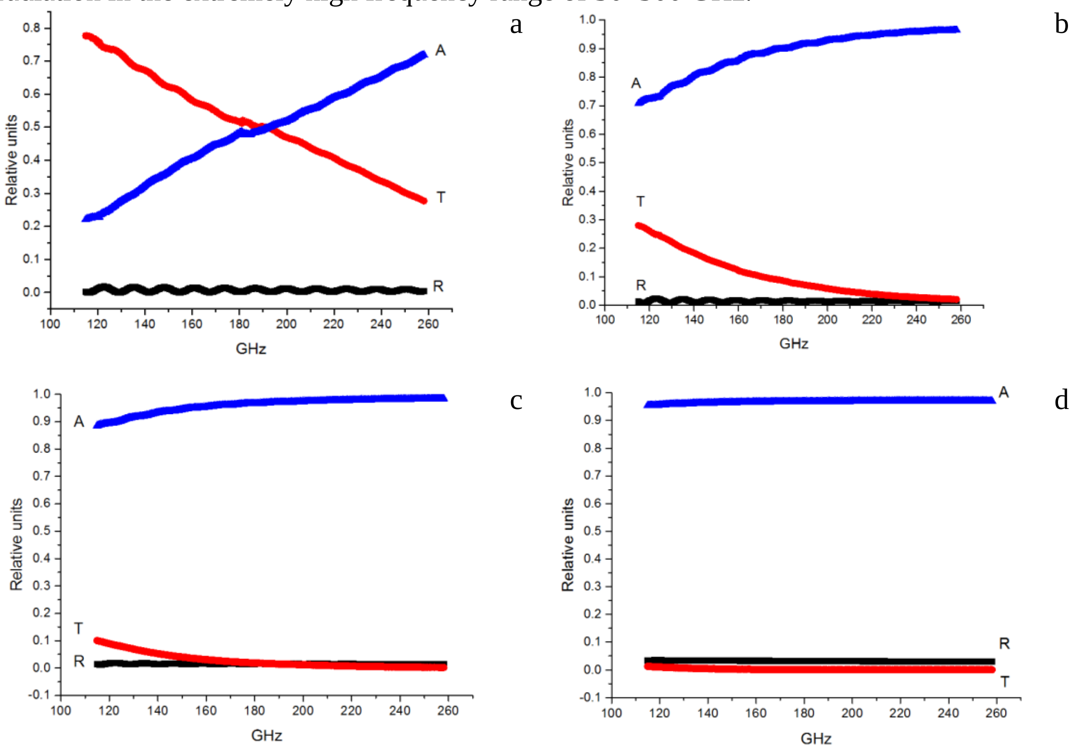

Figure 5. The dependence of the absorption (A), reflection (R) and transmission (T) coefficients of the frequency 120–260 GHz for the sample without waste (a) and with a waste of 10% (b), 20% (c), 30% (d).

A low-temperature (up to 400 °C) technology for producing a porous electromagnetic radiation absorber is proposing. The reflection coefficient equal zero. The absorption coefficient is 100% at a frequency of 260 GHz and 84% at a frequency of 40 GHz. The developed technology is a resource-saving and energy-efficient solution.

It is established that with an increase the waste amount in material from 10 to 30%, the material apparent density increases from 350 kg/m^3 to 560 kg/m^3 and compressive strength from 1.5 MPa to 6.0 MPa. This increases absorption efficiency of electromagnetic radiation, which is due to the influence of silicon carbide and gallium arsenide on the processes of polarization and conductivity in the composite during the absorption of electromagnetic radiation.

The resulting material meets the basic requirements for effective porous electromagnetic radiation absorbers of extremely high frequency range: maximum absorption and minimum reflection of electromagnetic radiation, fire safety, the minimum acceptable level of emission of toxic and harmful substances. The composite is recommending for use in anechoic chambers and high frequency devices.

Acknowledgments
The reported study was funded by RFBR, project number 19-33-90099.

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