Materials Today Communications 21 (2019) 100610

Contents lists available at ScienceDirect

Materials Today Communications

journal homepage: www.elsevier.com/locate/mtcomm

Magnetoactive elastomers with controllable radio-absorbing properties

Iren E. Kuznetsova[a,*], Vladimir V. Kolesov[a], Alexander S. Fionov[a], Elena Yu. Kramarenko[b], Gennady V. Stepanov[c], Michail G. Mikheev[b], Enrico Verona[a,d], Igor Solodov[a,e]

[a] Kotelnikov Institute of Radio Engineering and Electronics of RAS, Moscow, 125009, Russia
[b] Lomonosov Moscow State University, Faculty of Physics, Leninskie Gory 1, bld.2, Moscow, 119991, Russia
[c] Institute of Chemistry and Technology of Organoelement Compounds, Shosse Entuziastov, 38, Moscow, 111123, Russia
[d] Instituto di Fotonica e Nanotecnologie, IFN-CNR, Via Cineto Romano 44, 00185, Rome, Italy
[e] Institute for Polymer Technology (IKT), University of Stuttgart, 32 Pfaffenwaldring, 70569, Stuttgart, Germany

ARTICLE INFO

Keywords:
Magnetoactive elastomers
Influence of magnetic field
Radio-absorbing properties
Microwave frequency range
Reflection and transmission coefficients

ABSTRACT

Magneto-active elastomers (MAEs) based on a silicon polymer matrix filled with magnetic carbonyl iron microparticles have been synthesized. Both isotropic samples and samples micro-structured by an external magnetic field have been obtained. The radio-absorbing properties of the MAEs have experimentally been studied in the frequency range 2–10 GHz and at the central work frequency 30 GHz of the range 26–38 GHz in the absence and in the presence of an external magnetic field of 0.3 T. It has been shown that both the reflection and transmission coefficients of the MAEs change considerably when the magnetic field is applied, besides, their values strongly depend on the direction of the magnetic field as well as on the internal filler structure of MAEs. The developed MAEs could be used as controllable by an external magnetic field radio-shielding or polarizing covers.

1. Introduction

At present the elaborating smart materials with the magnetic field controllable properties is a very important task. There are such materials as magnetorheological gels [1], magnetorheological fluids [2], magnetorheological foams [3]. Besides, a new type of these materials is magneto-active elastomers (MAEs). These materials consist of a polymeric matrix filled with nano- and/or micro sized ferromagnetic particles [4–6]. The strong dependence of a wide range of the properties of these materials upon an applied magnetic field makes them very promising for various applications, from the tunable dampers and seals, already developed and implemented [7–11], to the magnetic field sensors [12].

There is a new field of MAE application as absorbers of electromagnetic (EM) energy [13]. This is a very important field due to dramatically increasing number of electronic devices operating at high frequency range (microwave oven, cellular phone, medical equipment, etc.), problems of EM radiation and pollutions caused, for example, by radars or transmission facilities. It is necessary to find such cover materials that will allow to reduce harmful effects of EM radiation to humans, to prevent mulfunctioning of various electronic components, etc.

It is known that the process of interaction of EM radiation with magnetic materials is accompanied by transformation of EM energy into Joule heat due to magnetization of magnetic structures in the material and by reflection of the part of EM energy from the material [14]. The possibility to use MAEs as radio-shielding materials is based on such their properties as magnetic hysteresis and high-frequency dielectric losses that lead to EM energy conversion into Joule heat. So the absorption of EM radiation in MAEs is connected with various loss mechanisms like magnetization and electric polarization processes [14]. It is known that carbonyl iron (CI) particles [15] and silver-coated CI powder [16] can be used as covers for electromagnetic interference shielding applications. The possibility to extend the operating frequency range by using frequency –selective surfaces or by incorporating NiZn, MnZn particles, graphite, multi-walled carbon nanotubes was reported in Refs. [17–20]. The radio-absorbing properties of MAEs based on polydimethylsiloxane (PDMS) elastomer with incorporated soft carbonyl iron particles in the frequency range 0.5–3 GHz have recently been investigated [21,22]. The authors considered not only isotropic MAE based on homogeneously distributed particles [21] but also anisotropic MAE with filler particles aligned into chain-like structures obtained by applying an external magnetic field during the polymerization process [22]. It has been shown that the alignment of

* Corresponding author.
E-mail addresses: kuziren@yandex.ru (I.E. Kuznetsova), kram@polly.phys.msu.ru (E.Y. Kramarenko), gstepanov@mail.ru (G.V. Stepanov), enrico.verona@ifn.cnr.it (E. Verona), igor.solodov@ikt.uni-stuttgart.de (I. Solodov).

https://doi.org/10.1016/j.mtcomm.2019.100610
Received 22 March 2019; Received in revised form 19 August 2019; Accepted 19 August 2019
Available online 20 August 2019

filer particles leads to improvement of microwave (MW) absorption in comparison with an isotropic sample [22].

However, influence of an external magnetic field on the radio shielding properties of MAEs both isotropic and structured has not been considered yet. The dependency of the reflection coefficient versus an angle between particle chain-like structures and microwave polarization is also absent.

In our paper the MAEs based on CI particles incorporated into silicon compound have been investigated. We suggest to use them for microwave shielding purposes. We considered isotropic samples and samples micro-structured in two directions by an external magnetic field during the polymerization process. The reflection and transmission coefficients of the designed MAE samples in the frequency range 2–10 GHz and at the central work frequency 30 GHz of the range 26–38 GHz have been investigated. The influence of an external magnetic field on these properties was studied. The obtained results allowed to suggest the developed material as smart radio-shielding material with controllable properties.

2. Experimental methods

2.1. Materials and sample fabrication

Polymer matrix of the MAEs was synthesized starting from the silicone compound SIEL produced by the State Institute for Chemistry and Technology of Organoelement Compounds (www.eos.su). Carbonyl iron particles with size 3–5 μm and concentration 80% in the mass were used as the filler. At first, the magnetic filler was processed in a rotor evaporator to remove any trace of the moisture from the surface and to provide its hydrophobic properties in order to ensure its compatibility with a polymeric matrix. Then the magnetic filler and SIEL consisting of a mixture of a low-molecular vinyl-containing rubber and a hydride-containing cross-linking agent were mixed in a porcelain beaker. The obtained mixture was homogenized using a roll powder dispenser. As a result, a stable liquid pre-composition was achieved. Finally, the catalyst was introduced into the pre-composition. Before polymerization the mixture was degassed in vacuum at a pressure of about 1–2 mm Hg. Then the obtained composition was poured into a mould previously treated with an anti-adhesion compound [23–27]. The polymerization was carried out at the temperature of 150 °C. As a result, the isotropic non-structured samples (S_0) with a homogeneous filler distribution were obtained. The structured samples were obtained by applying a uniform magnetic field H of 80 m T during the polymerization reaction. Under an external magnetic field CI particles form some 3D net with a predominant orientation along the lines of the applied magnetic field, which is fixed during the polymerization process. Depending on whether the magnetic field was applied parallel or perpendicular to the sample surface two different types of the structured materials ($S_{\|}$ and $S_{\perp}$, respectively) were obtained. The described process of the samples production and the photo of obtained samples are presented in Fig. 1a and b, respectively.

2.2. Samples characterization

The internal structure of the samples was investigated by an optical microscopy (Carl Zeiss Axio Imager) at a magnification of 1000 both in the reflection (DIC) and transmission (TIC) regimes. The magnetic properties of the materials under study were measured by a vibrating magnetometer (EG&G PARC-155) with a sensitivity of 5×10^{-5} G/cm^3 at 300 K under a magnetic field up to 0.5 T. The electrical permittivity of the samples was measured at the frequency 1 kHz by a high-precision LCR meter (Agilent E4980) equipped with a dielectric test fixture (Agilent 16451B).

The microwave measurements of a reflection coefficient were carried out in the central work frequency 30 GHz for range 26–38 GHz using a standing wave coefficient measuring set (KSVN R2-65, Russia)

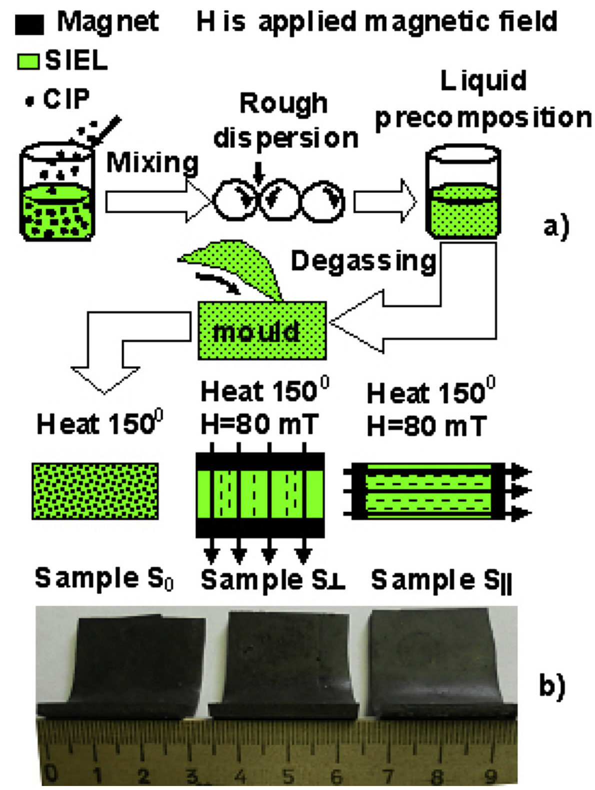

Fig. 1. a) Schematic diagram of the samples production, (b) Photo of the produced samples under study.

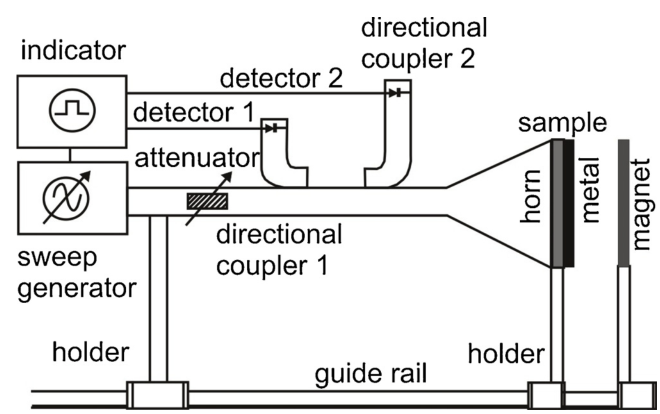

Fig. 2. Experimental setup for the measurement of the reflection coefficient of the MAE samples under study at the central work frequency 30 GHz of the range 26–38 GHz in the presence of an external magnetic field.

with a cross section of the waveguide of 7.2×3.4 mm^2 according to the experimental setup shown in Fig. 2. The MW signal generated by a sweep generator at a power of 4 mW was applied to the rectangular waveguide and adjusted by a calibrated attenuator. At the opposite side of the guideline the transition from the rectangular waveguide to the circular horn antenna with an aperture of 15 mm was carried out with the help of an additional waveguide section where the linear polarization is maintained.

To measure the influence of a magnetic field on the MW absorption properties of the MAE samples under study we used the free-space reflection method [28–30]. The horn antenna provides a plane wave at a short distance from a sample so that any diffraction effect at the edges of the sample as well as any interference from the surrounding are minimized. At first, the measuring system was calibrated for the full reflection by placing a copper plug in the mouth of the horn. After that,