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ORIGINAL PAPER

# Microwave Absorption Properties of $BaFe_{12}O_{19}$-$TiO_2$ Composite Coated with Conducting Polymer

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**Abstract** This study investigates microwave absorption properties of Ba-hexaferrite ($BaFe_{12}O_{19}$) and titanium dioxide ($TiO_2$) particles coated with conducting polymer (PANI) and $BaFe_{12}O_{19}$-$TiO_2$ mixture in the frequency range of 8–18 GHz. Samples having different magnetic to dielectric mass ratios and various thicknesses from 1.5 to 4 mm have been prepared to investigate effect of magnetic and dielectric fillers together with influence of conducting polymer layer on microwave absorption properties of $BaFe_{12}O_{19}$-$TiO_2$ composite. Structural, magnetic, and microwave absorption properties of composites have been investigated using X-ray diffraction, scanning electron microscopy and near field microwave measurements using vector network analyzer. Microwave measurements revealed that composites with PANI coating have much higher absorption values which are independent of an absorber thickness. Among PANI coated absorbers, sample having magnetic to dielectric mass ratio of 2 showed better microwave properties in 8–18 GHz range.

**Keywords** Magnetic and dielectric composite · Magnetic properties · Microwave absorption · Conducting polymer

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## 1 Introduction

Modern microwave absorbers involve the use of compounds, in an insulating polymer matrix, capable of generating magnetic and/or dielectric losses when exposed to an electromagnetic wave. As fillers, both soft and hard magnetic materials as well as dielectrics are used. Spinel ferrite-polymer composites have been widely used in lower end of the microwave band (1–3 GHz) [1]. One of the major problems for the absorbers of soft magnetic materials is the rapid decrease of permeability, i.e., magnetic loss, in the GHz range. For this reason, M-type hexagonal ferrites are a special kind of absorbers due to their magnetic and dielectric losses in the microwave band, and have been extensively studied to prepare high frequency absorbers [2]. Recently, intrinsic conducting polymers (ICP) appears to be good candidate and has opened new horizon in the field when they are used as an electromagnetic interference shielding material due to the higher electrical conductivity, ease of processability, low density, good corrosion resistance, and its shielding mechanism, which is absorption rather than reflection [3].

In this work, we have used BaM ($BaFe_{12}O_{19}$) and $TiO_2$ as magnetic and dielectric dipoles, respectively, and PANI was preferred as a conducting polymer. The structural, morphological, magnetic, and microwave absorption properties of this nanocomposite have been studied by XRD, TEM, SEM, and vector network analyzer (VNA) techniques.

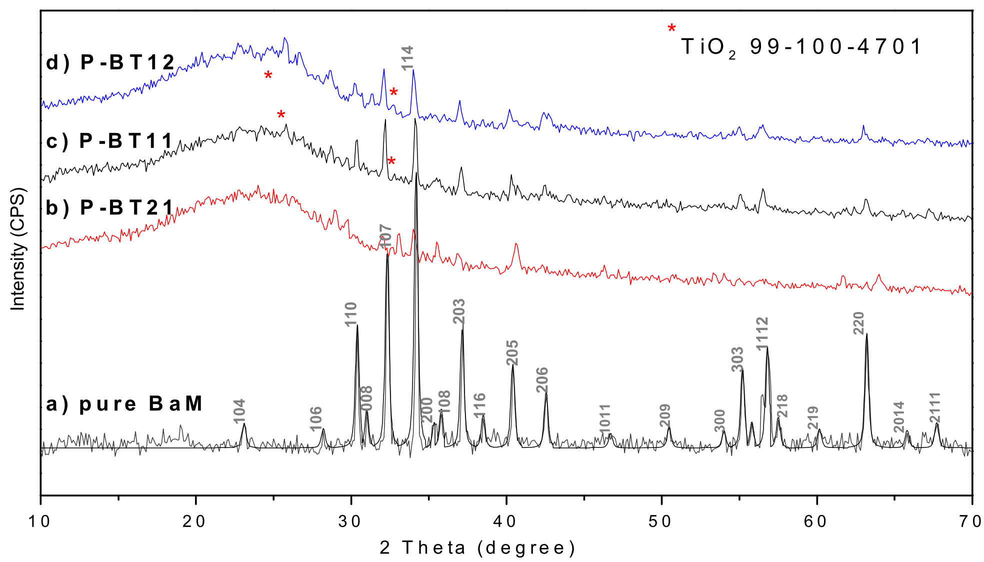


**Fig. 1** XRD powder patterns of (**a**) pure BaM, P-BT (**b**) (2:1), (**c**) (1:1), (**d**) (1:2)

## 2 Experimental

### 2.1 Synthesis

The composites of $BaFe_{12}O_{19}$ and $TiO_2$ were prepared with the sol-gel method as described in [4]. PANI-$BaFe_{12}O_{19}$-$TiO_2$ nanocomposite was prepared by in situ polymerization of aniline. Several samples, having different magnetic to dielectric mass ratios, have been prepared and labeled as follows. The composite having magnetic to dielectric mass ratio of 2, for example, is indexed as BT21 and the one which is coated with PANI, is labeled as P-BT21. We have totally prepared six composites, three of which are BT11, BT12, BT21, and PANI coated of these three (i.e., P-BT11, P-BT12, P-BT21).

### 2.2 Characterization

The crystallite size and phase fractions of the samples were determined from the XRD patterns (Rigaku Smart Lab, Cu-$K_\alpha$ radiation). The scattering parameters of samples for reflection (S11 or S22) and for absorption (S12 or S21) were determined by HP 8510C vector network analyzer. Full two-port calibration was performed to remove some errors due to the directivity, source match, load match, etc. in both forward and reverse direction. Scanning Electron Microscopy (SEM) analysis was performed, in order to investigate microstructure of samples, using a JEOL 6335F Field Emission Gun Microscope.

## 3 Results and Discussion

### 3.1 XRD Analysis

Figure 1 shows the X-ray diffraction pattern of pure BaM (Fig. 1a), polyaniline coated $BaFe_{12}O_{19}$-$TiO_2$ nanocomposite (Fig. 1b–d). All the observed peaks were matched with the standard XRD pattern of $BaFe_{12}O_{19}$ (JCPDS No. 84-0757), and additionally Fig. 1c and d were also matched with the standard XRD pattern of $TiO_2$ (JCPDS No. 84-1285).

### 3.2 SEM Analysis

The SEM (Fig. 2a) images of $BaFe_{12}O_{19}$ particles indicate that strong agglomeration of particles in the size range of ∼100 nm to ∼900 nm. Grains have rounded edges and do not have a hexagonal crystal structure probably due to the sintering at low temperature (850 °C). When BaM and $TiO_2$ particles were incorporated into the polymer matrix, they showed agglomerated morphology; see Fig. 2b. It is possible to see gray PANI layer around a black core, $BaFe_{12}O_{19}$-$TiO_2$ clusters, due to the different electron penetrability.

### 3.3 Microwave Absorption and Shielding Properties

The obtained BaM NPs and $TiO_2$ NPs microwave properties were investigated by reflection-transmission method, then S11 and S21 complex scattering parameters were measured between 8.2–18 GHz. The Reflection ($R = |S11|^2$), Transmission ($T = |S21|^2$) coefficients are calculated and the absorption coefficient is derived from the equation of $A = 1 - R - T$. The absorption characteristic of composites with and without coating and at different thickness is shown in Fig. 3a–d. Generally, uncoated samples have closer absorption percentages at all thicknesses. However, coated samples are 2–5 times better absorption values. Especially, the sample of P-BT12 (i.e., BaM:$TiO_2$ = 1:2 and coated with PANI) is the best absorber in all thicknesses. The absorption percentages of samples with 1.5 mm are 25 %,

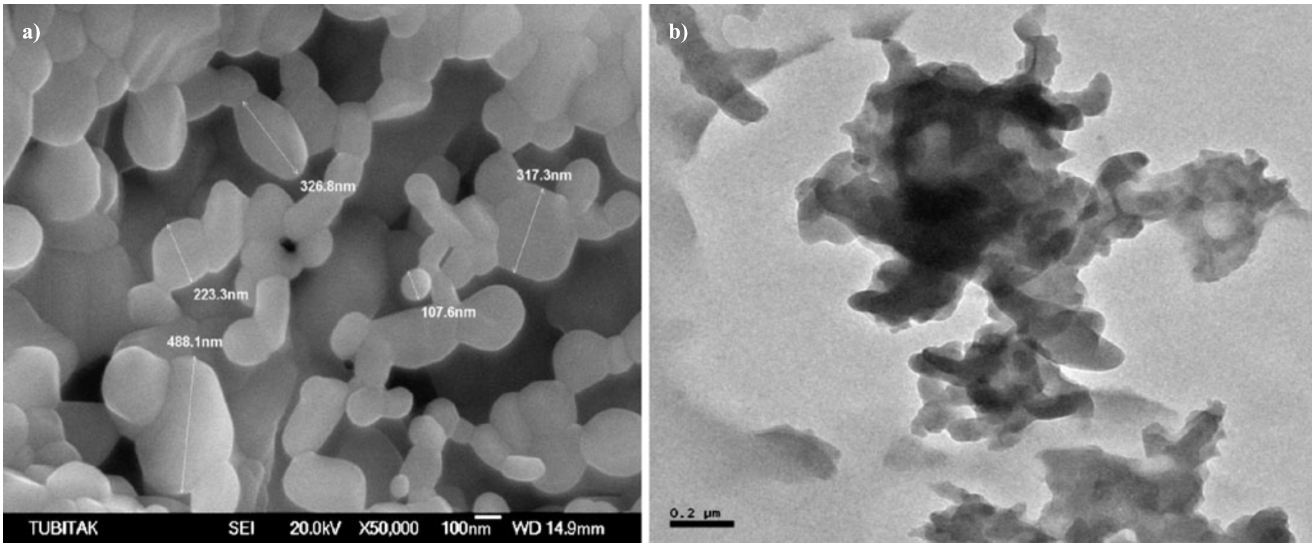


**Fig. 2** SEM micrographs of (**a**) pure Ba-hexaferrite, (**b**) PANI coated sample P-BT11

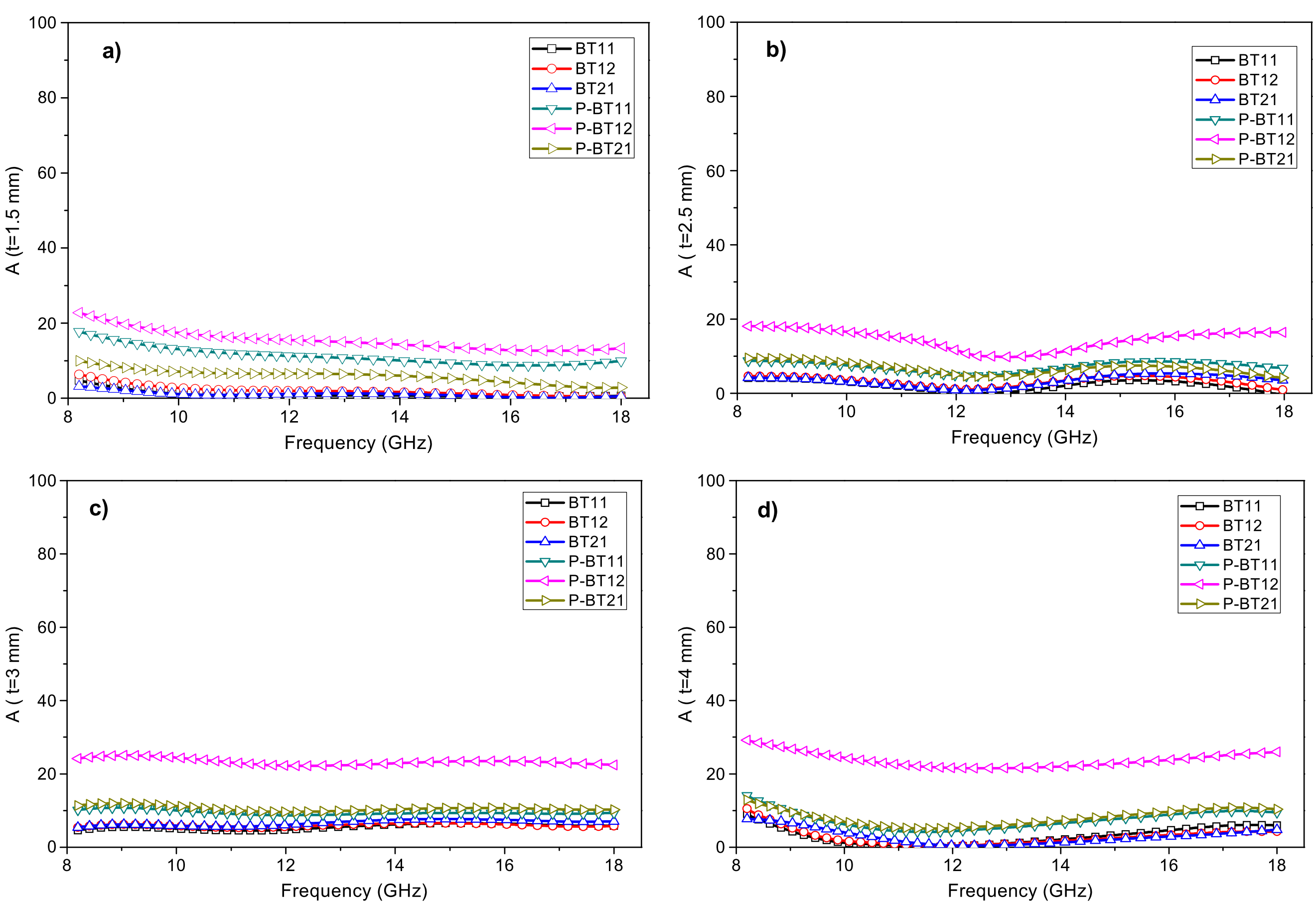


**Fig. 3** Absorption percentage vs. frequency plots of BaM-$TiO_2$ composites at various thickness: (**a**) $t = 1.5$ mm, (**b**) $t = 2.5$ mm, (**c**) $t = 3$ mm and (**d**) $t = 4$ mm

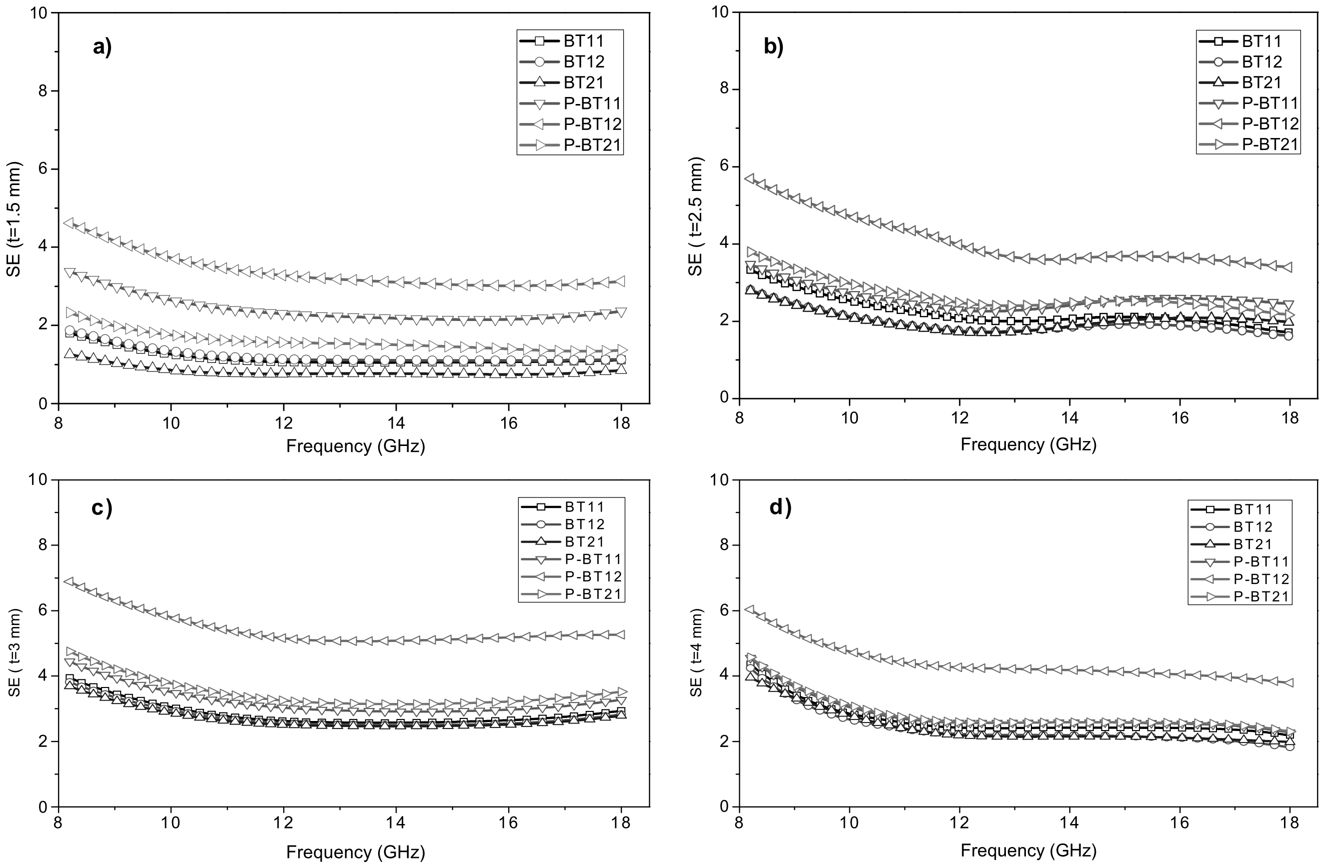


**Fig. 4** Shielding Effectiveness (SE) vs. frequency plots of BaM-$TiO_2$ composites at various thickness: (**a**) $t = 1.5$ mm, (**b**) $t = 2.5$ mm, (**c**) $t = 3$ mm and (**d**) $t = 4$ mm

18 %, and 5 % for PANI coated samples P-BT12, P-BT11, and P-BT21, respectively. By increasing frequencies absorption of microwave energy at these samples are slightly decreasing. At thicker P-BT12 gives better absorption results than whole samples (Fig. 3b–d). Microwave absorption of this sample is weakly frequency dependent in such a way that as thickness of the samples increasing, absorption decreases first and then increases again at high frequency values. The other coated samples (P-BT11 and P-BT21) have greater absorption values than the uncoated ones [5].

Figure 4a–d shows Shielding Effectiveness (SE) of all composites with various thicknesses. Composites without PANI have SE values in the range of 1 and 4 dB. With the PANI coating, it was doubled, for example, in the samples having thickness of 1.5 mm. The P-BT12 sample differs from other samples due to the higher shielding efficiency. At lower frequencies, PANI coated samples, P-BT12, P-BT11, and P-BT21, with a thickness of 1.5 mm have SE values of 4.8, 3.5, and 2 dB, respectively. The SE of these samples slightly decreases with increasing frequency. Except the sample P-BT12, all other absorbers with a thickness of 4 mm, almost the same SE in the frequency range of 8–18 GHz.

All reflection transmission and absorption measurements show that increasing thickness between 1.5 and 4 mm gives better absorption and the more $TiO_2$ in weight with respect to BaM in composites also reveals more absorption. This result is consistent with [6] that reports the addition of $TiO_2$ increases the SE value of the PANI coated $Fe_3O_4$ composite.

## 4 Conclusion

The microwave characteristic of Ba-hexaferrite:$TiO_2$ and PANI coated Ba-hexaferrite:$TiO_2$ composites with various thicknesses and different magnetic to dielectric weight fractions were investigated. We can conclude that the more dielectric material in weight in composites the more absorption is. Indeed, the weight ratio of Ba-hexaferrite:$TiO_2$ 1:2, 1:1 and 2:1 in composites have more absorption in order. In addition to this, presence of the PANI layer has a considerable effect on absorption and shielding effectiveness of the composites. It may increase the absorption rate up to 5 times compared to the uncoated composite.

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