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Determination of complex permittivity and shielding parameters in microwave frequency range using resonance and transmission based techniques

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Abstract- In the present work, microwave measurements have been carried out on natural rubber and with different concentration of expanded graphite in rubber matrix prepared using conventional melt mixing process. The transmission and resonance based techniques are employed to measure the dielectric parameters of composites using a Vector Network Analyzer (VNA). The detailed analysis of reflection loss/ absorption has been carried out with variation of frequency and the thickness of the samples. The transmission based technique in X-band frequency range has been used to extract the shielding parameters of the composite samples. The details of characterization techniques using VNA and the procedures for extracting dielectric and EMI shielding parameters are discussed.
Keywords: Complex permittivity, shielding parameters, microwave frequency range, resonance, transmission based techniques.

Introduction and Experimental

The explosive development of electromagnetic resources in commercial, military, and scientific fields has increased the problem of electromagnetic interference (EMI). Therefore, considerable attention has been paid to develop effective microwave-absorbing materials with lightweight and highly efficient absorption properties [1]. Therefore there is a great interest in measuring the dielectric and electromagnetic shielding parameters of electromagnetic absorbers in the microwave frequency range. The choice of adequate measurement technique depends on the value of real and imaginary parts of permittivity, shape, consistency and dimensions of the sample. In this paper, two types of measurements have been carried out for polymer composite materials viz. resonance method and transmission/reflection method [2] using a Vector Network Analyzer-VNA (Agilent 8722ES). The considered composite material is natural rubber with expanded graphite (EG) at concentrations of 5 and 20 percentages, synthesized with melt mixing process. The microwave dielectric properties were extracted from measured scattering parameters using the Nicolson Ross Weir method [3, 4]. The complex permeability is considered to be that of free space (μ_r=1). The EMI shielding parameters were calculated using the Scattering parameters of the composite samples having thickness of about 1.6mm.

Results and Discussion:

The microwave dielectric properties of the composite polymers are measured first using a technique that uses a Split Post Dielectric Resonator (SPDR) connected to the Vector Network Analyser [5]. The resonator used got a resonant frequency of 2.5 GHz. The measured real part of permitivty and loss tangent of the composites using SPDR technique is given in table 1. Measurments are carried out to determine the unloaded quality factor and resonance frequency of resonator with and without sample.

Table 1. Dielectric parameters measured with SPDR technique.

Sample code	Dielectric constant	Loss tangent	Frequency (GHz)
Rubber EG-0	2.9	0.0074	2.486
Rubber EG-5	5.2	0.0100	2.447
Rubber EG-20	(Resonance disappeared)	-------	-----------

The unloaded Q-factor depends on conductor and dielectric losses and all other related parameters. The dielectric parameters can be derived based on measurements of the resonant frequencies, quality factor and physical dimensions of the sample [5]. The measurement is not possible for Rubber EG-20 sample because of its higher conductivity and absorption or reflection.

Fig 1 shows the microwave dielectric properties of composite samples measured in broad band frequency range using a transmission technique. The dielectric constant as well as the dielectric loss are increasing with an increase in concentration of expanded graphite in rubber matrix. The values of ε' and ε" are slightly increasing with increase in graphite concentration from EG0 to EG5. However, the EG5 to EG20 composites are showing a drastic increase of ε’ and ε" values. The dielectric loss variation of rubber samples with different concentration of graphite are shown in fig. 1(b). Graphite is believed to be a major contributor of dielectric losses due to high dipole moments from reorientation of dipoles in composites. Dielectric loss tends to increase with increase in frequency for higher concentration of graphite and still higher concentration of it leads to increase of the conductivity.

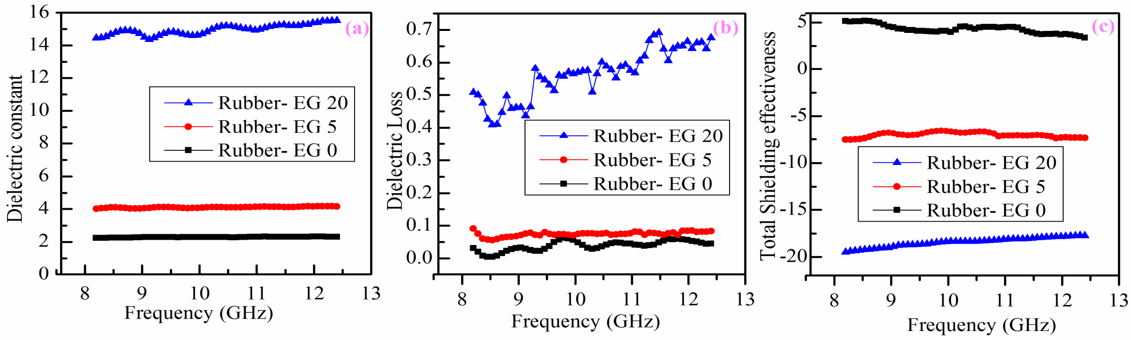

Fig.1 The variation of dielectric parameters and shielding efficiency with frequency for composites of rubber matrix with EG concentration

Fig. 1(c) shows the variation in EMI effectiveness of rubber matrix composites with various concentration of expanded graphite at the same thickness of 1.6 mm. The total SE of pure rubber is such that it is almost transparent to electromagnetic radiation and its EMI shielding is negligible. There is a significant improvement of total SE with increase of EG concentration. The increase of shielding efficiency may be due to the formation of good electrically conducting mesh-like networks within the rubber matrix which interacts with electromagnetic radiation and similar kind of response has been reported in polymer matrix also.

The reflection loss is calculated to understand the microwave absorption properties of the composite samples using the transmission line theory [6]. The calculated reflection loss curves of natural rubber with expanded graphite composites are shown in Fig 2. The intensity of microwave absorption as well as the peak position purely depends on the thickness of the sample as well as the dielectric parameters.

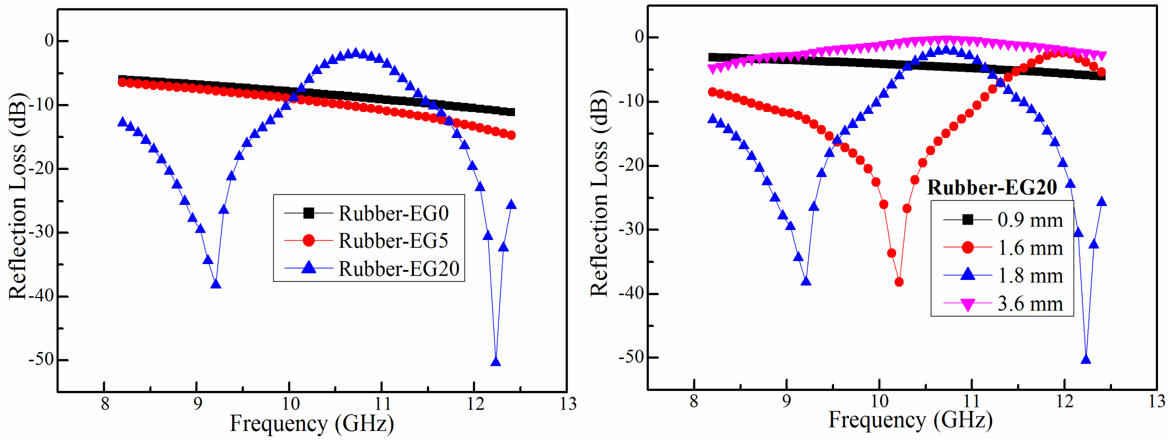

Fig 2. The reflection loss with variation of EG concentration in rubber and thickness of the sample.

Our results reveal that the complex permittivity increases with an increase in the percentage of expanded graphite on rubber matrix. The absorption peak position shifted towards the lower frequency with increasing the graphite concentration in rubber matrix, but the intensity of the peak is decreasing slightly. The microwave absorption for the Rubber EG0 and Rubber EG5 samples fall beyond the X-band frequency range. This kind of behaviour is already reported for the samples with larger thicknesses, but in the case of NR-20EG the two absorptions might be originating from the higher dielectric parameters. The narrowing of the bandwidth is due to the high dielectric constant of the samples.

Conclusions:

Two different techniques such as resonance technique and the transmission/reflection technique were employed to measure the microwave dielectric properties of natural rubber with expanded graphite. The EMI shielding parameters were measured for the same samples using scattering parameters. The variation of reflection loss/ absorption has been carried out with variation of frequency and the thickness of the samples.

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