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THIN FLEXIBLE MICROWAVE ABSORBER USING WASTE OF LI-ION BATTERY-RUBBER COMPOSITE FOR X-BAND APPLICATIONS

Dhruba Jyoti Gogoi[1], Dipangkar Borah[2] and N.S Bhattacharyya[3]

[1,2,3]Tezpur Central University, Napaam, Sonitpur, Assam-784028, India
E-mail: [1]dhrubag.gogoi@gmail.com, [2]dip.borah1991@gmail.com, [3]nidhisbhatta@gmail.com

Abstract—*The aim of this study is to develop a cost effective microwave absorber that can provide absorption over the whole X-band frequencies with -10 dB reflection loss (RL≥ -10 dB) with less coating thickness (i.e., ≤ 2.0 mm). To obtain the required specification, an electronic waste composite with silicone rubber is prepared. The waste part of expired Li-ion battery is used as inclusion with silicone based microwave absorber to fabricate high dielectric loss, flexible and thin single layer microwave absorbers and their reflection loss and microwave characterization were studied in the X-band (8.2-12.4 GHz) of microwave frequencies. The complex Permittivity (* $\varepsilon_r = \varepsilon_r^{/} - \varepsilon_r^{//}$ *) and permeability (* $\mu_r = \mu_r^{/} - \mu_r^{//}$ *) of the absorber samples have been measured for various weight fraction (wt. %) of the composite. The elements presents in composite material are confirmed through Energy Dispersive Spectroscopy (EDS). The wasted part of the battery when impregnated into the rubber matrix imparts the required complex dielectric permittivity and permeability to the composite. Thickness of the absorber is an important criterion influencing the absorber characteristics. Composites samples of 1.5mm thickness is found to absorb almost over the whole X-band frequencies with -10 dB reflection loss. The developed absorber possesses a peak reflection loss (RL) value of -40 dB at 10.3 GHz (calculated) for 1.5 mm absorber layer thickness for the composite with weight fraction 55 wt. % and loss tangent value* $\tan\delta_\varepsilon = 0.2$*. The calculated and measured results shows very good agreement between them.*

Keywords*: Microwave absorber, composite material, wasted battery and microwave absorber.*

1. INTRODUCTION

In recent decades the widespread development and use of the electronic and electrical equipment in gigahertz range such as wireless communication tools, local area networks, personal digital assistant and other communication equipment have created a new kind of problem called electromagnetic interference (EMI). It can wreak havoc with instruments, control systems, data-processing equipment, and communications networks in various commercial and military applications. Thus, EMI poses a significant challenge to equipment designers in a world that depends on electrical and electronic devices. The more critical and sensitive the equipment, the more important is the need to shield it. To provide a suitable solution for the EMI problem, the shielding or absorbing of the electromagnetic field is taken into account to make an electromagnetic compatibility (EMC) environment. The EMI shielding can be achieved either by reflection or absorption of interfering electromagnetic wave [1]. With progressive development of wireless technology thin, flexible and broadband EM wave absorption materials have attracted considerable attention as EMI shielding through absorption mechanism to today's advanced applications due to the fact that they can absorb microwave energy [2-3]. Microwave energy, when incident on a lossy dispersive material, creates heating within the material through the interactions of the electromagnetic field with the material's molecular and electronic structure [4].

In general, radar absorbing materials (RAM) are fabricated in the form of sheets that consist of insulating polymer, like rubber, epoxy resin and magnetic or dielectric loss materials such as ferrite, carbonaceous particles [5-12]. But it is still very challenging task to develop a thin broadband absorber with enhanced absorption capability in a cost effective manner. Waste materials have attracted increasing attention of researchers due to their excellent magneto-dielectric properties [13-14]. The density of the magnetic composite material for absorber is too high to use them in large quantity as filler of absorbers as it increase the weight of the absorber. Again, dielectric absorbers are thick compared to magnetic absorber leading to bulky devices and have larger impedance mismatch at the air-absorber interface. Therefore in recent years, the development of magnetic-dielectric composite materials have attracted increasing attention of researchers due to their excellent absorption characteristics. An effective microwave absorbing material need to satisfy the impedance matching condition $\mu_r / \varepsilon_r = 1$ at air-absorber interface where μ_r and ε_r represents complex magnetic permeability and dielectric permittivity, respectively [15]. Therefore, consideration of a wasted Li-ion battery from various electronic device having composites of both dielectric and magnetic particles may be a significant step towards the progress of a novel microwave absorber. Therefore, in this paper, the wasted materials of a Li-ion battery and silicone rubber composites is studied for its microwave absorption characteristics.

Generally, there are two types of absorbers: impedance matching or broadband absorbers and resonant absorbers. Broadband absorbers are independent of a particular frequency and can therefore be effective across a broad spectrum. The resonant absorbers are frequency-dependent because of the desired resonance of the material at a particular wavelength. Fig.1 shows the loss mechanism of resonant type microwave absorber.

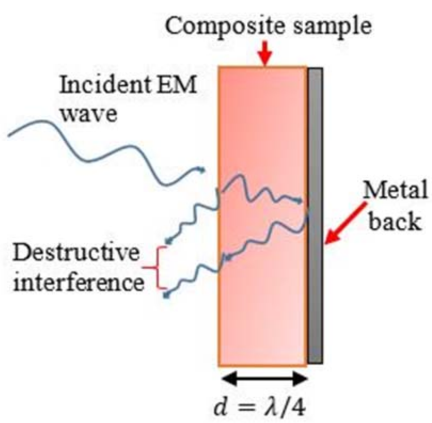


Fig. 1: Schematic diagram of absorption mechanism in single layer absorber

A useful visualization is that the incoming wave will be partially reflected by the front surface of the material while part is transmitted. The reflected wave undergoes a phase reversal of π. The transmitted wave then propagates through to the back of the absorber where it undergoes total reflection from the metal back and propagates back through the front face of the absorber. If the wave reflected off the front face is equal in magnitude and 180 degree out of phase with the wave reflected off the back face then the waves will cancel and there will be no total reflection [16].

2. MATERIAL AND METHOD

In this present work expired six cell Dell laptop Li-ion battery has been collected and subsequently crushed by mechanically to separate the powdered composite material used for anode and cathode of the battery from the outer cover, aluminum and copper sheets. The weight of collected powdered material from a single battery was found to be 8 gm. The morphology of the samples has been characterized by Scanning Electron Microscope, SEM (Model: JEOL JSM 6390 LV). The elements presents in composite material are confirmed through Energy Dispersive Spectroscopy (EDS). Samples of different thickness (d mm), are made from a three piece die mould with spacer, with varying the thickness for microwave characterization in the X-band with the sample dimension of 10.16 mm X 22.86 mm X d mm (Fig. 1).

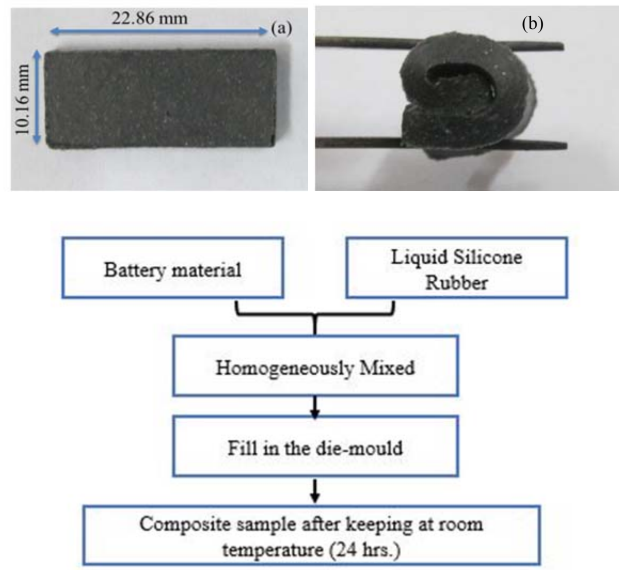


Fig. 2: (a) & (b) are the prepared powdered battery particles-rubber composites sample for X band characterization and Block diagram preparation of composite.

The microwave characterization i.e. the complex parameters of the material at microwave X-band frequency range (8.2 GHz-12.4 GHz) has been measured by Transmission/Reflection method using Agilent WR-90 X11644A rectangular waveguide line compatible with Agilent E8362C vector network analyzer.

3. RESULTS AND DISCUSSION

3.1 SEM and EDS analysis

Fig. 3. (a) shows the SEM image of the grinded wasted material composite, extracted from the die-out Li-ion battery. The existence of spherical shape particles have been noticed from the SEM image with some other irregular shape particles. The spherical shaped particles should be the carbon particles as it has the maximum 37.54 wt. % in the composite as found from the EDS analysis Table 1 .Fig. 2 (b) shows the EDS spectrum which reveals the presence of carbon (C), Manganese (Mn), cobalt (Co) and nickel (Ni) in the waste battery composite material. The proportion of the carbon wt. % has been seen maximum from the EDS analysis as Table 1, which indicates that the influence of carbon may be more for microwave absorption as compared to the other elements. However the presence of Mn, Ni and Co in the composite may

also be expected as a good contribution for the absorption mechanism as they have also very good absorption capability at microwave region [17-19].

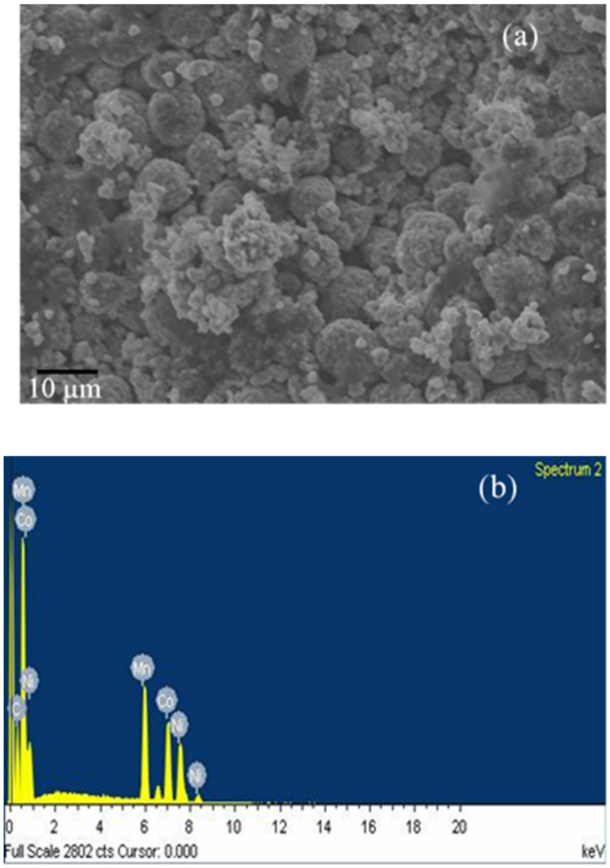


Fig. 3: An electronic-waste composite (a) SEM image and (b) EDS spectra representing the elemental contents present.

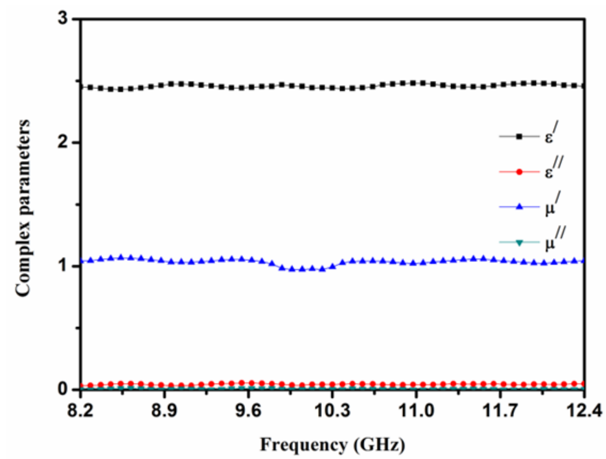
Table 1: The wt. % of different elements content in the battery composite from EDS spectra

Element	Weight %	Atomic %
Carbon	37.54	74.21
Manganese	20.84	9.00
Cobalt	23.15	9.32
Nickel	18.47	7.47
Total	100	100

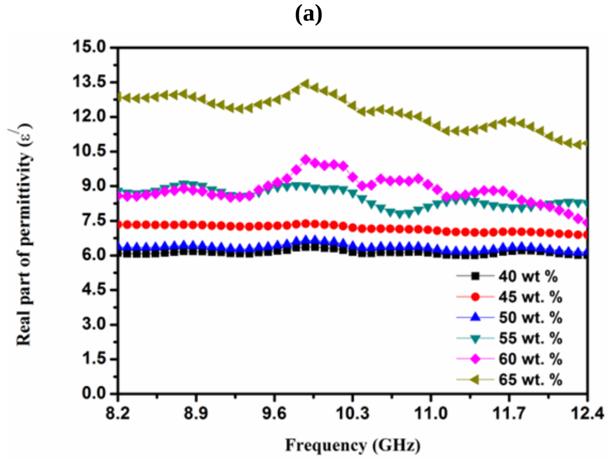
3.2 Microwave characterization

3.2.1 Complex permittivity and permeability

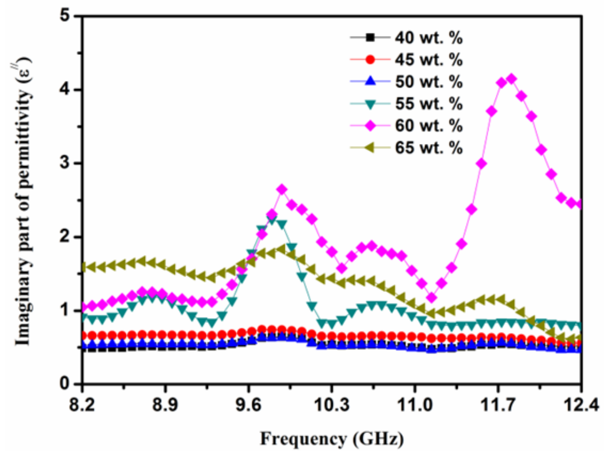
Material characterization at microwave frequency has been done by Transmission/Reflection method using Agilent WR-90 X11644A rectangular waveguide line compatible with Agilent E8362C vector network analyzer. Fig.4. (a) shows the frequency dependence of relative complex permittivity and permeability of pure silicone rubber sample, which has been used as base polymer matrix for making composites microwave absorber sample. From the material characterization of pure silicone rubber sample at X-band frequency range it has been seen that the silicone rubber can be used as a dielectric base material since it has real part of permittivity $(\varepsilon_r^{/})$ value near to 2.5 and permeability value $(\mu_r^{/})$ is 1. Fig.4. (b) and (c) show the frequency dependence of the real part $(\varepsilon_r^{/})$ and imaginary part $(\varepsilon_r^{//})$ of relative complex permittivity of different wt. % of powdered battery particles as filler material into the rubber composites at X-band (8.2–12.4 GHz) frequency range. The value of real part of complex permittivity has increased with increasing the filler concentration value from 40 wt. % to 65 wt. % as shown in fig (b). But the value of imaginary part of complex permittivity has increased with increasing the filler concentration value from 40 wt. % to 60 wt. % as shown in fig (b), after that the value fall downward as further increasing the filler concentration. Therefore the dielectric loss tangent $(\varepsilon_r^{//}/\varepsilon_r^{/})$ value increased correspond to increasing the filler concentration up to 60 wt. %, after that the value decreased as shown in fig. 4 (d). Composite with 50 wt. % and 60 wt. % shows maximum values of loss tangent approx. 0.02 and 0.12~0.045 respectively over the X-band frequency. Dielectric loss near to 0.2 suggest that the material has moderate dissipation factor rather than storage capacity.



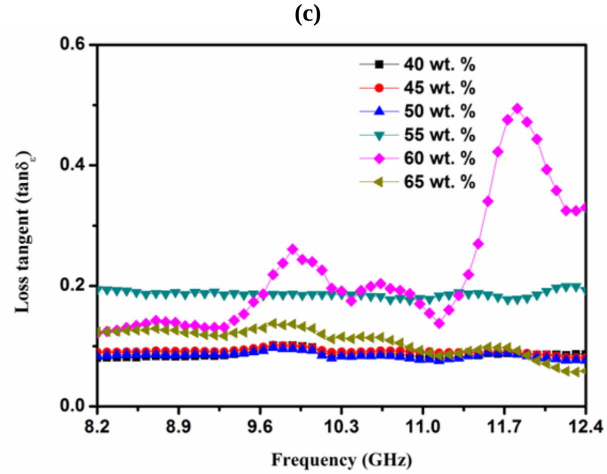
(a)



(b)



(c)



(d)

Fig. 4: (a) Complex parameters of pure silicone rubber sample (b) Real part of complex permittivity (c) Imaginary part of complex permittivity (d) Dielectric loss tangent $(\varepsilon_r^{//}/\varepsilon_r^{/})$ of different wt. % of powdered battery particles-rubber composites

3.2.2 Reflection Loss study

The experimentally measured complex parameters of the sample have been used for computation of reflection loss as per transmission line theory (TLM) [15]. According to transmission line theory the reflection loss for a conductor backed single layer absorber has been determined from the experimentally measured complex permittivity and permeability values of the composites. The reflection loss (RL) of the incident electromagnetic wave normal to the planar single-layered structure is expressed as

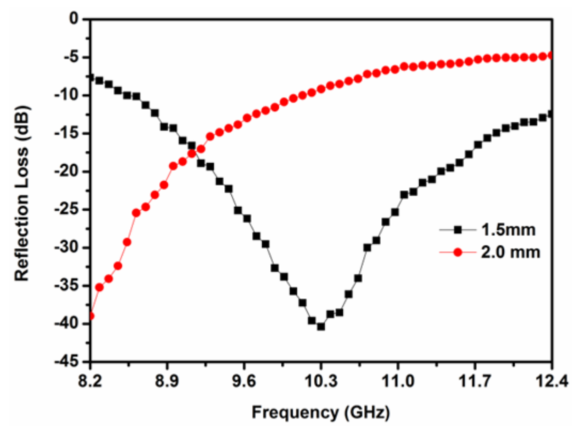
$$RL = 20\log\left|\frac{Z_{in}-Z_0}{Z_{in}+Z_0}\right|$$

Where,

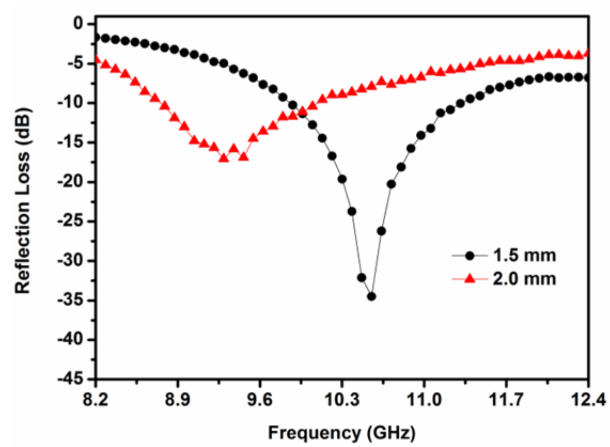
$$Z_{in} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\frac{2\pi fd}{c}\sqrt{\mu_r\varepsilon_r}\right)$$

Here f is the resonant frequency, d is the thickness of absorber sample layer and c is the velocity of light. The term Z_0 is the wave impedance of free space (377 ohm) and Z_{in} is the input impedance seen by the wave at the interface of the absorber.

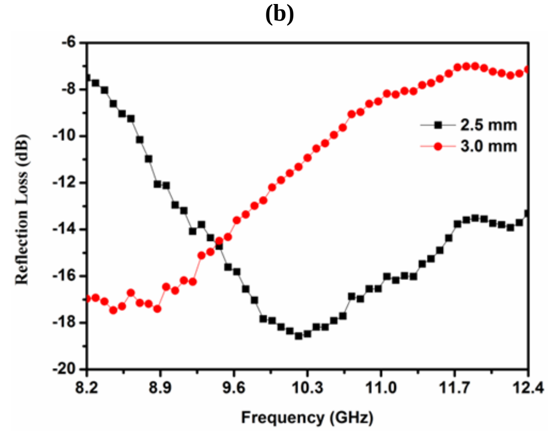
Higher the loss tangent value of the material implies the domination of microwave heat dissipation mechanism rather than the stored energy within the material. The filler concentration of 55 wt. % and 60 wt. % shows moderate dielectric loss tangent value as shown in fig 4. (d).



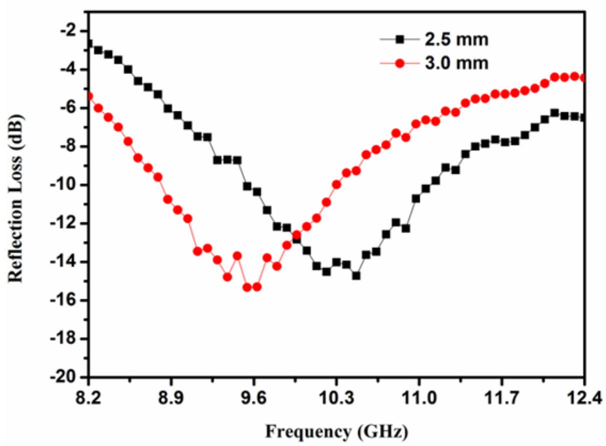
(a)



(b)



(c)



(d)

Fig. 5: Calculated RL (a) & (c) and measured RL (b) & (d) of 55 wt. % and 60 wt. % of powdered battery particles-rubber composites battery composite respectively.

Fig. 5(a) & (b) shows the calculated value obtain from the developed mat lab program using the material parameters of 55 wt. % and 60 wt. % measured from VNA analyzer respectively. From the results it has been that the resonant frequency of the absorber move towards the lower frequency range as the thickness of the absorber increased which is well agreement with the theory of the resonant type metal back absorber. The bandwidth is calculated as 3.78 GHz (reflection loss RL= -40 dB) and 1.98 GHz (reflection loss RL= -39 dB) for the thickness of 1.5 mm and 2.0 mm respectively for 55 wt. %. The corresponding measured B.W are 1.42 GHz (RL= -34 dB) for d=1.5 mm and 1.26 GHz (RL= -17 dB) for d=1.5 mm for 55 wt. %. As the filler concentration increased to 60 wt. % it was seen that the thickness of the absorber has increased to match the impedance at the air-absorber i.e. to acquiring maximum reflection loss. The bandwidth is calculated as 3.7 GHz (reflection loss RL= -18 dB) and 2.27 GHz (reflection loss RL= -17 dB) for the thickness of 2.5 mm and 3.0 mm respectively for 60 wt. %. The corresponding measured B.W are 1.5 GHz (RL= -14 dB) for d=2.5 mm and 1.34 GHz (RL= -15 dB) for d=3.0 mm for 60 wt. %.

4. CONCLUSION

The wasted material composite, extracted from the die-out Li-ion battery is used to prepare composite sample with silicone rubber for different filler wt. % and complex parameters was investigated in the X-band frequency (8.2–12.4 GHz). The different constituent of the powdered composite material has been verified by EDS analysis. Also from the SEM image it was seen that most of the material are spherical in shape which might be the graphite particles as it has the highest weight percentage in the composite confirmed by EDS analysis. Higher performance of microwave absorption with potential for applications in broadband frequency can be achieved using the electronic waste/silicone-rubber composites which have high dielectric loss compare to magnetic loss tangent over the entire X-band. Further, the developed composites are flexible, thin and relatively cost effective. Absorption can be further enhanced by structural modifications of the absorber.

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