DESIGN AND DEVELOPMENT OF COATINGS FOR RADAR ABSORBING MATERIALS AT X-BAND

Synopsis

Ph.D. THESIS

by

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SYNOPSIS

Radar absorbing materials (RAMs) have attracted more attention around the world since last several years, as they have considerable importance in stealth technology. With the development of advanced radar and microwave communication technology, the primary objective in defence is to detect threats as early as possible and be undetectable to increase the survivability. RAM is a class of material that masks the object from radar detection i.e., invisibility to a radar. In stealth technology, RAMs are coated on the surface of the structures to reduce radar cross section (RCS). A RAM actually soaks up the incident electromagnetic (EM) energy, thereby reducing the energy reflected or scattered back to the radar. Apart from radar cross section reduction (RCSR), EM absorbers find application in other fields such as, construction of anechoic chambers for scientific testing, microwave ovens, protection against electromagnetic interference (EMI) for electronic devices, etc.. The mechanism of radar absorption depends on the appropriate impedance provided by the arrangement (means matching thickness) of the dielectric and magnetic materials to the incident EM wave. Such materials can be applied to the surface of the structure to attenuate the incident EM wave, once it interacts with the material. Basically the performance of RAM majorly depends upon its composition. Depending upon the composition, a RAM can absorb the EM wave at some frequencies, however, a single RAM may not have sufficient absorption at all radar frequencies.

Though the current state of stealth technology is highly classified, still RAM suffers a trade-off among the microwave absorption for broadband, the weight of the absorber, cost and the requirement of high maintenance. There is a need to give more attention to develop such a RAM by which this trade-off can be considerably handled. Therefore, an effort to deal with the different aspect of RAM development to coat on the substrate has been made in this thesis.

The thesis is divided into eight chapters. **Chapter 1** presents introduction to the topic and gives a brief idea about the aim and scope of the work. It also gives an insight into the type of RAM used for absorption. The absorption of EM waves depends on the composition of materials and design of absorber such as multi-layering, use of frequency selective surfaces (FSSs), etc. **Chapter 2** outlines a brief review of literature, discussing the basic theories, loss mechanisms and existing absorbers. Further, it presents the techniques such as multilayer and role of FSSs for the improvement of microwave absorption. It also discusses about the various existing methods for synthesizing magnetic and non-magnetic RAMs.

The proposed formulation of the problem is discussed in **chapter 3**. It defines the scope of present work based on literature review and the adopted methodology. Methods used for the development of magnetic and non-magnetic RAM as well as the characterization techniques are presented in **chapter 4**.

Chapter 5 describes the optimization of parameters such as, ‘citric acid to metal ion ratio’, ‘iron to barium ion ratio’, annealing temperature and time for the synthesis of single phase barium M-type hexaferrites. The same optimized parameters have been further used for the synthesis of doped barium M-type hexaferrrites. This chapter is divided into four sections. The first section of this chapter deals the effect of particle size of magnetic RAM (i.e., $BaFe_{12}O_{19}$) on microwave absorption. Particles of $BaFe_{12}O_{19}$ are grown in size by increasing calcination time at a given temperature. Both average particle size and standard deviation increase with the increase in calcination time. It has been observed that the complex dielectric properties and loss tangents increase with the increase in average particle size and also a good bandwidth for reflection loss (RL) is observed. The maximum reflection loss -20.21 dB at 9.46 GHz is observed for average particle size 240 nm. Enhancement in microwave absorbing property may be due to the inhomogeneous growth of particles that create the network’s holes of suitable size (Kumar, 2013 and Zhou, 2006), which may lead to more internal reflections and inturn causing more RL. However, the related effect of microwave absorption will reduce, if standard deviation of particle size becomes too large. This study concludes that the particle size of the absorber plays a major role while controlling the absorption characteristics at X-band of the microwave spectrum which infers that by controlling the particle size microwave absorption can be controlled. Further, to see enhancement in microwave absorption, a detailed study of Co-doped Ba-M-type hexaferrite with chemical formula $BaCo_xFe_{(12-x)}O_{19}$ (x = 0.2 to 1.0 with an interval of 0.2) has been carried out in the second section. It has been observed that the formation of second phase starts when x exceeds 0.6, however, morphology of the particles does not change much with doping. The real part of permittivity and permeability decrease with Co-doping, on the other hand, imaginary part of permittivity and permeability increase. It is observed that the level of absorption and its bandwidth increases with Co-doping. The maximum RL value enhances from -13.82 dB at 11.14 GHz to -39.22 dB at 10.88 GHz with 1.34 GHz bandwidth (-20 dB level) for x = 0.8 and 2.8 mm thickness when Co is doped.

The effect of milling on microwave absorption of non-magnetic SiC is discussed in the third section of chapter 5. The reduction in particle size has been observed with the increase in milling time and subsequently amorphization of SiC takes place. The inclusion of iron in SiC also takes place during milling because of higher hardness of SiC. It has been observed that with the increase in milling time, both real and imaginary part of complex permittivity increase in the beginning, however, with prolonged milling these values decrease because of iron pick-up from the steel balls used for milling. The average value of complex permeability slightly increases with the increase in milling time and that may be due to the presence of iron and reduction in particle size. The values of RL and its related bandwidth increase with the reduction in particle size, however, after 6 hours of milling, the value of RL decreases because the iron atoms start entering into the crystal lattice of SiC and thereby reduces the complex permittivity. With prolonged milling, as the sufficient iron-pickup takes place, complex permeability slightly increases and therefore RL increases. RL of -50.71 dB at 9.46 GHz with 2.52 GHz bandwidth (-10 dB level) is observed for 3 h milled SiC sample. To see the effect of particle morphology on microwave absorption, 20 h milled SiC is annealed at 1400 ºC in N_2 atmosphere as discussed in the fourth section of chapter 5. After annealing in N_2 atmosphere, spherical-shaped particles change into micro-wire like structure. The complex dielectric properties enhance with change in the morphology from irregular to spherical and from spherical to micro-wire like structure. Hence, as a result, RL value for irregular morphology (i.e., -16.23 dB at 11.47 GHz) enhances to a maximum value of -26.62 dB at 9.88 GHz for spherical shaped morphology and -36.87 dB at 10.88 GHz for micro-wire shaped morphology.

In order to enhance microwave absorption, a study to disperse metallic elements in the dielectric medium has been carried out in **chapter 6**. The different metal powders are dispersed, using the mechanical alloying process in the dielectric mediums such as TiO_2, Al_2O_3 and SiC, to see the effect of metal dispersions on RL. It has been observed that with the dispersion of metallic elements in dielectric matrix, complex permeability of composite improves. Free electrons from the metallic atoms increase charge at the metal dielectric interface and raise space charge polarization, which inturn affects the electrical conductivity and improves the complex permittivity values of the composites (Lu, 2008). The maximum value of RL for pure TiO_2 observed is -4.96 dB at 10.21 GHz which improves to -13.67 dB at 10.13 GHz with Al metal dispersion and -7.24 dB at 10.38 GHz with Ni metal dispersion. For Al_2O_3-epoxy composite sample, a maximum value of RL -9.23 dB at 11.05 GHz is observed which improves to -16.48 dB at 9.29 GHz with Al metal dispersion and -12.75 dB at 11.22 GHz with Ni metal dispersion. In case of SiC, different metals like Al, Ni, Co, Cr, Mn, Ni, Ti and Zn are dispersed, and it has been observed that the values of RL improved with all metal dispersions, however, maximum improvement in RL is observed with Cr and Mn metal dispersions in SiC. The maximum value of RL for milled SiC is -15.94 dB at 10.3 GHz, which improves to the maximum value of -37.08 dB at 10.88 GHz and -43.35 dB at 10.3 GHz with a bandwidth of 3.02 GHz for Cr and Mn metal dispersions, respectively. The improvement in microwave absorption performance with dispersion of metal particles may be due to any of the following mechanisms:

a) EM wave attenuates as it penetrates into the material. This attenuation in EM energy is typically generated as electric field might interact with the mobile electrons within material and induce currents due to the presence of conductive metal present in a dielectric matrix composite (Phang, 2008). This electrical energy dissipates as heat due to the resistance of dielectric matrix of the epoxy-composite (Vinoy, 1995; Makeup, 2006).
b) Additional loss in absorber may also occur due to molecular polarization phenomenons, such as dipole rotation and space charge relaxation (Makeup, 2006) and
c) Once an EM wave incident on a metal-dispersed ceramic, it goes through multiple internal reflections within the material before coming out of the surface and as a result EM waves travel longer and more attenuation may be observed (Qin, 2012).

To check the further enhancement in microwave absorption, methods like multi-layering and FSS are explored in **Chapter 7.** Materials developed in the chapter 5 and 6 are used as a database. The most challenging aspect of multi-layering is the selection of material for different layer and their thicknesses. This challenge has been handled with the help of Genetic algorithm (GA) where a fitness function was developed using the transmission line model. Similarly, an equivalent circuit model was used to develop a fitness function in GA for the analysis of FSSs. Finite element models using GA optimized parameters have been simulated in Ansys 'High Frequency Structure Simulator' (HFSS) software, which is a solver for electromagnetic structures. Attenuation Testing Device (ATD) has also been used to observe the RL. Two multilayer models namely two-layers and three-layers have been optimized (using GA), simulated (using HFSS) and fabricated (using spray painting) with developed materials. It has been observed that the value of maximum RL and bandwidth increase by layering of RAMs, i.e., for two-layers and three-layers. The dimensions of FSSs, namely single square loop, double square loop and triple square loop have been optimized (using GA), and these optimized values are used in HFSS for simulation. These optimized values are further used to fabricate FFSs using photolithography which is then tested in ATD for RL. It has been observed that the values of RL depend on the type and dimensions of FSSs.

Finally **chapter 8** draws the conclusion and contribution made in this thesis as well as suggests scope for the future work of the study.

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