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Conclusion and scope of the Future Work

With growing threat of MW radiation in both the civil and defence sectors, the need of materials that absorb/attenuate this part of EM spectrum has increased and thus, gained momentum in last few decades. However, considering a strategic domain, very limited open literature is available, to understand and demonstrate functionality of these materials. Further, with the advancement of modern radar/antenna technology in wide band applications, it is difficult to design the materials and the derived products to cover the entire frequency window of MW absorption. In addition, the real time application of these materials on airborne platforms further poses numerous challenges, where other critical parameters viz. weight penalty, environmental stability, mechanical strength etc. are equally important for flight safety. In view of this, the main objective of the present thesis work is to explore the different material systems having MW absorption capabilities over wider frequency bands with lesser weight penalty and subsequently translation of these materials in rubber based flexible absorbers. The different magnetic, ferroelectric and magneto-dielectric classes of materials have been synthesized by simple, cost-effective and scalable wet chemical and solid state routes. The major thesis developments include:

1. The Ni-Zn spinel ferrite $Ni_{1-x}Zn_xFe_2O_4$; (x=0.50) showed significant magnetic loss tangent values $\tan\delta_m$ > -1.2 over 2 - 10 GHz with a maximum value ~-1.75 at 6 GHz among other Zn doping fractions. This (x = 0.5) has been selected for synthesizing $Ni_{0.5}Zn_{0.5}Fe_2O_4$ –NBR rubber composite to explore the MW absorption studies for any practical application. The 80wt% ferrite loaded rubber composites has shown two MW resonant absorption peaks at ~5 GHz and ~10 GHz with almost same R.L. values ~43 dB, at different absorber thicknesses of ~4.6 mm and ~3.25 mm, respectively. This observation suggests that such absorbers are suitable for attenuation of both lower and higher frequency MW signals, at customized thicknesses.

2. Core-shell nanostructured materials, with onion like graphitic shell (~7 nm) and Ni nano metal core (~40 nm) has been demonstrated good dielectric loss tangent $\tan\delta_e$ > ~0.5 over 12.4-18 GHz frequencies. The fabricated NBR rubber composites with loading fraction of 70wt% filler material having thickness t= 1.0 mm has shown the maximum R.L. ~48 dB at ~17 GHz. The absorber is highly useful for Ku-band MW absorption applications with advantage of less weight penalty.

3. Tetragonal $BaTiO_3$ has been studies for its MW absorption properties over 8-18 GHz. The 80wt% loaded rubber samples have shown the dual band resonant absorption in the range of 8-18 GHz at thickness ~ 6.5mm, with first resonance absorption at ~9.5 GHz (R.L. ~9 dB), attributed to its ferroelectric relaxation and second absorption peak ~16.5 GHz (R.L. ~18 dB), due to second order resonance. Therefore, these absorbers can be used where MW suppression is required in both X (8.2-12.4 GHz) and Ku-Band (12.4-18 GHz), simultaneously. Similar MW absorption performance has been observed for multiferroic $BiFeO_3$ material, where dual absorption peaks are observed at similar frequencies but at relatively larger absorber thickness. The observed larger thickness for $BiFeO_3$ is attributed to the weak ferroelectric characteristics of $BiFeO_3$ powder.

4. A process has been established to prepared phase pure Co substituted Z-type Sr hexaferrite ($Sr_3Co_2Fe_{24}O_{41}$) materials having significant magnetic loss tangent values $\tan\delta_m > 0.5$ over entire 8-18 GHz frequency range. The hexaferrite loaded rubber composite has shown significant R.L. values at relatively lower thicknesses in the range of 1.8-2.2 mm. Further, the pure hexaferrite powder has been used to fabricate ferrite based sintered tiles, showing maximum R.L. ~ 43 dB at relatively lower tile thickness ~1.4 mm. This materials system may serve purpose for developing MW absorbing product in 8-18 GHz with relatively lesser thickness, thus overcoming the weight penalty for possible applications.

The efforts have been made to explore the considered materials and their NBR rubber composite system for possible MW absorption applications. The present work may be extended further to enhance the functionality and their structure-property correlation for desired MW absorption applications. This may include:

1. Substitution of rare earth metal ions in Ni-Zn spinel structure to study the structure-MW absorption correlation in the modified material system, for possible broadening of absorption bandwidth.
2. Extended studies on graphite coated core-shell structured magnetic nanoparticles by varying the core size and shell thickness, to study the structural effect on MW absorption characteristics.
3. MW absorption studies in doped ferroelectric and multiferroic systems as well as double perovskite materials for possible reduction in absorber thickness below the reported values in the present studies.
4. Variation of substituted Co^{2+} ions concentration and substitution of other transition metal ions e.g. Zn^{2+}, Mn^{2+} etc. in pure Z-phase Sr hexaferrite, for enhancement of magnetic loss tangent over the frequency range of 8-18 GHz.
5. MW absorption studies of the synthesized materials in different rubber/rubber mediums to study the matrix dependent MW absorption studies.

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