To Theoritically model the physical properties of a Microwave Absorber and deriving its dielctric and magnetic parameters for the pre selection of suitable elements and material compositions for specific microwave absorbing applications

Aayushi Arya(EE Dept.)
Guide :Dr GVV Sharma(EE Dept.)
Guide :Dr Atul Deshpande(MSME Dept.)
IITH,EE dept

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REQUIREMENT OF MICROWAVE ABSORBERS

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- EXPANDING COMMUNICATION INDUSTRY:With a new digital era, communication devices and speed has all shoot up, leading to large exposure to EM waves . This affects the human body ,including hearing capacity, function of enzymes and proteins(albumin protein affecting blood flow to brain) (?)
- ELECTROMAGNETIC INTERFERENCE : NOISE generation and signal leakage due to overlapping of the radiation noises emitted from the electronic hardware
- high frequency operated circuit devices like mobile phones, LAN , WIFI etc [27].
- RADIATION ABSORPTION CHAMBERS FOR HIGH END EQUIPMENTSSome scientific equipments require high frequency waves to be send to characterize the sample. It has to be put in absorbing chambers
- RADAR and military applications : Stealth ,warships, armour coatings

Figure: Effects of EM wave exposure on human ear

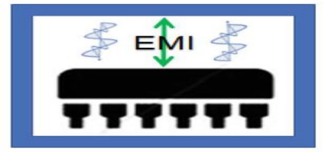
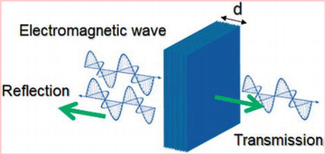
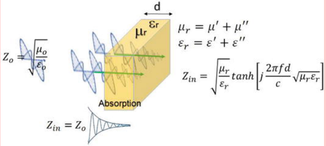


Figure: Electro Magnetic Interference

MICROWAVE ABSORBERS



(a) LAYOUT OF MA



(b) ELECTRICAL PARAMETERS OF MA

PERMITTIVITY AND PERMEABILITY

$$\epsilon = \epsilon^{'} + \epsilon^{''} \tag{1}$$

The real part => measure of amount of energy stored in the material due to external electric field. The imaginary part => measure of dissipation of electrical energy.

$$\mu = \mu^{'} + \mu^{''} \tag{2}$$

The real part => measure of amount of energy stored in the material due to external magnetic field. The imaginary part => measure of dissipation of magnetic energy.

LITERATURE REVIEW

reference	Work
[Ying Liu, Rui Tai, Michael GB Drew, and Yue Liu. Several theoretical perspectives of ferrite-based materials—part 1: transmission line theory and microwave absorption. *Journal of Superconductivity and Novel Magnetism*, 30(9):2489–2504, 2017]	Transmission Line Theory was used to model the ferrite base and find a relationship between the elctric and magnetic stru material to the microwave absorption. The work also shows of Transmission Line Theory to the band theory of solids
([B.R.K Gupta Jai Shankar, H.P. Sharma. Electronic polarizabilities of ions in transition metal oxides. *Solid State Communications*, 21(4):359–361, 1977])	Evaluation of Electronic Polarizability of tranistion metals fr spective ionic radii.The changes in the ionic state of a transit used to mathematically calculte the polarizabilities
[Robert D Shannon and Reinhard X Fischer. Empirical electronic polarizabilities in oxides, hydroxides, oxyfluorides, and oxychlorides. *Physical Review B*, 73(23):235111, 2006]	The mean total polarizabilities of oxides,hydroxides,oxyfluorid prically calculated from the free cation polarizabilities . Ther cation of polarizability additive rule and least square procedure the cation coordination
[MN Azlan, MK Halimah, SZ Shafinas, and WM Daud. Polarizability and optical basicity of er3+ ions doped tellurite based glasses. *Chalcogenide Lett*, 11(7):319–335, 2014]	Lorentz-Lorenz equation was used to theoritically calculate electronic and oxide ion polarizability of oxide glasses . T metallization criteria was observed on the refractive index

PARMETER DEFINITIONS

- The existing Transmission Line Theory , which is used to analyse the microwave circuits is now being used by material scientists to evaluate different materials used as microwave absorbers. This theory has benefitted in providing an insight into the electric and magnetic parameters of Microwave Absorbers[23, 24].

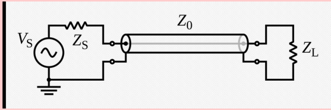


Figure: Transmission Line Schematic

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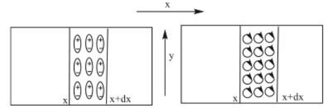

Figure: Electrical and Magnetic dipolar moments[23]

- Polarizability of ions(both cations and anions) is important in undersatnding the dieectric and lattice dynamical behaviour of the compounds.
- It can be associated with the dielectric constant and the refractive indices of a material with Lorentz=Lorenz equation
- Polarizability can be seen as a effect of the electronegativity of the atoms, creating a separation of positive and negative charges[25, 20].

Cont.

- The very basic understanding of polarizability as given by Kazimierz Fajans 1923, illustrates the effect of two oppositely charged ions on each other.When a cation which is more electropositive attracts electrons from the outer shell of the anion, thus deforming the anion.This ability of cation is called the polarisation power , the ability of anion to get polarized is called its polarizability.The factors affecting this are: cationic radii(higher concentration of positive charge),anionic radii(loose bound electrons),charged ions(electrostatistics).
- It is this deformation of ions which creates a dipole between the positive and negative centre of charges. This deformation can be inherent or can be induced by external field creating a dipolar polarizability. Not only can it induce new dipoles, but free rotate the pre esisting dipoles to orient in a particular direction.

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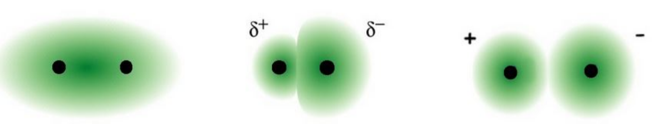

Figure: Deformation due to polarization[20]

- In some of the microwave absorbers , especially composite or dispersive materix based , there is MAXWELL-WAGNER POLARIZATION or space charge polarization ,induced by an electrical potential resulting from internal charge builds at the interfaces in a heterogenous material[**?**]
- The relationship between molar refraction to refractive index and molar volume of a polycrystalline material is given by **Lorentz-Lorenz** equation $R_m = (\frac{n_o^2 - 1}{n_o^2 + 2}) V_m$ [17, 25]

Cont.

- $R_M(m^3/mol)$ is the molar refractivity and is a measure of the total polarizability of a mole of a substance .V_M is the molar volume. Using the same the energy gap of the compound is calculated as $E_g(eV) = 20(1 - \frac{R_m}{V_m})^2$.This energy can be considered equivalent to the polarisation energy of an ion.

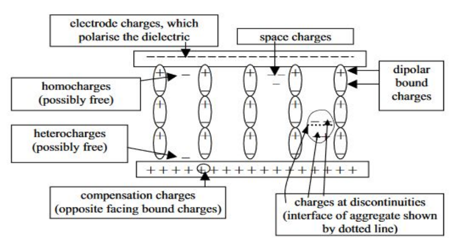

Figure: DIFFERENT TYPES OF POLARIZATIONS[16]

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THEORITICAL MODELLING OF MICROWAVE ABSORPTION

- USE OF TRANSMISSION LINE THEORY to theoritically model the resonant and non-resonant oscillation based microwave absorption.
- This theory , establishes the interaction of net absorption to the physical electric and magnetic parameters of the MA. The above model is independent of underlying absorption mechanism viz. as absorption from resonance, dielectric or magnetic media , from resonance or forced non resonance oscillation.
- GENERAL PREDICTIVE MODEL which can be used to understand the behaviour
- THis theory can be used to find the influence of a variety of physical parameters and material properties arising from the atomic configurations, on their microwave absorbing characteristics.
- This theory provides a way of deeper undersatnding into the required materislistic aspects of an ideal MA , which can lay a platform to design and explore new engineered materials for various applications

TRANSMISSION LINE THEORY

IMPEDANCE MATCHING

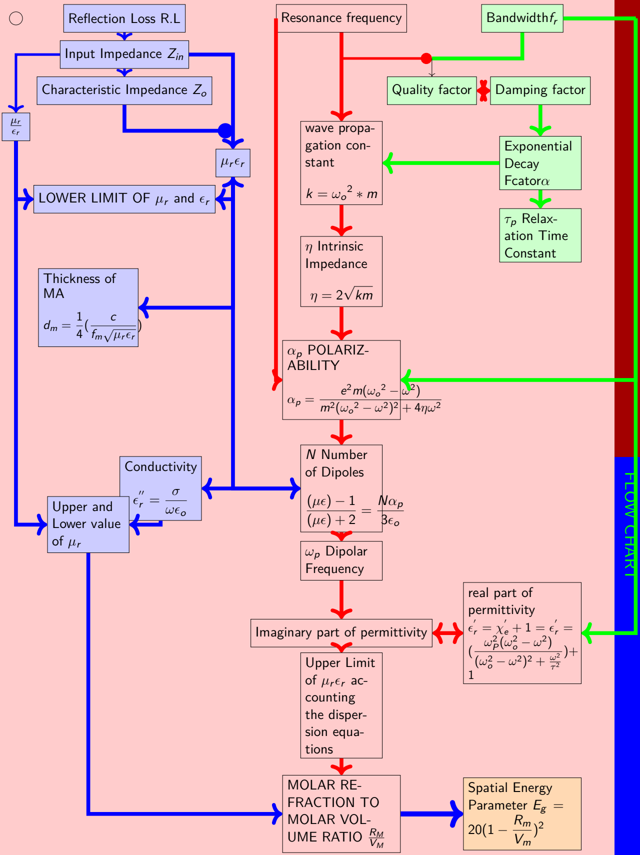
For the EMI shielding applications, the prerequisite is to minimize the reflection and maximize the absorption of the incident EM wave.Keeping the Relection Loss value to be R.L = -20 dB, which means that 99percenatge of microwave is absorbed, the input impedance *Zin* at the air–material interface can be calculated as:-

$$RL(dB) = 20log \mid \frac{Z_{in} - Z_o}{Z_{in} + Z_o} \mid \tag{3}$$

Using the above , we can evaluate the characteristic impedance of the microwave absorber , which is related to the intrinsic parameters of the material:-

To Theoretically model the physica

FLOW CHART



ATOMIC PARAMETERS

The polarisation Energy will be calculated using the principle of adding inverse values of volume energies and kinetic parameters whcih has been used in many different physical and chemical processes. Since Polarisation can be related to the force exerted by the valence electrons that is the electron affinity,and their inertness to form direct bond that is the ionization potential, screened through nucleus charges,it can be calculated proportionally via the inverse addition of orbital energy (accounting for the attraction or repulsion by electrons) and the effective nucleus energy.

$$\frac{1}{q^2} + \frac{1}{\eta} = \frac{1}{P_o}$$

where η is the global hardness factor $q = \frac{z^*}{n^*}$, z^* is the effective charge of nucleus and n^* is the effective main quantum number. $P_o(eV\text{Å})$ is called the spatial energy parameter and $P_E(eV\text{Å})$ is called the effective P-parameter for polarization. P_E is a physical parameter , accounting for the averaged polarisation energy over the valence electrons. η is the global hardness factor , which is calculated from the ionization potential and the electron affinity of the atom. By considering the simple electrostatic coulumbic forces across atoms,it can also be calculated as $\eta = \frac{e^2}{2R}$.

Effective principal quantum number can be calculated as a cumulative effect of the orbiatl exponent value ξ of each shell occupied, the outer shell value and the average spin of the outer shell.

Effective principal quantum number = orbital exponents of each shell (taking effect of screening charges)

outer shell Orbital exponent*outer shell quantum number*average spin

Similarlt the effective nucleus charge $q(eV\text{Å})$, can be calculated from the nucleus charge minus the screening effect.

The last parmeter that is P_E can be calculated as

$$P_E = \frac{P_o}{r_i}$$

,where r_i(Å) is the atomic radii of atom. The effective polaristaion parameter can be used for comparing the suitability of different elements in different material compositions for the Microwave Absorbing Applications. [Vineeta Shukla. Review of electromagnetic interference shielding materials fabricated by iron ingredients.

MATERIALS

- **METALLIC PERVOSKITE MATERIAL** Benefits of using pervoskite is broad EM wave absorption spectrum, environment stability, chemically inert,unique physical properties for metallic ground states,balance between permittivity and peremability[?].
- Pervoskite materials have already been established as a microwave dielectric used in wireless communication devices viz. resonators,filters, temperature stable capacitor as shown in figure.
- These materials , which have been studied for more than a half century, shows immense potential as microwave absorbers owing to its resonating dielectric polarization across its cryatal structure Some examples include $LaNiO_3$,.
- **HIGH ENTROPY OXIDES** HEOs are new engineered materials that have a multi cationic configuration , leading up to an increase in the entropy of the compound. The entropy stabalization imparts them functional properties(more stable dielectric behaviour).These properties can be engineered with much flexibility. Examples are $(Co_{0.2}Cu_{0.2}Mg_{0.2}Ni_{0.2}Zn_{0.2})O_3$ [28]

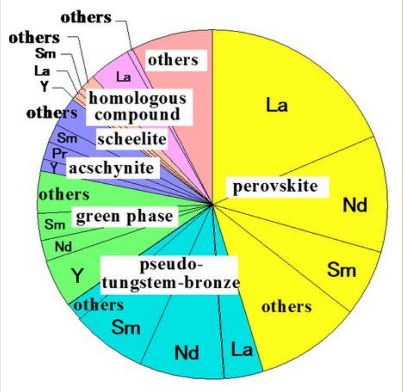


Figure: microwave dielectrics [26]

MATERIALS

- FERRITES Ferrites have found popularity as Microwave Absorbers owing to the magnetic losses along with dielctric losses giving high absorption at wide frequency range.Impedance matching of Ferrite is more improved than pure dielectrics because of low eddy current loss[18].
- X-type HEXAGONAL FERRITES, with high saturation magnetization, low coercivity, excellent chemical stability serve as good microwave absorbers.
- RARE EARTH elements have certain relaxation properties which enhances the EM wave properties of ferrites[27].
- MANGANITE MATERIALS manganites like $La_{0.8}Ca_{0.2-x}Ag_xMnO_3$ (x=0.05 to 0.15) have shown good microwave absorption propeties as shown in [22, 18]
- RARE EARTH doped OXIDES rare earth doped oxides have shown better microwave absorption properties with wide peak behaviour. The dynamic behaviour of compound changes with rare earth doping [19]

MAGNETIC PARAMETERS

S.No	d-shell	f-shell
Real Part of Permeability	$\mu^{'}$	$\mu^{'}$
Imaginary part of Permeability	$\mu^{''} = \frac{c}{2\pi df_m}$	$\mu^{''} = \frac{2\pi\mu_o(\mu^{'})^2\sigma\delta^2 f}{3}$
Suscpetibility	Atomic Susceptibilty χ_A	Molar Susceptibilty χ_M
Magnetic Dipole Moment	Spin Magnetic Dipole Moment $\mu_s = 2.84\sqrt{\chi_A T} B.M$	Orbital angular moment $\mu_J = [\frac{3kT\chi_A}{N{\mu_B}^2}]^{1/2}$

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