THEORITICAL PREDICTION AND MATHEMATICAL FORMUALTION OF THE MATERIAL COMPOSITION FOR MICROWAVE ABSORPTION APPLICATIONS

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***Abstract*—Microwave Absorbers has become an essential requirement in various fields including industrial uses like Radar, Stealth , commercial uses in mobile networking , EMI , EMC, electronic toll collection, social applications like in hospitals , schools , where the microwave flux has crossed the threshold. In the past few years, there has been an intense experimental work to explore various materials for the different applications , focusssing on their effectiveness, stability. The hit and trial cycles of the experimentation can be reduced with a theoritical model predicting the suitability of material for MA applications, allowing more accurate , rigorous and wide prespective for the experimentation. Thus, in this work , an attempt has been made provide a conceptual and theoritical mathematical formulation based model to predict the suitability of various elements and their composition for specified application. The model is based on Transmission Line Theory, Polarizability, dielectric response of material. The parameters are derived for the MA are characteristic impedance, input impedance , permittivity , permeability polarizability , Molar refraction ratio, Polarisation Energy. Using the above paramters and the material properties like its global hardness factor, we conclude to a set of theoritical atomic radii , which can be suitable for the absorption at the specified frequency , which is 2.54 GHz (ISM band -immensely used in various eelctronic applications). Further a composition of two or more elements viz. oxides of material, alloys , and multi cation oxides, can be predicted by comparing their spatial energy parameter , which depends on their individual valency and global hardness factor.This work is beneficial for not only understanding the fundamental molecular level perspective of the absorbers but also in providing a conceptual and engineering aspect to further explore new materials for the microwave absorption , with less error rate.**

***Index Terms*—EMI , Reflection Loss, Resonance, Dielectric Parameters,Polarisation Energy,Atomic Radii.**

I. Introduction

MICROWAVE ABSORBERS , has now become an area of immense research for both electronic field and materials design . The immediate need of Microwave absorbers is highlighted due to their necessity in the current technological scenario. need Due to the exponential growth of the usage of high frequency electronic hardware and wireless communication, there is a dramatical increase of the microwaves flux in the ambient surroundings , which causes ElectroMagnetic Interference amomg the underlying circuits undesirably by generating unwanted noise, cross connection ,false output etc. The critical exposure of microwaves also has harmful effects on the health , especially for hospitals, schools and highly populated residential areas. This creates a need to mitigate the surrounding EM wave noise, has driven researchers to develop materials that can effectively absorb the unwanted radiations ,protecting the underneath circuitry. Various materials and their composition are investigated using experimental procedures like Vector Network Analyzer, Impedance Analyzer to test their ability as absorbers. Meanwhile , there is also ongoing work to theoritically understand and model Microwave Absorbers. There are range of wave theory based electrical, magnetic parameters associated with the working of MA. First is the Reflection Loss and the Characteristic Impedance of a Microwave absorber that can be calculated using Transmission Line Theory [1].The latter is an intrinsic property independent of the thickness of the sample. Similar theory is applicable to ferrite based microwave absorbers conatining both electric and magnetic dipoles represnted by permittivity and permeability respectively [2].The oscillations of dipoles in a MA are both resonant and non resonant. . A detailed absorption model is then provided to include all the above elements in the basics of absorption formulas of transmission line theory.

There has been also works to correlate the electrical/magnetic parameter and physical parameters of microwave absorbers. Analyising polarizability gives an insight into the wave absorbing power of a material. Following this , in [3] , the Lorentz-Lorenz equation was used to estimate the electronic polarizability of ions in oxide glasses , based on their refractive indices and band gap energy.In [4] , the author further discusses an Interaction Parameter for oxides based on the polarizability of oxide ion, dtermined from the refractive index. This Parameter is used as a measure of the interionic interaction between cations and anions created due to the charge overlap of the outermost electronic orbitals.The charge overlap and the polarizability of cation and anions both affect the Interaction Parameter. This Parameter serves as an index to estimate the optical properties of oxide glasses. Siimilarly for magnetic based microwave absorbers the magnetic dipole moment can be used as a measure for microwave absprtion. This consecutive dependency of properties when modelled mathematically using energy parmeter can provide a useful tool for prediction of new compositions based suitable microwave absorbing materials. The energy parameter when normalized can be directly related to the atomic radii [5]. In this paper, an attempt has been made to theoritically derive the parameter related to a microwave absorber. First the

transmission line theory was used to determine the electrical parameters including characteristic impedance, reflection loss, permittivity and permeability, resonance frequency . From the above paremters and a set of equations expalined below we derived the physical parameters like polarizability, dipolar frequency . spatial energy parameter . From this we derived the atomic range of suitable atomic radii . The compositions can be predicted by comparing the effective Energy Parameter. This approach covers all the necessary properties required for a microwave absorber. It can be beneficial in filling the gap between the molecular and the physical properties of an absorber . It can help in predicting new compositions for efficient microwave absorbption.

A. RESONANCE PARAMETERS OF MICROWAVE ABSORBERS

Reflection Loss of a microwave absorber is given by :

$$R_L(dB) = 20log|\frac{(Z_{in} - Z_o)}{(Z_{in} + Z_o)}| \tag{1}$$

where Z_{in} is the input impedance of the MA , which it presents at the interface to the incident EM wave, when modelled as a transmission line.Z_o is the characteristic impedance of the incident medium, which in our application is air [6] [7].

1) Input Impedance and Quality Factor: Keeping Reflection loss -20 dB , which is a standard measure for 99 percent of absorption . Also , taking into account the free space impedance as $Z_o = 377$ ohm and above value of reflection loss in equation(1) , we get the input impedance of the microwave absorber as

$$Z_in = 460.78\Omega \tag{2}$$

The input impedance of the microwave absorber can be written in terms of a Transmission line , with an open circuit end as [1]:-

$$Z_(in) = Z_o\sqrt{\frac{\mu}{\epsilon}}\tanh(\frac{-j2\pi f d\sqrt{\mu\epsilon}}{c}) \tag{3}$$

CHARACTERISTIC IMPEDANCE OF MA:The value of characteristic impedance Z_o to be used in refeq1 is derived from the net reflection loss which is -20 dB , used in the below equation [8]

$$R.L = 20\log(\frac{Z_o}{4Z_{in}})Z_o = 184\Omega \tag{4}$$

The Q factor is the quality factor , which determines the damping ability of the absorber [1]. The Q factor, damping ratio ζ and exponential decay factor α are related as [9]

$$\zeta = \frac{1}{2Q} \tag{5}$$

$$= \frac{\alpha}{\omega_o} \tag{6}$$

$$\omega_n = \sqrt{\frac{k}{m}} \tag{7}$$

Quality factor is also expressed in terms of resonance frequency as [7]:

$$Q = \frac{2\pi f_r}{2\pi\Delta f_r} = \frac{\omega_r}{\delta\omega_r}$$

where ω_r is the resonance frequency and $\delta\omega_r$ is the bandwidth over which the absorption is greater than half of the maximum at the center frequency. Since damping of the waves in a medium is characterised by the amount and type of absorption. Using basic damping classification , we take Q $<$ 1/2 considering it as OVERDAMPED SYSTEM [10] . corresponding to this Q value we get

$$\zeta = 1.5$$

where ω_n is the natural resonance frequency of the system. k is the wave propagation constant Using $\zeta = 1.5$ and the following equations we can deduce the values of exponential decay constantα, natural resonant frequency of the system ω_o and the dipole relaxation time constant τ. The equations are as follows:-

$$Q = \frac{1}{2\zeta} = \frac{1}{2Xdampingratio} \tag{8}$$

$$= \frac{\alpha}{\omega_n} \tag{9}$$

$$= \frac{1}{\tau\omega_n} \tag{10}$$

Using the above equations, we get the values as:

$$Z_in = 460.77\Omega \tag{11}$$

$$\zeta = 1.5 \tag{12}$$

$$Q = \frac{1}{2\zeta} \tag{13}$$

$$= o.33 \tag{14}$$

$$f_r = 2.54GHz \tag{15}$$

$$\omega_r = 1.53X10^{10}rad/sec \tag{16}$$

$$Q = \frac{\omega_r}{\triangle\omega_r} \tag{17}$$

$$\triangle\omega_r = 4.83X10^{10}rad/sec \tag{18}$$

2) Exponential Decay Factor Natural Resonant frequencyand width(d) of MA: Using the Q as in refseven value , we can calculate α as

$$Q = \frac{\alpha}{\omega_0} \tag{19}$$

$$= \alpha = 2.39X10^{10} \tag{20}$$

Again using refseven , we determined the natural resonance frequency that came out to be

$$\omega_n = 7.25X10^{10}$$

WIDTH OF Microwave absorber: WIDTH 'd' of the microwave absorber is set to be around quarter wavelength, making it as an OPEN -CIRCUIT TRANSMISSION LINE with a reflection null [11]

$$d = \frac{c}{4f_m\sqrt{\epsilon_r}} \tag{21}$$

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B. LOWER LIMIT OF PERMITTIVITY AND PERMEABILITY

RATIO OF $\frac{\mu}{\epsilon}$

$$R_L = 20log_{10}|\frac{Z_d - Z_o}{Z_d + Z_o}| \tag{22}$$

$$R_L = 20log_{10}\left|\frac{\sqrt{\frac{\mu_r}{\epsilon_r}} - 1}{\sqrt{\frac{\mu_r}{\epsilon_r}} + 1}\right| \tag{23}$$

$$R_L = -20dB \tag{24}$$

$$\underbrace{\frac{\mu_r}{\epsilon_r} = 1.5} \tag{25}$$

$$\tag{26}$$

PRODUCT OF $\mu_r\epsilon_r$

$$Z_M = Z_o\sqrt{\frac{\mu_r}{\epsilon_r}}(\frac{2\pi\nu d\sqrt{\mu_r\epsilon_r}}{c}) \tag{27}$$

$$\tag{28}$$

Solving , it we get $\underbrace{\mu_r\epsilon_r = 1.6}$ using refone, we can derive the value of ϵ_r and μ_r, that is the relative permittivity and permeability as:- $\boxed{\text{First datapoint:- } \epsilon_r = 1.032 \ \mu = 1.55}$

C. POLARIZABILITY AND RELATED PARMETRS

The polarizability , of a material can be calculated in terms of the parameters like natural resonance frequency, operational resonance frequency , damping constant , as shown below [12]:-

$$\alpha_p = \frac{e^2m({\omega_o}^2 - \omega^2)}{m^2({\omega_o}^2 - \omega^2)^2 + 4\eta\omega^2} - \frac{2e^2\eta\omega}{m^2({\omega_o}^2 - \omega^2)^2 + 4\eta\omega^2} \tag{29}$$

The damping constant can be determined from the wave propagation constant k and the mass of electron m ,as given by :-

$$k = {\omega_o}^2 * m$$

$$\eta = 2\sqrt{km} \tag{30}$$

Using equation refeight , we get $k = 2.31^{-10}$ $\eta = 2.9^{-20}$ $\alpha_p = 2.36 * 10^{-28}$

1) Number of Dipoles per unit and time constant :

$$\frac{(\mu\epsilon) - 1}{(\mu\epsilon) + 2} = \frac{N\alpha_p}{3\epsilon_o} \tag{31}$$

This is the claussius Mosotti equation which links the relative permittivity to the number of dipoles per unit [3]. Since we have reached the relative permittivity in previous section, using the above equation we get $\boxed{N = 1.87X10^{16}}$

Similarly calculating the time constant we get $\tau = \frac{1}{\zeta\omega_o} = 8.88X10^{-12}sec$

2) Complex Permittivity and conductivity: Complex Permittivity is an important electrical property of absorbing materials. It depends on resonance frequency, bandwidth, time constant as per given matematical equations [13].

$$\epsilon_r^{'} = \chi_e^{'} + 1 = \epsilon_r^{'} = (\frac{\omega_P^2(\omega_o^2 - \omega^2)}{(\omega_o^2 - \omega^2)^2 + \frac{\omega^2}{\tau^2}}) + 1 \tag{32}$$

$$\epsilon_r^{''} = \frac{\omega_P^2(\frac{\omega}{\tau})}{(\omega_o^2 - \omega^2)^2 + \frac{\omega^2}{\tau^2}} \tag{33}$$

Here , the value of ω_p is given as

$$\omega_p^2 = \frac{n_e q^2}{\epsilon_o m} \tag{34}$$

where n_e is N , that is the total number of dipoles per unit volume, taking it from (reften) , 'm ' is the mass of electron . Solving above equation , we get ω_p Using the above value we can determine the natural dipolar resonant frequency as $\boxed{\omega_p = 2.4x10^9 rad/sec}$

Using the parameters mentioned in above equation , are as follows

$$N = 1.815X10^{15} \ 2x10^{15}$$
$$\omega_p^2 = 6.4X10^{19}(rad/sec)^2$$
$$\tau = 8.9X10^{-12}sec$$
$$\omega = 1.59X10^{10}rad/sec$$
$$\omega_o = 7.25X10^{10}rad/sec$$

Using these values and $\epsilon_r^{''} = \frac{\sigma}{\omega\epsilon_o}$, we get $\epsilon_r^{'} = 0.012 + 1 = 1.01$ $\epsilon_r^{''} = 3.95X10^{-3}$ $\sigma = 5.29X10^{-4}siemens$

D. UPPER LIMIT OF PERMEABILITY AND PERMITTIVITY

Based on the below equation as

$$\epsilon_r^{''} = \frac{na_pc}{2\pi\nu}$$

where $a_p = 0.1$ gives the power absorption coefficient , and n is $n = \sqrt{\epsilon\mu}$, ν is the working frequency. Evaluating the above equation we get $\boxed{n = \sqrt{\epsilon\mu} = 2.1}$ Permeability value can be considered by taking into account the required bandwidth , which gives the maximum damping constant value. Further calculating the width of the MA and using the absorption

formula to come to a permeability value, we can follow the previous method to attain E_g and R value.

$$d_m = \frac{1}{4}(\frac{c}{f_m\sqrt{\mu_r\epsilon_r}}) \tag{35}$$

$$\zeta_m ax = 2.05 \tag{36}$$

$$\triangle\omega_r = 6.519X10^{10} rad/sec \tag{37}$$

$$\omega_{r+} = \omega + \frac{\triangle\omega_r}{2} \tag{38}$$

$$(\omega_r)_+ = 5X^{10} rad/sec \tag{39}$$

$$f_r = 7.7GHz \tag{40}$$

$$(SE)_a = 8.7 d_{max}\sqrt{f_m\pi\mu\sigma} \tag{41}$$

$$\mu_r = 4.4 \tag{42}$$

$$\tag{43}$$

E. POLARIZATION ENERGY, GLOBAL HARDNESS FACTOR AND THEORITICAL RADII

F. Polarisation Energy

Below is the equation of the molar fraction of oxides [3]
$R_m = (\frac{n_o^2 - 1}{n_o^2 + 2})V_m$
n_o is the linear refractive index, V_m is the molar volume.

This equation relates the polarizability to Molar refraction ratio

$\boxed{\alpha_m = \frac{3}{4\pi N_A} R_M}$ α_m is the polarizability as given in (refpolar),
N_A is the avagadro number.

The relation between the energy gap of the oxide and the molar refraction ratio is given by :-

$$E_g = 20(1 - \frac{R_m}{V_m})^2 \tag{44}$$

Here , one important concept of metallization criteria should be considered which acts as a threshold for the possibility of the formation of the solid soluble compounds, M is given by

$$M = 1 - \frac{R_m}{V_m} \tag{45}$$

$$(\frac{R_m}{V_m}) < 1 NONMETAL \tag{46}$$

$$(\frac{R_m}{V_m}) < 1 METAL \tag{47}$$

$$\tag{48}$$

Putting all values together we get for $n = \sqrt{\epsilon_r}$

$$\alpha_m = 2.36X10^{-28}$$
$$R_m = 1.0X10^{-24}$$
$$V_m = 2.95X10^{-24}$$

Ultimately

1) R corresponding to Lower Limit: Keeping the value we get

$$R = 0.36\mathring{A} \tag{49}$$

$$E_g = 19.87eV \tag{50}$$

G. R corresonding to Upper Limit: Anionic

$$E_g = 4.34eV \tag{51}$$

$$R = 1.64\mathring{A} \tag{52}$$

$$\tag{53}$$

H. R corresonding to Upper Limit: Cationic

Using cauchy's dispersion equations, the upper limit for the cationic radii cab be found as follows. The electronic susceptibility can be given as :-

$$\chi_e{}' = \frac{\omega_p^2}{\omega_o{}^2} \tag{54}$$

The different constants for relating susceptibility to refractive index are:-

$$A = 1 + \chi_e(0) = n_o^2 \tag{55}$$

$$B = (2\pi c)^2 \frac{\chi_e(0)}{\omega_o e^2} \tag{56}$$

$$C = \frac{B}{2A^{1/2}} \tag{57}$$

$$n = n_o + \frac{C}{\lambda_o^2} \tag{58}$$

$$n_o = \epsilon_r(0) \tag{59}$$

$$A = 4.41 \tag{60}$$

$$B = 0.012 \tag{61}$$

$$C = 3.32X10^{-3} \tag{62}$$

$$n = 2.34 \tag{63}$$

$$\tag{64}$$

Radius value corresponding to the upper refractive index limit$n = 2.34$ is $R = 2.23\mathring{A}$

I. Theoritical Radii and Global hardness Factor : A COMMON DATABASE

By evaluating a common database from an observation point of view , with regards to the elements performance towards the polarisation process. While estimating a suitable compound for EMI application , the individual elements shoud have compatible polarizing ability leading to effective absorption of the microwaves. The cations and anions should exert polarising force on each other such that there is a balanced formation of dipoles [14] [15]. Below table is an effort to find easy referential parameter for comparing the suitability of various cations and anions with respect to each other. The P parameter is a measure of the overall energy characteristics of the outer orbitals taking into acoount the polarisability and the screening effect [16]. Use of this " spatial energy parameter" has already been proved in other physical phenomenons like self diffusion

, as already discussed above . Improvising the given parameter to contain the information regarding the polarisation extent of the element , a set of values can be obtained for the entire set of elements providing a means to predict the compatibility of new compound formations for their EMI performance. The general formula of spatial energy parameter is [5]

$$\frac{1}{q^2} + \frac{1}{\eta} = \frac{1}{P_o} \tag{65}$$

r_i is the atom orbital radius, η is the global hardness factor,Considering the polarization energy equivalent to the Global hardness factor , which is none other than the ability of a chemical species to form bond with its neighbouring atom/molecule, as given by :-

$$\eta = \frac{e^2}{2R} \tag{66}$$

q is given by below equation:-

$$q = \frac{z^*}{n*} \tag{67}$$

J. COMPUTATION OF POLARISATION ENERGY PARAMETER

q is given as the ratio of effective charge of nucleus to effective main quantum number. q is affected by the screening constant of the atom which depends on the orbital exponent of the electronic orbitals [17] .The effective quantum number depends on the valence electron distribution among the outer orbital. It is approximated as outer orbital quantum number multiplied by total number of valence electrons in the orbital multliped by spin factor (1/2). P_o is a spatial parameter indicative of overall polrisation energy . P_E is the effective polarisation energy considering the atomic extent of the molecule.Using the above analogy , a database table is created where we can compare the elements based on their polarisation parameter and find their compatability to form compounds for effective microwave absorption. Based on the parameters described above , the database was theoritically extracted to , as presented below:-

TABLE I: PERIODICAL TABLE WITH MICROWAVE PARAMETERS

Element	effective quantum number	$r_i Å$	ξ	$q_i{}^2(evÅ)$	ηeV	P_o	P_E
H	0.5292	.	.	¿	¿	¿	¿
Li	1.6282	.	3.71	13.76	4.4164	3.3433	2.0533
Be	1.0855		3.75	14.06	6.6244	4.5	4.1455
B	2	0.8141	2.574	6.625	8.8328	3.7856	4.65
C	2	0.6513	3.2175	10.35	11.0407	5.3420	8.202
N	0.5427	13.25	+5,4,3,1	132.5, 106,79.5, 26.5			
O	2	0.4652	2.275	18.40	13.4574	8.4/5.168	18.0567
Na	1.5	2.1649	0.7333	7.784	3.3215	2.3280	1.0753
Mg	1.5	1.6711	0.950	13.10	4.303	3.239	1.9382
Al	3	1.3607	1.1667	4.884	5.2846	2.5382	1.8653
Si	3	1.1476	1.3833	6.0	6.6259	3.148	2.8239
P	3	0.9922	1.6	8.01	7.2473	3.8047	3.8346
S	3	0.8738	1.8167	10.37	8.2293	4.5882	5.2508
K	2	3.5598	0.5946	5.110	2.02	1.4477	0.4067
Ca	2	2.7479	0.7703	8.35	2.6162	1.9920	0.7249
Sc	2	2.6106	0.8108	9.24	2.7545	2.1219	0.8328
Ti(II)	2	2.486	0.8514	11.36	2.8921	2.3054	0.9273
Ti(III)	5	2.486	0.8514	143.76	...	...	
Ti(IV)	5	2.4861	0.8514	143.76	...	...	
V(II)	2	2.3732	0.8919	12.47	3.03	2.4376	1.0271
V(III)	4.5	2.3732	0.8919	2.46	...	...	...
Cr(III)	4.5	2.2701	0.9324	2.69	3.1676	1.4546	0.6407
Mn(II)	2	2.1754	0.973	14.82	3.3055	2.7026	1.2423
Mn(III)	4.5	2.1754	0.973	2.92	...	...	...
Fe(II)	2	2.20885	1.0135	16.12	3.443	2.837	1.3583
Fe(III)	4.5	2.20885	1.0135	3.18	...	...	...
Co(II)	2	2.008	1.0541	17.39	3.5811	2.9695	1.4788
Co(III)	4.5	2.008	1.0541	3.42	...	...	...
Ni(II)	2	1.9337	1.0946	18.75	3.7187	3.1032	1.6048
Cu(I)	2	1.8648	1.1351	20.16	3.8561	3.2369	1.7358
Cu(I')	4.5	1.8648	1.1351	3.96	...	...	...
Zn'	2	1.8004	1.1757	21.72	3.994	3.3736	1.8738
Zn"	2	1.8004	1.1757	4.24	...	...	...
Ga	4	1.5663	1.3514	7.18	4.5909	2.80	1.7877
Ge	4	1.3862	1.5270	9.12	5.1874	3.3066	2.3854
As	4	1.2431	1.7027	11.35	5.7846	3.8317	3.0824
Se	4	1.1269	1.8784	13.84	6.3810	4.3673	3.8755
Br	4	1.0305	2.0541	16.56	6.978	4.9093	4.7639
Kr	4	0.9493	2.2297	19.45	7.5748	5.4516	5.7359
Rb	2.5	4.8106	0.55	4.74	1.4948	1.1364	0.2362
Sr	2.5	3.7135	0.7125	7.95	1.9364	1.5571	0.4193
Y	2.5	3.5278	0.75	8.76	2.0384	1.6536	0.4687
Zr(II)	2.5	3.3598	0.7875	9.73	2.1402	1.7543	0.5221
Zr(IV)	2.5	...	9.73	...	...	...	
Nb(III)	2.5	3.2071	0.8625	10.670	2.2422	1.8528	0.5778
Mo(II)	2.5	3.0677	0.8625	11.67	2.3440	1.9519	0.6363
Tc	2.5	2.9398	0.9	12.70	2.4460	2.05	0.6973
Ru	2.5	2.8222	0.9375	13.76	2.5479	2.1498	0.7617
Rb	2.5	2.7137	0.975	14.9	2.6498	2.1393	0.7883
Pd	2.5	2.6132	1.0125	16.08	2.7517	2.3496	0.8991
Ag	2.5	2.5199	1.05	17.28	2.8536	2.4492	0.9719
Cd	5	2..433	1.0875	4.64	2.9555	1.8053	0.7421

In	5	2.1167	1.25	6.13	3.3972	2.1858	1.0326
Sn	5	1.8732	1.4125	7.82	3.8388	2.5748	1.3745
Sb	5	1.6799	1.575	9.73	4.2805	2.9727	1.7695
Te	5	1.5228	1.7375	11.83	4.7221	3.3749	2.2162
I	5	1.3926	1.9	14.15	5.0636	3.7291	2.6778
Cs	3	6.0615	0.5238	4.3	1.1863	0.9297	0.1534
Ba	3	4.6788	0.6786	7.22	1.5369	1.2672	0.2708
Hf	3	1.0079	3.15	155.6	7.1344	6.8216	6.7681
Ta	3	0.9594	3.3095	171.76	7.4951	7.1817	7.4896
W	3	0.9165	3.4643	188.2	7.8459	7.5319	8.2181
Re	3	0.8773	3.619	205.38	8.1965 7.8819	8.9843	

II. MAGNETIC PARAMETERS OF MICROWAVE ABSORBERS

MAGNETIC MICROWAVE ABSORBERS has now been explored more vigorously owing to their exciting phenomenon of microwave absorption [18]. The concept of magnetic microwave absorption is described both theoritically and mathematically using different magnetic properties as described below.

Similarly , we have volume susceptibility , with units of χ_v, which is unitless. χ_m is the molar susceptibility , measured in$m^3/mol, orcm^3/mol$. Relationship between molar and volume susceptibility is given as:-

$$\chi_{mol} = \frac{M}{\rho}\chi_v \tag{68}$$

M is the molar mass in kg/mol or gm/mol ρ is the density in $kg/m^3 orgm/cm^3$ Daimagnetic Corrections to the molar susceptibility are made to account for the inner core electron ligands, atoms or ion in the compound or material which make the apparent molar susceptibility smaller than it is from the unpaired.

$$\chi_A = \chi_m + \sum(diamagneticcorrection) \tag{69}$$

The measured χ_A can be related to the effective magnetic moment in bohr magneton by:-

$$\mu_{eff} = [\frac{3kT\chi_A}{N{\mu_B}^2}]^{1/2} \tag{70}$$

Where k is the boltzmann constant, N is the avagadro number and μ_B is the bohr magneton. or

$$\mu^{eff} = 2.828(\chi_A T^{1/2})$$

A. CASE I(Permeability μ_r= 4.4) :-

III. MAGNETIC PARAMETERS OF MICROWAVE ABSORBERS

Magnetic material based microwave absorbers , shows two kinds of magnetism namely Diamagnetism and Paramagnetism. In a Microwave Absorber with permeability value $\mu > 1$ greater than unity, the latter is a predominant phenomenon. In a magnetic material based MA , there are additional magnetic losses along with the dielectric and ohmic losses. These are the losses due to magnetic resonance. The magnetic resonance is the result of the interaction between the magnetic field of the incident EM wave and the orbital as well as the spin angular momentum of the corresponding elements. When there is unpairing of the electrons in the outer orbital of the elements , there is an increase in the resultant magnetic moment, leading to enhanced magnetic losses [19] [20]. The magnetic losses can be accounted by the parameters like complex permeability, susceptilbility, magnetic moment etc. for a specific element composition or a chemical compound. For the prediction of the magnetic elements that can be suitable for a given Microwave Absorber specification, the permeability of the absorber is used to trace back to the atomic angular momentum [21].The permeability value , as derived above, will be used to calculate the susceptibility value by the given formula, giving $\chi_m =$

$$\chi_m = \mu_r - 1$$

From the susceptibility value , both of the magnetic moment that is the spin and the angular moment will be calculated separately , using two different formulae, taking consideration of the individual magnetic moment [22]. The equations are as follows

$$\chi_m = \frac{n\mu_o < {\mu_T}^2 >}{3kT} \tag{71}$$

$$\tag{72}$$

In the above equations, μ_T gives the average magnetic moment , contributed by tha angular magnetic moment, μ_B is the bohr magneton , J is the outmost filled orbital. Similarly taking into consideration , the spin angular moment μ_s, the equations are as follows:-

$$\mu_s = 2.84\sqrt{\chi_A T}B.M \tag{73}$$

$$\tag{74}$$

In the above equation χ_A is the atomic susceptibility, B.M is the bohr magneton in C.G.S units $\mu_{B_g} = 9.27x10^{-21}erg/gauss$. The microwave Absorption phenomenon leads to complex permeability, similar to the case of permittivity , with the real part showing the magnetic energy storage and imaginary part showing the dissipation of the magnetic energy.By observing the synchronization of the absorption phenomenon and magnetic moments of the atom , one can conclude that the effect of angular moment is dominant only when there is a symmetry of charge distrubition , maintained across the sample. Electron orbital angular

momentum is caused by the current due to the circulating charge, thus the energy stored can be seen as an increase in the circulating orbital charge. Similarly, spin dipole moment is associated to the spinning of the electron charge density , which can be related to the relaxation phenomenon during charge dissipation of the stored magnetic energy, hence is a dominant factor towards the contribution of imaginary part of permeability. In the aboe equations, the former one gives the orbital dipole moment , while the latter one gives the spin dipole moment

The imaginary part of permeability,for the d-shell elements, can be calculated as follows:-

$$\mu^{''} = \frac{c}{2\pi d f_m} \tag{75}$$

The atomic susceptibility can be calculated by the product of molar volume V_M and Avagadro constant N. The two limits for the spin dipole moment corresponding to the limits of the refractive index is :

n	f_m	$\mu^{"}$	$\chi_{V(c.g.s)}$	$\chi_{A(c.g.s)}$	μ_s B.M
1.6	2.54 GHz	1.0192	$1.53X10^{3}$	$2.32X10^{-3}$	2.53 B.M
2.1	7.7 GHz	1.3377	$2.69X10^{-2}$	$4.08X10^{-2}$	9.8 B.M

With the above limits of the effective magnetic dipole moment , it can be compared to the observed dipole meoments of the magnetic elements , and hence can provide base for the selection of suitable elements for the microwave absorber. A difference is to be noted here for d-shell and f-shell magnetic materials. Magnetic compounds like ferrites have quenched orbital angular momentum for d-shell magnetic materials by virtue of the orbital angular momentum being tied to the Easy Magnetisation Direction (EMD). While in the f-fhell electrons, due to the asymmetrical nature of the orbitals, the orbital angular momentum exists, which is more dominant then the spin angular momentum [23]. Hence for d-shell, $\mu = \mu_s$, the formula of which is specified above, and for f-shell $\mu_T = \mu_J$, which is given below:-

$$\mu_J = \frac{1}{\mu_B}\sqrt{\frac{\chi_m(3kT)}{n_l \mu_o}} \tag{76}$$

In above equation ,χ_m is the susceptibility, k is the boltzmann constant with value $k = 1.38X10^{-23}$, n_l is the total number of magnetic sites or the number of atoms oer unit volume. But a discrepancy occurs at magnetic resonance, which is the condition of maximum absorption, leading to the splitting of the energy spectrum of the outer d -orbital , the splitting occurs from one atom to a maximum of N atoms, integrating of the spliiting level , gives $n_l = N^2$. For the f-shell elements , considering the skin depth and the conductivity due to the associated orbital angular momentum , the dissipative factor of permeability can be calculated as [24]:

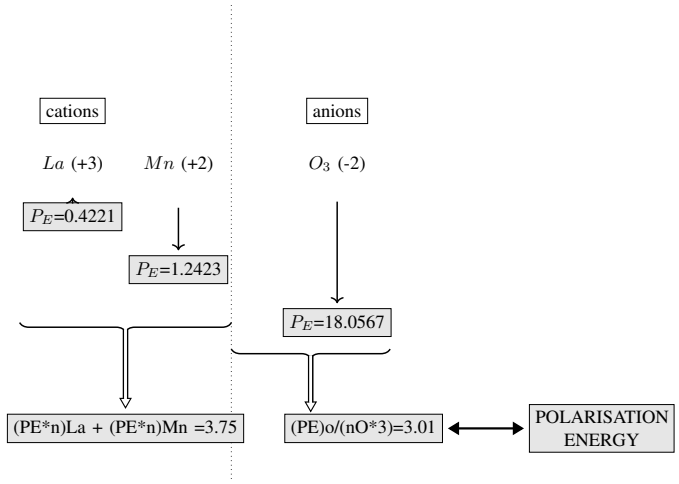
$$\mu^{''} = \frac{2\pi\mu_o(\mu^{'})^2\sigma\delta^2 f}{3} \tag{77}$$

With the skin depth given as :-

$$\delta = (f\pi\sigma\mu)^{1/2} \tag{78}$$

μ	$\mu^{''}$	δ	χ_m	μ_J
1.032	269	3.4	0.032	9.4
2.57	20.59	2.34	1.57	2.53

Element	Valency	effective dipole moment
Ti	+3	1.70
V	+2, +3, +4	3.85 , 2.61 , 1.70
Cr	+2, +3	4.85 , 3.85
Mn	+3	5.82
Fe	+2	5.36
Co	+2	4.90
Ni	+2	3.12
Cu	+1, +2	0, 1.83
Zn	+2	0
Ce	+3	2.51
Pr	+3	3.56
f-shell elements		
Nd	+3	3.3
Pm	+3	2.68
Sm	+3	1.74
Eu	+3	3.4
Gd	+3	7.98
Tb	+3	9.77
Dy	+3	10.63
Ho	+3	10.4
Er	+3	9.5
Tm	+3	7.61
Yb	+3	4.5
Lu	+3	0



A. Selection Criteria

Subsection text here.

1) Derived Radius values: The derived radius values can be used to conclude the cation and the anion required for the MA by matching their atomic radii to the derived values
2) P_o Parameter ,Based on the matching of the atomic radii , we can add the P_o values such that $\sum P_{ocations} = \sum P_{oanion}$. Based on this , we can select multiple cations for the sample.
3) 2.In case of mixed oxides , the mole fraction ratio of each cation or oxide compound can be derived as :- CALCULATION FOR THE MOLAR RATIO :-

Depending on the ratio of the polarizability of the cation to anion , we can have the estimated molar fraction as

$$m = \frac{N_a X {r_a}^3}{N_c X {r_c}^3} \tag{79}$$

Using the above derived values of the radius and the molar ratio calculation, we concluded for Ga_2O_3 with $m = 0.04$

4) In case of special crystal structures like pervoskite , spinel , fluorite , the radius ratio of the cation to anion has to be matched with the specified crystal requirement viz.

Subsubsection text here.

IV. Conclusion

The conclusion goes here.

Acknowledgment

The authors would like to thank...

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