K-band Co-Zr doped Strontium Hexaferrites Microwave Absorbers

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Abstract— In the current investigation, microwave K-band (18-26.5 GHz) electromagnetic and absorption characterization of Co-Zr co-substituted strontium hexaferrite have been presented. Vector Network Analyzer was used to determine the effect of microwave frequency on complex permittivity and complex permeability of the ferrite samples. Real permittivity was found to decrease while real permeability increased slightly with the increase in frequency. Imaginary permittivity and permeability have shown almost frequency independent behavior up to 21 GHz. Resonance peaks in the spectra were observed on further increase in frequency. Reflection loss values have been simulated for 3.5 mm thick ferrite pellets. Composition with x = 0.4 has achieved maximum absorption bandwidth (4.59 GHz) while that with x = 0.8 has minimum reflection loss value (-38.41 dB). The variation of reflection loss curves with change in thickness of pellet is also demonstrated. Thus, the complete K-band microwave analysis indicates that these materials are useful candidate for electromagnetic interference suppression applications in radar systems and wireless communication.

Keywords—Strontium Hexaferrites; Permittivity & Permeability; 18-26.5 GHz; Reflection Loss Curves; Sample Thickness.

I. INTRODUCTION

Research in the field of hexaferrites has now become more relevant than the past due to their absorption properties in gigahertz frequency range [1]. Materials with strong absorption, wide absorption bandwidth and less coating thickness have attracted lot of attention [2-3]. In addition to this, these ferrites have also applications in wireless communication. The heights of antenna elements have significantly reduced while maintaining the high gains and efficiencies with the use of these ferrites. Among hexaferrites, strontium hexaferrites have high magnetic anisotropy field, high electric resistivity and excellent chemical stability [5-6]. To synthesize these materials, different synthesis methods such as solid state reaction, sol gel, co-precipitation, oxalate precursor etc have been employed [1-3]. Use of different precursors such as sucrose, citric acid and tartaric acid in sol-gel method is also reported and found be helpful in tailoring the magnetic and electric properties [7].

In current investigation, cobalt and zirconium were doped in pure strontium hexaferrite using sol-gel citrate method. The electromagnetic and absorption properties were determined in 18 - 26.5 GHz frequency range.

II. EXPERIMENTASL PROCEDURE

Sol-gel method using citric acid as precursor is employed to synthesize substituted hexaferrites with chemical composition (x = 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0) due to advantages of this method such as low calcination temperature, energy efficient, short reaction rate, better particle size distribution, more probability of formation of single domain etc. [3]. The chemical equation representing synthesis process is:

$$Sr(CO_2)_2 + xCo(NO_2)_2 + xZrO(NO_2)_2 + (12-2x)Fe(OH_2)_2 \rightarrow Sr(CoZr)_xFe_{12-2x}O_{19}$$

Detailed synthesis process and structural characterization have been reported earlier by the authors [8]. Agilent N5225A PNA series network analyzer in conjunction with Agilent software module 85071 was used to determine electromagnetic and absorption properties. Prior to analysis, the ferrite powders were mixed with 5% poly vinyl alcohol (PVA) and were shaped in the dimensions of WR-42 (10.67 mm × 4.32 mm).

III. RESULTS AND DISCUSSION

A. Dielectric Constant & Dielectric Loss Tangent

Fig. 1 presents the complex permittivity of the samples in K-band. Real part of permittivity (dielectric constant) has shown slightly decreasing trend w.r.t. frequency in K-band which can be attributed to the dielectric relaxation. Ferrites are composed of conducting grains separated by poorly conducting grain boundaries [4]. Dielectric relaxation is observed due to increase in role of grains with incraese in frequency. There are four types of polarizations that play role in deciding dielectric properties of ferrites: ionic, electronic, interfacial and electric dipole. At low frequencies, all four types of polarization play role, while at high frequencies only electronic and ionic polarizations play role [8]. That is why, very small variation is observed in real part of permittivity w.r.t. frequency in microwave frequency range because electronic and ionic polarization are inherent properties of material and show very small variation with frequency. Also, the dielectric constant has decreased as a result of doping of impurity ions which can be attributed to the occupancy of octahedral $4f_2$ and 12k sites by dopant ions, thus, decreasing the availability of Fe^{2+}- Fe^{3+} pairs at the octahedral sites and hence decreasing the real permittivity [8]

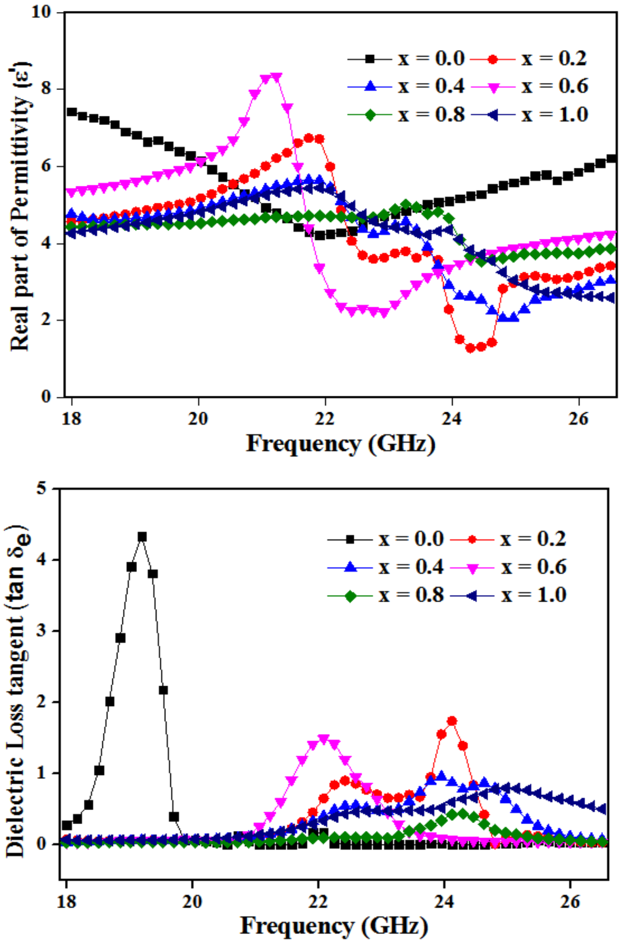


Fig. 1 Real part of permittivity and dielectric loss tangent variation for different ferrite compositions in K-band

Dielectric loss tangent of samples has shown almost similar trend as that of dielectric constant since polarization is the governing factor in both properties. The amplitude of resonance peak has decreased with increase in doping amount. These results are in conformity with variation of dielectric constant with frequency. Shifting of peak position with varying amount of Co-Zr has also been observed.

B. *Real Permeability & Magnetic Loss Tangent*

Complex permeability of the doped ferrite compositions is plotted in Fig. 2. Real part of permeability (μ') has shown very little variation w.r.t. frequency which can be attributed to the limited speed of the spin and domain wall movement (displacement/rotation) in the prepared ferrites [5]. Small values of μ' achieved in the studied frequency range can be attributed to the weak applied field. With doping of Co-Zr, lattice distortion has occurred that has generated internal stress. This has led to higher magnetic losses with doping. Natural ferromagnetic and exchange resonances could be the source of magnetic losses in these ferrites. Hysteresis can't be the reason due to weak applied field. Contribution of domain wall displacement is totally rejected because the ferrites are single domain [7-8]. This shows that the goal of doping has been achieved as the losses have increased with doping. Resonance peaks have been observed in the loss spectra.

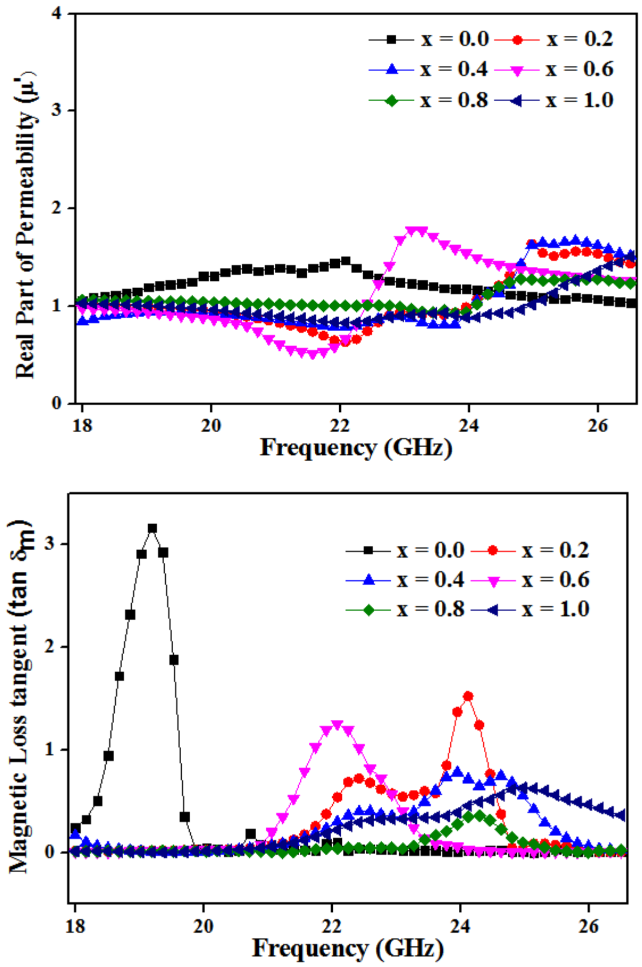


Fig. 2 Variation of real part of permeability and magnetic loss tangent w.r.t. frequency in K-band for different compositions

C. *Absorption as a function of doping of Co-Zr*

The reflection loss (RL) values of synthesized hexaferrites were simulated for 3.5 mm pellet thickness (Fig. 3a) using the formula [9]:

$$RL\,(db) = 20\log\left|\frac{Z_i - Z_o}{Z_1 + Z_o}\right| \text{ and } Z_i = Z_o\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left[j\frac{2\pi f d\sqrt{\mu_r \varepsilon_r}}{c}\right] \quad -(1)$$

where, Z_i is the wave input impedance, Z_o is the characteristic impedance (377Ω), f is the frequency of microwave, d is the thickness of sample, c is velocity of light in vacuum, ε_r is the complex permittivity and μ_r is the complex permeability. There is a parameter which is used for determination of quality of absorber: -10dB bandwidth. It represents the bandwidth that can achieve 90% absorption. It can be observed that all the compositions have observed reflection loss less than -10dB in 18 -26.5 GHz. The reflection dip has moved towards higher frequency range with increase in doping amount till x = 0.6 composition. For higher compositions, the reflection dip is observed in lower frequency range (as shown in table 1). Minimum reflection loss has been determined in case of x = 0.8 composition, followed by x = 0.2 and 1.0. -10 dB absorption bandwidth of the doped compositions is higher in comparison to the undoped composition. Highest absorption bandwidth has been achieved in case of x = 0.6 composition. This suggests that the doped samples exhibit better wideband absorption and higher absorption peaks (Table 1). The broken super-exchange bonds, resulting from doping, improve the absorption capability of material [6]. Fig. 3 (b) shows the absorption power (%) of the ferrites in the studied frequency band. The values were calculated using the relation [10]:

$$Absorption\ (\%) = 100 - [(10^{(-RL/10)} * 100] \quad - (2)$$

Absorption peaks are governed by two mehcnisms: impedance matching and high electromagnetic losses. Condition of impedance matching is achieved thrpugh use of equation (1) and high electromagnetic losses are achirved through proper doping. With increase in doping, EM losses have shown increase which leads to enhancement of absorption properties.

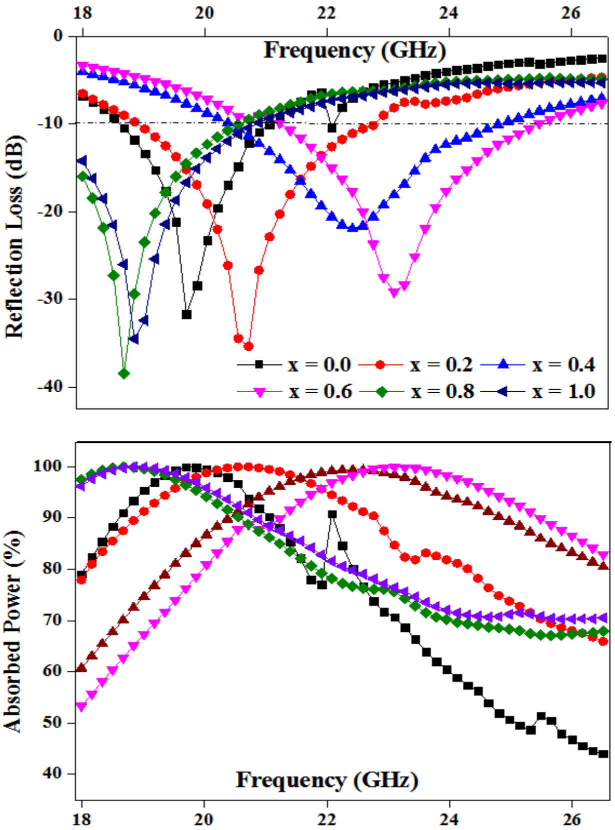


Fig. 3 (a) Reflection Loss Spectra and (b) Absorption (%) for different samples of thickness 3.5 mm in K-band

TABLE 1. ABSORPTION PROPERTIES OF PREPARED HEXAFERRITES IN K FREQUENCY BAND

Properties	Composition with varying Co-Zr content (x)					
	x = 0.0	*x = 0.2*	*x = 0.4*	*x = 0.6*	*x = 0.8*	*x = 1.0*
RL (dB)	-31.66	-35.38	-21.97	-29.15	-38.41	-34.53
f_r (GHz)	19.7	20.72	22.42	23.1	18.68	18.85
-10dB BW (GHz)	2.72	4.08	4.59	4.25	2.72	2.74

D. Absorption as a function of thickness of Sample

Absorption properties also depend on the thickness of sample. Smaller the thickness of ferrite, better will be the absorber. In Fig. 4, the variation of RL curve w.r.t. thickness is plotted. It can be seen that with increase in thickness, the dip shifts towards the lower side of frequency band (Table 2). Similar results have also been reported by Meena et. al. [9] and Kiani et. al. [6]. These results are in accordance to quarter wavelength model where matching thickness is inversely proportional to the frequency of applied field.

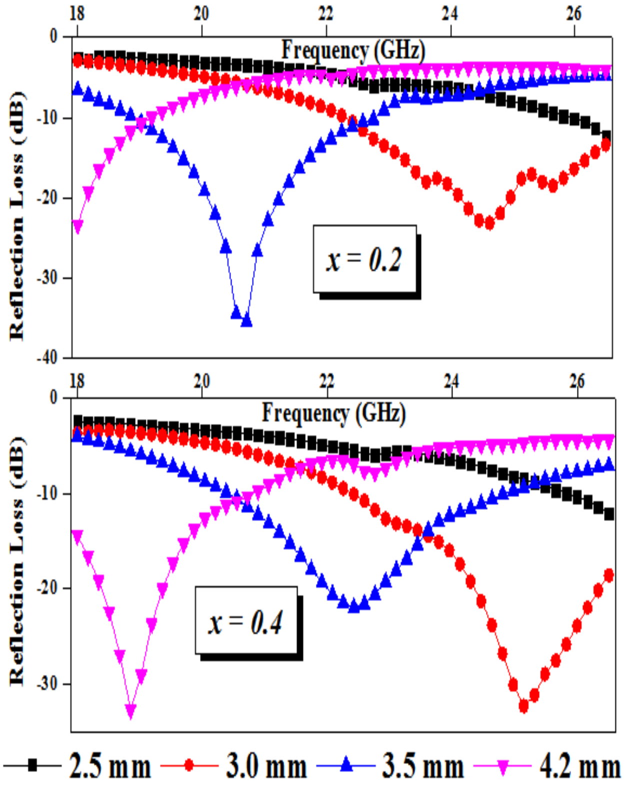
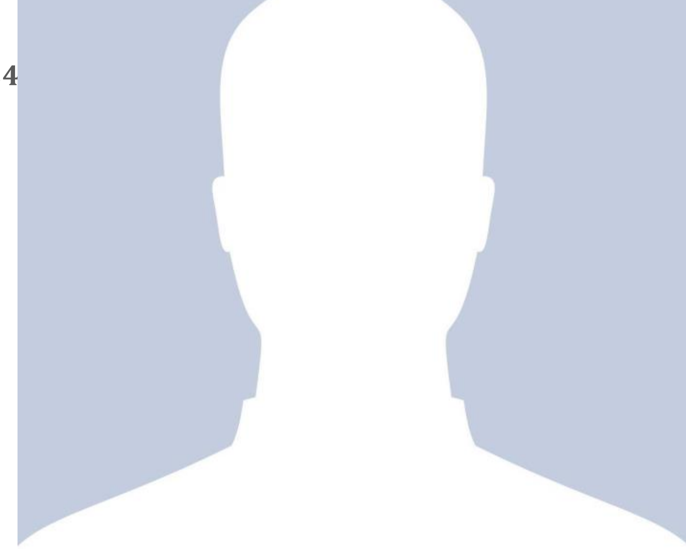


Fig. 4 Variation of reflection loss curves with thickness of sample for composition with x = 0.2 and x = 0.4

IV. CONCLUSIONS

Cobalt-zirconium hexaferrites, synthesized using citric acid sol gel method, were characterized in 18 - 26.5 GHz frequency range using vector network analyzer. Analysis shows that doping of impurity ions has produced important influence on the electromagnetic properties. These properties have increased with doping, while remained almost constant w.r.t. frequency in the scanned frequency range. Absorption analysis shows that all compositions have potential to be used as an efficient absorber in microwave and radar absorbing applications in K-band. The base composition with no substitution exhibits reflection loss of -28 dB at 19.9 GHz frequency with -10 dB absorption bandwidth of 2.3 GHz. The doping of Co-Zr has lowered the reflection loss to -38.41 dB, -35.38 dB and -34.53 dB for x = 0.8, 0.2 and 1.0 compositions respectively. -10 dB absorption bandwidth has increased to 4.5 GHz, 4.3 GHz and 3.9 GHz for compositions with x = 0.6, 0.8 and 0.2 respectively. The reflection loss spectrum shifts



towards lower side of frequency band with increase in thickness.

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REFERENCES

[1] P. Kaur, S.K. Chawla, S.B. Narang, K. Pubby, J. Magn. Magn. Mater. 422 (2017) 304-314.

[2] Y. Yang, X. Liu, D. Jin, Y. Ma, Mater. Res. Bull. 59 (2014) 37-41.

[3] P. Kaur, S.K. Chawla, S.S. Meena, S.M. Yusuf, S.B. Narang, *Ceram. Int.* 42(13) (2016) 14475-14489.

[4] F. Aen, M. Ahmad, M.U. Rana, *Curr. Appl. Phys*. 13 (2013) 41-46.

[5] R.S. Meena, S. Bhattachrya, R. Chatterjee, J. Magn. Magn. Mater., 322 (2010) 2908-2914.