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Microwave Absorption Characteristics Of Substituted Ba 0.5Sr 0.5M xFe (12-2x)O 19 (M = Co ²⁺-Zr 4+ And Co 2+-Ti 4+) Sintered Ferrite At X-band

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monolithic circuit (MMIC) technology, featured by a higher control of parasitic effects higher integration levels resulting in compact size, may lead to considerable improvements in bandwidth and return loss performance.

REFERENCES

1. Philips Semiconductor, Circulators and isolators, unique passive devices, Application Note AN98035, 1998.
2. A.G Gurevich and G.A. Melkov, Magnetization oscillation and waves, CRC Press, Boca Raton, FL, 1996.
3. A.M.T. Abuelma'atti, A.A.P. Gibson, and B.M. Dillon, Analysis of a 10 kW - 2.45 GHz ferrite phase shifter, In: 3rd European Radar Conference, EuRAD 2006, 2006, pp. 261–624.
4. J. Helszajn and P.N. Walker, Operation of high peak power differential phase shift circulators at direct magnetic fields between subsidiary and main resonances, IEEE Trans Microwave Theory Tech 26 (1978), 653–658.
5. R.E. Collin, Foundation for microwave engineering, 2nd ed., IEEE Press Series on Electromagnetic Wave Theory, New York, NY, 1992.
6. S.D. Ewing and J.A. Weiss, Ring circulator theory, design, and performance, IEEE Trans Microwave Theory Tech 15 (1967), 623–628.
7. A.E. Booth, Dual balanced reciprocal waveguide phase shifter, US Patent 3,833,868, 1974.
8. Y. Ayasli, Field effect transistor circulators, IEEE Trans Magn 25 (1989), 3242–3247.
9. A. Ohlsson, V. Gonzalez-Posadas, and D. Segovia-Vargas, Active integrated circulating antenna based on non-reciprocal active phase shifters, In: Proceedings of the Second European Conference on Antennas and Propagation, EuCAP 2007, 2007, pp. 1–5.
10. R.V. Garver, Broad-band diode phase shifters, IEEE Trans Microwave Theory Tech 20 (1972) 314–323.

MICROWAVE ABSORPTION CHARACTERISTICS OF SUBSTITUTED $BA_{0.5}SR_{0.5}M_XFE_{(12-2X)}O_{19}$ ($M = CO^{2+}—ZR^{4+}$ AND $CO^{2+}—TI^{4+}$) SINTERED FERRITE AT X-BAND

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ABSTRACT: *The microwave reflection loss (RL) of four series of synthesized ferrites, $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ and $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$, have been measured using network analyzer in the frequency range from 8.2 to 12.4 GHz. The comprehensive analysis of RL is carried out as a function of substitution, frequency, and thickness. The various models contributing to large RL are described. The composition accompanying maximum microwave absorption is suggested.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:1661–1665, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26912

Key words: *ceramics; ferrites; microwave absorption*

1. INTRODUCTION

An exponential growth of number of electronic devices for various applications has led to numerous electromagnetic compatibility (EMC)/electromagnetic interference (EMI) problems. The absorption of electromagnetic signal is required to tackle this situation, and ferrite-based microwave absorbers are known to be effective for reducing unwanted electromagnetic radiation and coupling. These absorbers are incorporated in enclosures of electronic devices, placed around known or potential sources of EMI, in shields around cables to reduce common-mode currents, in noise filters, as well as in such applications as anechoic chambers, stealth technology, etc.

Frequency range of application of conventional low-anisotropy monocrystalline, polycrystalline, and powdered ferrites (mainly, spinel-type ferrites) in shields, coatings, and filtering devices is limited by Snoek's law, and typically does not exceed a few gigahertz [1]. The hexagonal ferrites can be engineered to find their absorber application at microwave and higher frequencies [2–7].

An important characteristic that describes absorptive properties of lossy materials is their reflection loss (RL). A sample of an absorbing material under study is typically placed on a metal wall and exposed to a plane wave, usually normally incident. It may be also placed as a slab on the shorted termination of a transmission line with TEM mode, or a waveguide. Obviously, the RL from such a structure depends on frequency, thickness of the sample, electromagnetic mode structure, and constitutive parameters (complex permittivity and permeability) of the sample.

The objective of this article is the study of electromagnetic RL characteristics for the novel sintered M-type Ba—Sr hexagonal ferrites doped with Co—Ti and Co—Zr. Their formulas are $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ and $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$. The effects of the ferrite contents and sample thickness upon frequency characteristics of RL for these hexagonal ferrites are studied. The purpose of this article is to give an insight on how to find a composition to maximize absorption level in the frequency range of interest. We are reporting the investigation of mentioned ferrite series for the first time.

2. EXPERIMENTAL STUDY

The two series of M-type hexagonal ferrite have been investigated viz. $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ (Co—Zr series), and $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$ (Co—Ti series). Network analyzer (Agilent model 8722ES) is used for RL measurement (Fig. 1). The known Nicholson and Ross method [8] was used in the frequency range from 8.2 to 12.4 GHz. The RL was calculated as

Figure 1 Experimental set-up for the measurement of complex permittivity and complex permeability. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

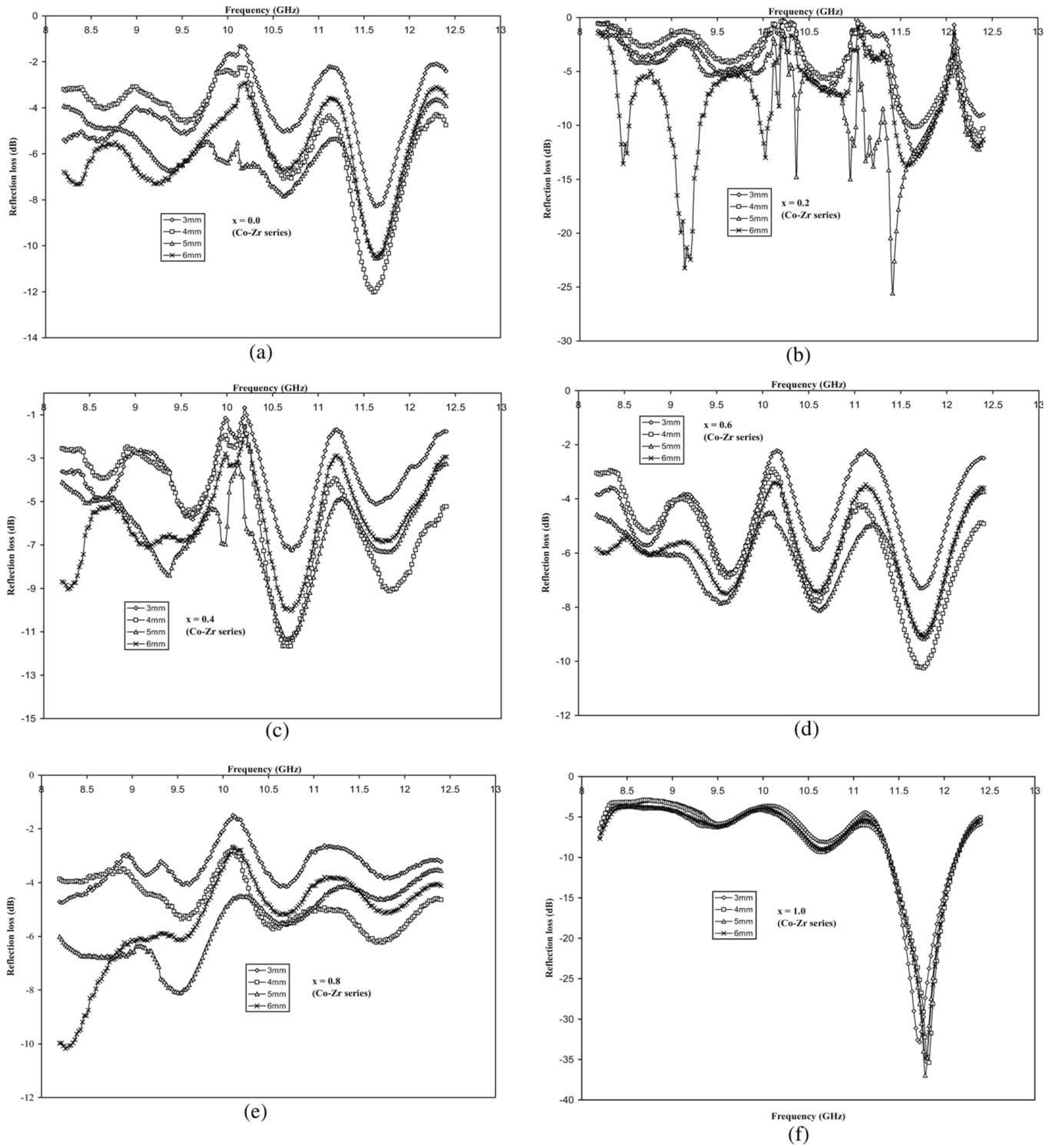

Figure 2 RL variation with frequency, thickness and substitution in $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ ferrite: (a) $x = 0.0$, (b) $x = 0.2$, (c) $x = 0.4$, (d) $x = 0.6$, (e) $x = 0.8$, and (f) $x = 1.0$

$$\text{Reflection Loss (RL)} = 20 \log\left|\frac{Z_{in}-1}{Z_{in}+1}\right|, \tag{1}$$

$$\text{where } Z_{in} = \frac{Z}{Z_0} = \sqrt{\frac{\mu^*}{\varepsilon^*}}\tanh\left[j\frac{2\pi}{c}\sqrt{\mu^*\cdot\varepsilon^*}ft\right]. \tag{2}$$

In (2), ε^* and μ^* are the complex relative permittivity and permeability, respectively, and t is the thickness of the wave absorber. The parameter c is the speed of light in vacuum, and f is the linear frequency of the electromagnetic wave. Calibration of the network analyzer was made in air before carrying out final measurements. The entire frequency region was divided into 201 points, i.e., readings were taken with successive increment (minimum resolution) of 0.021 GHz.

The synthesis, characterization, and static properties of Co—Zr series and Co—Ti series have been investigated in our previous reports [9, 10]. RL levels of −10 dB (90% of absorption) and −20 dB (99% of absorption) are typically used to evaluate the electromagnetic wave absorption. Herein, the −20 dB RL for evaluating performance of ferrite material is chosen. "High

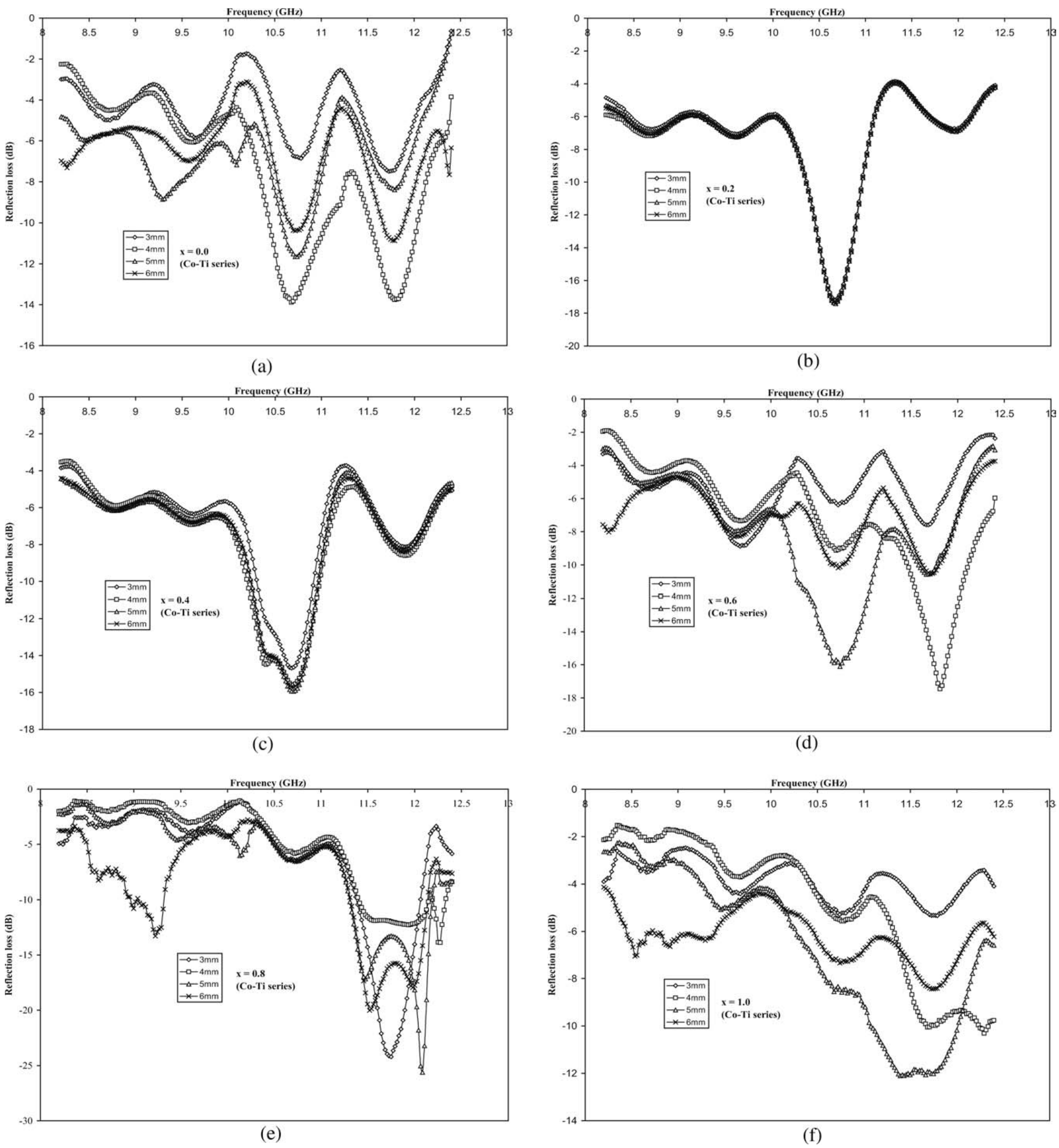

Figure 3 RL variation with frequency, thickness and substitution in $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$ ferrite: (a) $x = 0.0$, (b) $x = 0.2$, (c) $x = 0.4$, (d) $x = 0.6$, (e) $x = 0.8$, and (f) $x = 1.0$

return loss'' means that RL ≤ -20 dB. The results of experimental study of hexagonal ferrite samples are presented below.

2.1. Co—Zr series $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$

The samples with $x = 0.0$, 0.4, 0.6, and 0.8 shows RL (Fig. 2) less than 20 dB at all thickness along entire frequency region. The samples with $x = 0.2$ exhibits significant RL at low and high frequency region. RL is – 26 dB at 5 mm and 11.4 GHz, while it is -23 dB at 6 mm and 9.1 GHz.

The magnitude of the RL in the sample $x = 1.0$ increases nonlinearly with frequency and shoots to the maximum absolute value in the vicinity of 12 GHz. Sample 1.0 exhibits high RL at all thickness in high frequency region. RL of -37, -35, -34, and -32 dB is observed at 5, 4, 6, and 3 mm thickness with corresponding frequencies of 11.7, 11.8, 11.8, and 11.7 GHz.

2.2. Co—Ti series $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$

The samples with $x = 0.0$, 0.4, 0.6, and 1.0 exhibit RL less than 20 dB for all the thicknesses along entire frequency region, as is shown in Figure 3. The sample with $x = 0.2$ shows RL of -17 dB at all thicknesses at 10.67 GHz. Thus, the RL is almost independent of thickness at 10.67 GHz.

The sample with $x = 0.8$ shows high RL at two frequencies; -25 dB at 5 mm and 12.08 GHz while -24 dB at 3 mm and

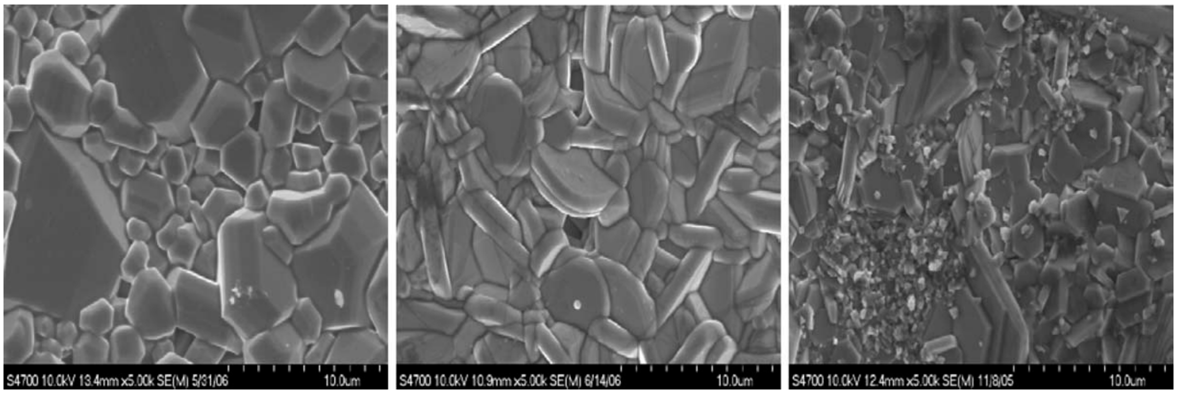

Figure 4 SEM micrographs images of ferrite samples (a) $Ba_{0.5}Sr_{0.5}Fe_{12}O_{19}$, $x = 0.0$ (b) $Ba_{0.5}Sr_{0.5}Co_{1.0}Ti_{1.0}Fe_{10}O_{19}$, $x = 1.0$, and (c) $Ba_{0.5}Sr_{0.5}Co_{1.0}Zr_{1.0}Fe_{10}O_{19}$, $x = 1.0$

TABLE 1 Maximum Stored Energy and Remanence Magnetization of Co—Zr and Co—Ti Series

	$BH_{max.}$ (KOe)		M_r (emu/gm)	
x	Co—Zr series	Co—Ti series	Co—Zr series	Co—Ti series
0.0	359	363	29	30
0.2	35	22	19	12
0.4	18	8	18	14
0.6	13	5	15	10
0.8	16	3	13	6
1.0	12	6	12	9

11.74 GHz. Sample 1.0 exhibits RL less than −20 dB for all the thickness values over entire frequency spectrum.

The microwave absorption depends on numerous factors, such as hysteresis loss, eddy current loss, residual loss, ferromagnetic loss, intragranular domain wall loss, coercivity, dielectric loss, porosity, and grain boundaries.

The propagating wavelength in (λ_m) a material is given as

$$\lambda_m = \lambda_o/(|\varepsilon^*| \cdot |\mu^*|)^{1/2} \quad (3)$$

where λ_o is the wavelength in air and $|\varepsilon^*|$, $|\mu^*|$ are the modulus of ε^* and μ^*.

The maximum RL occurs when thickness, t, is a multiple of quarter material wavelength, $t = n\ (\lambda_m/4)$ (n = integer). With this criterion, the incident wave is antiphase (180°) with the reflected wave in the material, and the reflected waves are cancelled at the air-material interface.

For the sample with $x = 0.2$ in Co—Zr series at $t = 5$ mm, peaks of large RL occur at $t = 5(\lambda_m/4)$ and for $t = 6$ mm, $t = 3(\lambda_m/4)$. Thus, high RL peaks at 5- and 6-mm thickness are successive odd multiple of $\lambda_m/4$, and these peaks are shifted from high to low frequency region with increase in thickness from 5 to 6 mm.

For sample $x = 0.8$ in Co—Ti series at $t = 3$ mm, peaks of large RL are formed at $t = 2(\lambda/4)$ and for $t = 5$ mm, $t = 4(\lambda_m/4)$. Hence, peaks at 3- and 5-mm thickness are even multiple of $\lambda_m/4$ and peaks in this composition are shifted from low to high frequency region with increase in thickness from 3 to 5 mm.

Maximum absorption also occurs when $|\mu^*| = |\varepsilon^*|$ irrespective of resonance or other conditions discussed before [11]. In the sample 1.0 of Co—Zr series, this condition is satisfied for all thicknesses over the high-frequency region. This results in the highest microwave absorption (RL = −37 dB) in sample 1.0 of Co—Zr series as discussed before.

The previous reports [9, 10] contain comprehensive study of the microstructure and hysteresis properties of the present ferrite series, $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$, and $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$. Figure 4 shows SEM micrographs of sample $x = 0.0$ and sample 1.0 of Co—Ti and Co—Zr series: There is decrease in porosity, increase in grain size, and enhancement of intergrain connectivity with substitution. The increase in grain size also increases the number of domains in the grain, thus, contributing more to intragranular domain wall motion. This followed by improved intergrain connectivity with substitution decreases pinning of domain wall motion, which in turn increases absorption. It is reported elsewhere that large grains increases eddy current loss [12], a plausible contributing factor behind large RL in Co—Ti and Co—Zr series at higher substitution. On the other side in Table 1, the intrinsic parameters BH_{max} (maximum stored energy) and M_r (residual loss) decrease with substitution in Co—Ti and Co—Zr series [9, 10], hence, absorption should decrease. Therefore, competition between domain wall movement, eddy current loss, and intrinsic parameter variation increase RL in substituted samples of Co—Ti and Co—Zr series.

Table 2 shows the RL values below −20 dB found in synthesized ferrites along with corresponding frequency and bandwidth. It is evident that samples having high RL exhibit narrowband behavior, sample $x = 1.0$ of Co—Zr series exhibits highest bandwidth of 336 MHz. The graph in Figure 5 exhibits matching frequency and

TABLE 2 Reflection Loss Data (≥ −20 dB) of Co—Zr, Co—Ti, and Ba—Sr Series

		Reflection Loss (dB)				Frequency (GHz)				Bandwidth (GHz)			
Ferrite	Sample	$d =$ 3 mm	$d =$ 4 mm	$d =$ 5 mm	$d =$ 6 mm	$d =$ 3 mm	$d =$ 4 mm	$d =$ 5 mm	$d =$ 6 mm	$d =$ 3 mm	$d =$ 4 mm	$d =$ 5 mm	$d =$ 6 mm
Co—Zr series	$x = 0.2$	–	–	−26	−23	–	–	11.4	9.1	–	–	0.067	0.084
	$x = 1.0$	−32	−35	−37	−34	11.728	11.833	11.791	11.812	0.336	0.294	0.294	0.315
Co—Ti series	$x = 0.8$	−24	–	−25	–	11.749	–	12.085	–	0.294	–	0.084	–

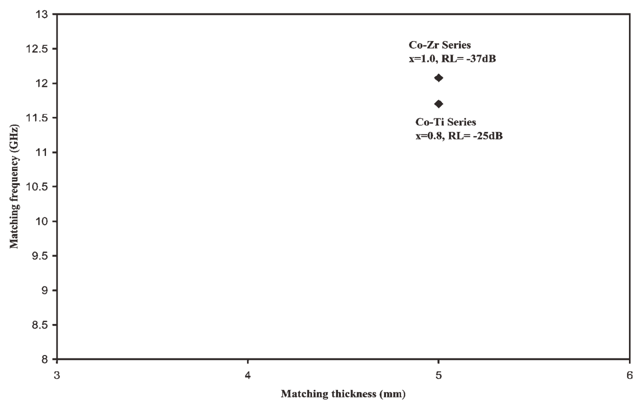

Figure 5 Matching thickness and matching frequency corresponding to maximum RL in $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ and $Ba_{0.5}Sr_{0.5}Co_xTi_xFe_{(12-2x)}O_{19}$ferrite

matching thickness corresponding to maximum RL in synthesized ferrites. The maximum RL occurs at matching thickness of 5 mm.

3. CONCLUSION

The microwave absorption varies with frequency, thickness, and substitution Co—Zr and Co—Ti series. The microstructure, intrinsic magnetostatic parameters, and geometrical condition influence microwave absorption. The Co—Zr and Co—Ti ferrite behave as narrowband absorber at high frequency region. The matching condition (absorption = -20 dB) is associated with material properties, $|\mu^*| = |\varepsilon^*|$, and cancellation of incident and reflected waves in the ferrite material, when thickness is equal to n.λ_m/4. It was found that the matching condition $|\mu^*| = |\varepsilon^*|$ is satisfied in the sample with $x = 1.0$ of Co—Zr series, while all the other samples obey the second matching condition.

The sample $x = 1.0$ of $Ba_{0.5}Sr_{0.5}Co_xZr_xFe_{(12-2x)}O_{19}$ ferrite shows maximum RL of -37 dB at matching thickness and matching frequency of 5 mm and 12.08 GHz with maximum bandwidth of 336 MHz. This opens up the possibility of these microwave absorbers for EMC/EMI applications. The work on composites of the mentioned different series is still under investigation and is a topic of a separate article.

REFERENCES

1. S. Sugimoto, S. Kondo, K. Okayama, H. Nakamura, D. Book, T. Kagotani, and M. Homma, M-type ferrite composite as a microwave absorber with wide bandwidth in the GHz range, IEEE Trans Magn 35 (1999), 3154–3156.
2. A.A. Kitaytsev and M.Y. Koledintseva, Physical and technical bases of using ferromagnetic resonance in hexagonal ferrites for electromagnetic compatibility problems, IEEE Trans Electromagn Compat 41 (1999), 15–21.
3. A.A. Kitaytsev, M.Y. Koledintseva, and A.A.Shinkov, Microwave filtering of unwanted oscillations on base of hexagonal ferrite composite thick films, IEEE International Symposium on Electromagnetic Compatibility, August 24–28, Denver, CO, Vol. 1, (1998) 578–582.
4. A.A. Kitaytsev, M.Y. Koledintseva, V.A. Konkin, V.P. Cheparin, and A.A. Shinkov, Application of composite gyromagnetic materials for absorbing radiation produced by microwave oven, Proceedings of International Symposium Electromagnetic Compatibility EMC'99 Tokyo, paper 19P204 (1999), pp. 405–407.
5. L.K. Mikhailovsky, A.A. Kitaytsev, and M.Y. Koledintseva, Advances of gyromagnetic electronics for EMC problems, Proceedings of International IEEE Symposium on Electromagnetic Compatability, Washington DC, 2 (2000) 773–778.
6. M.Y. Koledintseva, P.C. Ravva, J.L. Drewniak, A.A. Kitaitsev, and A.A. Shinkov, Engineering of ferrite-graphite composite media for microwave shields, Proceedings of International IEEE Symposium on Electromagnetic Compatability, August 2006, Portland, OR, Session Electromagnetic Interference IV (TH-AM-II), Vol. 3, 14–18 Aug. 2006, pp. 598–602.
7. L.K. Mikhailovsky, B.P. Pollak, and A.E. Hanamirov, Research and development of EHF hexaferrite devices in MPEI(TU), 11th International Conference on Spin-Electronics and Gyrovector Electrodynamics, 20–22 Dec., 2002, Moscow (Firsanovka), Publisher UNC-1 MPEI(TU), Moscow, Russia, 2002, pp. 559–573.
8. A.M. Nicolson and G.F. Ross, Measurement of the intrinsic properties of materials by time-domain techniques, IEEE Trans Instrum Meas IM-19 (1970), 377–382.
9. C. Singh, S. Bindra Narang, I.S. Hudiara, Y. Bai, and M. Koledintseva, Hysteresis analysis of Co–Ti substituted M-type Ba–Sr hexagonal ferrite, Mater Lett 63 (2009), 1921–1924.
10. C. Singh, S. Bindra-Narang, I.S. Hudiara, and Y. Bai, The effect of Co and Zr substitution on dc magnetic properties of Ba–Sr ferrite, J Alloys Comp 464 (2008), 429–433.
11. A.N. Yusoff and M.H. Abdullah, Microwave electromagnetic and absorption properties of some Li-Zn ferrites, J Magn Magn Mater 269 (2004), 271–280.
12. M. Maisnam, S. Phanjoubam, H.N.K. Sarma, L.R. Devi, O.P. Thakur, and C. Parkash, Hysteresis and initial permeability behavior of vanadium-subsituted lithium-zinc-titanium ferrite, Physica B 352 (2004), 86–90.

A VERY COMPACT CPW-FED ULTRA-WIDEBAND CIRCULAR MONOPOLE ANTENNA

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ABSTRACT: *A very compact printed circular monopole antenna for ultra-wideband applications is presented. To achieve wide bandwidth performance, the proposed antenna is fed by a coplanar waveguide feedline. The total size of antenna is as small as 12 mm× 22 mm × 0.787 mm. The simulated and measured results demonstrate an impedance bandwidth covering 2.9–11.6 GHz for return loss less than −10 dB, which indicates that the proposed antenna performance is appropriate for UWB applications.* © 2012 Wiley Periodicals, Inc. Microwave Opt Technol Lett 54:1665–1668, 2012; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.26920

Key words: *ultra-wideband; printed antenna; omnidirectional radiation pattern*

1. INTRODUCTION

After the Federal Communication Commission allocated the frequency spectrum 3.1–10.6 GHz in 2002 for commercial applications, ultra-wideband (UWB) technology has attracted a great research interest for use in wireless communication industry [1]. Small size antenna, omnidirectional radiation pattern, stable gain, and low dispersion of received signals are some of other major challenges of antenna designers. In addition, it is important interest to design antennas with low profile, low weight, low cost, and easy fabrication. All of these properties can be achieved in UWB planar monopole antenna [2–5]. Mostly one of these two types of feeding structures is used in planar monopole antennas: (a) a microstrip line [2, 3] or (b) a coplanar waveguide (CPW) line [4, 5]. However, CPW feedline can provide wider band width than a