LITHIUM FERRITES FOR MICROWAVE DEVICES*

D. H. Temme, Gerald F. Dionne and W. E. Courtney

Lincoln Laboratory, Massachusetts Institute of Technology
Lexington, Massachusetts

and

Gil Argentina and P. D. Baba

Ampex Corporation, Redwood City, California

ABSTRACT

Lithium ferrites with properties comparable to the more expensive garnets are discussed. Hysteresis loops are square. Magnetic and dielectric losses, stress and temperature sensitivities are good. Data on phasers and a circulator are given.

*This work was sponsored by the Department of the Army.

I. Introduction. Recent ferrite material development efforts for latching phasers have emphasized manganese-doped yttrium gadolinium aluminum garnets.[1] This paper describes microwave lithium ferrites with properties comparable to the more expensive garnets. Important material parameters are discussed from a device point of view together with performance characteristics of some latching ferrite phase shifters and one circulator.

II. Magnetization. Low saturation magnetizations have been obtained by titanium[2] rather than aluminum substitution since it produces significantly better microstructure, necessary for good hysteresis loops and low magnetic loss. Most compositions have been designed for magnetizations between 400 and 1000 G.

III. Temperature Sensitivity of magnetization is a major consideration for device applications. This has been the main limitation of the widely-used magnesium manganese ferrites. In Fig. 1 the characteristics of 600 G lithium titanium ferrite and yttrium gadolinium aluminum garnet are compared. Note the higher Curie temperature of the lithium ferrite.

IV. Anisotropy Field (H_a) is a fundamental parameter in determining coercive force H_c, remanence ratio, and stress sensitivity. It can be varied widely in the lithium titanium ferrites by zinc additions. For garnets, H_a is about 80 Oe while for the lithium ferrites discussed here it varies between 125 and 200 Oe. The effects of anisotropy field on microwave device performance will be noted in the following sections.

V. Magnetostriction. From the standpoint of stress sensitivity, lithium ferrite has some advantages over garnets. The magnitude and stress sensitivity of the remanent magnetization is primarily determined by the ratio of the magnetostriction to anisotropy constants.[3] For both materials, partial elimination of magnetostriction effects can be obtained by manganese additions.[4] However, since lithium ferrite can have higher anisotropy, the above ratio can be lower than that of garnet and result in superior remanence properties. However, this reduced stress sensitivity must be traded-off in latching devices for increased switching energy as will be discussed below.

VI. Dielectric Constant and Loss. The dielectric constant of lithium titanium ferrite is typically about 19. The possible presence of both trivalent and divalent iron in ferrites creates a conduction mechanism which in turn can cause a large dielectric loss tangent. To reduce the microwave dielectric loss in lithium ferrite generally attributed to divalent iron resulting from high temperature sintering,[5] minute quantities of bismuth oxide were added to permit sintering near 1000°C and still obtain densities suitable for microwave applications without requiring further anneals.[6] The densities usually obtained approach values close the the theoretical limits with dielectric loss tangent usually less than 5×10^{-4}.

VII. Magnetic Loss. The magnetic loss of a ferromagnetic material has generally been characterized by the linewidth ΔH. Early in this investigation it was found that a lithium aluminum ferrite could be fabricated with good ΔH characteristics; however, the magnetic loss in a latching phaser was enormous because the microstructure was poor. It was found that a more direct measure of the magnetic loss was the loss tangent near the operating frequency. The results of recent studies suggest that the magnetic loss is proportional to the fourth power of the magnetization ratio,[7] as well as the spinwave linewidth. For lithium ferrites it is necessary to also include the dependence upon anisotropy field, which can be quite large for this family of materials. Based on phaser measurements in th very high loss region of low field losses, it appears that the normalized magnetization ratio may be $(4\pi M_s + H_a)/\omega$. Precise demagnetized loss tangent measurements are underway to characterize the magnetic loss tangent in terms of the magnetization ratio, anisotropy field, and spinwave linewidth.

VIII. Spinwave Linewidth. Independently,[8] it was found that the spinwave linewidth in lithium ferrite could be controlled by cobalt substitutions. A linear increase in spinwave linewidth with cobalt substitution for a 1000 G material is shown in Fig. 2.

IX. Hysteresis Loop Properties. Hysteresis loops of these materials are generally very square. The remanence ratios are seldom less than 0.65 and typically greater than 0.70. The coercive force can be controlled by zinc additions. Although there is no well established theory for the coercive force of a polycrystalline magnetic material, it is generally agreed that for uniform grain size, it depends directly on both porosity and anisotropy field. Since the switching energy of a phaser is directly related to the coercive force, it should be designed as low as possible. However, a decrease in anisotropy field, hence coercive force, will also increase the temperature sensitivity, as indicated in Fig. 3. The zinc additions which cause the reductions in anisotropy fields also reduce Curie temperatures. The lower Curie temperature due to zinc additions accounts for the increased temperature sensitivity. It appears from these curves that lithium ferrite with a coercive force comparable to garnet will have similar temperature sensitivity. However, it is noted that when high average power is required, lithium ferrite compositions with better temperature sensitivity can be fabricated at the expense of increased switching energy. This is a degree of flexibility in design that is not available with the garnet materials.

X. Cost of Material. Because lithium ferrites do not require expensive rare earth oxides, the cost of an S-band lithium ferrite toroid for a latching phaser is estimated to be half that of a garnet toroid.

XI. Lithium Ferrite Latching Phasers. Table I shows comparative performance characteristics of magnesium manganese, garnet and lithium ferrite phasers. Although a detailed comparison is not possible because testing has not been completed and the configurations are not identical, some general conclusions may be drawn. A good figure of merit FM (degrees of phase shift per db of RF loss) is obtainable with all of these materials. The average power handling capability of the lithium ferrite can be increased at the price of increased switching energy. The anisotropy field should be taken into account when choosing the magnetization of the material to avoid unnecessary high magnetic loss. The chief advantage of the lithium ferrite materials is their lower cost and to some extent their stress insensitivity. The latter has not been well established since a material with a coercive force equivalent to that of garnet has not been fabricated and tested.

XII. Lithium Ferrite Circulators. A circulator with a stepped ground plane configuration[9] utilizing a 350 G lithium ferrite with anisotropy field of 200 Oe was fabricated. The 20 db isolation bandwidth extended from 1.7 to 2.2 GHz and the average insertion loss was less than 0.4 db. The temperature of performance of the device has not yet been determined; however, it should considerably better than a comparable low loss garnet since its Curie temperature is at least 75°C higher.

Acknowledgements. The authors gratefully acknowledge the interest and help of many colleagues.

References

1. W. J. Ince, D. H. Temme, F. G. Willwerth, and R. L. Huntt, G-MTT 1970 International Microwave Symposium, p. 327.

2. C. F. Jefferson and R. G. West, J. Appl. Phys. 32 390S (1961).

3. G. F. Dionne, IEEE Trans. Mag. MAG-5, 596 (1969).

4. G. F. Dionne, J. Appl. Phys. 40, 4486 (1969).

5. D. H. Ridgley, H. Lessoff, and J. D. Childress J. American Ceram. Soc. 53, 304 (1970).

6. T. Collins and A. E. Brown, J. Appl. Phys. 41, 1351, (1970).

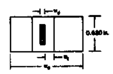
7. J. J. Green, and F. Sandy, Raytheon Research Division RADC-TR-69-338. (1969).

8. M. P. Bunina, E. V. Lebedeva, A. I. Pil' shchikov, and I. I. Sil'vestrovich, Soviet Phys. - Solid-State 12, 341 (1970).

9. E. J. Denlinger, D. H. Temme, and J. A. Weiss paper to be presented at G-MTT 1971.

TABLE I

	S-Band			C-Band		
	MnGdAl Garnet	LiTiZn Ferrite	LiTiZn Ferrite	MgMn Ferrite	MnGdAl Garnet	LiTiZn Ferrite
$4\pi M_s$(G)	680	680	570	1600	1600	[illegible]
f(GHz)	2.8	2.8	2.8	5.6	5.6	5.6
B_r(G)	470	380	400	520	635	[illegible]
H_a(Oe)	80	155	180	50	[illegible]	140
H_c(Oe)	0.7	1.5	0.9	0.5	0.7	1.0
ΔH_k(Oe)	4.5	3.2	7.0	5.0	6.0	4.3
ϵ_d	20	30	30	16	16	16
w_f(in.)	0.125	0.140	0.140	0.100	0.100	0.075
w_d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
w_g	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
$\Delta\phi$/in	70	[illegible]	70	40	75	[illegible]
FM(deg/db)	450	[illegible]	400	300	[illegible]	[illegible]
P_p(kW)	3.7	4.9	3.0	–	7.0	–
P_{av}(W)	200	–	200	30	200	–



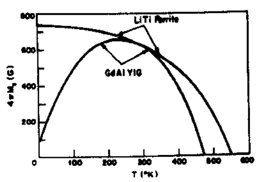


Fig. 1 Saturation magnetization versus temperature of 600 G LiTi ferrite and GdAℓYIG.

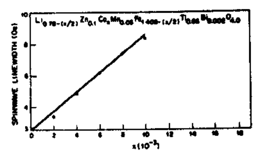


Fig. 2 Variation of spinwave linewidth with Co^{2+} concentration for a 1000 G LiZnTi ferrite composition.

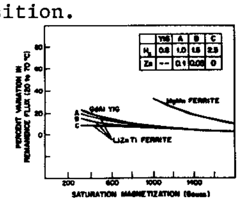


Fig. 3 Remanent flux temperature sensitivity as a function of saturation magnetization for various microwave ferrite materials.