APPLICATION NOTE

No. 691: Stabilization of Remanent Induction by Thermal Annealing

Introduction

In recent years microwave device engineers have increasingly employed the hysteresis loop characteristic of ferrimagnetic materials to obtain phase shifter device action. Two major advantages of this design technique are: (1) elimination of external d.c. biasing magnets, and (2) rapid switching between remanent induction states at low switching power.

A number of chemical and ceramic processing techniques are currently being studied to better control the remanent induction of ferrimagnets. The sensitivity of the remanent induction of a ferrimagnet to the fabrication method employed has been of major concern to material scientists because of its effect on device action. It has been found, experimentally, that there is a direct linear relationship between the magnitude of remanent induction and the differential phase shift obtained for a given material.

Machining or lapping and polishing of ferrimagnets into phaser toroids and substrates can result in a large change of the remanent induction from its nominal intrinsic value. This effect is most pronounced when a finished section is less than approximately one-tenth of an inch thick. This Tech Brief describes a thermal treatment for eliminating deleterious effects which may result from mechanical finishing.

Magnetostriction

Current theory suggests that magnetostrictive effects are the origin of observed variations in the remanent induction of mechanically finished ferrimagnets. Mechanical stress will change the direction of domain magnetization ($4\pi M$) via the magnetostriction. Under mechanical stress a component of magnetoelastic energy (E) exists which can be expressed as

$$E = \frac{3}{2} \lambda s \, \sigma \sin^2 \theta \qquad (1)$$

where λs is the isotropic magnetostrictive constant, σ represents a uniform applied tensile stress, and θ is the angle between the applied stress and the direction of magnetization.

Table I

Magnetostrictive Properties of Ferritest†

	Material	$4\pi M_s$ Gauss	$B_R/B_{R(0)}$** at 3000 psi
Mg-Mn	TT1-414*	680	1.0
	TT1-109	1250	1.0
	TT1-105	1700	1.0
	TT1-390	2150	1.0
	GE 42L	860	1.0
Ni-Co	TT2-116	1400	1.55
	TT2-115	1600	1.21
	TT2-101	3000	0.93
	M-52*	3150	0.84
Garnets	TTG-1002	1000	0.84
	TTG-1001	1200	0.88
	TTG-1200	1200	0.88
	TTG-113	1780	0.95
	SP 286*	1250	0.95

* Prefixes: TT-Trans-Tech, M-Motorola, SP-Sperry, GE-General Electric
** $B_r/B_{r(0)}$ is the ratio of remanent induction at 3000-psi compression over the remanent induction without stress.
† After Stern & Temme

Since nature tends to minimize energy, it follows that an alignment of $4\pi M$ and σ is favored when λs is positive while a 90° orientation between $4\pi M$ and σ is favored when λs is negative.

The effect of applied stress on the remanent induction of a number of ferrimagnetic toroids is given in Table I. Notice that Ni-Co ferrites and garnets exhibit greater magnetostrictive properties than Mg-Mn type ferrites. To date Ni-Co type ferrites have not been employed extensively in latching phaser applications because of their relatively large coercive force.

Thermal Annealing

Under the severe conditions encountered at the surface of a ferrimagnet during machining, it appears that a mechanical strain is induced in the material. The hysteresis loop of a machined toroid of garnet material type TTG-1001 is shown in Figure 1a. The remanent induction is severely degradated. This strain can be removed by thermal annealing. In Figure 1b the hysteresis loop of the same toroid is shown after being thermally annealed at 1200°C for one hour. The measured remanent induction value of 651 gauss compares favorably with that of toroids fabricated from the same ferrimagnetic material but not subjected to a machining step.

Although the magnetostrictive coefficients of garnets and nickel-cobalt ferrites are generally greater than those of magnesium-manganese type ferrites, a deterioration in remanent induction of the latter type ferrites may also occur if the part is thin enough.

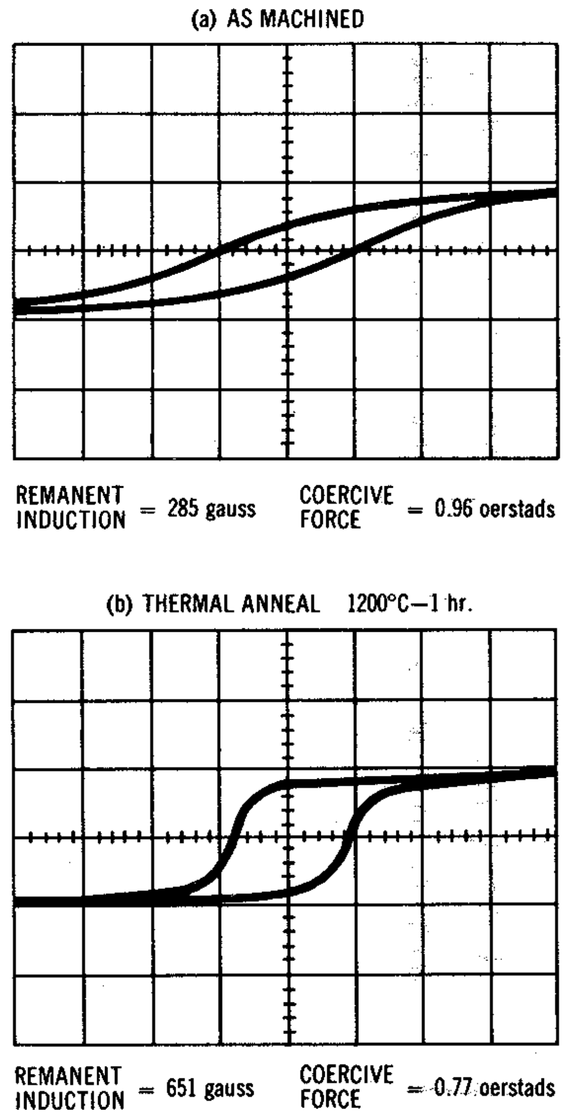
It appears quite feasible to eliminate deleterious effects resulting from mechanical finishing by means of thermal annealing.

The thermal annealing treatment consists of heating the part in the same atmosphere employed during sintering, which is normally air. For garnets this consists of a heating rate of approximately 100°C per hour up to 1200°C; holding for one hour at 1200°C; and cooling at approximately 100°C per hour to room temperature. For magnesium-manganese type ferrites, the treatment is the same with the exception that an 1100°C hold should be employed. In all cases care should be taken to avoid thermal shock. At these temperatures and heating/cooling rates, the mechanical integrity and chemical nature of the ferrimagnetic part are not affected so that no change in mechanical dimensions or technical properties should be encountered.

Thermal annealing should be considered as part of the fabrication process when a ferrimagnetic part for latched phase operation is mechanically finished to final dimensions of approximately one-tenth of an inch or less. If the microwave device engineer fabricates ferrimagnetic parts from bar stock for similar use, it is also advisable that thermal annealing be employed.

References

"Magnetostriction Effects in Remanence Phase Shifters", E. Stern and D..Temme, IEEE Trans. MTT, vol. MTT-13, p. 873 (November 1965).



EFFECT OF THERMAL ANNEAL ON HYSTERESIS LOOP CHARACTERISTICS OF A 0.025″ WALL TOROID OF GARNET TYPE G1001

Figure 1

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