

APPLICATION NOTE

Stabilization of Remanent Induction by Thermal Annealing

Introduction

In recent years, microwave device engineers have increasingly used the hysteresis loop characteristic of ferrimagnetic materials to obtain phase shifter device action. Two major advantages of this design technique are:

- Elimination of external DC biasing magnets.
- 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 used 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 Application Note describes a thermal treatment for eliminating deleterious effects that 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 changes the direction of domain magnetization ($4\pi M$) through the magnetostriction. Under mechanical stress, a component of magnetoelastic Energy (E) exists that can be expressed as:

$$E = \frac{3}{2} \lambda_s \sigma \sin^2 \varphi \quad (1)$$

Where:

λ_s = Isotropic magnetostrictive constant

σ = A uniform applied tensile stress

φ = Angle between the applied stress and the direction of magnetization

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

Table 1 provides the effect of applied stress on the remanent induction of a number of ferrimagnetic toroids. 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 used extensively in latching phaser applications because of their relatively large coercive force.

Table 1. Magnetostrictive Properties of Ferrites [reference 1]

Material Type	Material (Note 1)	$4\pi M_s$ (Gauss)	$B_r/B_r(0)$ (Note 2)
Magnesium Manganese	TT1-414	680	1.0
	TT1-109	1250	1.0
	TT1-105	1700	1.0
	TT1-390	2150	1.0
Nickel Cobalt	TT2-116	1400	1.55
	TT2-115	1600	1.21
Nickel	TT2-101	3000	0.93
Yttrium Gadolinium Garnet	G1002	1000	0.84
	G1001	1200	0.88
Yttrium Gadolinium Aluminum Garnet	G1200	1200	0.88
Yttrium Garnet	G113	1780	0.95

Note 1: TT = TT1 part #.

Note 2: The ratio of the remanent induction at 3000 psi compression over the remanent induction without stress.

Thermal Annealing

Under the severe conditions encountered at the surface of a ferrimagnet during machining, it appears that mechanical strain is induced in the material.

Figure 1 shows the hysteresis loop of the machined toroid of garnet material type G113. Although the remanent induction is severely degraded, this strain can be removed by thermal annealing.



Figure 1. Machined Toroid of G113

Figure 2 shows the hysteresis loop of the same toroid after being thermally annealed at 1200 °C for one hour. The measured remanent induction value compares favorably with that of toroids fabricated from the same ferrimagnetic material, but not subjected to a machining step.



Figure 2. Effect of Thermal Anneal on G113

Although the magnetostrictive coefficients of garnets and Ni-Co ferrites are generally greater than those of Mg-Mn type ferrites, deterioration in remanent induction of the latter type ferrites may also occur if the part is thin enough.

It is feasible to eliminate deleterious effects that result from mechanical finishing by means of thermal annealing. The thermal annealing treatment consists of heating the part in the same atmosphere used during sintering, which is normally air.

For garnets, the treatment consists of a heating rate of approximately 100 °C per hour up to 1200 °C, holding for one hour at 1200 °C, and then 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 used.

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 used.

Reference

- [1] E. Stern and D. Temme, *Magnetostriction Effects in Remanence Phase Shifters*, IEEE Transactions on Microwave Theory and Techniques, Volume MTT-13, November 1965, p. 873.

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