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:

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

Where:

λs = 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 λs is positive, while a 90 degree orientation between $4\pi M$ and σ is favored when λs 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 = TTI 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.

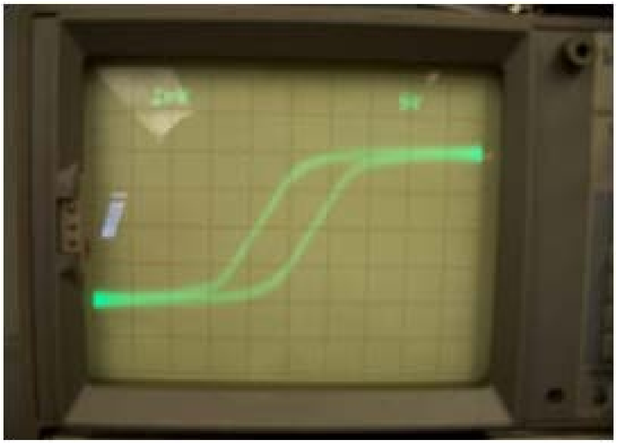

Figure 1. Machined Toroid of G113

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.

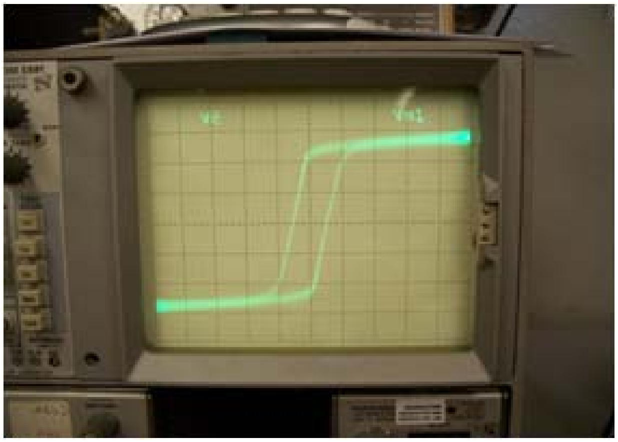

Figure 2. Effect of Thermal Anneal on G113

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.

Copyright © 2013, 2017 Trans-Tech Inc., All Rights Reserved.

Information in this document is provided in connection with Trans-Tech, Inc. ("Trans-Tech"), a wholly-owned subsidiary of Skyworks Solutions, Inc. These materials, including the information contained herein, are provided by Trans-Tech as a service to its customers and may be used for informational purposes only by the customer. Trans-Tech assumes no responsibility for errors or omissions in these materials or the information contained herein. Trans-Tech may change its documentation, products, services, specifications or product descriptions at any time, without notice. Trans-Tech makes no commitment to update the materials or information and shall have no responsibility whatsoever for conflicts, incompatibilities, or other difficulties arising from any future changes.

No license, whether express, implied, by estoppel or otherwise, is granted to any intellectual property rights by this document. Trans-Tech assumes no liability for any materials, products or information provided hereunder, including the sale, distribution, reproduction or use of Trans-Tech products, information or materials, except as may be provided in Trans-Tech Terms and Conditions of Sale.

THE MATERIALS, PRODUCTS, AND INFORMATION ARE PROVIDED "AS IS" WITHOUT WARRANTY OF ANY KIND,WHETHER EXPRESS, IMPLIED, STATUTORY, OR OTHERWISE, INCLUDING FITNESS FOR A PARTICULAR PURPOSE OR USE, MERCHANTABILITY, PERFORMANCE, QUALITY, OR NON-INFRINGEMENT OF ANY INTELLECTUAL PROPERTY RIGHT; ALL SUCH WARRANTIES ARE HEREBY EXPRESSLY DISCLAIMED. TRANS-TECH DOES NOT WARRANT THE ACCURACY OR COMPLETENESS OF THE INFORMATION, TEXT, GRAPHICS, OR OTHER ITEMS CONTAINED WITHIN THESE MATERIALS. TRANS-TECH SHALL NOT BE LIABLE FOR ANY DAMAGES, INCLUDING BUT NOT LIMITED TO ANY SPECIAL, INDIRECT, INCIDENTAL, STATUTORY, OR CONSEQUENTIAL DAMAGES, INCLUDING WITHOUT LIMITATION, LOST REVENUES OR LOST PROFITS THAT MAY RESULT FROM THE USE OF THE MATERIALS OR INFORMATION,WHETHER OR NOT THE RECIPIENT OF MATERIALS HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

Trans-Tech products are not intended for use in medical, lifesaving, or life-sustaining applications, or other equipment in which the failure of the Trans-Tech products could lead to personal injury, death, or physical or environmental damage. Trans-Tech customers using or selling Trans-Tech products for use in such applications do so at their own risk and agree to fully indemnify Trans-Tech for any damages resulting from such improper use or sale.

Customers are responsible for their products and applications using Trans-Tech products, which may deviate from published specifications as a result of design defects, errors, or operation of products outside of published parameters or design specifications. Customers should include design and operating safeguards to minimize these and other risks. Trans-Tech assumes no liability for applications assistance, customer product design, or damage to any equipment resulting from the use of Trans-Tech products outside of stated published specifications or parameters.

Skyworks and the Skyworks symbol are trademarks or registered trademarks of Skyworks Solutions, Inc., in the United States and other countries. Third-party brands and names are for identification purposes only, and are the property of their respective owners.