APPLICATION NOTE

Ferrimagnetic Substrates for Microwave Integrated Circuits

Introduction

A number of microwave investigators [references 1, 2, 3] have succeeded in demonstrating the feasibility of constructing useful microwave components on ferrimagnetic substrates using printed circuit techniques. This Application Note describes the methods for the ceramic fabrication of microwave ferrite substrates of a 4 square-inch area.

The economic production of Microwave Integrated Circuits (MICs) on ferrimagnetic substrates requires that as-fired geometric tolerances be held within values that are compatible with circuit design requirements. These parts exhibit intrinsic technical properties and as-fired mechanical tolerances that are suitable for the construction of microstrip ferrimagnetic devices.

The elimination of machining to obtain usable mechanical tolerances provides for a cost reduction of ferrite parts. This Application Note also discusses methods of improving the surface finish, when required.

Fabrication Methods

When fabricating ceramic parts, the attainable mechanical tolerances depend in considerable measure on the forming method selected, which also affects the magnetic and dielectric properties of the final part. Trans-Tech, Inc. (TTI) has found that the best forming powders are obtained by the spray drying method. These powders exhibit good die fill uniformity and require a minimum amount of binder, which is important in reducing non-uniform shrinkage and warpage during sintering.

The fraction of spray dried powder employed is 90 microinches to 150 microinches. The substrate compact is then pressed at 6000 PSI, which results in a green density that is high enough to ensure optimum substrate properties.

Ejection of the formed substrate under pressure is important in obtaining maximum flatness of the substrate surface. To accomplish this, relieve the upper punch pressure and eject with the lower punch, which forces the substrate and upper punch to go up simultaneously. Parts ejected in this manner show no edge deformation. The green formed substrate is strong enough to be easily handled and prepared for the final sintering operation.

A key step required to hold the mechanical flatness of the substrates to ±0.001 inches involves loading the substrate during sintering with a ceramic cover plate of approximately an equal cross-sectional area. This plate weighs approximately the same as the substrate it covers.

Figure 1 shows one arrangement that is used with the substrate sandwiched between two plates. Various types of ceramic cover plates can be used, such as yttria- stabilized zirconia for garnets and alumina, or mullite for spine 1 type ferrites. An isotherm is set up across the substrate thickness due to the presence of the cover plate, which results in a more uniform sintering and better mechanical integrity.

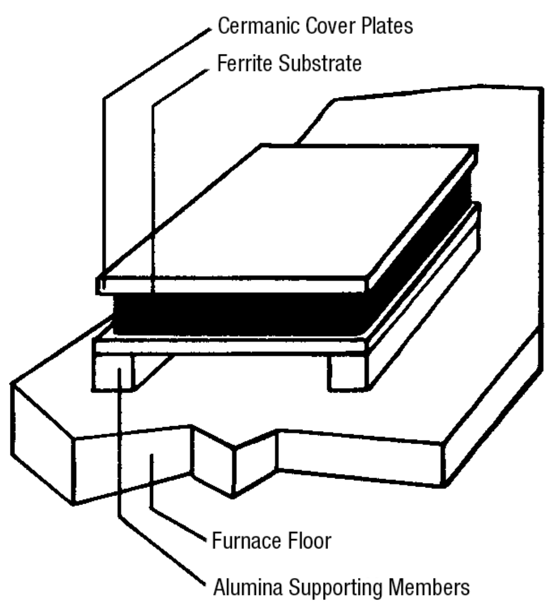

Figure 1. Preparation for Sintering Ferrite Substrate

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Results

Substrates have been fabricated that exhibit a surface finish (roughness) of 10 microinches to 15 microinches. Surface flatness to within 0.0015 inches can be obtained on the same substrates. Parallelism between the two flats can be held to ±0.001 inches.

Table 1 provides a summary of the mechanical tolerances obtained on the as-fired substrates.

Table 1. As-Fired Ferrite Substrate Mechanical Tolerances

Item	Tolerance Attained	
	1 Square-Inch Area	4 Square-Inch Area
Length, width (inches)	0.005	0.010
Thickness (inches)	0.001	0.001
Total indicated run out (waviness) (inches)	0.003	0.003
Surface finish (microinch)	10 to 15	10 to 15

When required, rapid lapping and polishing methods are used to reduce the surface finish to less than 5 microinches. Lapping and polishing is achieved using a planetary lapping machine that simultaneously removes equal amounts of material from each side of the work. The choice of the lapping compound is dependent on the preferred surface finish and stock removal. All polishing is done with chromic oxide polishing compounds on pellon paper.

To decrease the polishing time, it is necessary that the substrates be lapped flat first using a 25 micron lapping compound. Surface finishes of 1 microinch on garnet and 3 microinches on ferrite have been achieved. Annealing is needed for all magnetostrictive materials after lapping or polishing to remove strains that affect the hysteresis loop (refer to the *Stabilization of Remanent Induction by Thermal Annealing Application Note*, Document Number 202866) .

The technical properties and electrical characteristics of the as-fired substrates when compared to those of substrates cut from bulk material are found to be identical when the surface finishes are the same. Typical methods of forming microstrip components on ferrite substrates have been described in References 1, 2, and 3.

Cost Reduction

This section describes a measure of the cost reduction accomplished using the fabrication methods described in this document. To accomplish this, a typical cost estimate has been made for 10,000 substrates of a 4 square-inch area, and assumes that substrates are machined from bulk stock versus substrates formed and sintered to size and for three surface roughness criteria. The results are shown in Table 2.

Table 2. Cost Reduction Results

Material	Item	From Bulk Stock	As Formed and Sintered
Garnet	A.	$15.45 each	$6.75 each
	B.	$16.80 each	$7.05 each
	C.	$17.40 each	$7.20 each
Ferrite	A.	$6.35 each	$2.20 each
	B.	$7.55 each	$2.50 each
	C.	$7.60 each	$2.65 each
Surface Roughness	A ≤ 20 microinches		
	B ≤ 10 microinches		
	C ≤ 5 microinches		

Applications

The MICs find applications in areas similar to traditional ferrimagnetic components, except that they are smaller and lend themselves to higher reproducibility because of the printed circuit methods used in fabrication.

To date, MICs exhibit higher insertion loss and lower power handling capability than conventional ferrimagnetic devices. Some typical uses include phase shifters, isolators, phased arrays, latching circulators, multiple ports, and other similar devices.

Acknowledgments

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References

[1] G. T. Roome, H. A. Hair, and C. W. Gerst, *Thin Ferrite Phase Shifters for Integrated Microwave Devices*, Journal of Applied Physics, Volume 38, 1967, p. 1411.

[2] B. Hershenov, *Microstrip Junction Circulator for Microwave Integrated Circuits*, IEEE Transactions on Microwave Theory and Techniques, Volume MTT-15, 1967, p. 748.

[3] G. T. Roome, H. A. Hair and C. AuMiller, *Ferrite Devices for Microwave Integrated Systems*, International Solid-State Circuits Conference (ISSCC) Digest Technical Papers, 1968, p. 52.