ELEVATED SUBSTRATE FERRITE FILM CIRCULATOR

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SUMMARY

An elevated substrate ferrite film circulator has been designed. The ferrite film and the rf conductor are deposited completely above the substrate. The ferrite disc has its thermal expansion coefficient adjusted to match the sapphire substrate. Circulator insertion loss and isolation are 0.6 dB and 20 dB over a 5% bandwidth (f_o = 12.3 GHz), respectively.

Introduction

Most integrated ferrite components require fully or partially drilled apertures in the substrate. In order to make microwave LSI a reality, cutting and drilling of substrates must be eliminated. An elevated substrate ferrite circulator design, depicted in Figure 1, was investigated. The disc shaped ferrite and the rf conductor are deposited entirely above the sapphire substrate. The deposited ferrite film has a tan δ and linewidth comparable to that of commercially available ferrite (MgMn).

Ferrite Circulator Design

An elevated substrate ferrite film circulator is ideally suited for incorporation into microwave integrated circuits. The design relationships which will yield frequency and bandwidth as a function of ferrite disc geometry (diameter, thickness, $4\pi M_s$, etc.) are essentially outlined in literature.[1,2] These results will be applicable to the case of the mixed dielectric (ferrite, $\epsilon_r \approx 12$ and sapphire, $\epsilon_r \approx 9$).

The radius, R_F, for the dielectric filled ferrite junction is given in terms of the effective permeability, μ_{eff}, of the ferrite, and the center frequency, f_o, by

$$R = 1.84/k \quad (1)$$

where k = effective wave number = $2\pi f_o\sqrt{\epsilon_r \epsilon_o \mu_o \mu_{eff}}$

Hartwig[3] has shown that the ferrite thickness can be related to the 20 dB bandwidth and the effective composite thickness, t, by the relation (assuming quarterwave transformer coupling):

$$(t/b) = (\Delta f/f_o)_{20\ dB} \cdot (f_o/\gamma 4\pi M_s) \quad (2)$$

where

γ = 2.8 MHz/oe
t = thickness of ferrite film
b = thickness of composite (dielectric + ferrite)

The step discontinuity at the transformer-ferrite junction interface behaves as a shunt capactive reactance which has negligible effect on the impedance of the junction. A typical discontinuity capacitance for this design is .04 Pf.

Ferrite Film Preparation

A chemical transport deposition (CTD) method[4,5] was used to prepare ferrite-on-sapphire samples. The essential difficulty in this deposition is the thermal expansion coefficient mismatch, $\Delta\alpha$, between the film and the substrate. If the deposition temperature is 1000°C or above, and $\Delta\alpha$ is greater than 1×10^{-6}/°C, then the tensile stress in excess of 10^9 dynes/cm^2 (values calculated assuming Youngs Modulus value of 10^{12} dynes/cm^2 and Poissons' Ratio of 0.2) is obtained and cracking of the deposit occurs. In the 0 to 1000°C temperature range, the typical Mg-Mn ferrites have expansion coefficients of $\alpha_f = 11 \times 10^{-6}$, whereas sapphire has $\alpha_s = 8.9 \times 10^{-6}$. Thus, $\Delta\alpha = \alpha_f - \alpha_s > 1 \times 10^{-6}$ and cracking of thick ferrite films should be expected. The ferrite thermal expansion coefficient can be reduced, however, by substituting nonmagnetic ions, such as Al^{3+} or Cr^{3+} for the magnetic Fe^{3+} ion. Such substitution, also results in a decrease in the saturation magnetization, $4\pi M_s$. The effect of chromium substitution, u, on α_f and $4\pi M_s$ is shown in Figure 2 for a Mg Mn ferrite series ($Mg_{1.2}$ $Mn_{0.2}$ $Fe_{1.6-u}$ Cr_u O_4). For operation in the x-band frequency range a minimum saturation magnetization allowed is 1600 - 1700 gauss, which implies a maximum chromium substitution u of 0.42. Although a better thermal match could be obtained by further increasing the chromium, the resultant $4\pi M_s$ would be too low. Ferrite discs, 5 mm in diameter and 0.25 mm thick were deposited through a mask from u = 0.42 ferrite sources having $4\pi M_s$ = 1800 gauss and $\alpha_f = 10.6 \times 10^{-6}$/°C. Ferrite cracking was substantially reduced in comparison with samples having u = 0. Major cracks were, in fact, eliminated but some microcracks persisted since $\Delta\alpha > 1 \times 10^{-6}$. These microcracks (indicating the presence of minor, local crazing on the grain boundaries) deteriorated the surface quality achievable after polishing. The resonance linewidth, $4\pi M_s$ and tan δ of the deposited films were measured (at x-band) to be 480 oe., 1750 gauss, and 3×10^{-4}, respectively.

Elevated Substrate Ferrite Film Circulator Fabrication and Test

A chrome-gold conductor was vapor deposited and a circulator pattern etched from it with a resulting 0.25 mm step of the transmission line at the disc edge. The center frequency and 20 dB isolation bandwidth, as predicted by equations 1 & 2, are 12.0 GHz and 12%, respectively. The elevated substrate film circulator, a photograph of which is shown in Figure 3, provides 20 dB of isolation and 0.6 dB insertion loss over 5% frequency range, centered at 12.3 GHz. Swept frequency data is given in Figure 4. Since the tan δ and the linewidth of the ferrite films are comparable to those of commercially available ferrite, the relatively high loss must be attributed to the poor surface finish of the ferrite. Maximum surface roughness of several microinches are required to obtain low loss operation in this frequency range.

Conclusions

The feasibility of an elevated substrate film circulator has been demonstrated. More effort needs to be expended in following areas:

a) improvement of surface texture of the ferrite film
b) analysis of the transmission line step discontinuity

References

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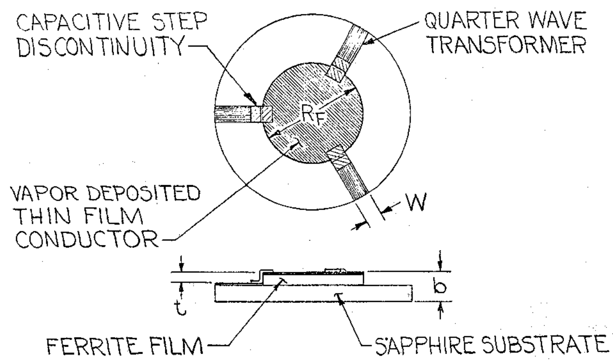

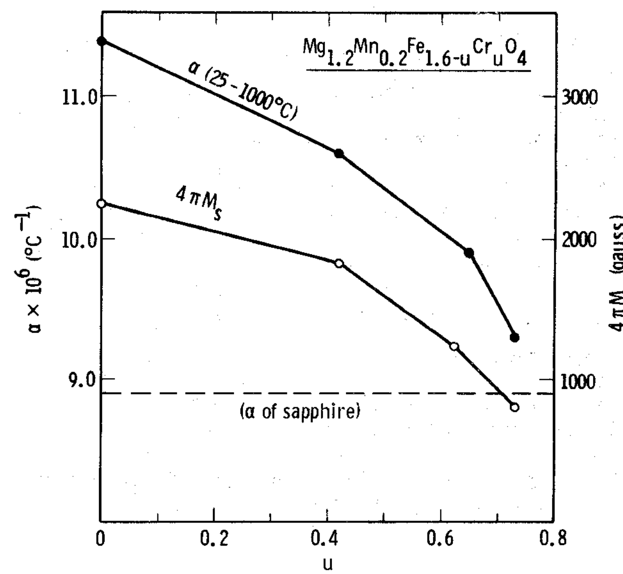

Fig. 2 The effect of chromium substitution on the ferrite thermal expansion coefficient, α, and saturation magnetization, $4\pi M_s$ measured at room temperature

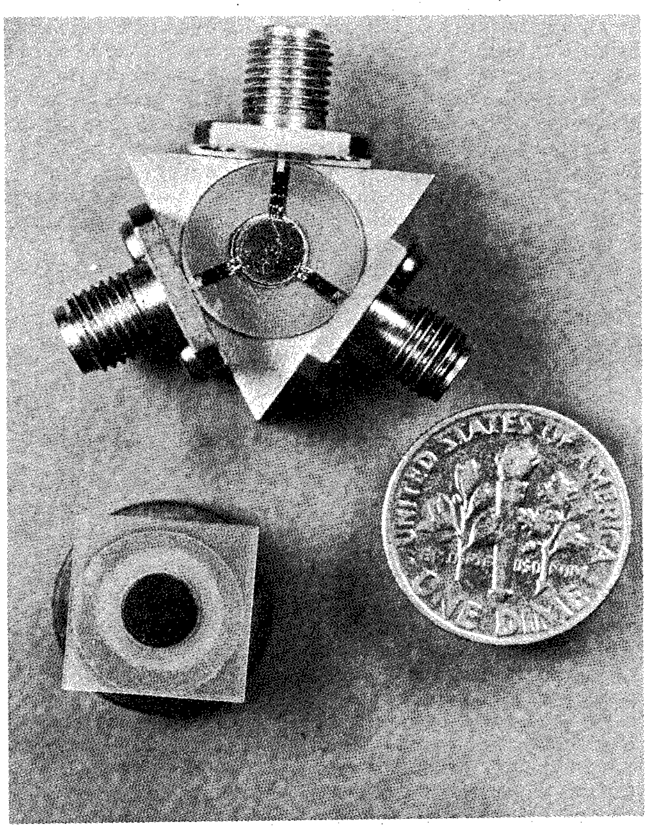

FIG. 3 ELEVATED SUBSTRATE FERRITE FILM CIRCULATOR

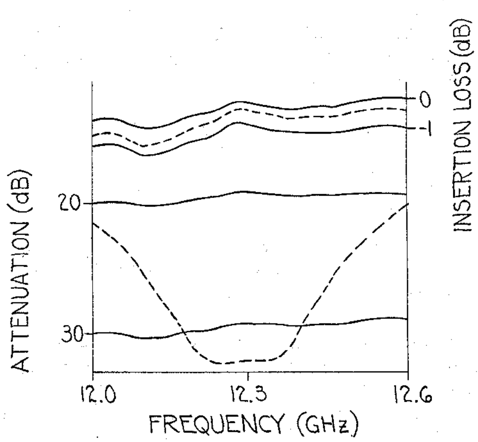

FIG. 4 INSERTION LOSS & ISOLATION VS FREQUENCY