MONOLITHIC INTEGRATION OF AN X-BAND CIRCULATOR WITH GaAs MMICs

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ABSTRACT

Monolithic integration of circulators with GaAs MMICs offers the potential of lower cost, reduced size and improved uniformity over the present hybrid approaches. Development of MMIC compatible ferrite film deposition techniques, device design and fabrication will be described. Results on ferrite film circulators deposited on Si and GaAs substrates will be presented and integration with FETs discussed

INTRODUCTION

Major cost and size reductions of microwave systems have been achieved through the incorporation of GaAs MMICs. Little effort has gone into similar integration of essential passive components such as circulators and filters. Here we describe the monolithic integration of an X-band circulator with a GaAs MMIC power amplifier. Monolithic integration of circulators offers the potential of lower cost, reduced size and improved uniformity, and becomes increasingly attractive at high microwave and millimeter wave frequencies.

Even encapsulated GaAs cannot be exposed to temperatures exceeding 900C without degradation. Thus traditional ceramic techniques used in the fabrication of conventional circulators are not compatible with monolithic MMIC integration because of the high firing temperatures, >1200C. Fortunately ferrite films require significantly lower processing temperatures and thus promise the potential for process compatibility with GaAs device fabrication.

RESULTS

Several ferrite film deposition techniques have been investigated including sputtering[1] and spin spray[2], but pulsed laser deposition (PLD)[3] has been found most attractive for production of films with good magnetic and dielectric properties at moderate growth rates (>5 micron/hour). PLD is a simple flash evaporation technique which maintains the stoichiometry of compound materials and has been widely used for the deposition of superconductors, ferroelectrics, phosphors and dielectric films. Typical PLD process parameters are; wavelength 248nm, pulsewidth 25nS, repetition rate 150Hz and energy density 4J/cm^2. Substrates up to 75 mm diameter can be uniformly coated at deposition temperatures between 25C and 850C.

The mismatch in coefficient of thermal expansion (CTE) between GaAs and ferrites, table 1, causes significant strains which can lead to cracking of the film and the substrate. CTE induced strains are minimized through the use of low thermal budget processing, involving rapid thermal anneals, and use of a thick (>5micron) compliant gold layer between the GaAs and the ferrite film.

Material	CTE($\times10^{-6}$/°C)
Si	3.8
GaAs	6.8
$Y_3Fe_5O_{12}$	10.4
$MgMnZnFe_2O_4$	8.2
$BaFe_{12}O_{19}$	7

Table 1. Coefficient of thermal expansion for semiconductor and ferrite materials.

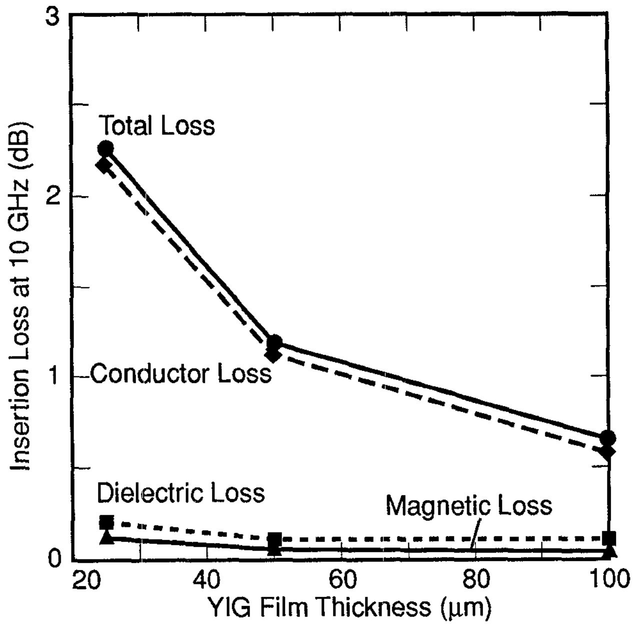

Figure 1. Calculated insertion loss for an X-band junction circulator as a function of YIG film thickness. Magnetic, dielectric and conductor loss contributions are also shown.

Modeling of the loss contributions in a thin film YIG circulator at 10GHz, Figure 1, shows that conduction losses dominate and that film thicknesses of 100 microns are necessary for total losses below 1dB. Initial development was performed using YIG films deposited on a gold coated silicon substrate. Silicon was selected because of its mechanical strength and processing tolerance. Circulator patterns were selectively deposited through a shadow mask by PLD from a YIG target onto 75 mm diameter wafers as shown in Figure 2. The growth temperature is in the 400C to 500C range and results in an amorphous film as deposited. Single phase polycrystalline YIG films are subsequently produced by a rapid thermal anneal at 850C for 20 sec. A YIG film circulator and part of a matching section test structure are shown in Figure 3.

Measurements obtained on a YIG film circulator fabricated on silicon are shown in Figure 4a. The minimum insertion loss (S_{21}) was 3 dB with insertion loss less than 5 dB over the 6.2 GHz to 11.5 GHz range. Isolation (S_{12}) was greater than 11 dB over this frequency range. Insertion loss measurements on the test matching sections, shown in Figure 2, are given in Figure 4b and show a loss of approximately 2 dB over the 6.5 GHz to 13 GHz range. These results

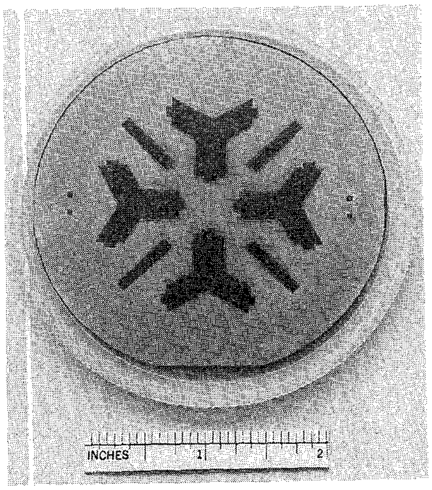

Figure 2. Ferrite film patterns for junction circulator fabrication are selectively deposited onto metalized semiconductor substrates by pulsed laser deposition through a shadow mask.

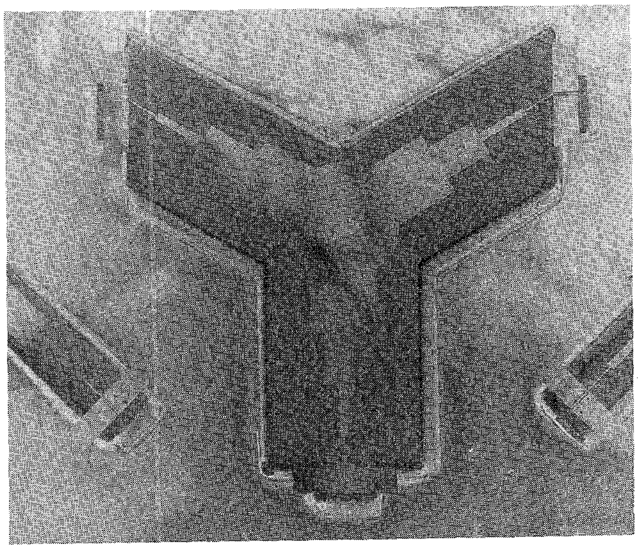

Figure 3. X-band junction circulator fabricated with a 50 micron YIG film on a silicon substrate.

indicate that 1 to 3 dB loss occurred in the junction and elongated microstrip "tabs". The measured losses are several times higher than calculated. This discrepancy is attributed to use of 80 μm thick YIG film compared to 100 μm for the circulator design, surface roughness on the YIG film and cracking of the YIG film. Further development is underway to reduce the surface roughness and film cracking.

YIG films up to 100 microns thick have been selectively deposited onto gold coated GaAs wafers and circulator metalization defined. The YIG films show reduced cracking and their high microwave magnetic quality is verified by measurements of the 35 Oe ferromagnetic resonance line width obtained by a non-destructive measurement technique[5], at 9 GHz. . Characterization of the circulators fabricated on GaAs is underway and optimization of the ferrite deposition is continuing in order to eliminate cracking of the film.

Designs for the GaAs MMIC power amplifier are complete and several monolithic processing options are being developed so that the process offering the optimum compatibility between the ferrite and GaAs requirements can be selected.

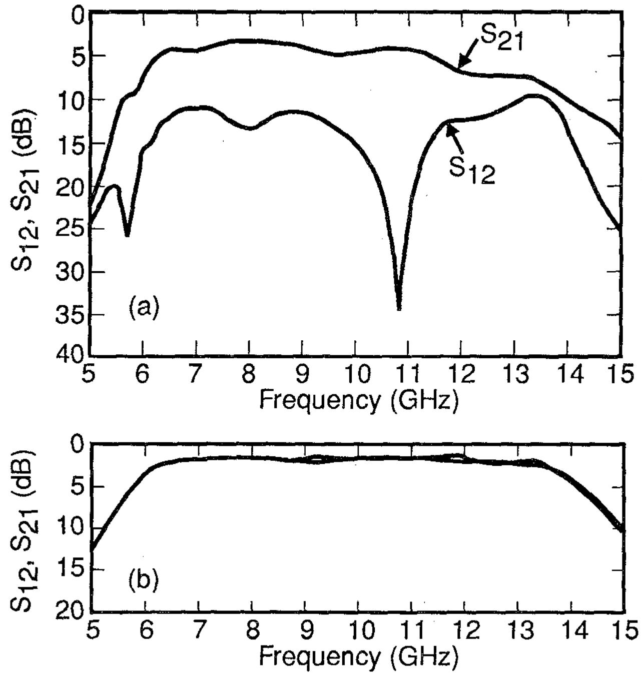

Figure 4. Measurements on a YIG film circulator fabricated on a silicon wafer (a) Insertion loss (S_{21}) and isolation (S_{12}) (b) Insertion loss on matching section test structure. Actual YIG film thickness was 80 μm (cf 100 μm design) and the bias field was 3 koe.

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