RF CHARACTERIZATION OF A LOW COST MULTICHIP PACKAGING TECHNOLOGY FOR MONOLITHIC MICROWAVE AND MILLIMETER WAVE INTEGRATED CIRCUITS

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ABSTRACT

This paper describes a unique multichip module technology based on highly impermeable *liquid crystal polymers* (LCPs) to interconnect and package Microwave and Millimeter Wave Monolithic Integrated Circuits (MIMICs). Because of the low moisture permeability of the LCPs, the packages can be made hermetic without heavy expensive housings, and can be two to four times lighter and one-fifth the cost of conventional ceramic based transmit/receive (T/R) modules. Preliminary results indicate that the LCP has a low dielectric constant, and low loss transmission lines can be manufactured on LCPs using large area processing techniques that provide a tremendous cost advantage over competing technologies. Using flip chip bonded MMICs attached to a high thermal conductivity, low coefficient of thermal expansion substrate, this innovative technology can meet a variety of commercial, military and space requirements.

1. INTRODUCTION

On account of their ability to form multiple beams and provide variable power among beams, phased array antennas using GaAs MIMICs are gaining significance in aircraft and space-based radar as well as communication applications. These systems require highly complex transmit/receive (T/R) modules, each containing a large number of GaAs MMICs required to meet the wide range of system performance, and also have the following properties: low cost, small size, high density housing and thin profile.

Although multichip packaging approaches have been in use for many years for digital ICs, packaging microwave and millimeter wave MMICs is, in general, more demanding than packages typically encountered for digital and low frequency analog applications. These packages are characterized by a low lead count, high lead-to-lead isolation, tightly controlled transmission line impedance levels, and very low interconnect and transition losses.

At present, typical T/R modules contain several MIMICs which must be interconnected using single or multilayer RF substrates. The interconnect should have low insertion loss, wide bandwidth, low dispersion, small size and ease of reproducibility. In addition, the substrate should be able to incorporate both RF and control signal lines as well as DC bias lines without mutual interference and buried compact structures such as couplers, filters, power dividers, etc.

Traditionally these substrates have metallization of both sides and have either a thick film or a thin film circuitry on the top surface, whereas the bottom surface is either soldered or attached using epoxy to a metal base (4-5). Alumina (ε_r~9.9) is typically used as a substrate in the microwave frequencies whereas quartz (ε_r~3.78) is used in millimeter wave range. With increased system requirements it becomes necessary to include many GaAs MMICs as well as digital ICs together with thin film bypass capacitors and off-chip matching networks for power amplifiers on the same package. One method of solving this problem is by combining thick film and thin film metallization on the same substrate. The RF circuitry is on the top thin film, while a multilayer thick film interconnect circuit is at the bottom. Laser drilled via holes connect the thick film and thin film metal layers. Although such a technique has some advantages, these substrates do have many drawbacks of which the following are of prime importance:

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- Increased overall cost due to non-compatibility of thick and thin film processes.
- Interconnection vias limit the chip density and also degrade the electrical performance.
- Thin film passive RF components and network occupy a large area resulting in further decrease in chip density, thereby increasing the overall package cost.
- Need for a hermetic package to protect the MMICs.

Our unique approach solves these problems by combining the RF, control signal lines and the DC bias lines on a single multilayer LCP substrate.

2. THE TECHNICAL APPROACH

Our approach is based on exploiting the barrier and dielectric properties of liquid crystal polymers to interconnect and package MMICs. To meet the permeability requirements the key is the utilization of the extremely low permeability of liquid crystalline polymers compared to other polymers. The permeability of Vectra™ and other LCP films has been measured because of the interest in their use as barrier films by the food packaging industry. Although unoriented films exhibit good barrier properties, biaxially-oriented films show orders of magnitude lower values. Foster-Miller has developed a unique extrusion process based on a patented counter-rotating die technology. This process differs from conventional extrusion processes in that it biaxially orients the polymer chains as they are being extruded, imparting balanced mechanical properties. Thus, due to the low moisture permeability of the LCPs, the packages can be made hermetic without heavy expensive housings, and can be *two to four times lighter* and *one-fifth* the cost of conventional ceramic based T/R modules.

2.1. RF Characterization

In order to fully exploit the dielectric properties of the LCP it is necessary to determine the dielectric constant and loss tangent of the LCP material as well as the characteristics of various planar transmission lines designed using this material in the microwave and millimeter wave region. Traditionally used microstrip lines and coplanar waveguides (CPWs), shown in Figure 1, were the planar transmission lines chosen to be characterized. Moreover, the highly accurate microstrip ring resonator techniques were used to measure the dielectric properties of the LCP material.

For measurement purposes the LCP films were bonded onto a 20 mils thick alumina substrate having metallization on one side and laminated with conventional high ductility copper foil of 9 μm thickness. The tooth structure of the copper file gives excellent adhesion over a wide range of temperature, although its roughness may increase losses at higher frequencies. Numerous microstrip and CPW structures having a wide range of impedances were designed and placed on the LCP substrate (Table 1). These LCP substrates have thicknesses of approximately 4, 5, 6 and 20 mils, respectively.

These microstrip and CPW test structures were characterized (S-parameters) on-wafer, in the 0.5-40 GHz frequency range, using high frequency Cascade Microtech Probes and an HP 8510C network analyzer. The dielectric properties of the LCP were calculated using the multiple resonances in transmission ($|S_{21}|$) measurement in the ring resonator structures. Since the resonant frequencies are measured very precisely by the network analyzer, the calculated dielectric properties of the material are very accurate. Similarly, the complete characteristics of the transmission lines, namely, characteristic impedance (Z_o), effective dielectric constant (ε_{eff}) and loss (α) were calculated from the measured S-parameters.

Figure 2 shows the measured multiple resonances in a typical ring resonator structure and Table 2 shows for the first time the derived relative dielectric constant (ε_r) of the LCP substrate. From this it is clear that the LCP has a fairly uniform relative dielectric constant of 3.08 in the 0.5-40 GHz range. Figure 3 shows the measured 'Z_o', 'ε_{eff}', and 'α' of a 50Ω microstrip line and an 80Ω conductor-backed CPW. These results indicate that the lines have *extremely low dispersion* and *uniform characteristic impedance* in the 0.5-40 GHz region. Moreover, the line losses of ~0.3 dB/cm (@ 35 GHz), although slightly higher than similar lines on Duroid, are still low enough for packaging applications. In addition, these results were found to be in good agreement with theoretical predictions. We are highly encouraged by these initial results which represent first ever measurements on an unoptimized LCP package in the microwave and millimeter wave frequency band. Finally, since reducing the conductor surface roughness will result in lower losses, we believe that the RF performance of an optimized LCP package in a system will greatly exceed that of the state-of-the-art packages. Figure 4 shows the design process of LCP package technology.

2.2. Advantages of Our Approach Over Current Approaches

This unique and new approach provides many advantages over current packaging techniques. Our approach uses the highly reliable flip chip technology which is ideally suited for large volume applications compared to ribbon bonding. The interconnects can be designed either as microstrip lines or CPW. The need for a hermetic package is eliminated due to the highly impermeable characteristics of the LCP, which results in tremendous cost and weight savings. Finally, this new approach enjoys many advantages of the chips-first approach (separation of electrical and thermal paths, high device packaging density, low inductance, short chip interconnections) but overcomes the following limitations:

- Easier defective IC replacement - no need to rebuild the entire interconnect.
- ICs not subjected to processing stresses - chips last versus chips first.
- Weight and cost penalty due to the hermetic package.

3. CONCLUSIONS

This paper describes a novel technique for packaging MMIC devices which takes advantage of the unique dielectric and barrier properties of LCPs. Preliminary data on microstrip line transmission lines on the LCP indicate that the material is suitable for microwave and millimeter wave system applications. Helium leak tests clearly indicate that near-hermetic packages can be achieved without using conventional metal or ceramic packages. Elimination of a conventional hermetic package coupled with large area processing techniques results in a low cost approach for MMIC based T/R module array systems.

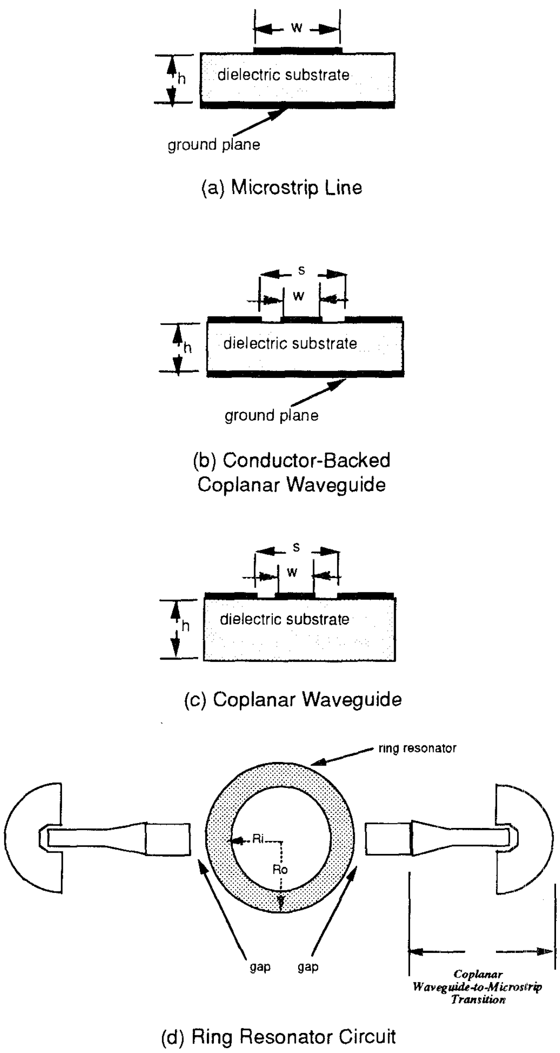

Figure 1. (a), (b) & (c) Cross-section of Microstrip Line, Conductor-Backed Coplanar Waveguide and Coplanar Waveguide Transmission Lines; (d) Ring Resonator Circuit Layout

Table 1. Dimensions of a Few Test Structures

Structure Type	Impedance (Ω)	W (μm)	S(μm)
Mstrip	20	965	
Mstrip	35	475	
Mstrip	50	275	
Matrip	75	150	
CBCPW	90	50	100
CBCPW	66	100	150
CBCPW	50	125	150
CPW	110	50	150
CPW	150	50	350

Length = 1250 μm, 2500 μm
Mstrip - Microstrip, CPW - coplanar waveguide.
CBCPW - Conductor backed CPW

Table 2. Results from Ring Resonator Measurements

Resonator Number	Resonant Frequency (GHz)	Relative Dielectric Constant
LCPRR-I-1	33.02	3.18
LCPRR-I-2	32.15	3.07
LCPRR-II-1	10.43 20.81 31.13	3.08 3.08 3.08
LCPRR-III-1	6.97 13.93 20.87 27.78 34.66	3.08 3.08 3.08 3.08 3.08

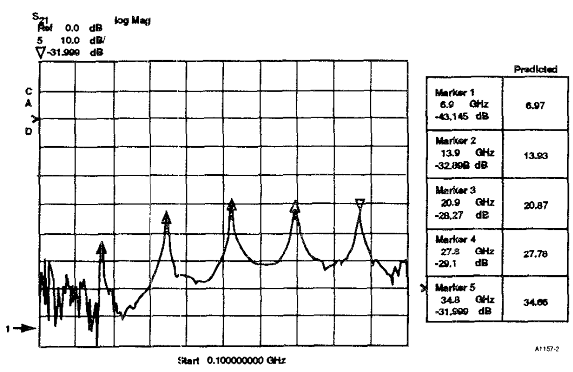

Figure 2. Measured Transmission Characteristics of Microstrip Ring Resonators

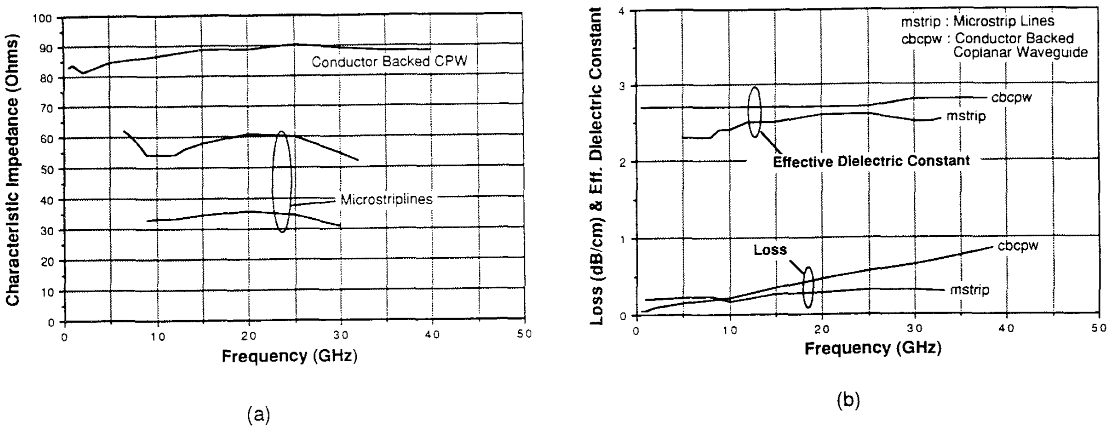

Figure 3. Measured Characteristics of Microstrip and Coplanar Waveguides on LCP

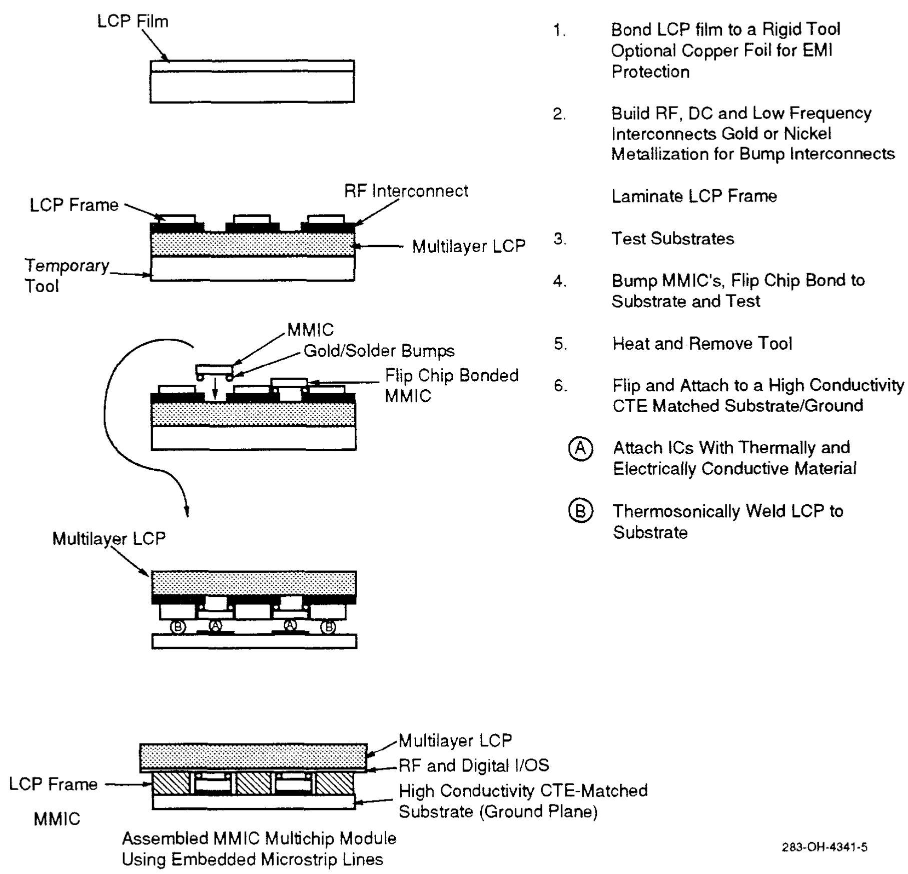

Figure 4. Process Flow of LCP Packaging Technology