Fully Integrated Passives Modules for Filter Applications Using Low Temperature Processes

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Abstract

Although discrete surface mount passive components (resistors, capacitors, and inductors) have been well developed, the development of integrated passive components suitable for integration with printed wiring boards is relatively recent. Since in some applications the number of passive components can exceed both the number and area of IC chips on a circuit board or in a package, such integration is desirable. To address these issues, integration technology for passive elements in the same manner as for transistors is necessary. An additional issue to be considered is that the fabrication sequences of all integrated passive components must be compatible is they are to be integrated on the same substrate. In this paper, a fully integrated passives module is presented. This passives module contains eleven resistors, four capacitors, and four inductors, and is fabricated using techniques which are compatible with organic substrates such as fiber-epoxy board. A variety of materials appropriate for low temperature fabrication of integrated passives in a mutually compatible fashion were investigated, including chromium and nickel-chromium resistors, composites of high dielectric constant materials in epoxies for capacitor dielectrics, and composites of magnetic ferrite particles in polyimides for inductor cores and shielding. The as-fabricated devices showed good agreement between the design values and the corresponding measured values .

Keywords: Passive components (resistors, capacitors, and inductors) , MCM-L, MCM-D, integration, low temperature, packaging, batch fabrication

Introduction

There are a large number of passive components which are used in consumer electronic products such as VCRs, camcorders, television tuners, and other communication devices. To meet these needs, many miniaturized discrete surface mount passive components (resistors, capacitors, and inductors) have been mounted on boards and modules in a hybrid fashion. Such discrete mounting introduces additional expense of manufacture, requires large board area, and can introduce additional parasitics into the system which may limit system performance. An approach to addressing these issues is integrating these passive components directly into a multichip module (MCM) substrate along with other IC chips [1]. Using this approach, the size of the board can be reduced (especially if chips can be placed above embedded passive components) and the parasitics associated with the passive components can also be reduced due to the elimination of leads and the shorter connections between passive components and other IC chips. The integration of passive elements can also result in reduced assembly costs, improved electrical performance, improved packaging efficiency, mass production by batch fabrication, low power loss, low volume, low weight, low profile, etc.

Much research has been done to realize integrated passive components based on MCM-C (ceramic) and MCM-D (deposited) technology [2-4]. In much of this research, it is usually necessary to undergo a high temperature fabrication steps such as firing of ferrite-based pastes or ceramics. However, in many cost-driven applications, the use of an organic substrate is desirable, which necessitates the use of low temperature fabrication steps in the realization of these passive components. In this paper, a fully integrated passive module shown in Figure 1 is designed, fabricated, and characterized using low temperature fabrication processes, MCM-L, and MCM-D technology to test the feasibility of integration of passive components such as inductors, capacitors, and resistors. The proposed passive module (dimension is 8 mm x 10mm x 0.06 mm) is fabricated with two lithography masks and one screen printing mask, and includes 11 integrated resistors (5

- 80 ohms), 4 capacitors (14 - 160 pF), and 4 inductors (145 - 650 nH).

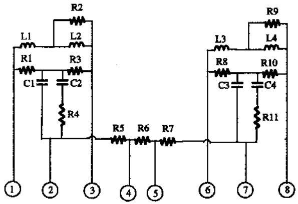


Figure 1. The electrical schematic diagram of proposed integrated passives module

Design Consideration

Integrated resistors are designed based on a rectangular cross section. Chromium metal is used as resistive material due to the fact that the required resistances in this module are of a low value. The resistance (*R*) of a rectangular resistor is defined as follows:

$$R = \frac{\rho}{t} \times \frac{l}{w} = R_s \frac{l}{w} \qquad (1)$$

where ρ is the intrinsic resistivity, t is the thickness, l is the length, and w is the width of the rectangular resistor. l/w is defined as the number of "squares" in the resistor. Figure 2-a shows a photomicrograph of an integrated meander type rectangular resistor using chromium metal.

The capacitance (*C*) of a parallel plate MIM (metal-insulator-metal) capacitor is defined as follows:

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d} \qquad (2)$$

where ε_0 is dielectric constant of free space, ε_r is the dielectric constant of the capacitor dielectric material between the electrode plates, A is the area of the two electrode plates (bottom and top electrodes), and d is the distance between top and bottom plates. In this research, the dielectric composite material is composed of photodefinable epoxy binder and high dielectric constant ceramic particles. Such polymer ceramic composites are a favorable choice for thin film capacitors in low temperature MCM-L technology [5-7]. These dielectric materials are two-phase composites in which the polymer allows low temperature fabrication and the filler enhances the dielectric constant of the resulting composite far beyond that of the unfilled polymer. Cost is an important attribute of these systems. A photodefinable epoxy material has been studied to evaluate the possibility of material cost reduction and compatibility with the FR-4 substrates.

Probimer-4959, a product of Ciba-Geigy, is selected for making small capacitor structures using lithographic techniques. This epoxy material has a dielectric constant of 3.5 and can be readily photodefined with good resolution. Finer particle size of the filler material (< 1 μm) is needed for making thin films (to achieve higher specific capacitance) with a smooth surface. Lead magnesium niobate (PMN) (average size of ~ 1μm) has been selected as the filler material for its high dielectric constant value and low loss. Properties of these materials are given in Table 1.

Test structures for these materials were processed as follows. The filler and the liquid polymer resin were mixed using ball milling for 3-4 days to achieve good dispersion. Samples were then spin cast on glass substrates at ~ 3000 rpm for 60 to 90 minutes. The composite dielectric layer was then exposed, developed, and cured.

Table 1. Polymer/Ceramic Materials

Material	Supplier	Diel. Const (100 KHz)	Loss Tangent (100 KHz)
Probimer 4959	Ciba-Geigy	3.5	0.02 - 0.03
Lead Magnesium Niobate	TAM Ceramics	17,800 (sintered)	0.015

Theoretically, the dielectric constant of the composites can be enhanced by selecting higher dielectric constants of the individual phases and maximizing the filler loading. The basic equation for permittivity of a two phase composite system (ε_r) is given by the Lichtenecker [8-9] equation

$$\varepsilon_r^n = v_1 \varepsilon_1^n + v_2 \varepsilon_2^n \qquad (3)$$

where ε_1 and ε_2 are the permittivity of the individual phases, v_1 and v_2 are the respective volume fractions, and exponent n equals 1 or -1 for parallel or series connections. This equation is not concerned with the physical geometry of the composite system; neither does it take into account the size and shape factors of the individual constituents. Various modifications of this equation have been made to compare experimental data with the predicted values, the most accepted one for the filled polymer system being [10-11]:

$$\log \varepsilon_r = \log (\varepsilon_{rP}) + (1-K)\, v_f \log (\varepsilon_{rF}) \qquad (4)$$

where K is a constant and depends on the filler and polymer systems, v_f is the volume fraction of filler, and ε_{rP} and ε_{rF} are the dielectric constants of the polymer and the filler, respectively. This modified equation has been previously utilized to calculate the dielectric constant of the two phase composite and showed good agreement with the experimental values [5,6]. Figure 2-b shows a photomicrograph of an integrated epoxy composite capacitor. Figure 3 shows a scanning electron micrograph of the surface of the epoxy composite high dielectric material at 29 vol. % filler. Using appropriate processing conditions, PMN shows good particle dispersion with minimal particle agglomeration; such agglomeration is believed to cause a decrease of dielectric constant of the composite material. The specific capacitance of the epoxy composite at 49 volume percent is in the range of 8 to 9 nF per cm^2 at 100 kHZ. Preliminary studies showed that the photodefinable Probimer 4959 has a good potential for application as a thin film capacitor compatible with MCM-L substrates. Manufacturability issues and cost prospects are currently being evaluated.

Integrated inductors can be designed with differing geometries such as spiral, meander, and bar type. Spiral type inductors are commonly used because of their simple geometries and easy fabrication sequences. NiZn ferrite is an appropriate core material for integrated magnetic devices at higher frequencies due to its high resistivity and low dielectric constant. NiZn ferrite particles are mixed with polymer binder and the well mixed polymer-filled ferrite is deposited using screen printing to realize integrated inductive components. Polymer filled NiZn ferrite is also used as a shielding material at high frequency, which is desirable since integrated inductors and transformers, which may be in closer proximity to other components than their hybrid-assembled counterparts, need to be shielded to reduce electromagnetic interference (EMI) during high frequency operation. Finally, integrated inductors should have compatible fabrication sequences with integrated capacitors and resistors to be used as integrated passives for multichip modules, miniaturized integrated power converters, and other miniaturized electronic systems. The characteristics of integrated inductors are strongly dependent on many parameters such as device structure, number of windings, conductor width/space sizes, device substrate, and the magnetic properties of the core [12]. Integrated inductors for this passives module were designed based on measurement results from a variety of test structures. Figure 2-c shows a photomicrograph of an integrated polymer filled ferrite inductor.

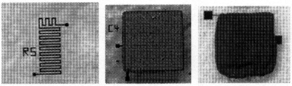


Figure 2. Photomicrographs of fully integrated passives: (a) A meander type metal resistor; (b) A epoxy composite capacitor; (c) A ferrite composite inductor

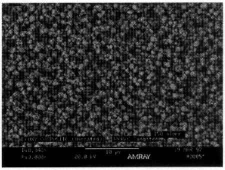


Figure 3. Scanning electron micrograph of the surface of high dielectric epoxy composite material (approximately 3000x)

Fabrication

A brief fabrication process of the integrated passives module is shown in Figure 4. The fabrication began with a glass or Printed Wiring Board (PWB) substrate. After cleaning the substrate, meander-type resistors are patterned on the substrate using evaporated chromium, photolithography, and lift off techniques. This step also simultaneously formed the lower capacitor electrodes. The photodefinable epoxy composite dielectric material was spun on top of the meander type metal resistors and patterned electrodes, baked, and patterned using standard lithography techniques.

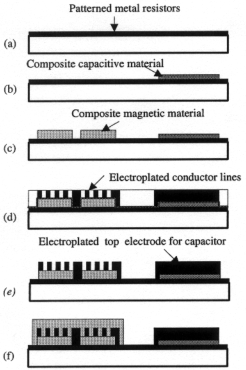


Figure 4. Fabrication sequences of the passives module: (a) formation of metal resistors; (b) deposition of high dielectric constant material ; (c) deposition of composite magnetic material; (d) electroplating of spiral type conductor lines, top electrode for capacitor, and interconnections of integrated passives components; (e) removal of thick photoresist and bottom seed layer; (f) deposition of composite magnetic material on top of spiral type conductor lines by screen printing

After curing the dielectric composite material to remove solvents at 150 - 180 °C for 3 hours in an oven, the composite magnetic material was deposited selectively by screen printing. The screen printed magnetic material was cured at 150 - 180 °C for 5 hours in a vacuum oven. Titanium/copper/titanium layers were deposited to form an seed layer for electroplating using an electron beam evaporator. Thick photoresist was coated, and molds for spiral type conductor lines, top electrodes for capacitors, and electrical connection of passive components were formed. After removing the top seed layer, copper was electroplated into the photoresist molds, and the molds were removed. The seed layer was wet-etched to isolate the conductor lines and other passive components. Ferrite-filled polymer was screen printed on the top of the electroplated copper conductor lines and between the conductor lines, and cured to remove the solvents. Upon completion of the fabrication, the samples were diced and tested.

Figure 5 shows the photomicrograph of the fully integrated passives module prior to deposition of the magnetic composite material on the top and between the conductor lines. Figure 6 shows the photomicrograph of the completed fully integrated passives module. The fabricated passives module is diced and mounted on an IC package, and is tested as shown in Figure 7

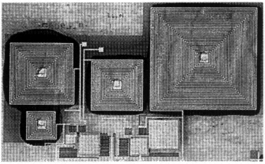


Figure 5. Photomicrograph of integrated passives module prior to deposition of polymer filled ferrite on the top of spiral type conductor lines

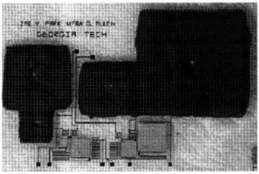


Figure 6. Photomicrograph of completed integrated passives module (12 resistors, 4 capacitors, and 4 inductors; dimension: 8mm x 10mm x 0.06mm)

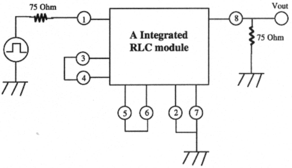


Figure 7. Test circuit configuration of integrated passives module

Experimental Results and Discussion

The individual passive components, i.e, integrated meander type metal resistors, MIM capacitors, and inductors, were characterized by a Hewlett-Packard impedance / gain-phase analyzer 4194A and a Kiethley LCZ meter. Figure 8 shows the capacitance characteristics of the embedded integrated composite MIM capacitors as a function of time at 85 °C and 85 % relative humidity, and shows that these capacitors are not prone to aging over the time periods tested. As shown in Table 2, the values of the fabricated integrated passive components are well matched with the expected designed values. In particular, integrated composite capacitors and inductors have less than 5 % error compared with the designed values.

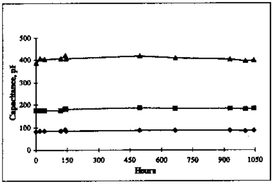


Figure 8. The capacitance vs time of the epoxy composite capacitor at 85 °C and 85 % relative humidity

Table 2. Comparison of designed and achieved values of embedded passive components

Passives	Designed values (dc)	Achieved values (100k)	Error rate (%)
R1,R3, R8, R10	75 OHM	68 OHM	9.3
R2	19.1 OHM	16.5 OHM	13.6
R4	294 OHM	275 OHM	6.4
R5, R7	280 OHM	267 OHM	4.6
R6	43.2 OHM	39.7 OHM	8.1
R9	38.1 OHM	35.2 OHM	7.6
R11	187 OHM	169 OHM	9.6
C1	15 pF	14.5 pF	3.3
C2	68 pF	71.2 pF	4.7
C3	47 pF	49 pF	4.2
C4	150 pF	156.2 pF	4.1
L1	0.1 uH	0.145 uH	4.5
L2	0.39 uH	0.41 uH	5.1
L3	0.27 uH	0.256 uH	5.2
L4	0.82 uH	0.78 uH	4.8

The module shown in Figure 6 was not functional due to interconnection problems between several of the components. However, to gain an understanding of the operation of this module, a circuit simulation was performed in which the simulated performance of the module using designed values of passive components was compared with the simulated performance of the module using the experimentally achieved (Table 2) values of the passive components *as well as their measured parasitics.* Figure 9 shows output wave forms for the module circuits using design and measured (with parasitics included) values, respectively, when an ac pulse voltage with 2 ns rising and falling time, 10 ns delay time, and 11 ns width time is applied into the input terminal as shown in Figure 7. Figure 10 shows the gain characteristics of the module using designed and measured component values as a function of frequency and shows that the integrated circuit has lower gain due to the stray capacitance and parasitic effects of the integrated passive components at high frequencies. Figure 11 shows the output impedance characteristics of the module using designed and measured component values. In particular, the stray capacitance of the integrated inductors causes lower resonant frequency in the integrated module compared with the designed circuit.

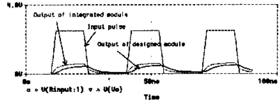


Figure 9. Comparison of an input wave form and output waveforms of the module using designed and measured component values (with parasitics)

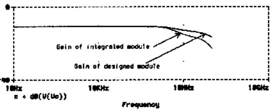
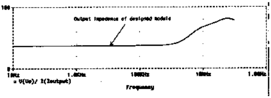
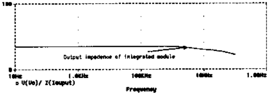


Figure 10. Comparison of gain of the module using designed and measured component values (with parasitics)



(a)



(b)

Figure 11. Comparison of output impedance of the module using designed (a) and measured (b) component values (with parasitics)

Conclusions

The fully integrated passives module including 11 resistors, 4 capacitors, and 4 inductors has been fabricated using low temperature processes and micromachining techniques to demonstrate the feasibility of integration of passive components into the package or onto the board rather than on the chip. Thus, these integrated passive elements will be compatible with the next generation of low cost packages utilizing large area processing and organic or MCM-L substrates, which require low temperature processes (less than 230 °C). The integration of passive components can result in a number of advantages, including reduced assembly cost, improved packaging efficiency and electrical performance, and mass production by batch fabrication, and low volume and profile. The integrated passive components are applicable to integrated miniaturized power converters, multichip modules, analog circuitry, and other consumer electronic products.

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