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MICROSYSTEMS PACKAGING ROADMAP FOR NEXT GENERATION WIRELESS RECEIVERS

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Abstract: - Future high-performance wireless communication applications such as wireless local area networks (WLANs) around 5 GHz require low power and high quality integrated transceiver solutions. The integration of RF front end especially poses a great challenge to these applications as traditional system on chip (SOC) approach is quite inefficient. A system on package approach (SOP) can address the problems in an optimum way. A challenging task is to design integrated passives. These passives are then fabricated using MCM-D technology. Inductors and capacitors are compared on the bases of their Q-factors and SRF (self resonance frequency). RF receiver module is implemented using benzocyclobutene (BCB) as interlayer material and liquid crystal polymer (LCP) as substrate.

Key-Words: - Integrated passives, Integrated RF Front Ends, Multichip Module (MCM), System-on-Chip (SOC), System-on-Package (SOP), Wireless Local Area Network (WLAN), Bezocyclobutene (BCB), Liquid Crystal Polymer (LCP).

1 Introduction

For future wireless communication systems we see an important trend toward more flexible wideband (multimedia) applications and toward higher carrier frequencies. Good examples of these trends are the upcoming standards for wideband wireless local area networks (WLANs) in the 5-6 GHz band. It is quite a challenging task to design their analog front ends. Apart from high operating frequency critical aspects are the wide band width, large dynamic range and a good linearity.

For portable and battery powered applications, low power consumption as well as a high level of integration to reduce size and weight are essential. In current digital communication transceivers, the large number of discrete passive components-mainly in the radio front end is an important bottleneck for further integration. The new implementation paradigm called "system-on-a-package" (SOP) can increase the level of integration of these future wireless transceivers and at the same time reduce power consumption.

First we take a look on SOP and MCM-D technology. We then move over to discuss interlayer materials and the substrate material for our choice i.e, LCP.

A 5GHz WLAN RF receiver module is implemented. Passives are designed using two metal layers with BCB as interlayer material and are found to be having high Q and SRF.

2 MCM-D Technology

An alternative implementation of integrated systems is to partition the RF transceiver in multiple chips and to use a thin film multichip module technology (MCM-D) to interconnect these different chips. At the same time, this MCM technology can be used to integrate a large number of the required passive components with very good quality factors. With this implementation approach, several RF components-each implemented in the most suitable IC technology-can be assembled in a relatively simple and economical way [1], [2].

Thin-film MCM-Ds are fabricated by a sequential deposition of conductor, typically Cu or Al, and dielectric layers, typically polyimide or benzocyclobutene (BCB), on a substrate base made of ceramic, silicon, or metal. MCM-D processing most closely parallels the processing techniques used in the semiconductor industry. The thin dielectric layers (120 μm thick) are usually deposited by a conventional spin coating process, yielding a uniform and well controlled thickness. Vias can be formed by laser ablation, reactive ion etching, or wet etching of the dielectric. The thin metal layers are deposited by sputtering (tens of nanometers upto few micrometers thick) and patterned by etching. Further additive processing by electroless plating or electroplating (upto 10 μm thick) may also be done. The curing of the dielectric layers require much lower temperature steps compared with low temperature co-fired ceramic (LTCC). Temperatures are in a range of of 200˚C (BCB) to 400˚C (polyimide). The widths and spaces of the conductors in MCM-D range from about 100 µm down to a few µm, depending on the metal thickness. The IMEC MCM-D technology [3]-[5] consists of alternating thin layers of photosensitive benzocyclobutene (BCB) dielectric and low-loss copper metallizations deposited on low-loss alumina or borosilicate glass carrier substrates. The BCB dielectric has low dielectric losses (tanδ ≈ 8.10-4) and a low dielectric constant (εr = 2.65). The material is spin coated in thin films of 1-10 µm thick, then developed and cured. The curing temperature profile of BCB does not exceed 250o C, which is significantly lower than for most other dielectric materials (such as, e.g., polyimide).

Depending on the required metal thickness, the metal layers are sputtered and patterned using wet etching or electroplated on a thin titanium-copper seed layer. Via holes through the BCB dielectric allow the connection of the different metal layers. Due to the photosensitive property of BCB, the vias are immediately formed after the developing step. The via diameter is typically 30 µm.

The MCM layer structure can also be used to integrate passives. The TaN resistors (with R□=25Ω) and Ta2O5 capacitors (εr = 25) are realized immediately on the carrier substrate. They are contacted with an aluminum metallization, while the further interconnections and spiral inductors are made using the other high-conductivity copper layers. The top copper layer is coated with NiAu in order to allow easy mounting of other devices (flip-chip (to be discusses later), wirebonding). The uncovered BCB at the air interface serves also as a passivation layer since it is very stable, very corrosion hard and it has very low moisture absorption. A comparison of BCB with other materials of choice is given in Table 1 [6].

	Perovskite	SiON	SiO_2	BCB
Range	2.2pF-400nF	0.01pF-150pF	0.01pF-500pF	1-50pF
pF/mm^2	8800	55	35	25
Rated Voltage	2-4	≤100	≤100	≤25
Voltage Stability	>1.25% volt from 0-5V	Independent	Independent	Independent
Frequency Range	≤10 GHz	≤40 GHz	≤40 GHz	≤75 GHz

Table 1: Comparison of Interlayer Material

3 Liquid Crystal Polymer (LCP)

LCP’s are high performance materials that combine the properties of polymers with those of liquids.It is a state of condensed matter between crystalline solids and isotropic liquids. The condensed matter characterized by a combination of physical properties of a liquid crystalline state and specific polymer properties. LCP’s are highly crystalline materials based on aromatic ring-structured compounds that are very stable after polymerizing [7]. The liquid crystalline material can have its molecules realigned using magnetic or electrical fields, and in the process acquire the properties of both solids and liquids.

LCP’s have a high modulus, high melting temperatures, and good impact strength as a result of the fibrous nature of liquid crystal morphology. They are unaffected by acids, dilute bases, and organic solvents over a broad temperature range and demonstrate minimal dimensional changes after exposure to a wide range of solvents. Strong concentrated bases at elevated temperatures hydrolyze LCP’s. This is convenient for molded circuit board applications and as a method of promoting copper adhesion to LCP’s. Other important properties relative to electronic packaging include a low coefficient of thermal expansion, flame retardant, low moisture absorption, and the ability to resist attacks by solvents used in defluxing and cleaning printed wiring boards.

4 Integrated Passives

Integrated passives are passive electronic components that are fully integrated in a layered carrier structure during fabrication of that structure. This is opposite to discrete passive devices which are passive electronic components surface mounted after fabrication of the carrying structure.

Passives can be integrated using each of the three MCM technologies: MCM-L [3], MCM-C [4]-[5], [8]-[12] or MCM-D [13]-[17]. MCM-D materials have better electrical material properties compared to MCM-C (e.g., tanδ is at least one order of magnitude better). This is especially important when going to higher frequencies. The spin coated thin dielectric layers in MCM-D generally have a much lower dielectric constant compared to ceramic materials. At high frequencies, this translates to longer physical lengths to given electrical lengths which results in easier control of dimension.

The control of the layer thickness and feature dimensions is much better in MCM-D. Minimum line widths and spaces in MCM-D are in the order of a few micrometers. With low frequency MCM-C may be used. Also for high power but low frequency applications LTCC may be preferred. Otherwise, MCM-D is required. MCM-D passives have been demonstrated in the range of several tens of GHz.

Some advantages that are offered by integrated passives over those of surface mounted devices are:

- Improved package efficiency
- Improved electrical and high frequency performance due to reduced parasitics
- Elimination of a separate package for passive yielding lower cost, and reduced profile weight
- No assembly to board
- Improved reliability due to solder joint failures.

In MCM-D, inductors with values between 1-40 nH with unloaded Qs up to 80 (depending upon inductance value) can be realized, as well as capacitors upto 1 nF/mm^2 (Ta_2O_5).

Capacitors: In MCM-D, capacitors may be realized in different ways [14]. A fisrt type is the classical parallel plate capacitor consisting of a metal-insulator-metal (MIM) build up. The insulating dielectric may be BCB (this case) for small capacitors or anodized tantalum for large values.

A second type consists of two capacitors in series connected through a common floating metal patch. For small capacitance values, this capacitor has the advantage that its size doubles, moving the feature size away from process tolerance prone dimensions. Furthermore the parasitic effects may be reduced using this type of capacitor.

A last type is the radial stub capacitor. This component is narrow at one end and fans out radially on the other. It is generally used as a precise located shunt capacitor to the surrounding ground plane.

Inductors: High quality integrated spiral inductors are hard to realize. In standard silicon the low resistivity of the silicon causes dielectric losses, which limits the quality of the inductor to about five at 1 or 2 GHz. The developments in silicon processing use copper-damascene techniques on low loss substrates to realize higher quality factors upto 15 at 3 GHz for 1.5 nH coils [18]. However these new techniques are quite expensive and not always compatible with the rest of the silicon processing. When realizing the same spiral inductors in MCM-D on a low loss alumina or glass carrier substrate, its quality factor increases tremendously at an overall low cost [13], [14]. Values up to 80 may be achieved at GHz frequencies.

5 5-GHz WLAN RF RECEIVER MODULE

The RF part of a 5-GHz WLAN receiver has been implemented to demonstrate the usefulness of above mentioned concepts and techniques. It is implemented using commercial bare die integrated with MCM-D technology. The receiver incorporates two 5-GHz bandpass filters, a low noise amplifier (LNA) and a down –conversion mixer. The structure is two layered with BCB as interlayer material. LCP is used a substrate (Loss tangent = 0.0045, $\varepsilon = 3.0$) having a thickness of 100µm. Metal layers are of aluminum ($\sigma = 3.5e+07$).

The two identical second-order bandpass filters are directly embedded in the MCM substrate. A detailed micrograph is shown in Fgure.1. The measured transfer function of the bandpass filters is shown in Figure.2. The filters show a measured insertion loss of 3 dB and a -1 dB bandwidth of 427 MHz centered around 5.2 GHz. The bandwidth still is with in acceptable limits. The return loss of the filter is around 17 dB. Their size is 3.37 mm by 2.12 mm.

The LNA is built around a GaAs HEMT transistor. This transistor is available as bare die and was mounted with flip-chip technology. The highly linear amplifier is matched for 50 Ω at the output and for the optimal noise at the input. It consists of a single class A stage and has a measured gain of 12.8 dB and a noise figure of 1.42 dB. The size of LNA is 2.5 mm by 1.6 mm. Measured S22 and S11 parameters are given in Figure.3.

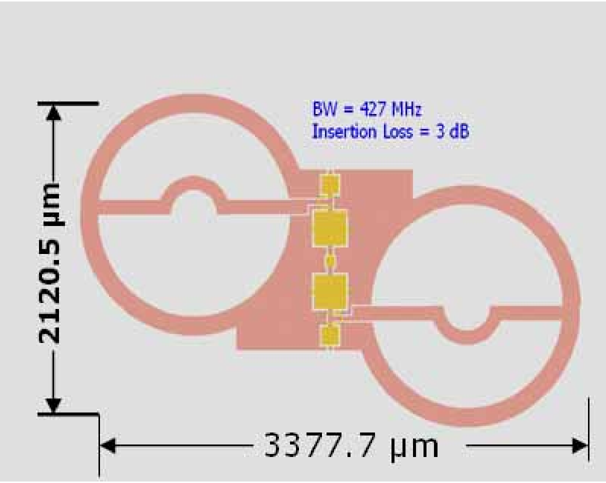

Figure 1: Micrograph of a second order 5-GHz bandpass filter.

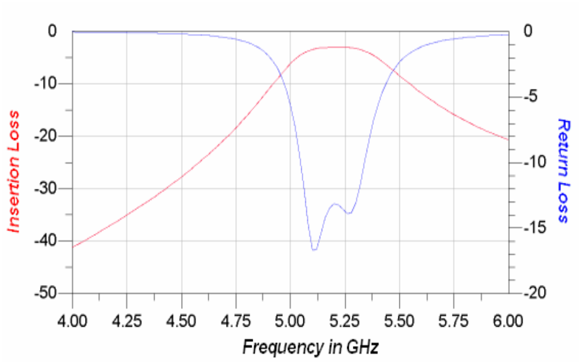

Figure 2: Measured insertion and return loss of the bandpass filter.

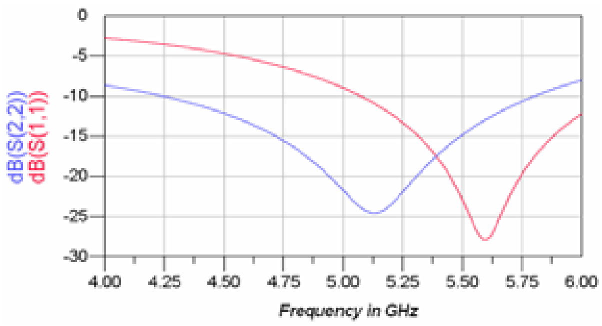

Figure 3: Measured S22 and S11 parameters of LNA.

6 Conclusion

Fully integrated single-chip transceivers in standard digital CMOS will probably not be feasible in future, especially for high performance and high-frequency applications such as the new 5-GHz WLAN standards. As an alternative implementation methodology, a system-in-a-package (SOP) approach has been proposed for wireless transceivers. Such a package contains different ASICs that are interconnected with an MCM-D technology. In this technology, high-quality passive components and MEMS can be directly integrated.

The SOP implementation approach has been demonstrated with the design of a 5-GHz WLAN receiver front-end module. The high quality factors of the integrated passive components can yield low-power solutions. In some RF circuits (e.g., LNA), the use of higher quality passives means that power consumption can be reduced for the same performance. High quality passives also lead to lower insertion loss for the integrated.

MCM filters. Less insertion loss in the antenna filter of a transmitter can also lead to a significant power reduction in the power amplifier. Power can also be reduced at the system level using this SOP approach. By using materials different than Al, e.g, Cu can yield better results due to high conductivity. Moreover interlayer materials such as SiO2 can enhance the results. Much better performance can be obtained by using integrated passives built on three or more layers; however that solution might be a little expensive. Nevertheless the advantages of building components on more than two layers surpass its cost. The design will be challenging and more difficult also.

The “single package” integrated system design, proposed here as an alternative for single-chip integration, is not incompatible with the expected future improvement of CMOS. It is not a temporary solution that will become obsolete with predicted CMOS technology scaling. Instead, these single package transceivers will only benefit from the evolution in RF CMOS design and the development of new front–end architectures: the resulting single-package solutions will only become denser and cheaper. There will be fewer devices mounted on the MCM substrate, but the cost and performance gain by implementing the large passives in the MCM substrate instead of on-chip will remain. Moreover, a number of RF components will not be integrated on-chip, e.g., RF filters, Tx/Rx switch, antennas, etc., and these components can be integrated in the package.

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