Advances in microwave MCM-D technology

Philip Pieters
IMEC, MCP/MCM-group, Leuven, Belgium

Walter De Raedt
IMEC, MCP/MCM-group, Leuven, Belgium

Eric Beyne
IMEC, MCP/MCM-group, Leuven, Belgium

Abstract
The thin film multilayer multichip module technology (MCM-D) was originally used for the interconnection of high-speed digital circuits in a single module. Nowadays, the technology is more and more evolving towards use in the interconnection of RF and microwave circuits with integrated passive components. This paper gives an overview of this evolution towards microwave MCM-D technology and the recent advances with respect to the integration of high quality passive components. With a discussion on the flip chip mounting of active devices, the link towards fully integrated high frequency front-end systems is pointed out.

Evolution overview and new perspectives
At the end of the 1980s, thin film multichip module or MCM-D technology emerged as a new technology for the interconnection of high-speed digital integrated circuits in one module or package. At that time it was believed that using this new interconnection technology, one would be able to realize complete high-speed digital systems in one large package or multichip module (MCM). Lots of bare dies would then be interconnected through the high quality interconnection substrate, reducing the overall packaging parasitics and boosting the system performance. However, later on it turned out that due to yield and known-good-die (KGD) problems, the power of digital MCM-D lies more in the concept of interconnecting only few bare dies with related functionality in one module and putting many of these MCMs together on a carrier board, increasing the overall system performance.

Simultaneous with this evolution, a new and promising utilization of the MCM-D technologies arose. The high accuracy and reproducibility at which the MCM-D circuits could be processed allowed the technology to be used for radio-frequency (RF) and microwave analogue circuits. In this way, lumped integrated passive components such as inductors, capacitors and resistors were demonstrated (Arnold and Pedder, 1992; Pieters et al., 1997a, 1998a; de Sambro et al., 1998). By using low loss dielectrics (e.g. BCB) and low loss metallisation (e.g. copper), spiral inductor unloaded quality factors of almost 40 could be achieved for inductors of a few nH in the GHz frequency range. Combining the inductors with lumped capacitors and interconnecting lines, passive lumped filter structures integrated in the MCM-D substrate could be realized (Pieters et al., 1996, 1997b, 1998b). When moving to higher frequencies, the lumped elements cannot be used anymore as such, but distributed structures have to be employed instead. Examples of fully integrated Lange couplers at 20 GHz and baluns at 10 GHz using coplanar coupled transmission lines have been demonstrated recently (Pieters et al., 1999).

Components may not only be integrated in the MCM-D substrate. Also on top of the substrate various other components such as active devices may be mounted using different connection techniques. Flip chip connections are becoming of increasing importance. The reduced parasitic effects in this connection technique are of primary importance for RF and microwave applications (Wadsworth et al., 1998). These parasitics are approximately one order of magnitude smaller than when using other connection techniques (e.g. wire-bonding), yielding an easier design approach, an improved noise performance, a reduction of the power consumption and in the end an overall cost reduction.

Exploiting the possibilities of integrating various passive components in the MCM-D substrate and mounting active components on top of it, new perspectives for fully integrated RF and microwave front-end systems are arising. Since such front-end systems typically consist of many passives and only few active devices they are very well suited for the integration in microwave MCM-D technology. The first examples of such integrated systems have been presented in Arnold et al. (1997).

Microwave MCM-D technology
The IMEC MCM-D technology consists of alternating thin layers of photosensitive benzocyclobutene (BCB) dielectric and low loss copper metallisations deposited on a borosilicate glass carrier substrate. The BCB dielectric has very low dielectric losses, a low dielectric constant and low moisture absorption (Beyne et al., 1995; Krishnamurthy et al., 1996). The material is spin coated in thin films of 1 to 10 μm thick. The 2 μm thick copper metal layers are sputtered and patterned using wet etching. Thicker metal layers up to 5 μm are realized by electroplating. Via holes through the BCB dielectric allow the connection of the different metal layers. The via diameter is typically 30 to 50 μm. A typical layer build-up structure is shown in Figure 1. The build-up is very flexible and may be adapted to any specific application.

Examples of integrated components in microwave MCM-D
Examples of different components which may be integrated in the MCM-D substrate are shown in this section. All these integrated passives are realized in a coplanar fashion. Also an example of flip chip connected high frequency high electron mobility transistors (HEMTs) on the alumina MCM-D substrate is shown.

The presented examples, together with many other possible components, form the basis for integration of complete front-end systems in MCM-D.

Capacitors
In MCM-D, capacitors may be realized in different ways. In Figure 2 a photograph of a classical parallel plate capacitor consisting of a metal-insulator-metal (MIM) build-up is depicted. In this example the insulating dielectric is the BCB dielectric (capacitance/area ratio ≈ 3 pF/mm²) but also anodized tantalum (capacitance/area ratio

---

The current issue and full text archive of this journal is available at http://www.emerald-library.com
0.6 nF/mm²) may be used for large capacitor values. Typical measurement results of a MIM capacitor in MCM-D are presented in Figure 3.

**Inductors**

When realizing spiral inductors in MCM-D on a low loss alumina or glass carrier substrate, very high unloaded quality factors up to a little more than 100 may be achieved at GHz frequencies. Figure 4 shows a photograph of such spiral inductor in MCM-D. The spiral is multi-turn circular and in a coplanar fashion. The center of the spiral is connected to the outside through an underpass on a lower metal layer. In Figure 5, typical plots of the reflection, transmission and unloaded quality factor of a MCM-D inductor are shown.

**Filters**

Filters are essential components in many electrical circuits. For RF and low microwave applications, the filters may be realized by combinations of capacitive and inductive lumped passive components. These passive filters may then be integrated in the MCM-D interconnection substrate, creating a functional interconnection. Figures 6 and 7 show an example of an integrated low pass filter with cut-off frequency at 12 GHz. Such type of filter is basically a ladder network of series inductors and shunt capacitors to ground (in this example series inductive lines and shunt radial stub capacitors).

**Lange couplers**

Lange couplers are widely used broadband ±3 dB power splitters. They are traditionally realized in a microstrip style with bond wires interconnecting the interdigitated fingers. In MCM-D we have realized a coplanar version in which the bond wires are replace by vias and connections through the lower metal layer. This makes the component more robust, more reproducible and in the end cheaper. Figure 8 shows a photograph of such a 20 GHz coplanar Lange coupler in MCM-D, while network analyzer measurements are presented in Figure 9.
Flip chip mounting of HEMTs

Active devices, such as, for example, HEMTs are important components for the integration of high frequency front-end systems. Figure 10 shows a photograph of HEMTs mounted on an alumina MCM-D carrier substrate by flip chip. The HEMTs are put on 30 μm gold bumps using thermo-compression. In Figure 11 a typical comparison of the maximum available gain (Gmax) of a HEMT before (on chip) and after flip chip is shown. Only a small reduction of the gain is observed due to the flip chip, i.e. about ±0.3 dB at 5 GHz and a little more at higher frequencies. This indicates the excellent performance of flip chip connections for the mounting of high frequency and high performance active devices.

Conclusions

In this paper, advances in microwave MCM-D technology are discussed. Through a overview of the evolution of...
MCM-D, new perspectives such as the integration of RF and microwave front-ends have been identified. Examples of various passive components integrated in MCM-D and the example of flip chip mounted HEMTs on the substrate demonstrated the potential of the technology for RF and microwave applications.

References


Beyne, E. et al. (1995), "The use of BCB and photo-BCB dielectrics in MCM-D for high speed digital and microwave applications", Proc. 4th International Conference and Exhibition on Multichip Modules, MCM'95, 19-21 April, Denver, CO.


Pieters, P. et al. (1998b), "Spiral inductors integrated in MCM-D using the design space concept", Proceedings of the International Conference and Exhibition on Multichip Modules and High Density Packaging MCM’98, 15-17 April, Denver, CO.

Pieters, P. et al. (1999), "Distributed microwave MCM-D circuits for X- and K-band applications", IMAPS International Conference and Exhibition on High Density Packaging and MCMs, HDP’99, 7-9 April, Denver, CO.
