Improved Design Options and Microwave Performance by Combining Thin Film with LTCC

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Abstract — **Thin film technology has been the traditional method to manufacture microwave circuitry for many years. An outstanding line resolution, excellent conductor edge definition combined with superb ceramic substrate properties in regard of high frequency and thermal behaviour are ideal prerequisites for these applications. On the other hand, this approach can be critical in terms of cost. Complex modules are often assembled in a special hermetic housing using a patch work arrangement of certain substrates.**

Multilayer substrates based on Low Temperature Cofired Ceramics (LTCC) offer a variety of design options for microwave designs. However, fine line printing resolution and associated tolerances might be the bottle neck. Though lines and spaces down to 50 micron are achievable, this is not sufficient for certain elements like edge coupled filters, couplers etc.

FINEBRID - a novel approach, combining the advantages of both technologies, was developed and evaluated within a funded programme. Thin film structures are applied on fired LTCC substrates without special surface treatment. This process allows a combination of printed thick film and thin film structures on the surface. Hence, the combined technology offers improved technology features like smaller line and spaces. Thin film features can be reduced to necessary areas and special thick film materials for hermetic sealing can be applied - thus providing options to reduce costs, size and weight.

Keywords: Thin Film, LTCC, Hermetic Packages, Integrated Passives

I. Introduction

A. LTCC Technology

Low Temperature Cofired Ceramics is a multilayer technology that offers numerous options for the design of circuits. For microwave applications DC-connections and digital control functions can be implemented in separate layers, chip tailored cavities can improve the return loss of the signal interconnections, various transmission line types as well as wave guides are available and the hermetic substrate itself can be used as a part of the package with integrated feed throughs. Embedded resistors and capacitors are additional features to further shrink the designs.

Though, the bulk materials have a medium thermal conductivity (2-4 W/mK) LTCC provides options to remove heat from active components effectively. By using thermal vias underneath the die, the thermal conductivity can be increased by a factor of 10 or more [1]. Additionally, a very low inductive ground inter-connect is established by the fully metallised vias. The matched thermal coefficient of expansion (TCE) to both GaAs and Si leads to highly reliable die to substrate interconnections.

The conductive pattern is usually structured by screen printing thus providing the cost and environment advantages of an additive process. However, line resolution is limited to a standard line width and space of about 100 µm. Special screens can be used to extend this range to about 50 µm (Fig. 1). New screen developments in conjunction with fine particle pastes are being made to further reduce the feature sizes and tolerances.

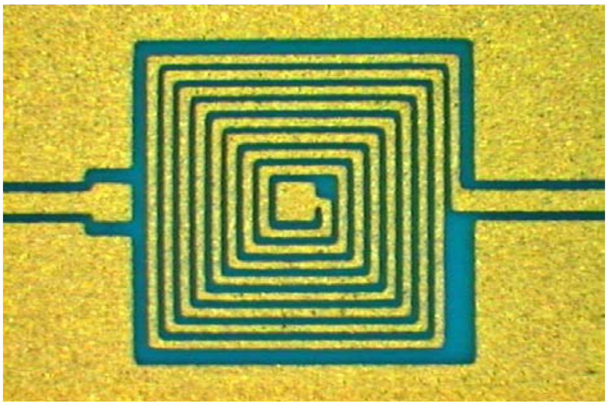

Fig. 1. Printed coil with 50µm lines and spacing

Other approaches are focussing on subtractive methods by photodefined conductors to increase the line resolution.

B. Thin Film Technology

By using chrome glass masks and processes used in the semiconductor industry extremely fine conductor tracks, typically 10 µm across, can be deposited and precisely structured. This allows especially for microwave substrates a low loss integration of passive components such as Lange couplers, filters or coils. The precise and very small thin film resistors are ideal for integrated attenuators, voltage- and power- dividers.

Thin film on alumina is widely used for microwave applications for decades. It comprises many advantages like outstanding microwave performance, high thermal conductivity, mechanical stability and good TCE match to semiconductors.

Hermetic microwave modules are usually very expensive due to the fact that the entire electrical module consists of several small substrates which are arranged in a patch work style. The major reason to divide the circuit into sub-circuits is related to yield figures obtained on large substrates. Positioning accuracy of these substrates is crucial to avoid gaps and related impedance changes. The housing itself needs to have expensive hermetic rf-interconnections.

II. Motivation

By combining the advantages of both technologies it would be possible to improve the performance of microwave modules while reducing the costs for the entire module simultanously. The intended properties of this mixed solution are:

- multilayer capability with impedance matched inner signal lines (layer thickness control)
- reduced substrate size
- good microwave performance of dielectrics
- high line resolution on the surface
- good line resolution on any inner layer
- good thermal behaviour (TCE and thermal conductivity)
- substrate is part of the hermetic package
- passive elements can be integrated on the surface and inside the multilayer

Fig. 2 shows a schematic view of a microwave module. Microwave interconnections can be routed from outside using an impedance matched LTCC feed through under the shielding walls of the frame. The internal lines, ground planes, backside metallisation as well as “coarse” structures on the top surface are screen printed.

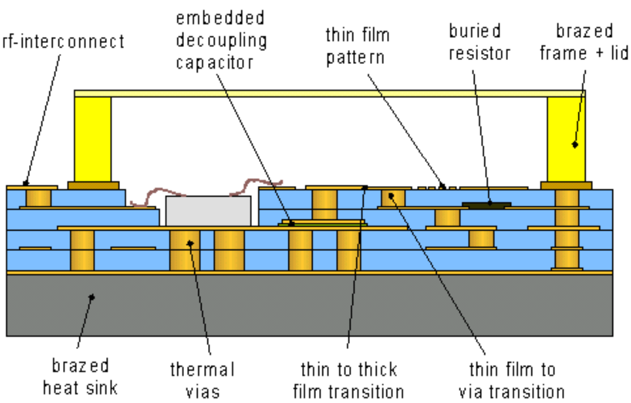

Fig. 2. Vision of the features realised by the combination of LTCC with thin film technology.

Decoupling capacitors can be arranged close to the MMIC embedded in the LTCC [2] thus reducing parasitics. Buried resistors with tolerances of about 30% can be used as wave absorbers. A detailed investigation focussing on trimming of embedded resistors is ongoing [3]. Tighter tolerances will allow to integrate more resistors into the LTCC.

The MMIC is placed in a cavity. This approach not only shortens the thermal path to the heatsink, it helps also to reduce wire bond lengths and the associated inductances.

Microwave structures like couplers, mixers and filters are integrated on the surface in thin film technology.

The heat sink and frame is soldered at high temperature prior to mounting of components. The entire module can be hermetically sealed with a lid after the component assembly.

The same concept can be applied for the assembly of small low power modules with a Ball Grid Array (BGA) interface underneath (Fig. 3).

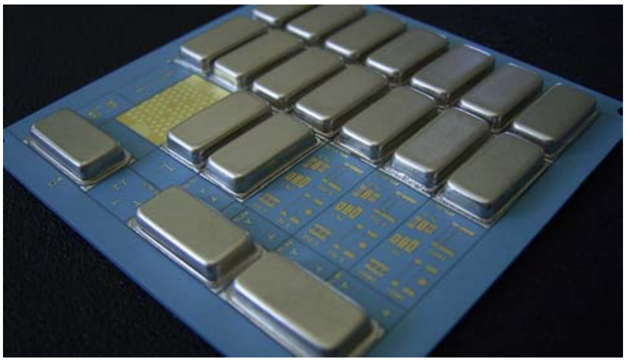

Fig. 3. Packaging of microwave BGA modules

III. Process

To achieve the mentioned goals a joint development by Reinhardt Microtech (RMT) and Micro Systems Engineering (MSE) was started within the BMBF project PROKOSMOS. Both companies agreed to cooperate to enhance the synergies of their thin film and LTCC know-how.

This combi-technology with the name Finebrid substantially expands the technical potential of both the Low Temperature Cofired Ceramic (LTCC) and the thin film systems. Two material systems were included in the development acitivities. Green Tape DP951 is a widely used material system for standard applications. It offers low dielectric losses over a wide frequency range. The second material, DP943 (low loss LTCC), is specially designed to achieve very low dielectric losses at microwave frequencies.

On the smooth glassy surface of the sintered LTCC a high resolution photolithography is possible. Without any lapping or polishing steps, 5 µm thick standard thin film patterns in the range of 20 µm line with and spacing has been realized. In this way passive microwave components like couplers or filters can be accurately integrated on multilayer ceramic substrates. A Lange Coupler with a 23 µm line width and 25 µm gap is depicted in Fig. 4.

The sputtered NiCr-layer, which is used as an adhesion layer with high oxygen affinity on LTCC substrates, can also be patterned for precise resistors. Dimensions smaller than 50 µm can be realized. Laser trimming is possible for tolerances better than 5%. In this way thin film resistor networks, attenuators and power dividers can be integrated on LTCC substrates.

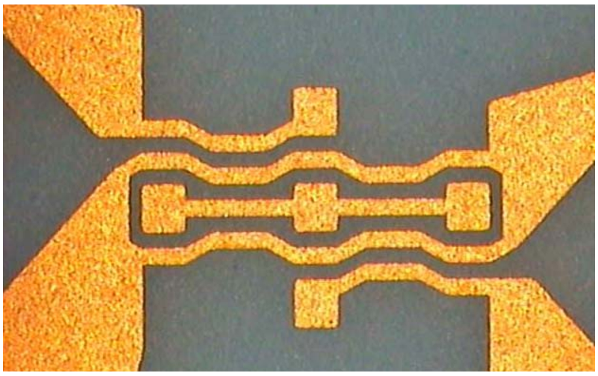

Fig. 4. Integrated Lange Coupler on LTCC

Fig. 5 shows NiCr resistors integrated on the low loss LTCC material.

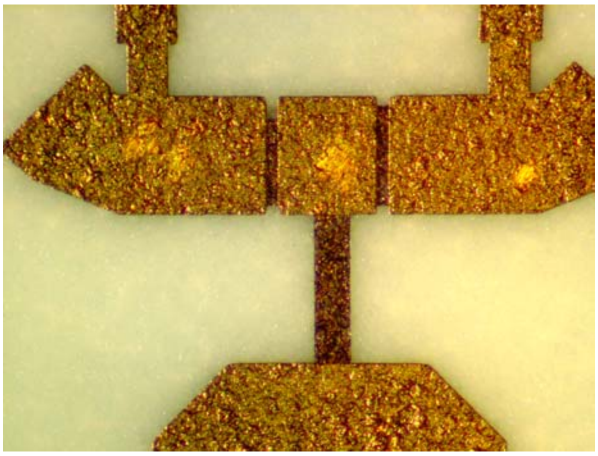

Fig. 5. Attenuator on Low loss LTCC material

In one sputter run resistance layers were attached on DuPont 951 and 943. The TCR was below 50 ppm for all materials. The final resistor values are influenced by the surface roughness of the substrates.

In the temperature range of – 55°C to 150°C the resistors show the following electrical characteristic:

Substrate	Resistance	Thermal Coefficient
DP943	46,6 **Ω**	-29,0 ppm/°C
DP951	26,0 **Ω**	-27,5 ppm/°C

TABLE I
Electrical characteristic of integrated resistors

IV. Compatibility and Reliability

The first step in developing this new packaging techno-logy was testing of the chemical resistance of the LTCC-tapes to thin film wet and dry etch mediums. The material is fully compatible with these processes.

The interface between the LTCC-metallisation and the thin film metallisation was investigated in the 2nd step. Two interfaces between thick and thin film metal are possible. On the one hand, thin film can be applied over a LTCC via, on the other hand, the thin film pattern can have a transition to a printed conductor. Fig. 6 shows several pad designs to connect vias on the LTCC (via diameter 130 µm) to form a daisy chain structure. Interconnections between cofired printed structures and thin film lines are depicted in Fig. 7.

Both test structures were stressed by temperature cycling, thermal shock and temperature storage tests. All test hybrids (both LTCC materials) went through all of these tests without any problem.

Wire bonding and adhesion tests showed the characteristically good values known from the thin film technology on alumina ceramic.

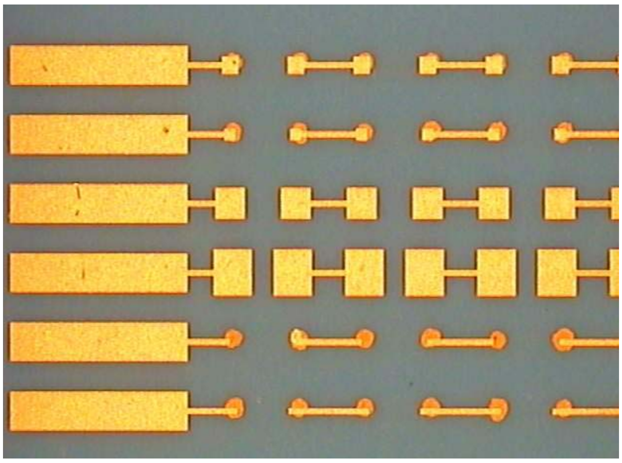

Fig. 6. Connection of LTCC vias with thin film lines

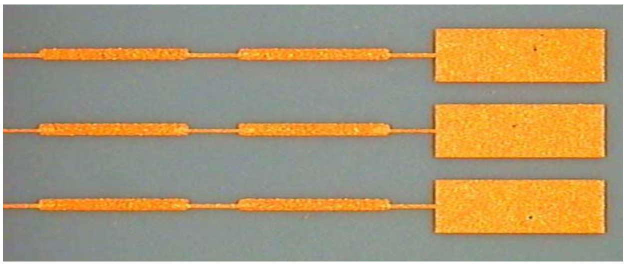

Fig. 7. Connection of printed cofired structures with thin film lines

V. Demonstrator

A High-Power Sub-Assembly was chosen as demon-strator for the realisation of a circuit in FINEBRID technology. The demonstrator combines the thick-film multilayer LTCC-technology with the thin-film technology for outstanding line resolution.

The Sub-Assembly is used as the output power stage in the transmit chain of a Transmit/Receive Module, that operates in the X-Band frequency range.

The workshare for the demonstrator was the following:

- Design and Layout at EADS
- LTCC-Manufacturing at MSE
- Thin-Film Patterning at RMT
- Verification and Measurements at EADS

The High-Power Sub-Assembly mainly consists of a balanced amplifier configuration. This configuration is often used in output power stages for the enhancement of the output power. At the input the RF-signal is split (one half each) by a power divider into two single-ended amplifiers, connected in parallel. At the output a second splitter is used to add the two amplified RF-signals in phase. In this way the achievable output power is doubled (neglecting the coupler losses) in comparison to a single-ended amplifier stage.

For the realisation of the power splitters Lange-Couplers are used. They are interdigital couplers with quarter wavelength sections of coupled microstrip lines. The fourth (isolated) port is terminated with a 50 Ohm integrated resistor to ground by a via hole. For the X-band application the lines and the spaces of the Lange-Coupler are in the range of 40 µm and 20 µm, respectively. The only way of realisation of such fine structures is the thin-film technology.

The toplayer of the LTCC-substrate supports the RF-structure of the High-Power Sub-Assembly with microstrip RF-lines, two Lange-Couplers, integrated resistors and coplanar probe pads for contacting and measuring. All these RF-elements are realised in the combined thin-film technology as described in this paper to achieve the required line resolution and conductor edge definition.

The DC-structures on the toplayer, which need not to be processed by thin-film, are part of the standard thick-film LTCC-technology. Among these structures are bias lines and contact pads for the population with discrete components.

The complete LTCC-substrate consists of in total six layers. The bias and control lines of the Sub-Assembly are mainly located in the lower layers to minimise the bond interconnections on the topside.

For the amplifiers of the balanced configuration a chip tailored cavity is recessed in the upper two layers of the LTCC-substrate. Into this cavity two identical High-Power Amplifier MMICs (Monolithic Microwave Integrated Circuits) are electrically conductive attached. The bottom of the cavity is provided with a pattern of thick thermal via holes building a heatsink to lead off the dissipation heat of the amplifiers. The cavity also supports plating structures for the biasing of the amplifiers and is populated with blocking capacitors.

The High-Power Sub-Assembly is operated in pulsed mode, i.e. the amplifiers are switched on in transmit mode (Tx) to generate the required RF output power and are switched off in receive mode (Rx) to reduce the overall DC power consumption. A Tx-modulator consisting of a MOSFET switch and driver is mounted on the topside of the LTCC. A storage capacitor is used to improve the Tx pulse performance. Furthermore blocking capacitors at the DC-supply voltages are included.

A photo of the realised and populated High-Power Sub-Assembly is shown in Fig. 8.

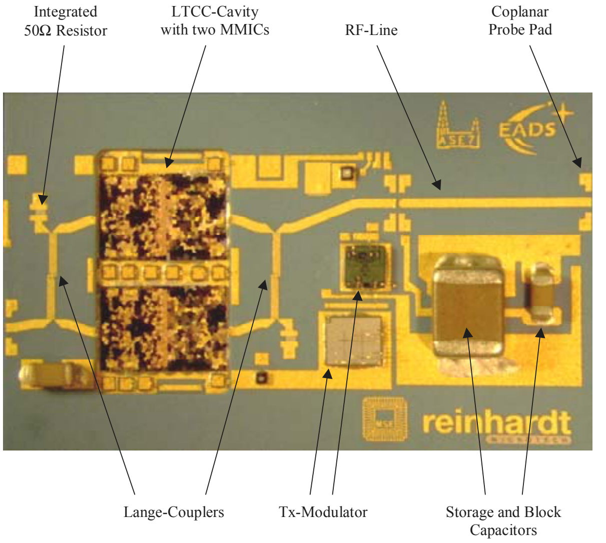

Fig. 8. Photo of the High-Power Sub-Assembly

VI. Summary and Outlook

The first RF-results of the High-Power Sub-Assembly are very encouraging and the characterisation measurements are ongoing, but not included in this contribution. More conclusions will be derived after the full electrical evaluation of the circuit.

To achieve more functionality further investigations are necessary to assess the thin film compatibility with the brazing process as well as with the integrated capacitors and resistors.

Acknowledgement

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References

[1] T. Jaakola, K. Kautio, J. Lenkkeri, "Thermal Management of Power MMIC on LTCC Substrate", in *Proceedings of the 14th European Microelectronics and Packaging Conference*, Friedrichshafen, Germany, June 2003.

[2] J. Müller, D. Josip, "Integrated Capacitors using LTCC", in *Proceedings of Microtech 2002*, Manchester/UK, January 2002.

[3] W. Ehrhardt, H. Thust, J. Müller, "Manufacturability and Reliability of trimmed buried resistors in LTCC" in *Proceedings of the 2003 Ceramic Interconnect Technology Conference,* Denver/USA, April 2003.