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Experimental LTCC platform for millimeter-wave applications

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Abstract—Since 2009, Lab-STICC has established an LTCC prototyping laboratory where we, to this day, have worked on microwave devices, devices based on gaped waveguide technology for millimeter-wave/fluidic applications (60 GHz), grooved laminated waveguides (30 to 170 GHz), grid array antennas (145 GHz), spintronic devices as well as more basic subjects as design kit and design rule check development, passive component design, and most recently LTCC cooling implementation.

This paper presents an overview of the aforementioned devices from simulation, fabrication and measurement phases as well as our fabrication possibilities and limitations.

Keywords— LTCC; millimeter wave; gapped waveguide; grooved laminated waveguides; fluidic; spintronics; grid array antenna; heat pipes;

I. INTRODUCTION

Since 2009 an LTCC fabrication and research platform is established at the Lab-STICC laboratory. The purpose is to develop future millimeter-wave devices. The closeness between microwave designers and fabrication staff is of great importance for such development. In our case, both competencies are held within the laboratory and one ambition is that the circuit designers do perform most of the fabrication steps themselves, while few steps are executed by specialized operators. The design rules are continuously reviewed and adjusted by the involved designers and staff on the basis of new findings throughout the different prototype runs.

Since 2009 we have been able to produce in-house prototypes covering a large range of device types, from microwave modules, gaped waveguides for electromagnetic-fluidic interaction, grooved laminated waveguides for high frequency systems, grid array antennas, passive circuitry (inductors and capacitors), spintronic devices and most recently we have started looking at heat-pipe development.

II. TAPE MATERIAL

The LTCC material used comes from Electro Science Laboratory, ESL, [1]. We use three tapes; a low, a medium and a comparatively high relative permittivity material in order to optimize the trade-off between size and manufacturability. The LTCC materials are the ESL41110, the ESL41020 and the

ESL41060 tapes¹. These tapes have been characterized at 15 GHz at ambient temperature by XLIM - University of Limoges - who found the relative permittivity and loss tangent, as presented in TABLE I.

TABLE I. ESL MATERIAL DATA MEASURED AT 15 GHz AND T AMBIENT

Material	Characteristics	
	Relative permittivity, ϵ_r	Loss tangent, $\tan\delta$
ESL41111-G ^a	4.08	0.00380
ESL41020	7.27	0.00498
ESL41060	16.3	0.00375

^a. See footnote 1

The ESL41111-G material was also measured in our quasi-optical bench [2] in the frequency band of 75-110 GHz where we found a relative permittivity of 4.11 and a loss tangent of 0.008. Preliminary measurement in the D-band (110-170 GHz) resulted in a relative permittivity of 4.11 and a loss tangent of 0.006 in this band. The data in the D-band should be considered with less assurance.

III. DEVICES

The LTCC technology is used in several of our research projects. Before and after each prototype run, a briefing and debriefing session is held with the staff directly involved and also the project staff of other LTCC projects. The presentations are also uploaded in a common file folder. This way, new findings are spread to a large number of people in order to prevent mistakes to be reproduced. An overview of our design and fabrication capacity will be given by some recent examples.

A. Gap waveguide devices for microfluidic application

In the last two decades, the interest in microfluidic applications has grown for biological and chemical sensor applications. These systems offer many advantages over conventional bench top analytical systems such as portability

¹ These tapes have recently been replaced in Europe by their equivalents ESL41111-G, ESL 41020-G and ESL41060-G, which contains a new softener. After firing the composition is exactly the same for the original and the replacement tape.

or disposability [3]. The integration of microwave sensing into microfluidic systems is based on the analysis of the electromagnetic properties of a fluid in order to obtain information about its composition. Current solutions are based on a local perturbation of transmission line (coplanar waveguide, CPW) or resonator using SIW (Substrate Integrated Waveguide) technology. However, the technical constraints for the CPW and the SIW topology in the millimeter-wave range limit the frequency band and the proposed sensor's sensitivity is limited by the fact that the electromagnetic field is not maximized in the interaction zone between the medium and the electromagnetic field.

To provide a technical solution, we suggest to use the recently proposed gap waveguide technology (Fig.1) [4] adapted for millimeter-wave application which allows concentrating the electromagnetic field within an open structure to allow fluidic access. (Fig.2)

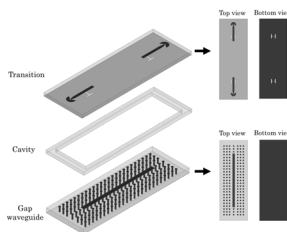


Fig. 1. Gap waveguide technology

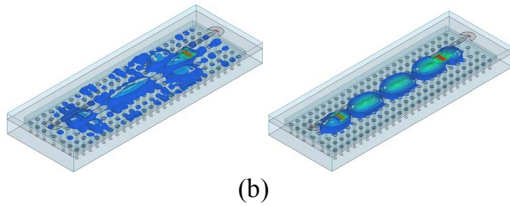


Fig. 2. Gap waveguide (a) no guided propagation, (b) guided propagation

For microfluidics applications and millimeter-wave devices, LTCC technology is an attractive candidate. The LTCC offers numerous advantages over silicon, making it a good material for developing microfluidic devices [5] with the possibility to realize internal channels or cavities and to integrate passive and active millimeter-wave components.

The prototype is composed by 21 LTCC layers: nine layers for the metallic pins and transmission line, six layers for the air cavity and six layers for the transition coplanar to microstrip. A cross-section of the prototype is depicted in Fig. 3.

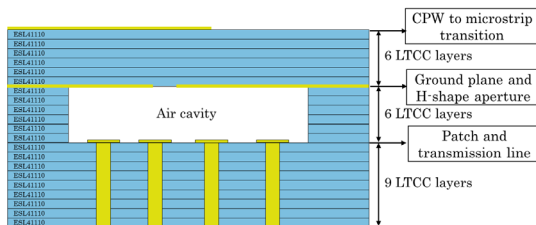


Fig. 3. Cross-section of the LTCC gap waveguide prototype

The realization of the prototype is done using the following LTCC process: stacking of the 21 layers with introduction of

fugitive material to avoid deformation in the lamination process, see Fig. 4 and Fig. 5.



Fig. 4. Stacking of all the first 15 layers; before the insertion of the fugitive tape (left), after insertion of the fugitive tape (right).

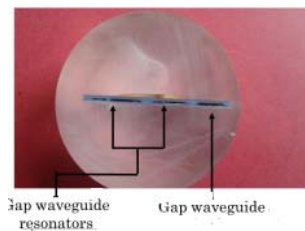


Fig. 5. LTCC gapwaveguide finalized prototype with internal cavity.

A microfluidic sensor based on a millimeter-wave resonator, realized with the gap waveguide technology [6] is illustrated in Fig. 6.

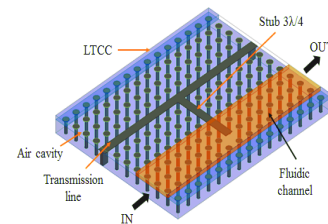


Fig. 6. Gap waveguide stub resonator

B. Grooved laminates waveguides

Grooved Laminated Waveguides (GLWG) were realized in ESL41110 tape, on one and four layers. The layer design cross-section is presented in Fig. 7. Different devices such as straight line, bends and tees were designed for the U-band and the straight line was also realized at V, W and G-band [7]-[8]. The metallized grooves are advantageous as compared to metallized vias rows normally used in SIWs since the waveguide is completely closed and no radiation will take place across the via rows.

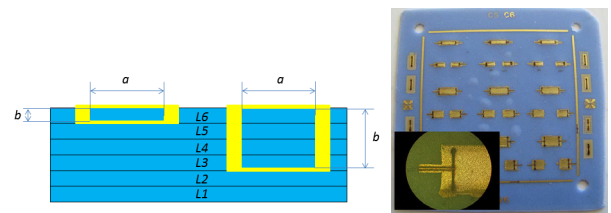


Fig. 7. In total six LTCC layers are used and the GLWG is placed on one or on four layers. Cross-section of the GLWG stack up (left). Full prototype of GLWG lines with GLWG to COW transitions (right).

To our findings the GLWG on one layer is rather straightforward to produce, the filling of the grooves was made with a regular screen-printer. Some difficulties related to the choice of the width of the grooves (150 μm width on a 100 μm thick green tape) were experienced and a smaller groove width might help the gold paste to stay in the groove until the LTCC stack is finalized. The transition used, inspired by [9] allows measurements in a probe-station with GSG probes. TABLE II. gives the loss data found for the GLWGs. A typical value of 0.55 to 0.59 dB/λ_g is obtained, where λ_g is the guided wavelength in the material. The four layered GLWG presents, as expected, less losses. However, the complexity of fabrication is higher for this item.

TABLE II. GLWG TRANSMISSION LOSS IN ESL41110 SUBSTRATE

Frequency band		U	V	W	G	
Number of layers		1	1	1	1	4
Loss	dB/mm	0.15	0.19	0.26	0.49	0.41
	dB/ λ_g	0.57	0.59	0.55	0.58	0.50

The proof of concept of these GLWGs provides us with a good transmission line support for system in package design. Transitions for flip chip integration to the waveguides are now under work.

C. D-band Grid Array Antenna

A medium-gain 145 GHz Grid Array Antenna (GAA) was designed at Chalmers University of Technology and successfully fabricated at Lab-STICC in 2015, [10]. This antenna is designed on four layers of ESL41110 tape with a coplanar to microstrip feed on one the bottom of the first layer and the grid arrays placed on top of the fourth layer, see Fig. 8. The low relative permittivity constant is advantageous as compared to other LTCC tapes to achieve good radiation. The resulting measured data is presented in Fig. 9 and compared with the simulated data using a slightly erroneous relative permittivity of 4.18 and $\tan\delta$ of 0.018 which was the values at hand at the time.

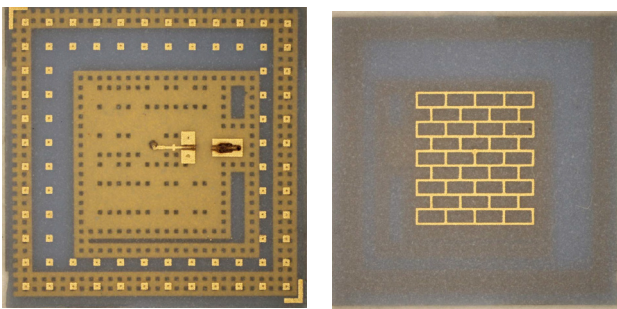


Fig. 8. GAA antenna, designed at Chalmers University of Technology and fabricated at Lab-STICC. The complete antenna module measures 12 mm \times 12 mm \times 0.3 mm. Feed layer (left), grid array pattern (right).

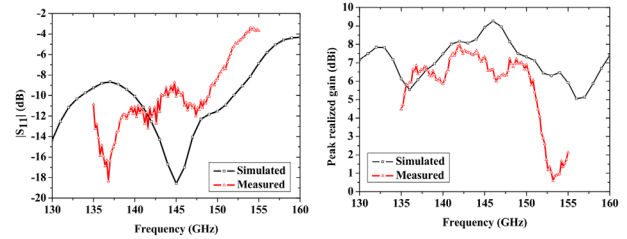


Fig. 9. Measurement and simulation results of the GAA; S11 (left), peak gain(right). The measurements are performed at Karlsruhe Institute of Technology.

The outcome of this work together with the GLWGs encourages us to continue our D-band packaging efforts with the aim to include active components as well.

D. Spintronics

We have recently reported thermal control of mode hybridization between the ferromagnetic resonance (FMR) and a planar resonator (notch filter) working at 4.74 GHz [11]. The chosen magnetic material is a ferrimagnetic insulator (Yttrium Iron Garnet: YIG) covered by 6 nm of platinum (Pt). A current-induced heating method has been used in order to enhance the temperature of the YIG/Pt system. The device permits us to control the transmission spectra and the magnon-photon coupling strength at room temperature, as shown below:

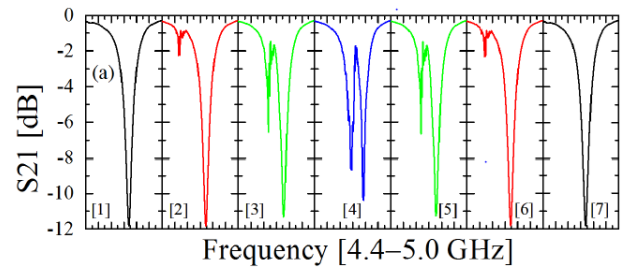


Fig. 10. Frequency dependence of the S parameters at the resonant condition for different applied charge current. Labels [1] to [7] correspond to the magnitude of the applied charge current

These experimental findings reveal potentially applicable tunable microwave filtering function. The idea is to progress well beyond the state of the art by simultaneously introducing the concept of magnetic insulator spintronic, magnon-photon coupling regime, and energy harvesting in a full integrated microwave applications realized by an advanced packaging solution (Low Temperature Co-fired Ceramic, LTCC).

E. Passive devices

Capacitors, inductors and resistors are passive components that are necessary for a full system in package design on LTCC. Students were asked to design capacitors and inductors in the order of 1 and 10 pF and 10 nH, and to limit the real estate area to 1 mm \times 1 mm using the in house LTCC platform.

Several designs were proposed, such as Metal Insulator Metal (MIM) and interdigital capacitors and inductors using the ESL41060 tape. In order to measure the devices, while

buried in inner layers, openings were produced in the covering tape layers to access measurement pads.

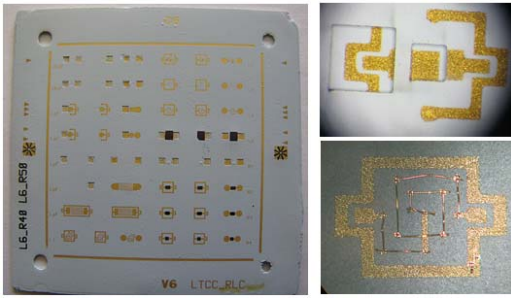


Fig. 11. Passive components prototype (left). Example of buried capacitor (high-K material to be inserted in center square hole) with RF measurement pads (upper right), wire bonded inductor (lower right).

For this first prototype run, the capacitances and inductances were inferior of 2 pF and 6 nH respectively. Nevertheless, the fabrication techniques developed during this work are useful findings. To improve the result, while decreasing the real estate area, the use of more layers should be further investigated.

F. Heat pipes for thermal management

Heat pipes are passive structures used to transport heat from one hot spot to another position where the heat is evacuated. Recently, LTCC integrated heat pipes have been proposed [12], [13] and [11] which are of interest when designing modules including power amplifiers. With the objective to learn more, we have launched a prototype run of heat pipes designed in the ESL41020 tape. For this first prototype, 14 different designs were considered in order to identify the difficulties in fabrication. The design parameters using the same nomenclature as in [10], Fig. 2a, are as follows: The total length, L_{tot} , is 8 mm, the total LTCC substrate thickness, t , is 1 mm, the groove height, t_g , is 75 μm , the groove width, $2W$, is varied from 100 μm to 200 μm while the distance between grooves, $2L_1$, is kept at 100 μm , finally the vapor space height, t_v , is varied from 150 to 450 μm in steps of 75 μm . No matter of what vapor space height is used, the top grooved layer is always the fourth from the top, then comes one grooved layer, then two to six cavity layers to build the vapor space and under those lies the bottom grooved layer which is placed on the base layers. The schematic cross section of the prototype heat pipe stack is shown in Fig. 2b. To cut out the heat pipe grooves, the parameters of the laser were set to a frequency of 20 kHz, a laser displacement speed of 20 mm/s, a power of 5.0W. The tenth layer during stacking and the full prototype after firing is shown in Fig. 12.

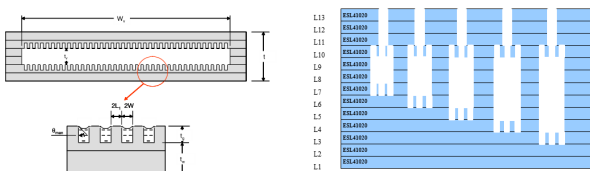


Fig. 12. Heat pipe dimension nomenclature, from [14] (left) and heat pipe prototype LTCC stack (right).

In order to realize the heat pipes, fugitive tape, ESL49000, was inserted on the vapor space layers to protect the cavities during the lamination phase. However, no specific protection was used to protect the grooves. "Chimney holes" in both ends of the heat pipes were used to help evacuate the oxidized carbon resulting from the dissolution of the sacrificial material.



Fig. 13. Prototype stacking layer 10 with the top heat pipe grooves (left) and the full prototype after firing (right).

The resulting prototype exhibits some swelling for most of the 14 designs. Cross sectional analysis shows that there is some residual fugitive tape left in the heat pipes and that the grooves have been deformed in the lamination process why more work must be done to develop this procedure.

CONCLUSIONS

Different LTCC devices for a large range of applications have been presented in this paper. The research on different subjects is continued to improve our design and fabrication capacities even further.

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REFERENCES

- [1] "ESL ElectroScience Products - Ceramic Tape Systems," [On line]. Available at: <http://www.electroscience.com/ceramic tapesystems.html>. [Visited on: 16-july-2015].
- [2] D. Bourreau, A. Peden, et S. Le Maguer, "A Quasi-Optical Free-Space Measurement Setup Without Time-Domain Gating for Material Characterization in the W-Band," *IEEE Trans. Instrum. Meas.*, vol. 55, n° 6, p. 2022-2028, déc. 2006.
- [3] R. J. Buford, E. C. Green, et M. J. McClung, "A microwave frequency sensor for non-invasive blood-glucose measurement," in *2008 IEEE Sensors Applications Symposium*, 2008, p. 4-7.
- [4] P. S. Kildal, E. Alfonso, A. Valero-Nogueira, et E. Rajo-Iglesias, "Local Metamaterial-Based Waveguides in Gaps Between Parallel Metal Plates," *IEEE Antennas Wirel. Propag. Lett.*, vol. 8, p. 84-87, 2009.
- [5] A. Vasudev, A. Kaushik, K. Jones, et S. Bhansali, "Prospects of low temperature co-fired ceramic (LTCC) based microfluidic systems for

- point-of-care biosensing and environmental sensing," *Microfluid. Nanofluidics*, vol. 14, n° 3-4, p. 683-702, mars 2013.
- [6] C. Arenas-Buendia, F. Gallée, A. Valero-Nogueira, et C. Person, "RF sensor based on gap waveguide technology in LTCC for liquid sensing," in *2015 9th European Conference on Antennas and Propagation (EuCAP)*, 2015, p. 1-4.
- [7] C. Kärnfelt, P. Coant, M. Sinou, J. P. Coupez, D. Bourreau, et A. Péden, "Grooved Laminated Waveguide devices for U-, V-, W- and G-band applications," in *2015 European Microwave Conference (EuMC)*, 2015, p. 777-780.
- [8] C. Kärnfelt, P. Coant, M. Sinou, J.-P. Coupez, D. Bourreau, et A. Péden, "Grooved Laminated Waveguides in LTCC for mm-wave packaging," *Micro/Nano-electronics Packaging and Assembly, Design and manufacturing Forum, (MiNaPAD2015)*, Grenoble, 2015.
- [9] D. Deslandes et K. Wu, "Integrated transition of coplanar to rectangular waveguides," in *Microwave Symposium Digest, 2001 IEEE MTT-S International*, 2001, vol. 2, p. 619-622 vol.2.
- [10] C. Kärnfelt, B. Zhang, et H. Zirath, "A QFN packaged grid array antenna in low dielectric constant LTCC for D-band applications," in *2016 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP)*, 2016, p. 1-4.
- [11] V. Castel *et al.*, "Thermal Control of the Magnon-Photon Coupling in a Notch Filter coupled to a Yttrium-Iron-Garnet/Platinum System," Arxiv:1704.08896v3 july 2017.
- [12] W. K. Jones, Yanqing Liu, et Mingcong Gao, "Micro heat pipes in low temperature cofire ceramic (LTCC) substrates," *IEEE Trans. Compon. Packag. Technol.*, vol. 26, n° 1, p. 110-115, mars 2003.
- [13] P. Z. Shi, K. M. Chua, S. C. K. Wong, et Y. M. Tan, "Design and performance optimization of miniature heat pipes in LTCC," *J. Phys. Conf. Ser.*, vol. 34, p. 142-147, avr. 2006.
- [14] M. A. Zampino, W. K. Jones, et Y. Cao, "Substrate Embedded Heat Pipes Compatible with Ceramic Cofire Processing," *Int. J. Microcircuits Electron. Packag.*, vol. 21, n° 1, p. 52-58, 1998.