Post-Doc position (5 months)

New miniature mmW probes for precision on-wafer microwave measurements

Laboratory: TIMA, 46 avenue Félix Viallet - 38031 GRENOBLE
Supervisors: Jean-Daniel Arnould, Philippe Ferrari
Phone: + 33 (0)4 76 57 48 71
E-mail: jean-daniel.arnould@grenoble-inp.fr, philippe.ferrari@univ-grenoble-alpes.fr

Gratification: 2400€/month approximately net pay

I. Preamble

The consortium of the ANR-Project (named PRECISE) consists of 3 laboratories: IMS-Bordeaux, TIMA-Grenoble, IEMN-Lille and a company MC2-technologies-Lille.

We search a Post-doctoral fellow to help on this Project (5 months).

II. Context of the ANR Project « Precise »

While significant progress has been made in the semiconductor technology and high speed integrated-circuit (IC) fabrication, the measurement infrastructure for characterizing such ICs remains largely undeveloped especially for on-wafer measurements. In particular, commercial probes for applications below 110 GHz use technologies that have been developed and patented about 15 to 20 years ago *[1-4]* and are nearly expired. Moreover, these commercial technologies are very expensive since they typically rely on manual assembly of several components. Furthermore, this assembly method leads to large dispersion from product to product as illustrated in Fig. 1. Manual assembly also limits possible geometrical down scaling of the probe—something required to improve their performance. From an electrical performance point-of-view, current commercial probes are not sufficiently down-scaled—thus inducing a high coupling between the substrate and/or adjacent circuits, and the probes, or a high coupling from probe-to-probe. This leads to unreliable measurement results above 60 GHz *[5]* (see Fig. 2). Hence, scaling down the probe is required; but becomes increasingly difficult to the point that an innovative probe design is the only option. Finally, measuring broadband up to 500 GHz requires one to measure frequency band per frequency band, inducing the contact issue, increasing man-power cost and making more difficult the analysis of the results. **In this ANR project (named PRECISE), we propose a new approach for the design of broadband probes working from DC to at least 220 (and eventually 325) GHz with strongly reduced probe-to-substrate coupling. (i) The front-end element of the probe, i.e. the probe tips, will be realized using silicon microtechnology—having a well-controlled fabrication process with highly scaled dimensions. (ii) The back-end of the probe, i.e. their packaging, to connect the micrometer world to the measurement instrument, will benefit from a carefully optimized procedure**. A packaging will be developed to connect the front-end to the external world through a mechanically optimized connector. This packaging will guide both the processed die (the front-end) and the connector leading to a straightforward assembly. Using the silicon technology for probes development will open new opportunities for smart probing, ie. the integration of mm-wave circuit directly within the probe. A first demonstration of this smart probes will be given in this project with the design and integration of an integrated tuner or balun within the probe.

State of the art: Limitations of commercial probes:

The IMS laboratory has led many studies on the subject for silicon technologies up to 500 GHz, in particular EM probes models of major probe providers (Picoprobe - GGB and Cascade

Infinity) have been realized and benchmarked on different layouts [8] (see Fig. 3) emphasizing the limitations of measurement accuracy with available probes.

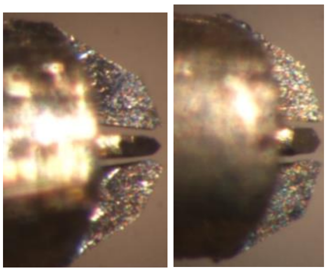

Fig. 1: Image of the Picoprobe GGB, 50 µm pitch highlighting the dispersion between two probes (Port 1 & Port 2).

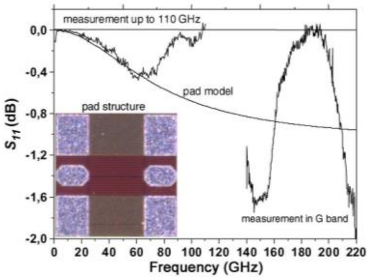

Fig. 2: Measured and simulated parameters of a dummy pad structure using FormFactor Infinity probe; inside, layout of a on wafer-GSG pad ULille.[15]

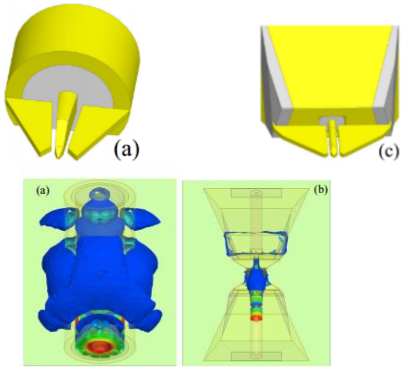

Fig. 3: GGB probes EM model developed at UB, EM field highlighting difference of coupling with the environment @ 110 GHz depending on probe geometry.

The ANR-PRECISE project proposes the development of a technology below 110 GHz where is located the highest part of the business market, in particular 5G and automotive radars, and up to 325 GHz. Up to 220 GHz, the micro-machined probes can be directly connected to a coaxial connector (0.6 mm), the whole using an original packaging. This will allow addressing new broadband vector network analyzers (VNA) such as Anritsu VNAs working from 70 kHz up to 220 GHz, recently acquired at Grenoble and future VNAs that will benefit from the results of the project. Moreover, concerning the interest of smart probe technology, [23] underlines that beyond 100 GHz, external tuners revealed important losses that significantly limit the maximum reflection coefficient to be synthesized. This constraint being amplified with frequency can be only solved by integrating the tuner at a close proximity of the DUT. Similar aspects can be found in other circuits [24].

Innovation:

Tunable loads design can be the core of the future work. To reduce the cost of the technological development and reduce the numbers of iterations, EM simulation will anticipate possible difficulties by carrying out an accurate and complete study including the front-end of the probes, the connection with the micro-coax cable, the whole packaging as well as the silicon wafer (DUTs) and the cal-kit calibration structures. The calibration procedure will be performed on EM data to evaluate the probe behavior under practical conditions. In addition, mechanical modelling will be performed to optimize the silicon die thickness and metal type with regards to contact quality, repeatability, and probes robustness. The front-end part, i.e. the silicon die, will be processed in the IEMN laboratory advanced cleanroom. IEMN laboratory is very experienced in micromachined technology and has already developed RF nano-probes [21], [22]. Finally, packaging will be in part performed at MC2 technologies thanks to an advanced 3D metal printer and then finalized at IEMN laboratory. MC2 will investigate the industrialization of the product making endurance tests, repeatability of the contact, reproducibility from probe-to-probe, and by optimizing production cost.

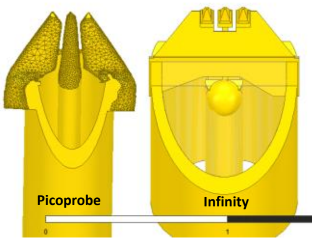

Fig. 4 : EM Model of the different probes topologies, GGB Picoprobe, Formfactor Infinity

Figure 4 compares three different probe topologies. The two first topologies are well-known commercial probes, e.g. GGB Picoprobes and Formfactor Infinity probes for 110 GHz measurements. The GGB approach cannot be scaled down at moderate cost due to its manual fabrication; thus limiting the possibility of EM field confinement. Whilst the Formfactor probe is highly-scaled in the region of the microstrip line— a large solder joint is made between the coaxial cable and the microstrip, which engenders coupling to the substrate. In comparison, the third topology (*undisclosed in the job offer*), i.e. the innovative approach proposed here is scaled down until the far end of the probe tips and can be used over a broad frequency band from DC to beyond 325 GHz (not considering the connector) with large attenuation of the coupling phenomenon. Our silicon-based microfabrication approach offers the possibility of stress sensor integration for optimal contact (tilt and force). **Even more interesting is also the opportunity for active probe fabrication which cannot be offered by more conventional probe technology. Indeed, developing the smart probe in silicon technology will lead to a new paradigm in term of on-wafer measurement approach: mm-wave silicon circuit dies can be directly integrated on the silicon probe front-end minimizing the loss between the DUT and the input of the measurement**. For example, introducing an impedance tuner for noise measurement or a VNA extender to measure above 110 GHz will open the road to new measurement tools. The future exploitation of this smart probe concept will take advantages of the experience of the numerous circuits dedicated to characterization that have been developed by the consortium (tuner [23], noise source [24], in situ VNA [7]). This unrivaled technology will greatly reduce the instruments cost and extend measurement capabilities beyond the state-of-the-art. The ANR-PRECISE project will provide a considerable advance to French laboratories and companies concerning mm-wave on-wafer tests, as potential future applications such as 6G, automotive radars and medical imaging, require frequency characterization tools well above 100 GHz.

III. Bibliographie (in blue consortium contribution)

[1] A. Rumiantsev *et al.*, « RF Probe Technology: History and Selected Topics », *IEEE Microw. Mag.*, pp. 46-58, nov. 2013.
[2] G. G. Boll *et al.*, « Broadband impedance matching probe », EP0985154B1, 31-mars-2004.
[3] J. Burr *et al.*, « Coaxial wafer probe with tip shielding », US5565788A, 15-oct-1996.
[4] K. R. Gleason *et al.*, « Shielded probe for testing a device under test », US7518387B2, 14-avr-2009.
[5] C. Andre et al., https://doi.org/10.1109/ICMTS.2007.374494
[6] C. McIntosh et al., https://doi.org/10.1109/ESTC.2008.4684429
[7] M. Margalef-Rovira et al., https://doi.org/10.1109/NEWCAS49341.2020.9159829
[8] C. Yadav *et al.*, "Importance and Requirement of Frequency Band Specific RF Probes EM Models in Sub-THz and THz Measurements up to 500 GHz," in *IEEE Trans. THz*, Sept. 2020, https://doi.org/10.1109/TTHZ.2020.3004517.
[9] N. Waldhoff, et al., « Improved Characterization Methology for MOSFETs up to 220 GHz », *IEEE Trans. Microw. Theory Tech.*, vol. 57, nº 5, p. 1237-1243, mai 2009.
[10] M. Seelmann-Eggebert et al., https://doi.org/10.1109/TMTT.2015.2436919
[11] G. N. Phung et al., https://doi.org/10.23919/EuMC.2013.6686655
[12] F. J. Schmückle *et al.*, « Mutual interference in calibration line configurations », *89th ARFTG Conference* 2017.
[13] S. Fregonese *et al.*, IEEE Trans. MTT 2018, https://doi.org/10.1109/TMTT.2018.2832067
[14] S. Fregonese *et al.*, IEEE Trans. Terahertz Sci. Technol., https://doi.org/10.1109/TTHZ.2018.2884612
[15] N. Waldhoff *et al.*, https://doi.org/10.1109/TMTT.2009.2017359
[16] G. Dambrine *et al.*, https://doi.org/10.1016/B978-0-12-401700-9.00002-1
[17] R. M. Weikle, *et al.*, « Micromachined probes for on-wafer measurement of millimeter- and submillimeter-wave devices and components », in *2013 IEEE Global Conference on Signal and Information Processing*, 2013, p. 707-710.
[18] T. J. Reck *et al.*, « Micromachined Probes for Submillimeter-Wave On-Wafer Measurements—Part II: RF Design and Characterization », *IEEE Trans. Terahertz Sci. Technol.*, vol. 1, nº 2, p. 357-363, nov. 2011.
[19] I. R. M. Weikle, *et al.*, « Micromachined on-wafer probes and related method », US9366697B2, 14-juin-2016.
[20] « UT-013 Micro-Coax RF Cable|CDIRF ». https://rf.cdiweb.com/products/detail/ut013-micro-coax/259524/.
[21] J. Marzouk *et al.*, https://doi.org/10.1088/0960-1317/25/7/075024.
[22] J. Marzouk *et al.*, https://doi.org/10.1016/j.sna.2015.10.043
[23] M. Deng *et al.*, in IEEE MWCL, vol. 24, no. 9, pp. 649-651, Sept. 2014, https://doi.org/10.1109/LMWC.2014.2331762.
[24] H. Ghanem *et al.*, in IEEE MTT, vol. 68, no. 6, pp. 2268-2277, June 2020, https://doi.org/10.1109/TMTT.2020.2980513.