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M2 Internship Offer

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Title : Optoelectronic mixer integrated with coplanar probe for broadband characterization of THz devices

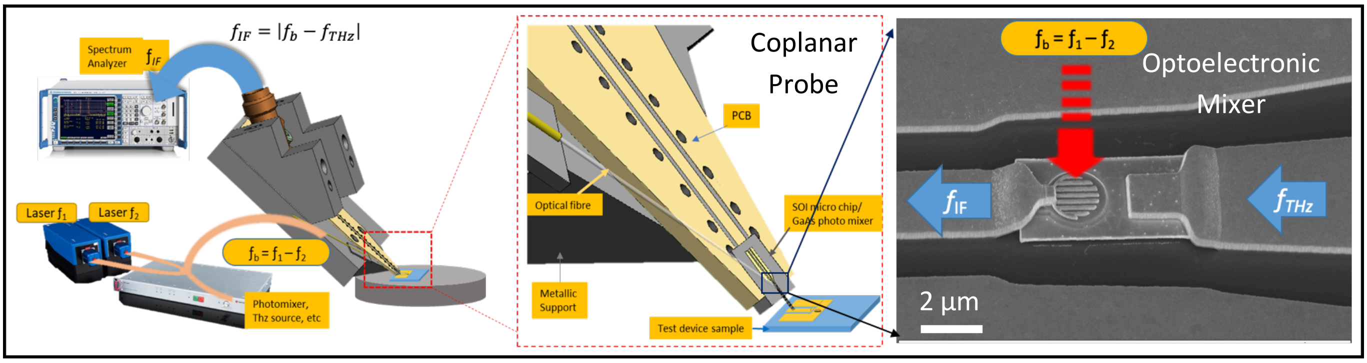

Figure 1: Principle of optoelectronic mixing on coplanar probe for broadband characterization of dynamic electrical properties of THz components on wafer. The signal's frequency, f_{THz}, is converted to a low frequency, f_{IF}, for analysis by a standard measuring instrument, directly on the measuring probe by the optoelectronic mixer, which is pumped by an optical frequency beat $f_b = f_{THz} \pm f_{IF}$.

Context : Wireless telecommunications systems in the millimetre wave (MMW) range are already a reality since the 5G FR2 band extends from 24 GHz to 52 GHz. A further expansion to higher frequencies for 6G seems almost unavoidable in order to increase the data rate capabilities: the spectrum from 100 GHz to 1 THz is the natural candidate for 6G systems carrier frequencies. Future telecommunication systems will therefore require semiconductor devices such as mixers, amplifiers, detector diodes, oscillators, antennas, waveguides, etc. operating at THz frequencies. Beyond telecommunications applications, components operating in the MMW range are also used in automotive radar at 77 GHz / 79 GHz, radar for defence applications, sensors, etc.

Many challenges remain to be addressed before fulfilling the increasing needs in efficiency, cost, reliability of emerging devices operating in these frequency range. One major bottleneck is the lack of spectrum analysers (SA) or vector networks analysers (VNA) with sufficient bandwidth to measure accurately their linear and nonlinear electrical response. This current bottleneck hampers their optimization and limits the precision of the compact models which are essential to the design of MMW and THz integrated circuits (MMIC). Commercial spectrum analysers (SA) and vector network analysers (VNA) have frequency limits below 100 GHz and frequency conversion heads are needed to cover the frequencies range beyond. For example, 6 extension systems are needed in addition of the baseband SA (VNA) to characterize a device in frequency band of 1 THz! Only one converter can be used at a time resulting in multiple manual operations and time-consuming calibration procedures. Furthermore, each band requires a different set of coplanar probes to ensure electrical contacts with the components studied when the electrical characterization of the components takes place directly on the semiconductor wafer before dicing and packaging. These probes have a limited lifetime (~10000 contact cycles) and a significant cost: between 10-30 k€ per tip depending on the frequency band! Achieving band continuity within six frequency measurement ranges is very challenging. The main issues are contact deterioration due to multiple contacts on the same pads (at least one contact for each frequency band), possible probe misalignment and the appropriate design of the calibration structures for on-wafer calibration. Only one manufacturer, Anritsu, is now trying to market instruments with a slightly wider bandwidth with a product covering the 0-220 GHz range2 but at a very high cost (~1 M€ on list price).

One promising way to overcome this bottleneck consists in taking advantages of the continuous development of photonic technology to develop wideband THz signal analysis systems. Numerous studies on THz sources and detectors using photonic techniques have indeed been performed for more than twenty years in the wake of the continuous improvement of near-infrared lasers sources at wavelengths between 780 and 1550 nm. Laser-driven sources and detectors are now key components of commercial THz spectroscopy systems and have enabled the race to high data rates in THz wireless communications by bridging the gap between optical fibers and wireless communications technologies. Optoelectronic detection of continuous THz waves is basically based on frequency mixing, as in the electronics solution, since the THz input wave is down-convert to an intermediate frequency f_{IF} in a photoconductor/photomixer illuminated by an optical signal modulated at a frequency f_b such as $f_{IF}=|f_b-f_{THz}|$. The output photocurrent is indeed proportional to the product of the photocarrier density- modulated by the optical signal at f_b - times the photocarrier drift velocity -modulated by the THz wave at f_{THz}.

For the past decade, the Photonics THz team has developed optoelectronic mixers utilizing photoconductor technology in plasmonic microcavities. These mixers have achieved conversion losses of approximately 1% in the THz range, representing only a 10X reduction compared to electronic mixers. The measurement dynamics of such systems will be on par with existing solutions. It is thus now feasible to envision a spectrum analyzer and/or vector network analyzer with a broad range of 0-1 THz employing these technologies. This theme is currently being supported by the French National Research Agency (PISA, PRCE 2023) through a collaborative research project involving IEMN, the FOTON Institute of the University of Rennes, and MC2 Technologies.

Tasks : The successful candidate will be involved in the design, fabrication and characterization of a first-generation optoelectronic mixer integrated on a coplanar probe, enabling on-wafer characterization of electronic components up to 500 GHz (see operating principle in Figure 1).
Design will be done by using SILVACO software to optimize the mixer's optoelectronic properties, HFSS and CST Microwave software to study the electromagnetic properties of the probe, and ADS software for circuit design.
Fabrication will be carried out on the MicroNanofabrication platform, which covers 1,600m² of clean room space and has a wide range of equipment, from the basics of the semiconductor industry to cutting-edge micro-nanofabrication equipment.
Characterization will be carried out on the THz optoelectronic characterization benches of the Photonics and Optics Microwave Characterization Platform (CHOP).

Given the quantity and diversity of the tasks and themes of the project - semiconductor physics, nanophotonics, electromagnetism, microwave design, microfabrication, optoelectronic and THz characterization - the student's precise work will be discussed on a case-by-case basis and will depend on his or her tastes and abilities.

Expected profile: For this multidisciplinary internship, we're looking for a student with solid background in at least one of the following fields: microelectronics/microtechnology, microwaves, semiconductor devices physics or optoelectronics, and who is motivated by research in applied physics.

Career Opportunities offered by this internship: The trainee will have the opportunity to start a PhD thesis as part of the PISA project (funding has already been secured). Additionally, they may apply for other doctoral grants or pursue a career in the telecommunications or defense industries focused on semiconductors, components, and High Frequency systems.

Salary : ~600€/month. **Duration : between 4 and 6 months** **Starting date : Mars 2024**