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# Micromachining and Packaging of Smart Probes for Sub-mmW on-Wafer Measurements

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## Motivations

In recent years, wireless communication technology has continued to evolve towards high frequencies (HF) to benefit from wider data bandwidth and higher speed performance. This growth has increased the demand for transmissions at high data rates, spurring the advancement of technologies in millimeter wave (mmW) and sub-terahertz (sub-THz) bands [1].

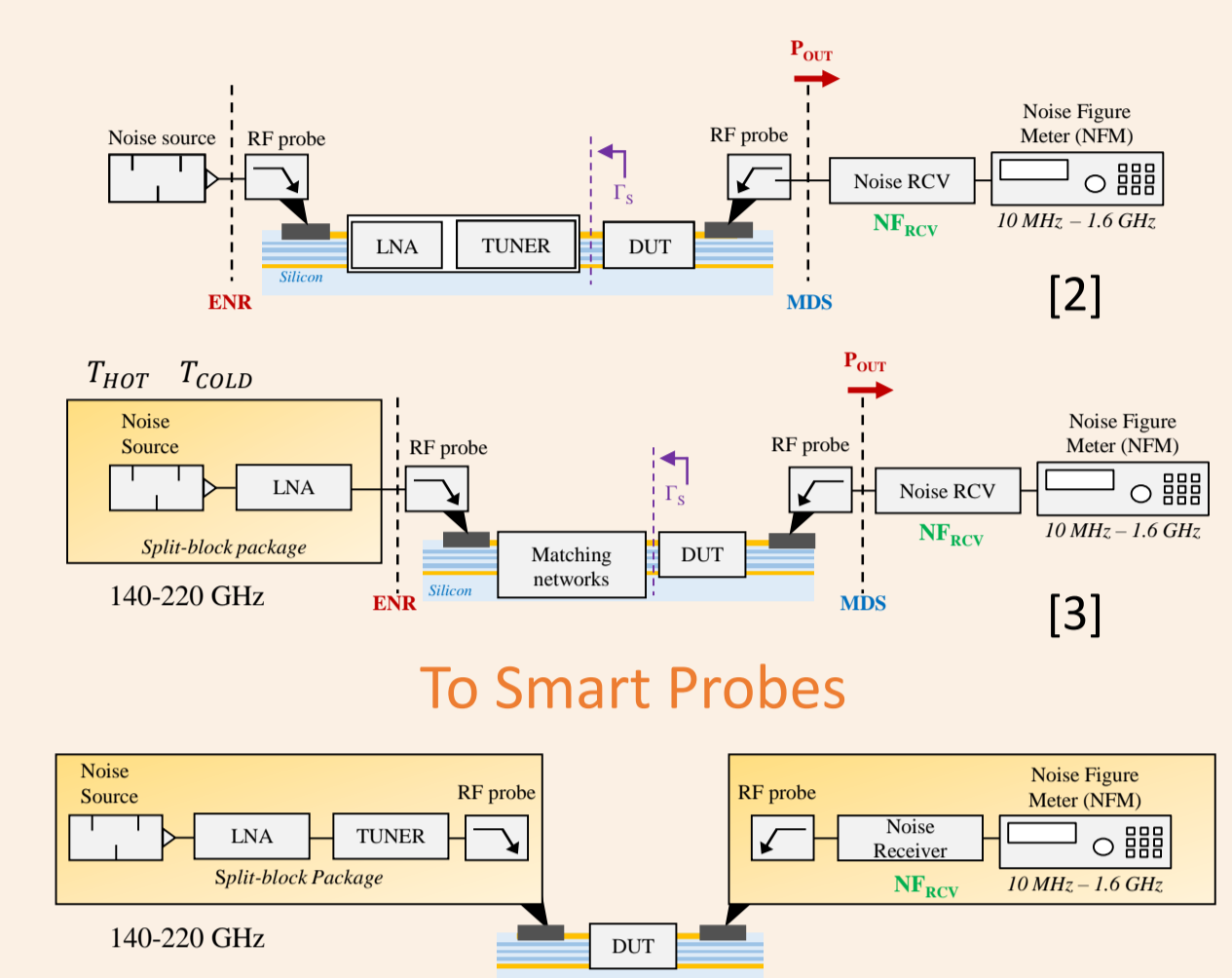


Cutting-edge silicon technologies like BiCMOS B55X from STMicroelectronics, aiming for  $f_T/f_{max}$  cut-off frequencies beyond 400GHz, now enable the design of circuits on silicon in the G-band 140-220GHz.

To validate the development of these technologies, microwave characterization means are required to extract transistor performance figure of merits such as noise figure and power efficiency.

[1] H. Tataria, "5G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities", 2021  
[2] S. Bouvor, Thèse "Contribution au BIST in-situ: Intégration sur silicium d'un banc de caractérisation en bruit en bande D", 2018  
[3] V.Fiorese, Thèse "Nano sonde active intelligente pour mesures de bruit et de puissance dans la bande de fréquence 130-260 GHz", 2022

### From in-situ testing or Built-in-Self Test (BIST)



BIST is not a viable solution

- Consumes substantial amount of Silicon
- Not cost effective

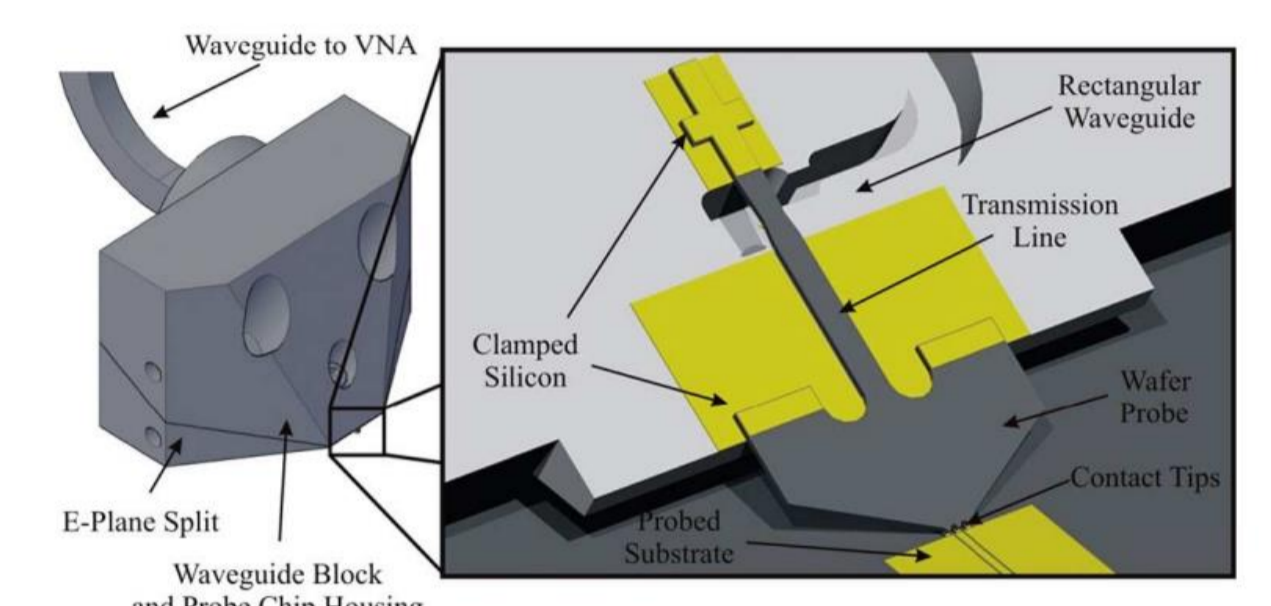
→ Integration of broadband tools in the form of a functionalized active probe.

## State of the art

### Micromachined Probes for Sub-mmW on-Wafer Measurements

A scalable approach to wafer probe development for WR-1.5 (500-750 GHz) is presented in [4], where this development integrates a rectangular waveguide probe and a coplanar waveguide (CPW) wafer probe onto a 15 $\mu$ m thick silicon substrate.

As major steps in advanced packaging can be realized based on material innovations, many materials compatible with the micromachining process can be used to form the probe but not all of them have the mechanical properties that can withstand before the failure of the probe.



### Smooth, stable and sturdy

In this project, SCHOTT glass AF32 is used as the substrate material of the integrated active probe, offering a low coefficient of thermal expansion similar to a silicon wafer, making it ideally suited to wafer-level packaging in the semiconductor industry [5].

[4] T. J. Reck et al., "Micromachined Probes for Submillimeter-Wave On-Wafer Measurements- Part I: Mechanical Design and Characterization", 2011  
[5] Schott-brochure-technical-glasses\_2011

## Design

❖ The RF probe design follows two step structures:

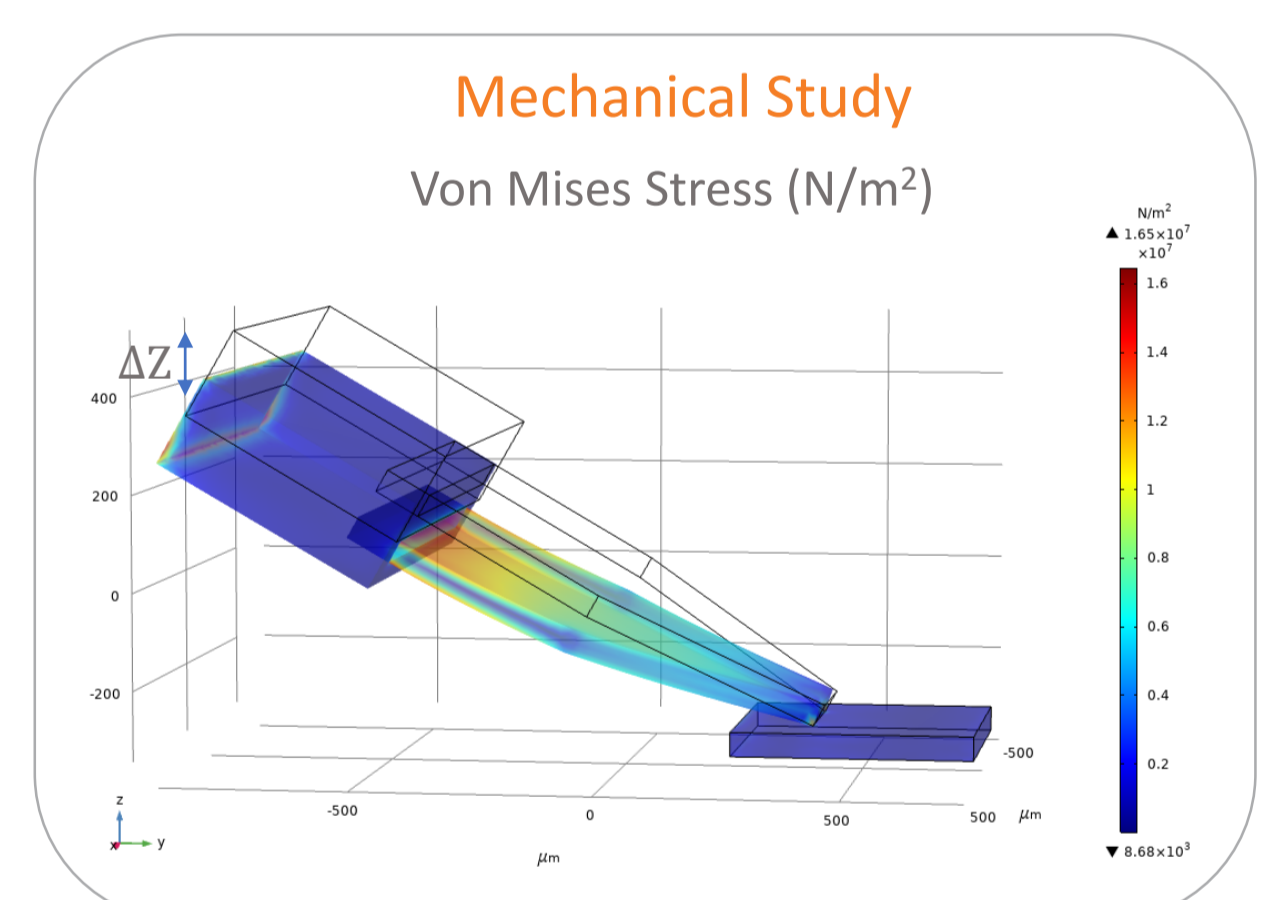
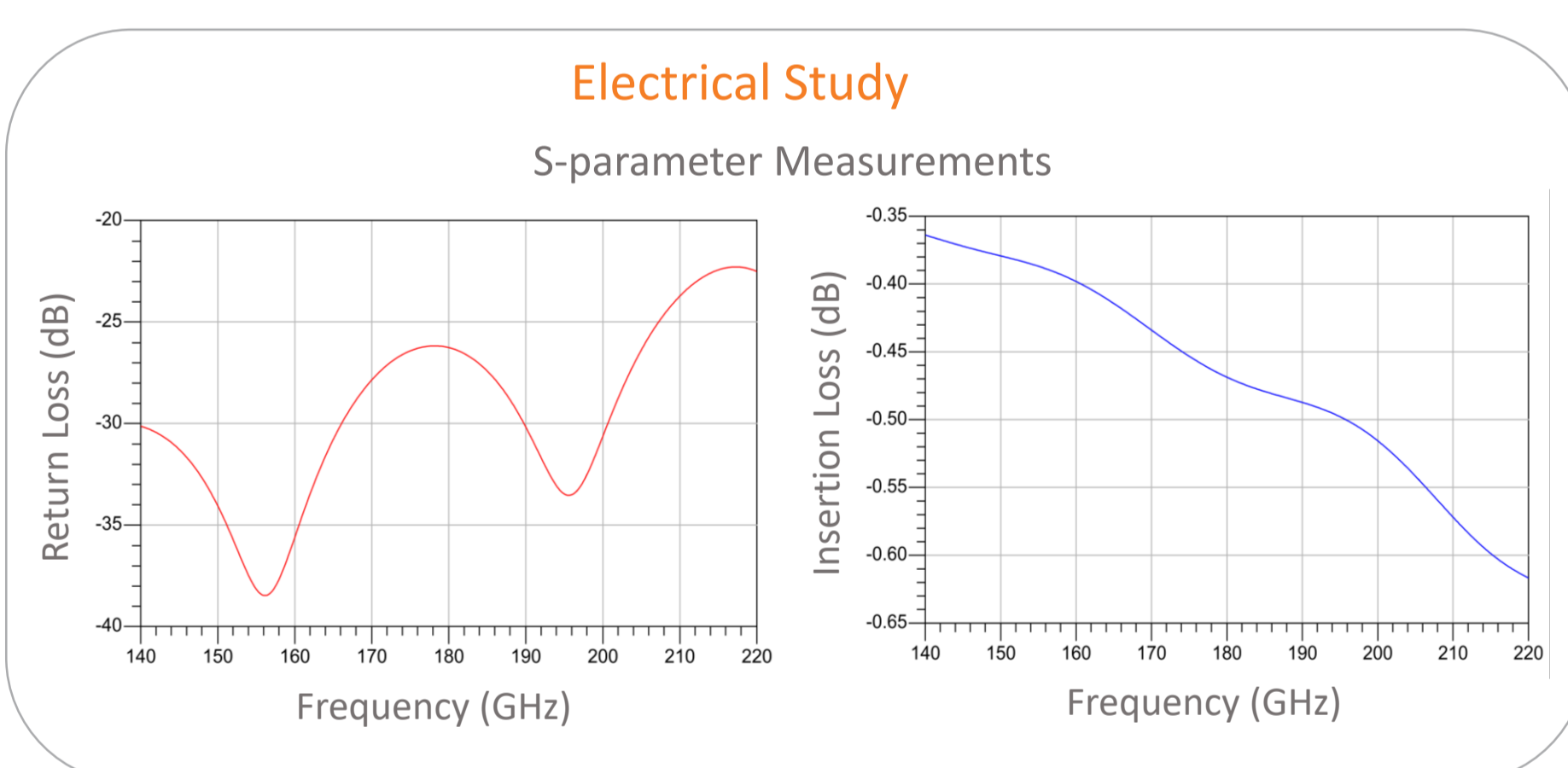
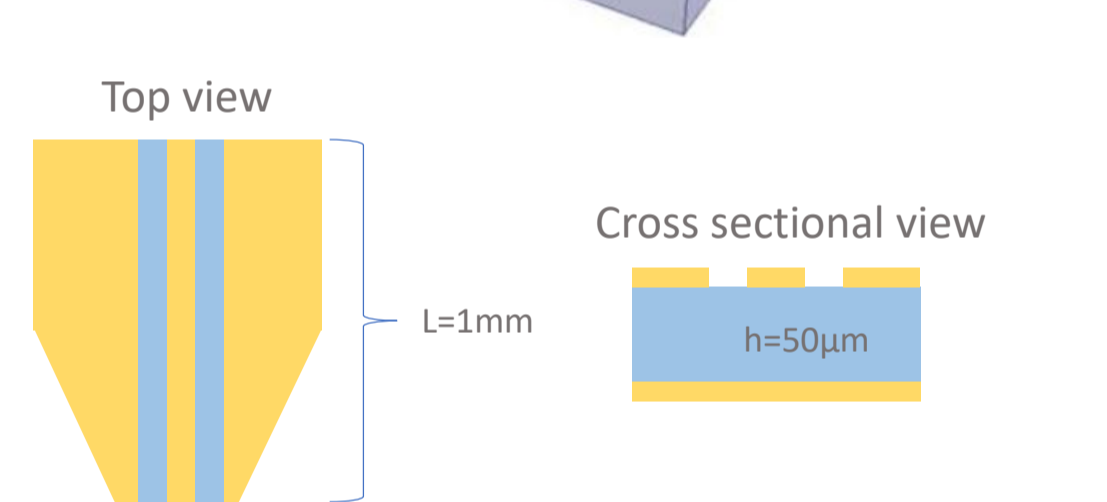
**1<sup>st</sup> test vehicle: Development of a GSG probe technology for passive measurements**  
In which the probe design must satisfy three main functions:

- Contact probing onto on-wafer contacts pads
- Signal propagation through transmission line
- Transition to a rectangular waveguide using a radiating E-plane structure

**2<sup>nd</sup> test vehicle: Development of an active GSG probe integrated with a noise source**

❖ The probe is in the form of tapered coplanar structure having a dielectric substrate AF32 glass 50 $\mu$ m thick. Electrical and Mechanical properties of AF32:

- Dielectric Permittivity  $\epsilon_r=5.1$
- Density  $\rho=2.43g/cm^3$
- Young's Modulus  $E=74.8 KN/mm^2$  (GPa)
- Poisson's ratio  $\mu=0.238$

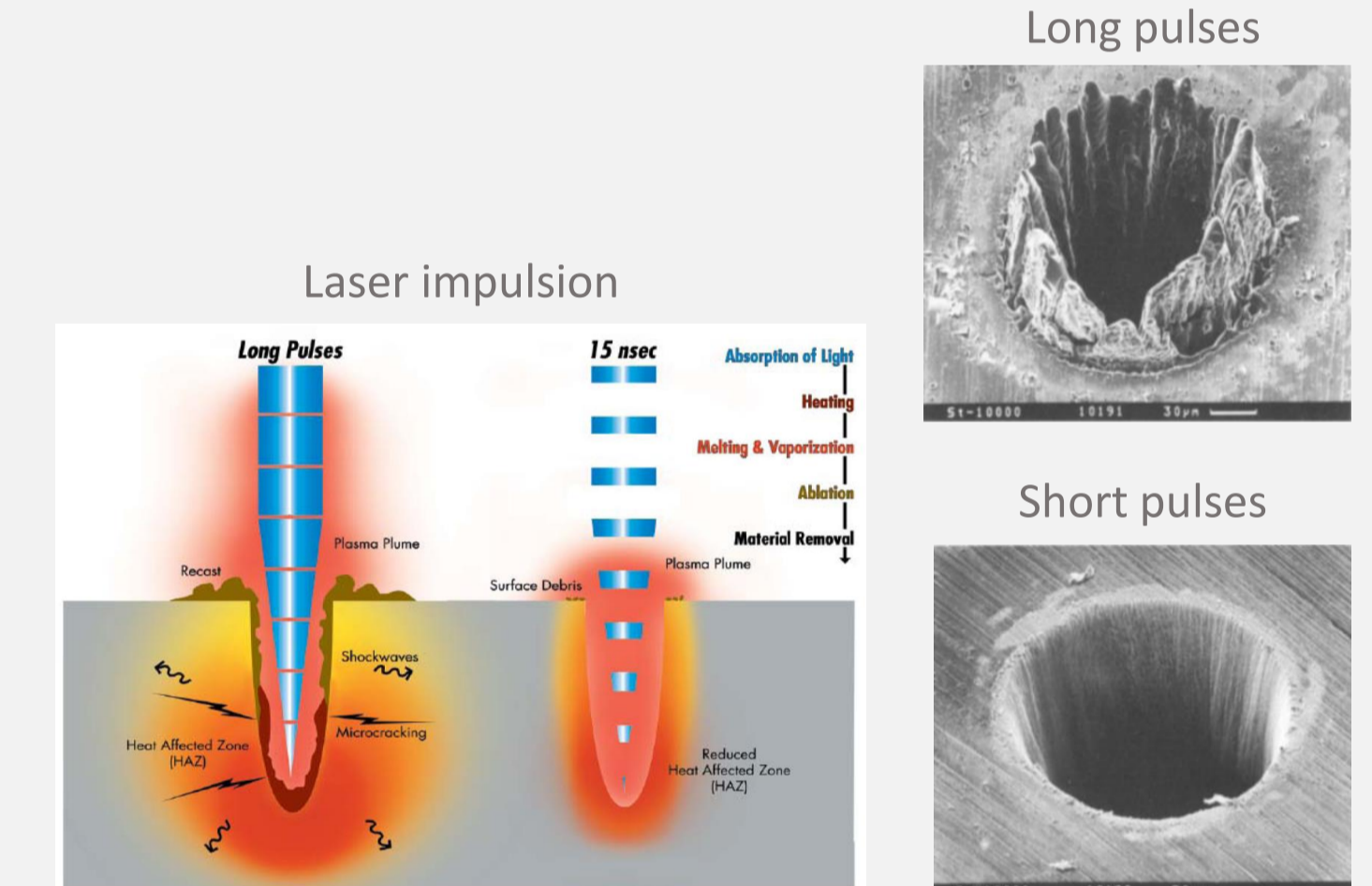


## Fabrication

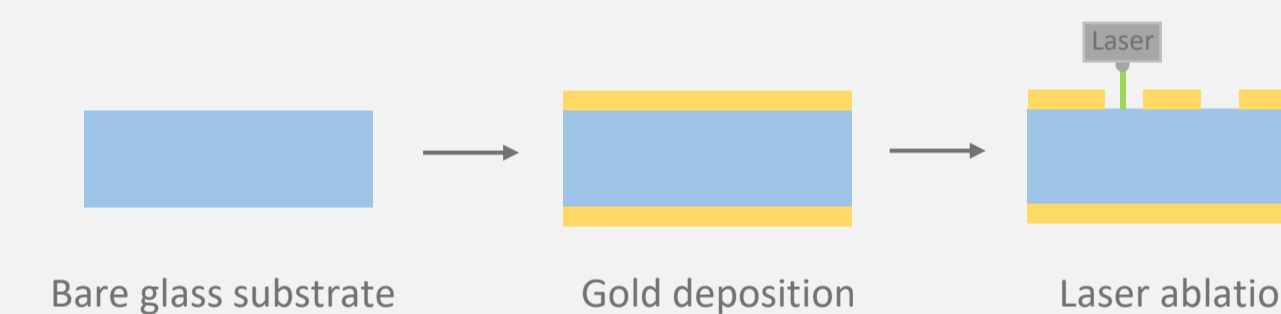
### Fabrication Technique

Femtosecond Laser has become increasingly relevant due to its characteristics [6]:

- Produces ultra-short laser pulses
- Achieves optimal spatial resolution without collateral damage such as heat affected zone (HAZ)
- Enables structuring, cutting, and milling of a wide range of materials



### Fabrication Process followed

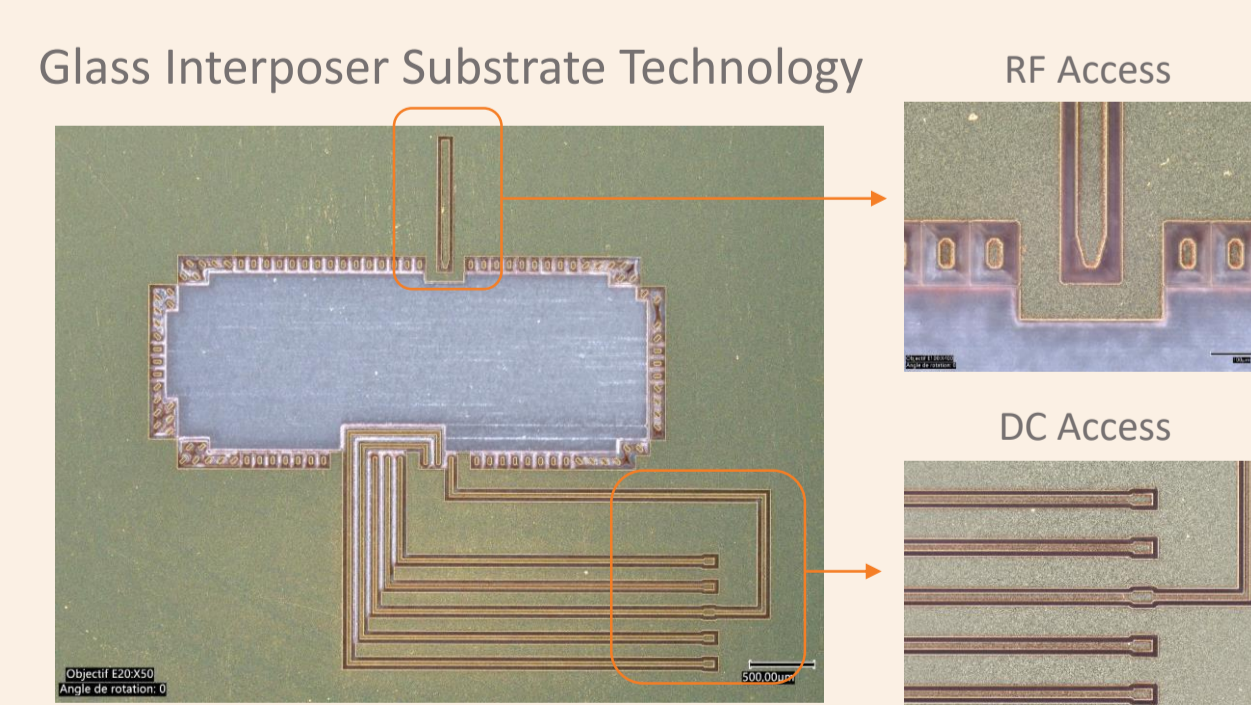


[6] Q.Hivin, Thèse "Laser Microstructuring for advanced electro-optical packaging", 2019

## Glass Interposer & Flip Chip Assembly

An active tunable noise source (NS) was developed in the 140 to 170 GHz (D-band) [7]. The extracted available excess noise ratios ( $ENR_{av}$ ) of the NS were ranged from 0 dB to 37 dB when wafer-level noise measurements were performed in D-band. While the  $ENR_{av}$  values of the packaged NS were limited to 25 dB in the G-band, indicating a loss of ~12 dB in the packaged configuration.

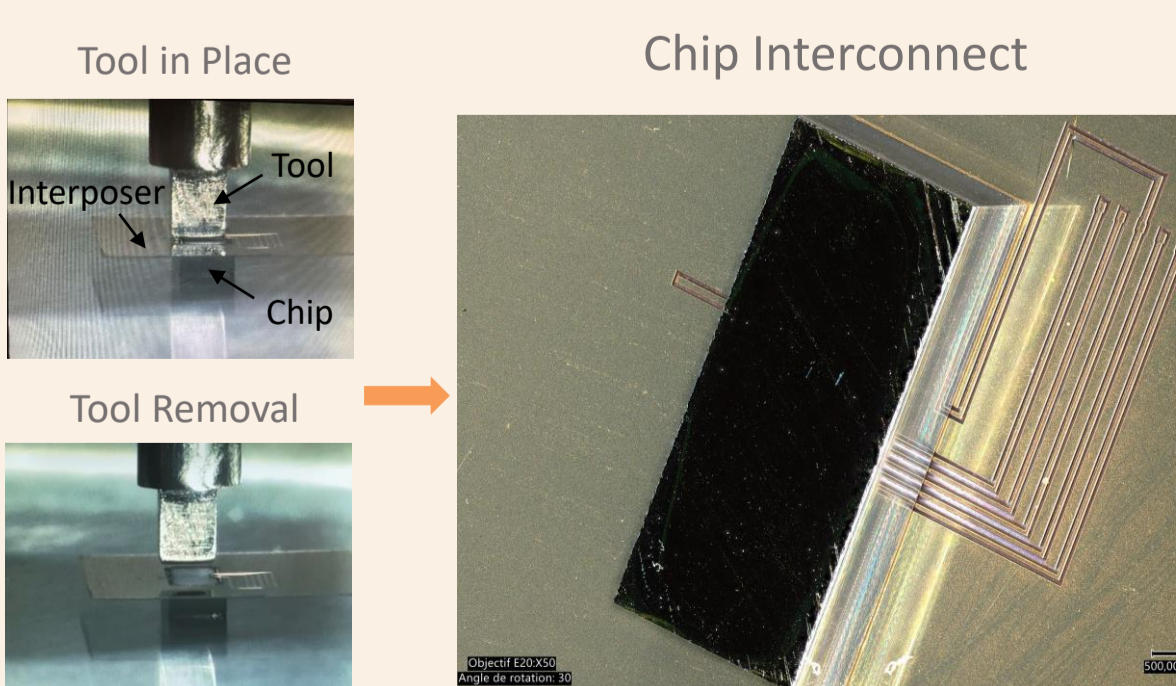
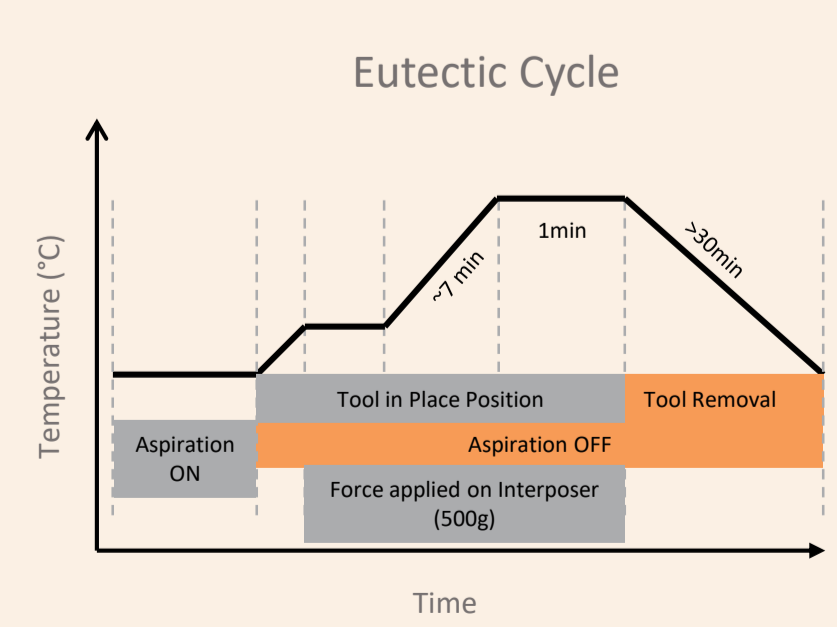
→ A substrate technology based on ultrathin glass AF32 is proposed for identifying the source of losses in the packaged NS. Femtosecond laser micromachining technique is used to pattern the interconnects with the NS chip.



### Flip Chip Assembly

Steps followed using the Pick & Place machine:

- Flipping the interposer upside down
- Aligning the interposer
- Picking up the interposer
- Aligning the chip
- Placing the interposer on the chip



The solder balls composed of Tin and Silver (Sn-Ag) demonstrate a melting point approximately at 220°C [8]. This characteristic initiates the eutectic cycle, encompassing both temperature elevation and compression phases.

[7] V.Fiorese, "A G-Band Packaged Amplified Noise Source Using SiGe BiCMOS 55-nm Technology", 2023  
[8] L. Zhang, et al., "Development of SnAg-based lead free solders in electronics packaging," Microelectron. Reliab., vol. 52, no. 3, pp. 559-578, Mar. 2012

## Conclusion & prospects

This project highlights the design, fabrication, and testing of advanced active probes optimized for measuring silicon components in the G-band.

❖ The main areas of focus include the following aspects:

- The potential of AF32 Glass from SCHOTT as a catalyst for advancing packaging in this domain.
- The two-step approach to RF probe design:

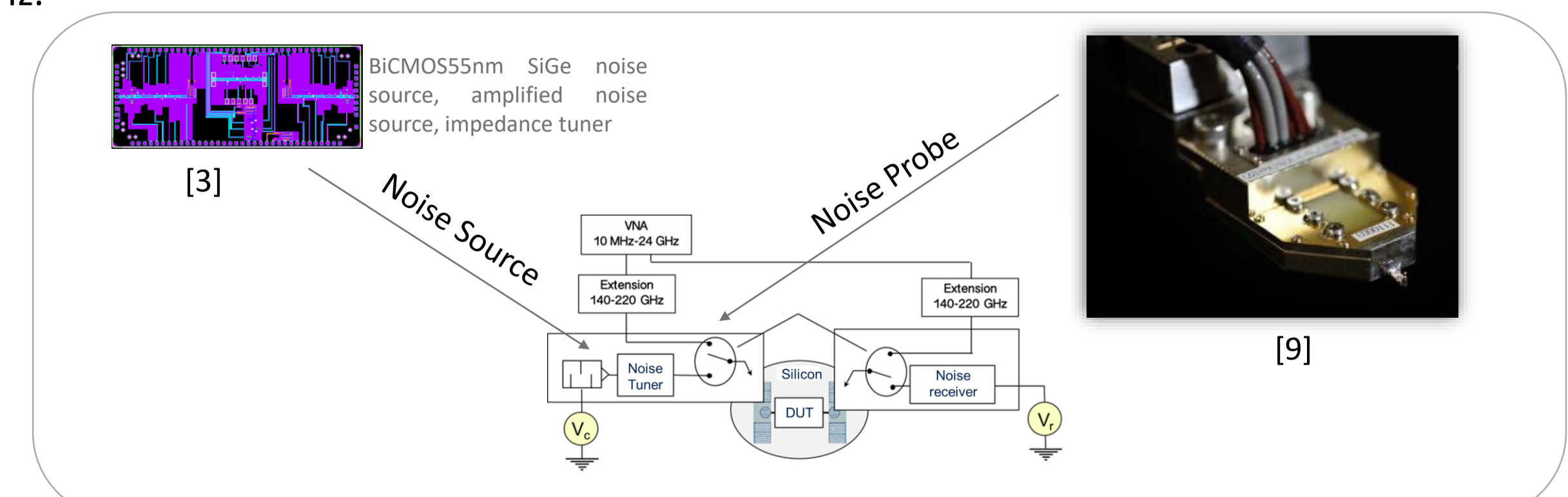
Step 1: The development of GSG probe technology for passive measurements.

Step 2: The integration of an active GSG probe with a noise source.

- Utilizing femtosecond laser ablation to machine various structures.
- Designing and fabricating a glass interposer to identify and address sources of losses within the packaged active noise source.

❖ Future studies will involve:

- Development of an active GSG probe integrated with a noise source.
- Conducting S-parameters and noise measurements for the amplified noise source integrated using the substrate technology outlined in this poster.
- Designing a multi-impedance tuner within the developed package NS, capable of measuring four noise parameters up to 220 GHz.



[9] K. Ohmori et al., "Direct White Noise Characterization of Short-Channel MOSFETs", 2021