TERAmeasure Non-contact millimeter and Terahertz frequency measurement paradigm for instrumentation and sensing applications unlocking metrology-grade results

D2.2: First photonic-based VNA signal source

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Dissemination level		
PU	**Public**	**x**
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Document updates

Version	Date	Author	Organisation	Changes
1.0	30.11.2020	D. de Felipe	FhG-HHI	First vesion
2.0	31.03.2021	D. de Felipe	FhG-HHI	Including information on fabrication process
3.0	24.03.2021	Guillermo Carpintero	UC3M	Revision of document after First Period Review, with inputs from HHI
4.0	30.03.2021	D. de Felipe	FhG-HHI	Additional pictures, and inclusion of targeted performance

Abbreviations

VNA	Vector Network Analyser	**mmW**	Millimetre wave frequency
THz	Terahertz wave frequency	**PIC**	Photonic integrated circuit
Tx	Transmitter	**Rx**	Receiver
MMI	Multimode-interference devices	**TFF**	Thin film filter
GRIN	Graded-index	**DFB**	Distributed feedback laser
PS	Phase shifter	**PD-MO**	Photodiode for power monitoring
PD-TFF	Photodiode after the thin-film filter	**PD-E1**	Photodiode after the first etalon
PD-E1	Photodiode after second etalon	**DBR**	Distributed Bragg reflector laser
CW	Continuous wave	**VOA**	Variable Optical Attenuator

Statement of independence

The work described in this document is genuinely a result of efforts pertaining to the TERAmeasure project. Any external source is properly referenced

Confirmation by Authors:

David de Felipe, Fraunhofer HHI

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Executive Summary

This deliverable reports by means of photographic documentation on the successful fabrication of the first iteration of photonic integrated circuits for the photonic-based vector network analyser (VNA) signal source.

1. Introduction

In this deliverable, the successful fabrication of the photonic integrated circuits for the photonic-based VNA signal is reported in the form of photographic documentation. This device generates the two C-band optical signals that will be used for the photonic generation and detection of THz signals at the optoelectronic mmW/ THz transceiver chip. Additionally, this device allows for the on-chip read-out of the wavelengths of the generated optical signals, which enables extracting the frequency of the generated mmW/THz signal.

The Photonic Integrated Circuit (PIC) is be based on Fraunhofer HHI's hybrid photonic integration platform, namely PolyBoard [1-3]. The PolyBoard technology allows integrating the following features in one device: passive photonic structures such as multimode-interference devices (MMIs), arrayed waveguide gratings (AWGs), and gratings; thin-film filters (TFFs) which can be inserted on the polymer waveguide for compact and efficient wavelength multiplexing; polarization rotators, splitters and combiners; 45° mirrors for coupling towards back-side illuminated photodiodes; highly efficient thermo-optic devices (e.g. variable optical attenuators, switches, and tunable lasers); active components such as gain sections, photodiodes, distributed feedback (DFB) lasers, and modulators, which can be integrated as single elements or as arrays; and etched U-grooves for adjustment-free insertion of optical fibers and graded-index (GRIN) lenses to implement on-chip free-space sections. All those features enable the flexibility and large number of optical functionalities required for the photonic-based VNA signal source.

The schematic of the photonic-based VNA signal source (reported already in D1.4) is shown in Figure 1. On the left-hand side, an InP chip with two active sections bonded on an AlN submount is end-fire coupled to the polymer chip. Those InP active sections are part of the available InP building blocks for the PolyBoard platform. After each active section, the PolyBoard chip comprises thermo-optically tunable phase shifters and Bragg gratings to implement two tunable distributed Bragg reflector (DBR) lasers [4-5].

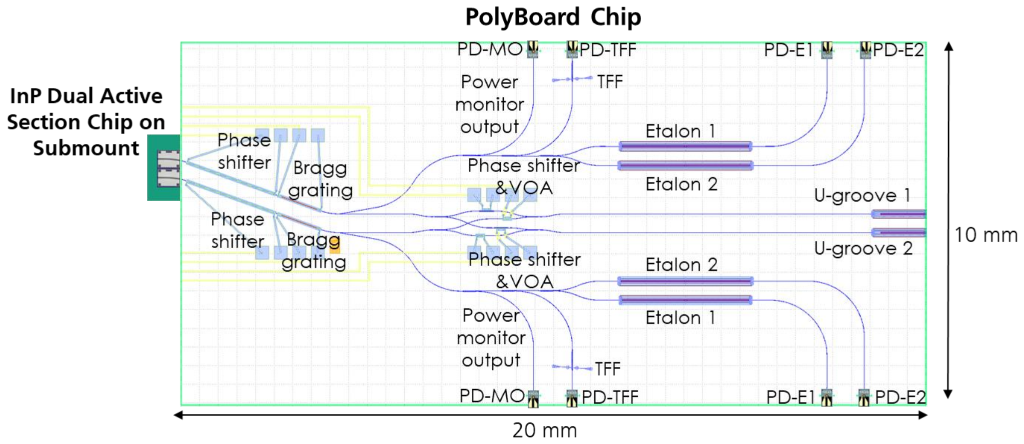

Figure 1. Schematic of the Photonic-based VNA signal source PIC based on Fraunhofer HHI's PolyBoard hybrid photonic integration technology. VOA: Variable optical attenuator; TFF: thin-film filter; PD-MO: photodiode for power monitoring; PD-TFF: photodiode in the thin-film-filter path; PD-E1: photodiode after the Etalon 1; PD-E2: photodiode after the Etalon 2

In the central part of the PIC, thermo-optically tunable phase shifters allow for phase tuning of the generated optical signals. Additionally, variable optical attenuators (VOAs) have been included in order to allow for equalization of the amplitude of the two signals generated by the tunable lasers. Those VOAs are part of the available optical building blocks of the PolyBoard platform [2].

On the right-hand side of the chip, U-grooves are been placed in order to connect the fibres that will launch the signal to the transmitter (Tx) and receiver (Rx) elements of the optoelectronic mmW/ THz transceiver chip.

Finally, the upper and lower parts of the PIC feature the power-monitor photodiode (PD-MO) and the wavelength-meter. The wavelength-meters comprise a slot for the insertion of a TFF which shows a monotonic frequency dependence (those TFFs are part of the available PolyBoard building blocks), and U-grooves for the insertion of GRIN lenses for the implementation of the two etalons.

2. Fabrication process

In the previous section, we have shown the layout of TERAmeasure photonic-based VNA signal source chip, which is fabricated using the PolyBoard platform of the Hybrid PIC group at HHI. This hybrid PIC comprises:

- InP active sections, which are InP building blocks for the PolyBoard platform. In TERAmeasure, an InP chip that includes two active sections will be used. This chip will be mounted on an AlN submount, and edge-coupled to the PolyBoard chip.
- A polymer-based chip from HHI's PolyBoard photonic integration technology, specifically designed for TERAmeasure application. The PolyBoard features a buried-channel type single-mode polymer waveguide with a square core with width w_{core} and height h_{core} of 3.2 µm and a refractive index μ_{core}=1.48, and top

and bottom claddings with refractive index μ_{cladd}=1.45. The polymer material used is the ZPU-12 series from the company ChemOptics.

Both the InP and polymer waveguides are tilted at the coupling interface as an additional mechanism to avoid reflections. The schematic cross section of the active section on submount and the polymer chip are shown in Figure 2 (a) to (c).

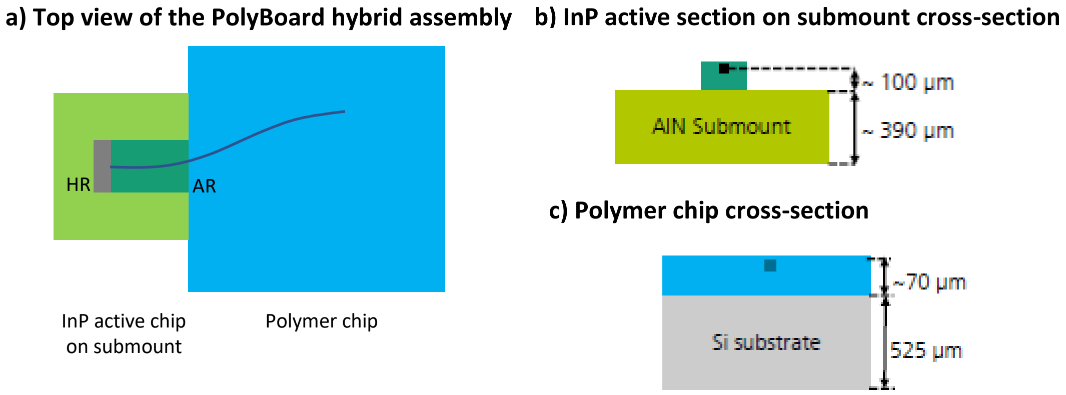

Figure 2. Schematic of Fraunhofer HHI's PolyBoard hybrid photonic integration chip structure [6].

The fabrication process of the polymer waveguides is depicted in Figure 3.

The ZPU-12 cladding material is spin-coated on a 4" Si substrate with a thickness of 525 µm, cured by UV illumination and baked at a temperature of 200 °C.

Following, metal is evaporated on top of the bottom cladding in order to form the micro-heater stack, which is subsequently structured. A second layer of bottom cladding is spin coated and cured, serving as a buffer between the micro-heater and the core of the waveguide.

After that, the core layer is coated, cured and etched using reactive ion etching with oxygen plasma to form the waveguide. Notice that the sidewall corrugations are also lithographically defined at the same step, hence no additional processes are necessary for the fabrication of grating structures. Air trenches are etched on both sides of the thermo-optically tunable waveguide sections for enhanced heat confinement.

In a final step, the 45° mirrors for coupling of backside illuminated photodiodes are diced on a wafer level, and subsequently metallized.

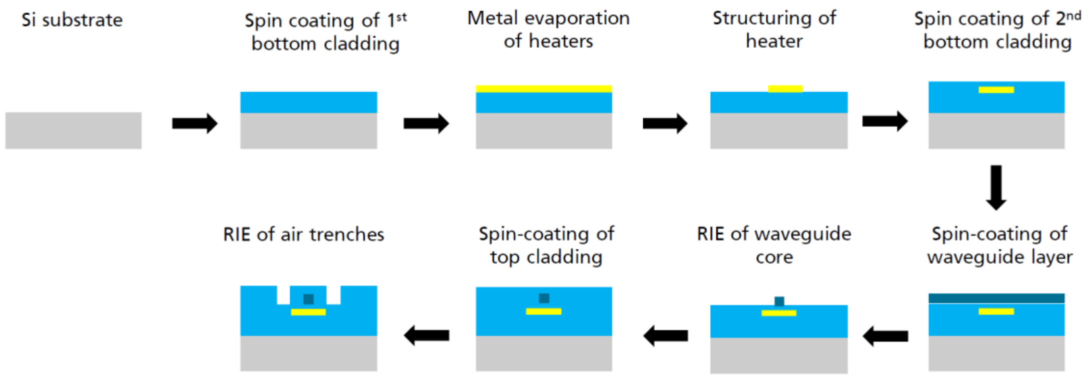

Figure 3. Schematic of Fraunhofer HHI's PolyBoard hybrid photonic integration chip structure [6].

3. Fabricated PolyBoards for the first iteration of the photonic-based VNA signal source

After the fabrication of the mask-sets comprising the designs that resulted from T1.4, the fabrication of the first iteration of PolyBoard-based photonic VNA signal source PIC has been carried out successfully.

An example picture of a fabricated PolyBoard chip is shown in Figure 4. The different features of the PolyBoard chip, namely waveguides, heater electrodes, grooves for etalons and U-grooves, and slots for the TFFs, have been successfully resolved in all chips fabricated in this first run.

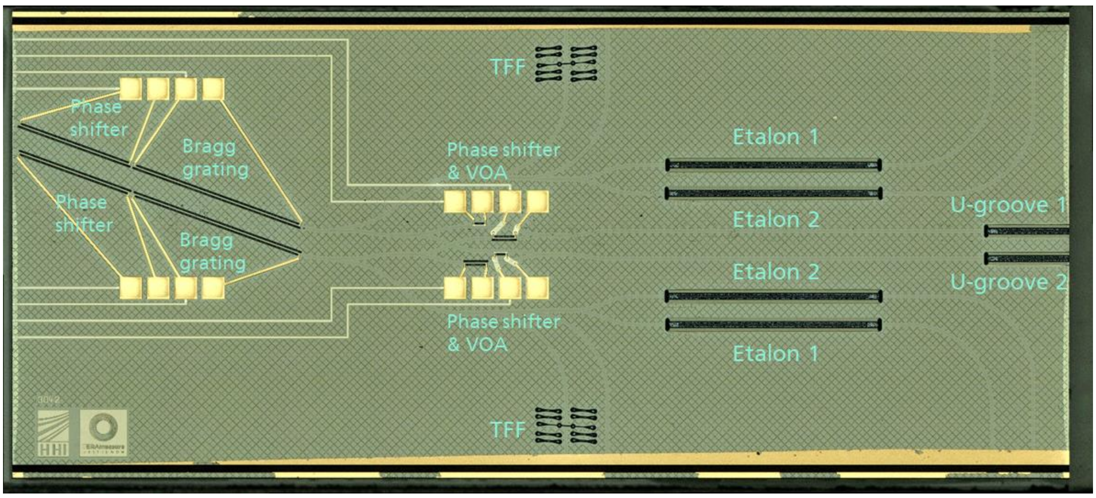

Figure 4. Picture of the fabricated PolyBoard chip for the photonic-based VNA signal source PIC. VOA: Variable optical attenuator; TFF: thin-film filter.

In Figure 5 (left), a detailed picture of the phase and Bragg sections of the tunable laser is shown. The electrodes for the thermo-optical tuning and the air trenches for efficient heating can be seen to be adequately resolved, and without discontinuities. In Figure 5 (right), the section of the PIC that combines both tunable lasers and implements phase shifters and VOAs is shown in detail. As with the tunable laser sections, it can be seen that the electrodes and air trenches have been adequately structured.

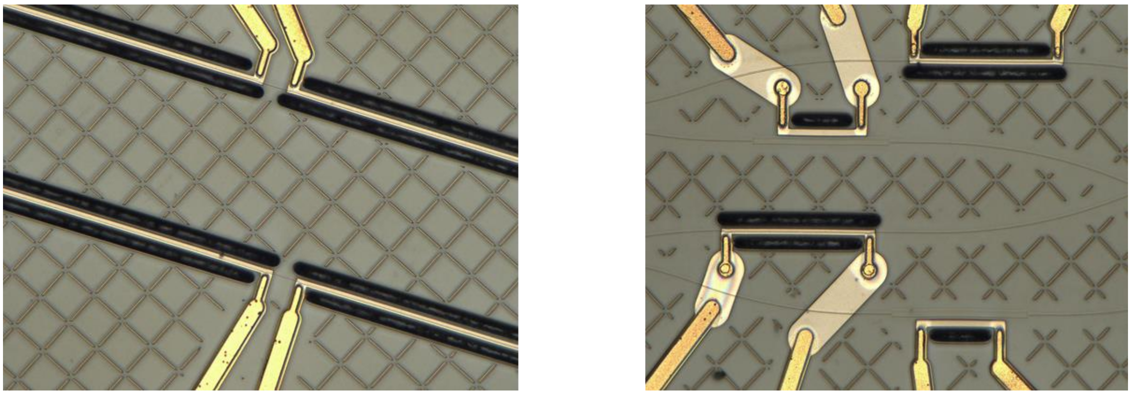

Figure 5. (Left) Picture of the phase shifter and Bragg grating sections of two tunable lasers. (Right) Detailed picture of the central PIC section that combines the two tunable lasers and comprises phase shifters and variable optical attenuators.

A final key part for the PIC are the 45° mirrors, which allow coupling the planar photodiodes that are required for the wavelength-meter. These mirrors are micro-machined with a dicing blade, and subsequently metallized. In Figure 6, a side-view of the mirror in the PolyBoard is shown, where it can be observed that the structuring has been carried out successfully.

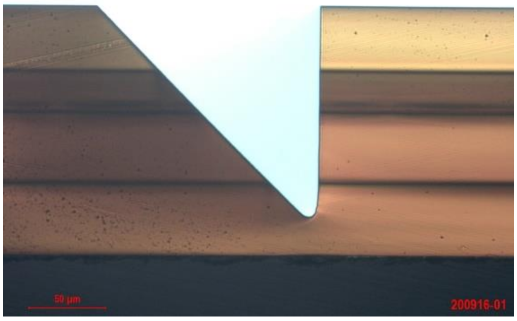

Figure 6. Side-view of the diced 45° mirrors for the coupling of the backside illuminated PDs required to implement the on-chip wavelength meters.

4. Conclusions and next steps

The pictures of the PolyBoard chips for the 1st generation of photonic-based VNA signal sources show that the device fabrication has been successful. Currently, the hybrid assembly of InP active sections, photodiodes, TFFs and GRIN lenses is taking place, and will be followed by the PIC characterisation. The results will be reported in D1.5 (due in month 22). The key targeted specifications of this first run are: (a) a PIC output power ex-fiber per laser of 7 dBm, (b) a continuous tuning range per laser of 12 nm (1.5 THz in the C-band), and (c) a resolution of 1-GHz for the wavelength meters.

References

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