Marie Skłodowska-Curie (MSCA) – Innovative Training Networks (ITN)
H2020-MSCA-ITN European Training Networks

Wideband Optical Networks

Wideband Optical Networks [WON]

Grant agreement ID: 814276

WP4 – Transceiver components design

Deliverable D4.4 Wideband laser source

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement 814276.

Document Details

Work Package	WP4 – Transceiver components design
Deliverable number	D4.4
Deliverable Title	Wideband Laser Source
Lead Beneficiary:	UG
Deliverable due date:	30 April 2022
Actual delivery date:	6 May 2022
Dissemination level:	Public

Project Details

Project Acronym	WON
Project Title	Wideband Optical Networks
Call Identifier	H2020-MSCA-2018 Innovative Training Networks
Coordinated by	Aston University, UK
Start of the Project	1 January 2019
Project Duration	48 months
WON website:	https://won.astonphotonics.uk/
CORDIS Link	https://cordis.europa.eu/project/rcn/218205/en

WON Consortium and Acronyms

Consortium member	**Legal Entity Short Name**
Aston University	Aston
Danmarks Tekniske Universitet	DTU
VPIphotonics GmbH	VPI
Infinera Portugal	INF PT
Fraunhofer HHI	HHI
Politecnico di Torino	POLITO
Technische Universiteit Eidhoven	TUE
Universiteit Gent	UG
Keysight Technologies	Keysight
Finisar Germany GmnH	Finisar
Orange SA	Orange
Technische Universitaet Berlin	TUB
Instituto Superior Tecnico, University of Lisboa	IST

Abbreviations

BHF:	Buffered hydrofluoric acid
BOX:	Buried Oxide Layer
DVS-BCB:	Divinylsiloxane-bisbenzocyclobutene
FSR:	Free spectral range
GC:	Grating coupler
IMEC:	Interuniversity Microelectronics Centre
OSA:	Optical Spectrum Analyser
PICs:	Photonic integrated circuits
RIE:	Reactive Ion Etching
SiPh:	Silicon Photonics
SMF:	Single-mode fiber
SOA:	Semiconductor optical amplifier
SOI:	Silicon on insulator
UG:	University of Ghent
WTL:	Widely tunable laser

LIST OF FIGURES

CONTENTS

EXECUTIVE SUMMARY

The present scientific deliverable is a part of the Work Package 4 “Transceiver components design” of the ETN project WON “Wideband Optical Network”, funded under the Horizon 2020 Marie Sklodowska-Curie scheme Grant Agreement 814276.

In this document we demonstrate for the first time a narrow-linewidth widely tunable III-V-on-Si laser with 110nm tunablity realized using micro-transfer printing technology. This work is based on the integration of pre-fabricated III-V SOAs onto IMEC’s SiPh platform using UGent’s micro-transfer-printing technology. The design, fabrication and characterization of the III-V/Si lasers are discussed.

1. Introduction

By leveraging the CMOS fabrication infrastructure, silicon photonics (SiPh) enables the realization of photonic integrated circuits (PICs) on 200 mm or 300 mm Silicon-on-Insulator (SOI) wafers with high yield and uniformity. III-V semiconductors have been introduced to SiPh as Si does not provide optical gain, enabling the realization of complex PICs for a wide range of applications, such as optical communication. Various heterogeneous III-V-on-Si integration methods have been intensively investigated in the past, such as die-to-wafer bonding, flip-chip integration, and even hetero-epitaxial growth. However, these methods suffer from drawbacks like a dedicated III-V process flow and modified back-end process on 200 mm wafers in the case of bonding, limited throughput for the flip-chip method and inferior III-V material quality for hetero-epitaxial growth. Here, we use micro-transfer-printing (µTP) [1] for the realization of a narrow-linewidth III-V-on-Si widely tunable laser (WTL) with 110 nm tunability. The technique allows for densely integrating different non-native components on a silicon photonics platform with minimal disruption to the SiPh process flow in a high-throughput manner while not requiring the singulation and handling of individual III-V chips.

2. Design

The 100nm tuning range widely-tunable laser is realized by combining the output of two laser cavities in a single mode waveguide. Each laser is based on an SOA with a different gain peak wavelength (1525nm and 1575nm), providing around 45 nm of tunability as discussed before in WP4-MS15. The individual devices are formed by a linear cavity, shown in Figure 1. The cavity consists of a tunable Sagnac loop mirror, to optimize the out-coupling mirror reflectivity, a recess to print the pre-fabricated SOA, a phase section based on thermo-optic tuning, a pair of thermally tunable micro-ring resonators with a slightly different radius (27µm and 29.3µm) to form a Vernier filter to provide wavelength selection, and a grating coupler (GC) as the output of the laser. The free spectral range (FSR) of each ring is around 4nm and the combined FSR of the Vernier filter is around 45nm. The length of the III-V SOA fabricated by III-V Lab is 1mm, including a pair of 180µm long adiabatic tapers for efficient coupling between the III-V SOA and the underlying Si-waveguide. An additional pair of adiabatic 50µm long Si tapers is used to couple the optical mode between the 3µm wide Si-waveguide underneath the III-V SOA and the single-mode rib waveguide. The design and fabrication of the III-V SOAs is similar to what is described in detail in [2]. The PICs are fabricated in IMEC’s SiPh pilot line on 200mm

SOI wafers with a 400nm thick silicon device layer and a 2µm thick buried oxide layer (BOX), including a back-end stack incorporating the heaters and metal tracks, as shown schematically in Figure 2.

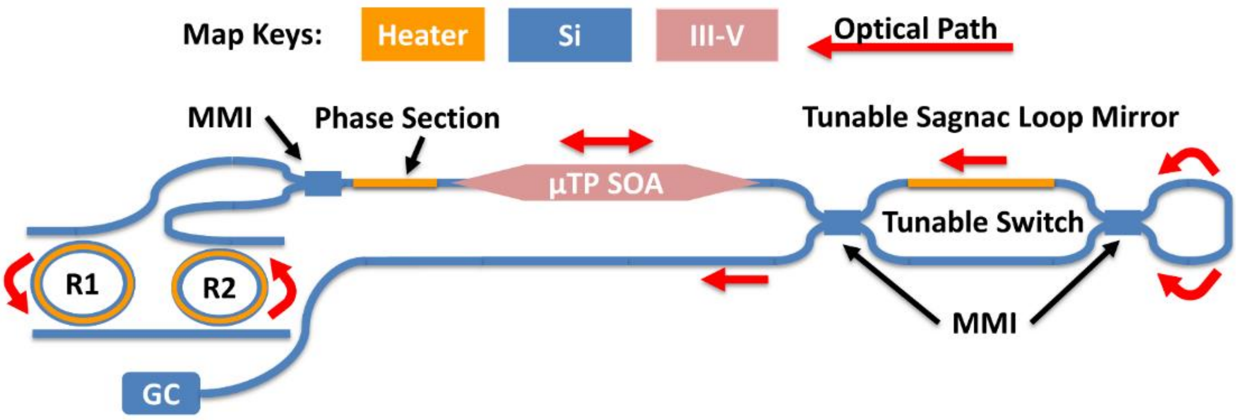

Figure 1: Schematic layout of the laser cavity design of the individual tunable lasers.

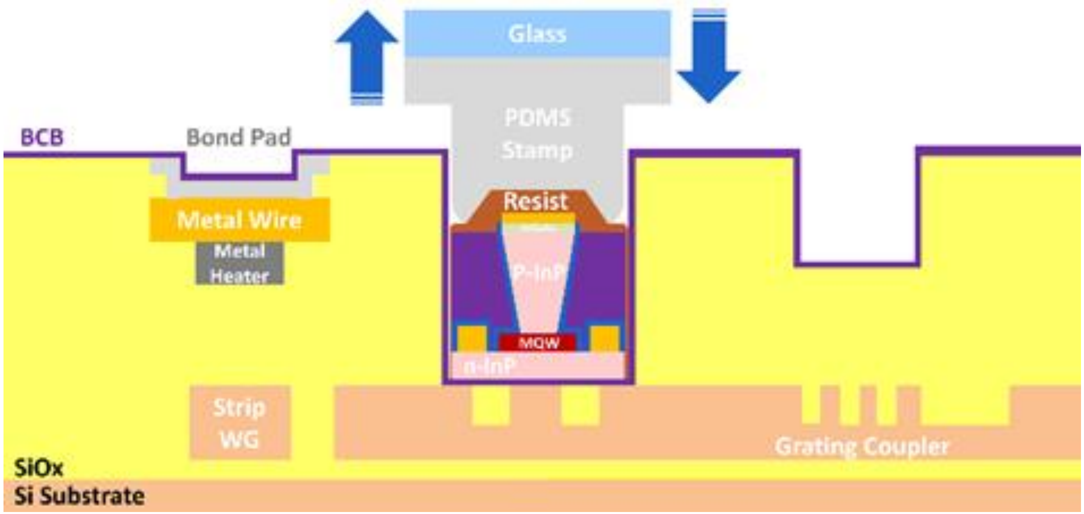

Figure 2: Schematic of µTP of a pre-fabricated III-V SOA on imec's 400nm SOI platform (not-to-scale)

2. Fabrication

The mask layout of the SiPh chip with the post-printing metallization is shown in Figure 3. Prior to the µTP a combination of dry-etch (by RIE) and wet-etch (by BHF) was firstly applied to the SiPh chip to remove the back-end stack containing 2µm of oxide on the Si-waveguide, to form the recess where the InP-based SOA will be integrated. The locally opened recess is slightly longer and wider than the pre-fabricated III-V SOA. The etching process is illustrated in Figure 4. Using ~45min of SF6-CF4-H2 reactive ion etching made it possible to stop exactly above the Si waveguide. The process completed by immersing the structures for about 1 minute in buffered-HF, where full etching of the oxide layer resulted in exposing the Si-waveguides.

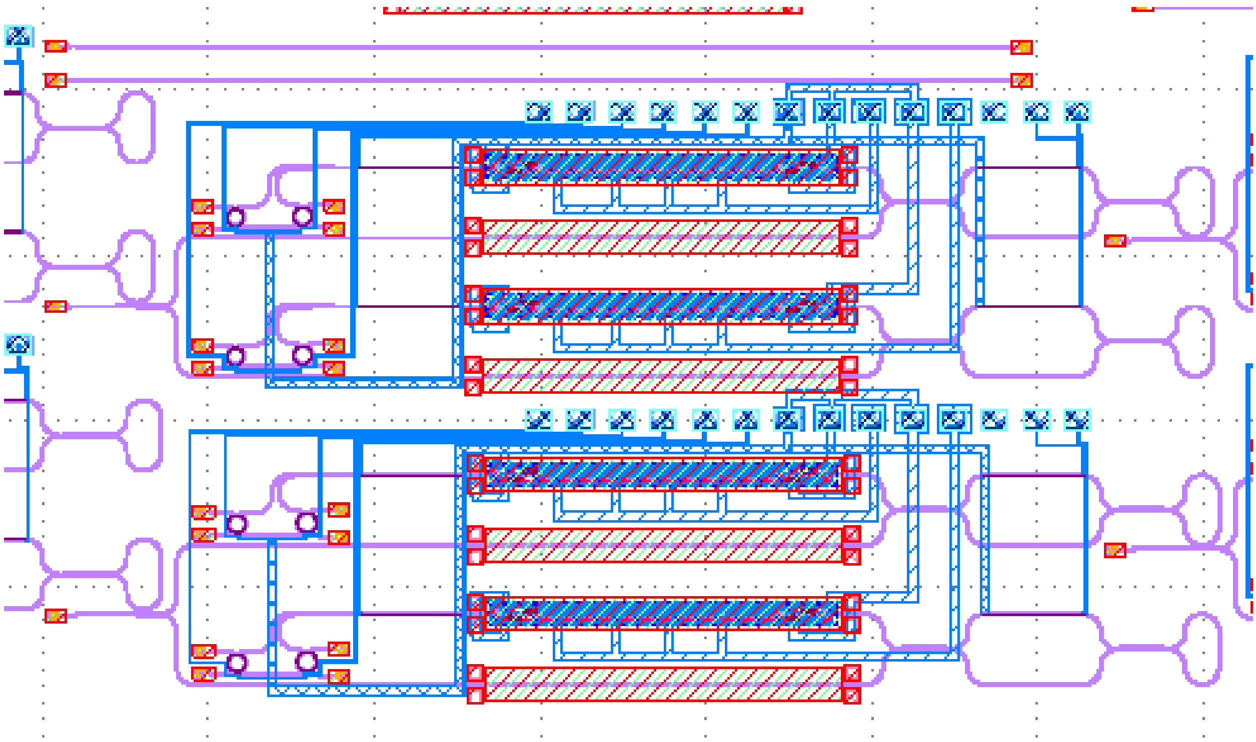

Figure 3: Mask layout of the widely tunable lasers with final metalization

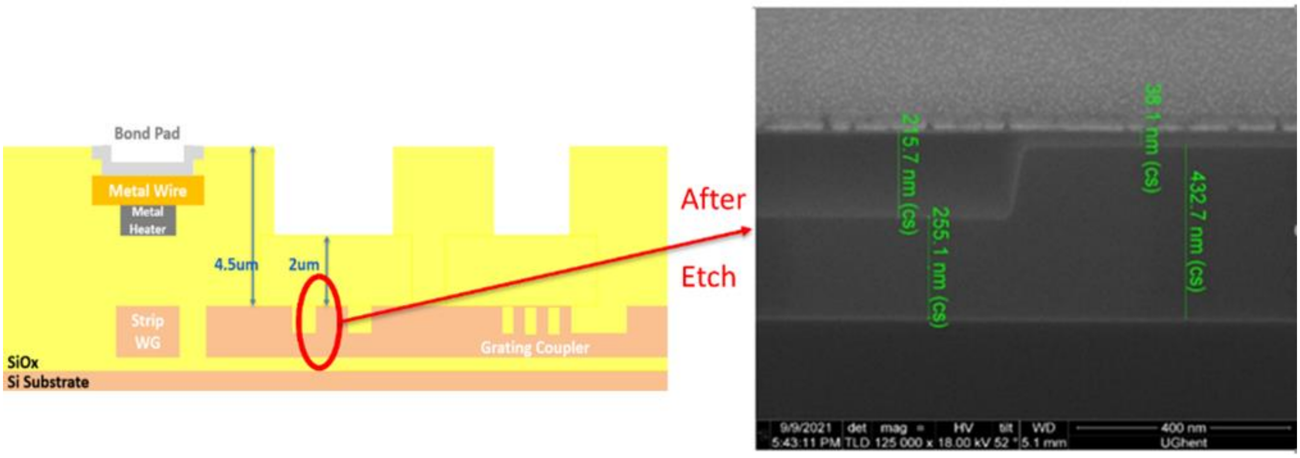

Figure 4: Schematics of the IMEC's SiPh platform cross section with the integrated metal layers and back-end stack (left) and the focused ion beam cross-section after completing the silicon oxide plasma etching (right)

Next, a thin divinylsiloxane-bisbenzocyclobutene (DVS-BCB) adhesive layer with a thickness of 100nm was spray-coated to enhance the bonding strength between the III-V SOA and the underlying Si-waveguide, followed by a short soft bake at 110℃. During the spray-coating DVS-BCB will build up at the edges of the cavity allowing the metallization to run over the sidewall of the trench, which here is about 4.5µm (see Figure 4). A short soft bake of the spray-coated sample at 150℃ was done before the µTP. µTP of III-V SOAs was done by using a X-Celeprint µTP-100 lab-scale printer onto selected silicon cavities, containing combined widely tunable lasers with 300nm ring gaps as schematically illustrated in Figure 2, followed by an oxygen-plasma etch to remove the photoresist encapsulation on the III-V SOA. The post-processing finishes by electrically connecting the printed coupons to the silicon photonics back end using 1µm of Au. Figure 5 shows a microscope image of two fabricated lasers with the two transfer-printed SOAs, both combined in a single output waveguide using a 3dB combiner. The SOA printed on the first laser (Laser 1) has a gain peak around 1575nm and the other one around 1525nm (Laser 2).

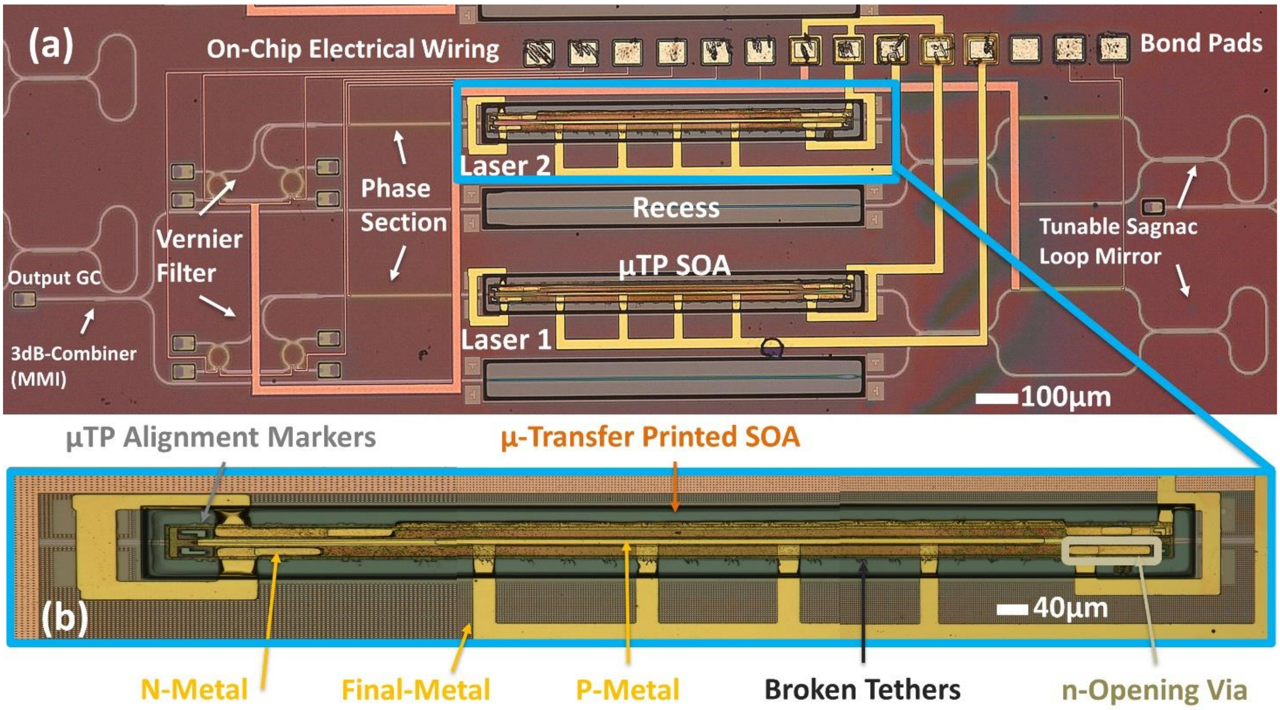

Figure 5: a) Microscope image of the combined widely tunable laser. (b) micro-transfer-printed III-V amplifier in the recess (after final metallization)

3. Characterization

The schematic layout of the setup, shown in Figure 6 is used for laser characterization to discover the power level and tunability range of the fabricated combined laser. The laser under test is placed on a temperature-controlled stage stabilized at 15℃. The output of the laser is coupled to a single-mode fiber (SMF), which is connected to a 90/10% optical power-splitter. The 10% branch of the splitter is connected to an optical power-meter and the 90% branch to an optical spectrum analyser (OSA). The heaters and the gain section of each individual laser are biased with electrical probes. Figure 7 shows an image with a close look on the measurement setup.

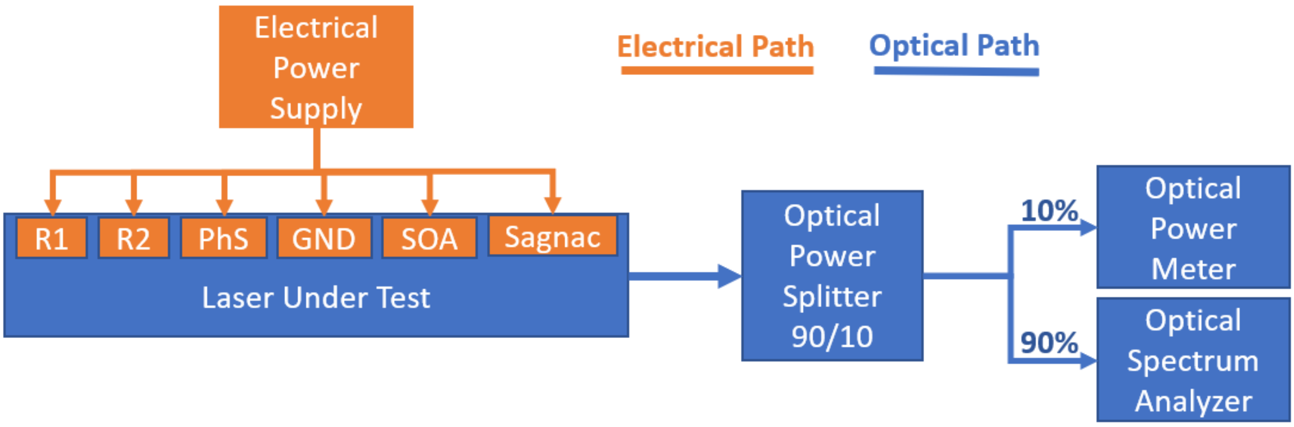

Figure 6: Schematic layout of the laser characterization setup

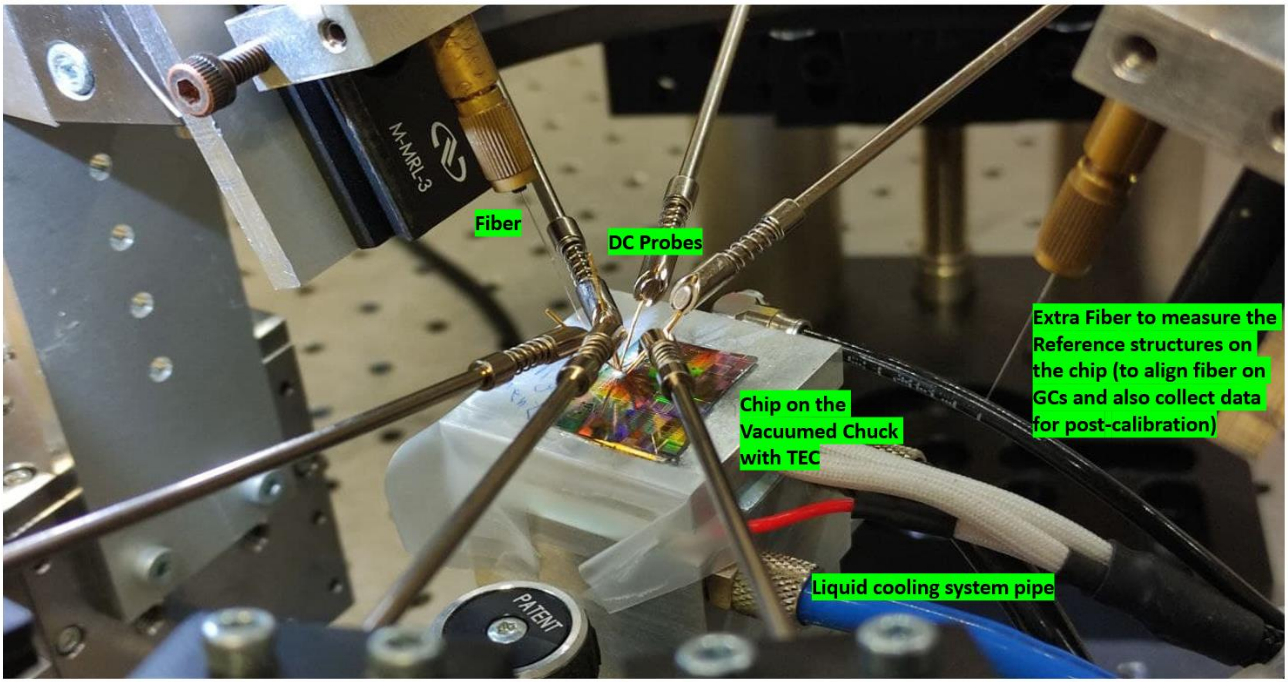

Figure 7: Image of the micro-transfer printed III-V-on-Si laser on the IMEC's SiPh 400nm platform under test

The threshold current of both the lasers (Laser1 and Laser2) is around 60 mA and differential resistance of both the lasers' SOAs is about 10 Ω while biased at 120 mA. Discrete wavelength tuning of 110 nm and fine tuning in a range of 4 nm with steps of 100 pm is shown Figure 8 in Discrete-tuning is achieved by thermally tuning one of the micro-rings and phase section of each laser while fine-tuning is achieved by thermally tuning both the micro-rings and the phase section of each laser, simultaneously.

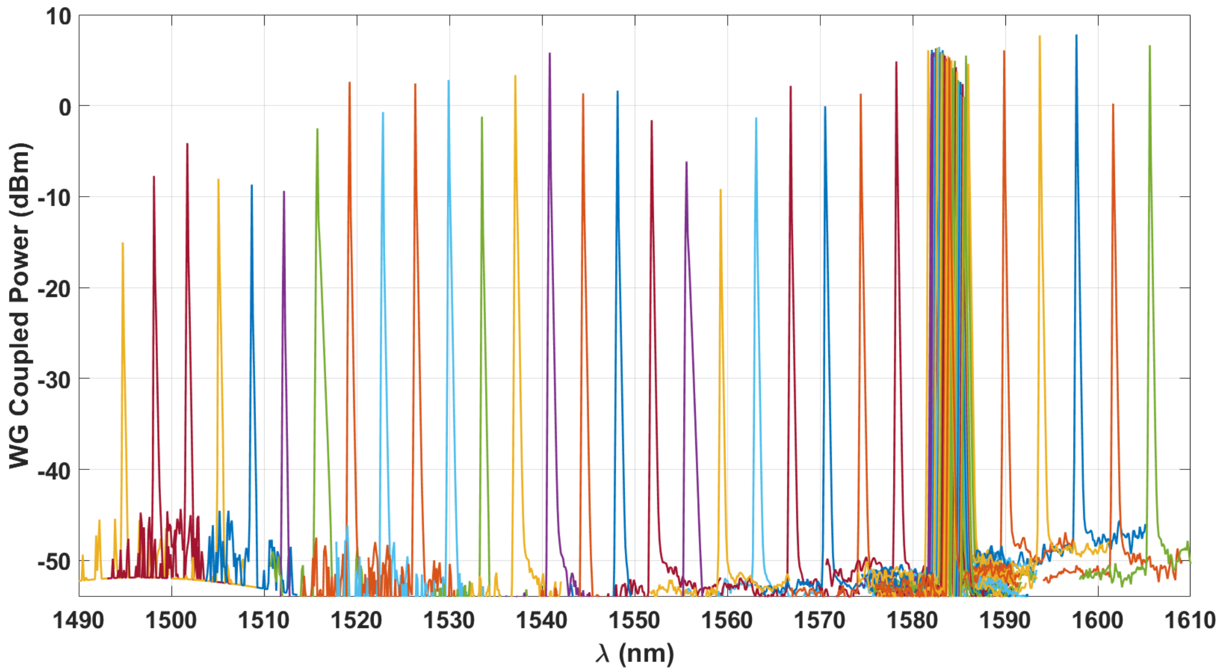

Figure 8: Wavelength tuning behavior of the combined widely tunable laser (Fine-tuning is done in the steps of 100 pm over a 4 nm range)

By replacing the OSA in Figure 6 with an OEwaves-OE4000 Optical Phase Noise Test System, the laser's frequency noise power spectral density, shown in Figure 9, biased at 120 mA, is measured while the lasing wavelength is 1530 nm. The Lorentzian linewidth corresponding to the shown frequency noise spectrum is about 20 kHz. Linewidth variations are observed over the combined laser tuning range, but the frequency noise spectrum consistently remains below the linewidth threshold mask provided by OIF-400-ZR [3].

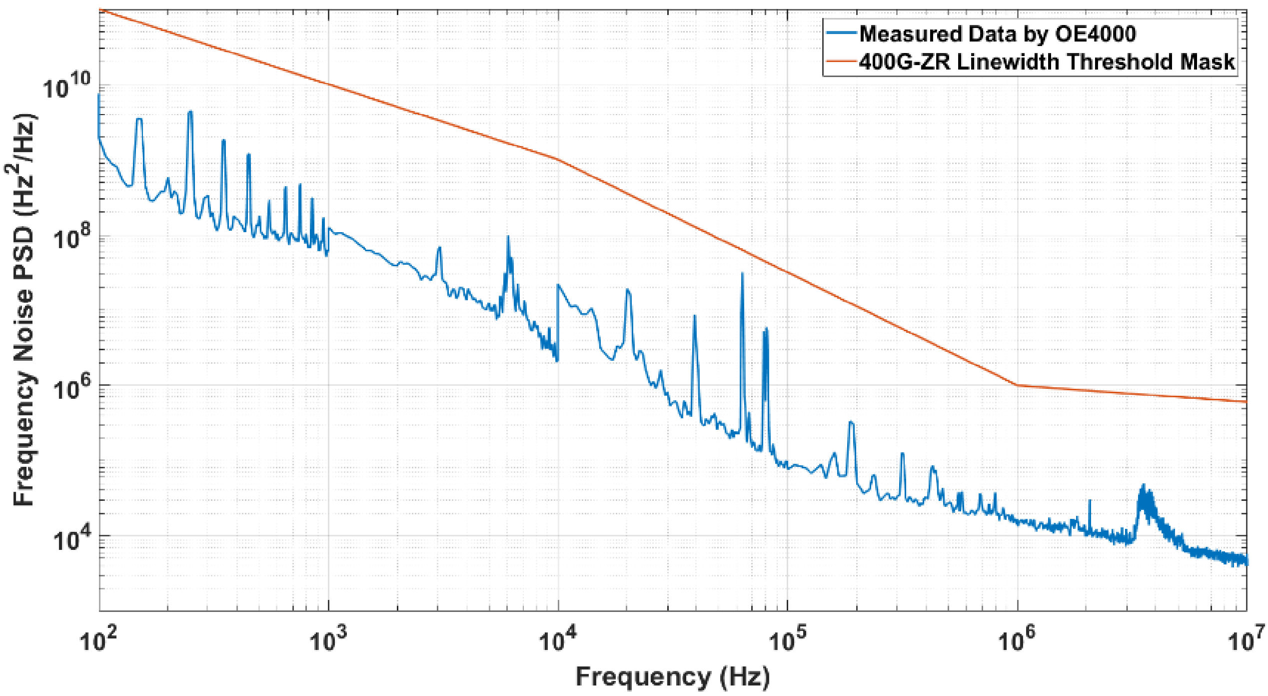

Figure 9: Frequency-noise power spectral density of the widely tunable laser characterized by OE4000 Optical Phase Noise Test System

4. Conclusions

In this deliverable, we presented for the first time, a narrow-linewidth (< 500kHz) III-V-on-Si laser with 110 nm tuning range by micro-transfer printing pre-fabricated InP-based SOAs on a SiPh platform. By increasing the operating temperature (thereby red-shifting the gain spectra) we expect to cover the entire C+L-band. Output power needs to be further increased by adding booster SOAs.

ESR14 will continue the work with an extended PhD grant for the 4th year to meet the extra requirements of OIF-400-ZR [3]: a laser output power level higher than 10 dBm (by integrating a high saturation power SOA) and laser frequency accuracy of ±1.8 GHz (by integrating a wavelength locker system to the laser's output).

5. REFERENCES

[1] J. Zhang et al., "III-V-on-Si Photonic Integrated Circuits Realized Using Micro-Transfer-Printing", APL Photonics (invited), vol. 4, pp. 110803-1108013, 2019

[2] B. Haq et al., "Micro-Transfer-Printed III-V-on-Silicon C-Band Semiconductor Optical Amplifiers", Lasers & Photonics Reviews, vol. 14, 1900364, 2020

[3] https://www.oiforum.com/wp-content/uploads/OIF-400ZR-01.0_reduced2.pdf