# Towards passive hybridization of high-power and high-speed InP transmitters

*(Invited paper)*

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**We present a versatile InP technology, applied for lasers, laser-modulators and semiconductor optical amplifiers, particularly adapted for hybrid integration with silicon photonics. In particular we show examples of passive hybridization of high power lasers for silicon photonics modulators, 100Gb/s PAM4 laser-modulators with fiber for datacom, and reflective SOAs in tunable external cavity lasers.**
***Keywords***: *photonic integration, hybridisation, semiconductor lasers*

## INTRODUCTION

In order to face the permanent increase of optical data rates and the reduction of transmitter costs, photonic integration has been the focus of many researchers, either by monolithic integration on InP [1], or by hybrid integration with the active material in InP and other passive optic functionalities integrated in Silicon (SiPho) with waveguides constructed in different materials such as Silicon, SiN, SiO2, Thin film LiNbO3 etc. The hybrid integration approach benefits from low propagation losses, and utilizes a mature and low-cost technology platform compatible with electronics. Moreover, the hybrid integration approach is particularly adapted for wafer scale integration, and for transmitters with intensity and phase modulation.

Different integration techniques have been developed in recent years:
- Micro-packaging using 3D-printing directly on the components to transform and guide the optical mode between InP and SiPho platform [2, 3].
- Hybridization that butt-joints the InP chip in front of SiPho waveguides with precise alignment. Transfer printing with automatic InP chip placement is an emerging approach aiming at industrial quasi-automatic hybridization [4].
- Heterogeneous integration that positions InP material directly onto SiPho waveguides before final processing, the optical wave propagating locally in the InP gain region by evanescent coupling. This technologically complex approach, which requires a very specific process, has been the subject of numerous works over the last twenty years, and has finally led to excellent performances [5]. The direct epitaxy of InP on Si is also a promising way [6].

In this paper, we present our InP technology based on Semi-Insulating Buried Heterostructure waveguide (SIBH) which allows to reach excellent performances for several types of devices, and is particularly adapted to the hybridization method with SiPho.

## InP TECHNOLOGY OPTIMUM FOR HYBRIDIZATION

Our SIBH technology, the result of many years of research and optimizations, presented in detail in [7], allows us to develop various optical components mainly for telecom applications: Distributed FeedBack (DFB) lasers, possibly integrated with electro-absorption modulators (DFB-EAM), as well as Semiconductor Optical Amplifiers (SOAs). After etching the waveguide, it is buried into semi-insulating iron-doped InP by selective Metal-Organic Vapor Phase Epitaxy (MOVPE), then the SiO2 mask is removed, and the structure is buried again by p-doped InP. A lateral H+ proton implantation allows to limit the diode capacitance, and possibly to electrically separate the different sections (fig.1a). This technology, a little more complex than the ridge waveguide, brings many advantages such as excellent thermal dissipation and mechanical robustness. But most important for hybridization, the optical mode is quasi-circular. And by a simple reduction of the waveguide width, it can be progressively enlarged for an optimal and tolerant optical coupling, reaching for example, with a waveguide at 0.35µm, a $1/e^2$ mode diameter of 3.4µm x 4.5µm (divergence of 17° x 11°) as illustrated fig.1b.

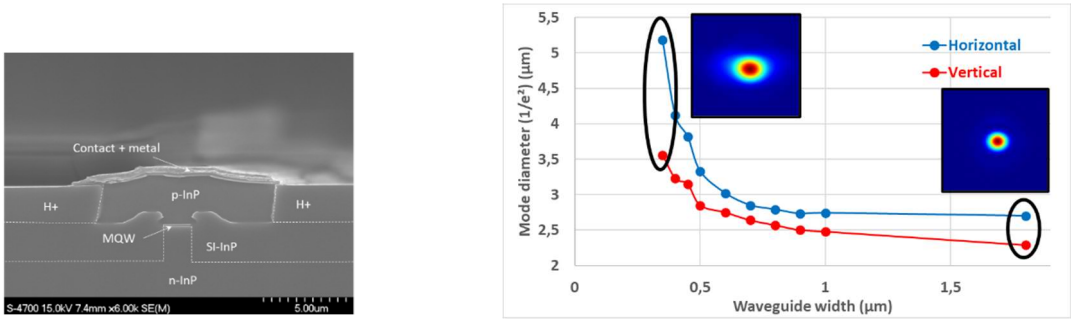



*Fig. 1: (a) SEM photography of a SIBH waveguide at facet, (b) experimental measurements of 1/e² mode diameters versus waveguide width ( near field profiles in insert for 0.35µm and 1.8µm waveguide widths)*

Moreover, Almae Technologies has the specificity to use both MOVPE epitaxy for selective SI-InP growth, but also Gas Source Molecular Beam Epitaxy (GSMBE) for all other growths, thus combining the advantages of the two techniques. The multi-quantum well structures, for example, are grown by GSMBE, and integrated by butt-joint to optimize independently the different sections. And the p-InP regrowths in GSMBE use the Beryllium p-dopant rather than the Zinc p-dopant of MOVPE. Since Beryllium diffuses much less than Zinc, this avoids any risk of electrical leakage through the SI-InP, and allows to efficiently and homogeneously apply the electric field in the electro-absorption modulators, leading to very steep extinction curves and reduced the modulation voltage swing Vpp.

Finally, we use an e-beam technology for the definition of Bragg gratings of the DFBs, allowing a perfect control of emission wavelength, and the possibility of realizing DWDM transmitter arrays [8].

This technological mastery has allowed us to develop a wide range of components, and to develop hybrid InP / SiPho subsystems in the framework of partnerships, with a co-design of the InP chip and the SiPho platform.

## HYBRIDISATION OF INP DEVICES ON SIPHO PLATFORMS

**High-power DFBs:** we have developed high power DFBs lasers, in O-band (25 to 85°C) and C-band, either as power source for coherent SiPho modulators or for LIDAR applications (fig 2a). We are developing with POET Technologies a visually assisted passive assembly with an interposer including SiN guides (figure 2b). The simultaneous optimization of mode converters in the InP laser and in the SiN guides allows an excellent mode overlap, alignment tolerance compatible for passive alignment, reaching coupling rates around 1dB.

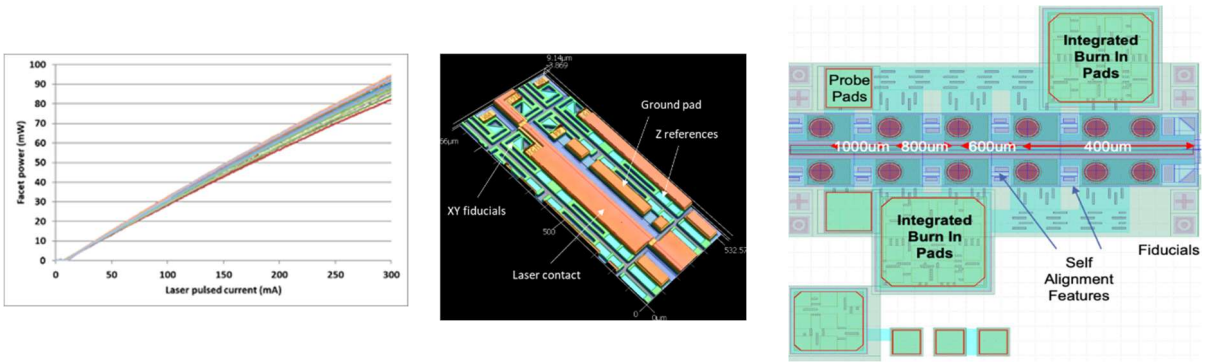
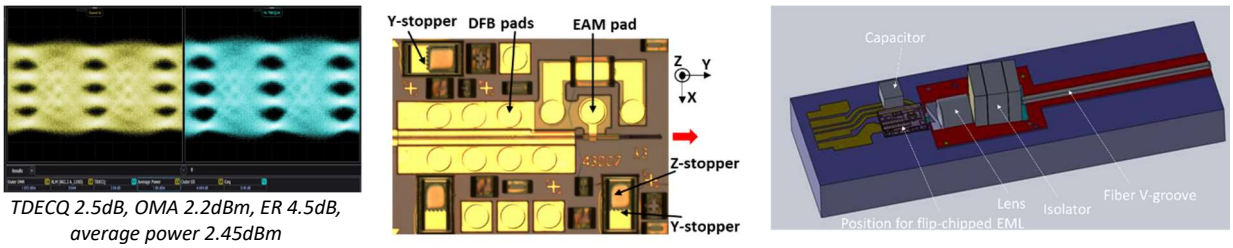



*Fig.2: (a) facet power versus pulsed laser current of high-power C-band DFB lasers at 25°C, (b) 3D photography of DFB laser with mechanical fiducials, (c) scheme of the SiPho interposer for coupling into SiN waveguides and SiPho coherent modulators.*

**400Gb ethernet transmitter for datacom:** within European ECSEL project APPLAUSE, we aim to demonstrate a low-cost industrial assembly solution for 400Gb Ethernet, using our uncooled (20-70°C) 100Gb/s PAM4 DFB-EAMs in O-band (fig.3a). The chip implements a metallization compatible for flip-chip, Z stoppers aligned with the quantum wells, and X-Y stoppers defined at the same time as the waveguide (fig.3b). The Silicon submount developed by IZM Fraunhofer includes AuSn bumps for flip-chip and HF lines for high-speed EAM driving. Plus, trenches for a lens and isolator, and a V-groove for a fiber are defined at the same stage as stoppers in X, Y and Z, that will face those of the InP chip (fig.3c). During the flip-chip, the InP chip is automatically translated during soldering by capillarity, until the InP chip and SiPho stoppers come to stall together. The InP waveguide, lens, isolator and fiber in the V-groove are then automatically self-aligned.




*TDECQ 2.5dB, OMA 2.2dBm, ER 4.5dB, average power 2.45dBm*

*Fig. 3: (a) DR4 module experimental results at 100Gb/s (53GBaud PAM4) at 60°C, (b) photography of DFB-EAM for self-alignment, (c) scheme of the SiPho submount with HF lines, lens, isolator and V-groove*

**External cavity tunable laser:** we also develop SOAs or reflective SOAs which integrate under the quantum wells a sole material with a slightly higher index, allowing to reduce losses, increase saturation power and obtain an ultra-wide optical mode. These RSOAs, are particularly suitable for tunable lasers with external cavity by butt-joint coupling with a tunable passive filter in SiPho [9], or as boosters at the exit of photonic circuit.

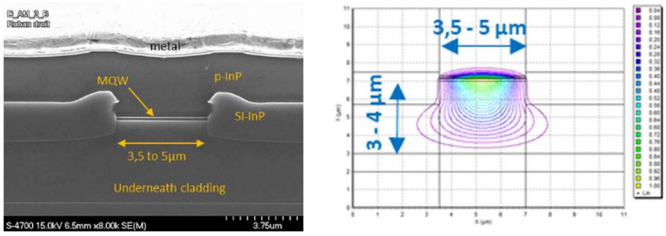



*Fig. 4: (a) SEM photography of an SOA facet with broad waveguide and underneath layer, (b) simulated ultra-broad optical mode*

## CONCLUSION AND PERSPECTIVES

The integration of InP and SiPho platforms seems to be the key solution for many applications. Heterogeneous integration now provides excellent performance, and is reaching sufficient maturity to become open source, which suggests significant developments in the coming years. But this requires complex and specific technology, very large investments, and only few actors can master it. Therefore it seems essential to us to develop hybridization in parallel because it is a flexible approach, which allows an independent optimization of the different components. It provides economic autonomy with a multiplicity of possible collaborations, and the rapid implementation of new components.

We have developed a SIBH technology particularly suitable for hybridization, and are studying different approaches (passive alignment with fiducials or self-alignment). The key factor for success will be performance, but also industrialization with the possibility of achieving large quantities, automation, yields, costs.

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