Photonics FOR TOMORROW‘S PRODUCTS

Photonic System-in-Package (pSiP) by Applying Thin Glass

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More Information

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OIT – Optical Interconnection Technologies

The group includes three teams

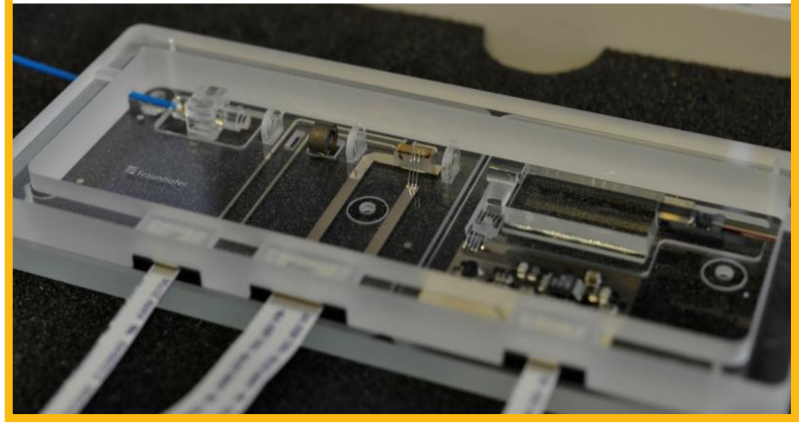

Head: Henning Schröder


Ind. Relations Manager: Gunnar Böttger

PSA

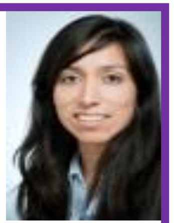
Photonic System Assembly

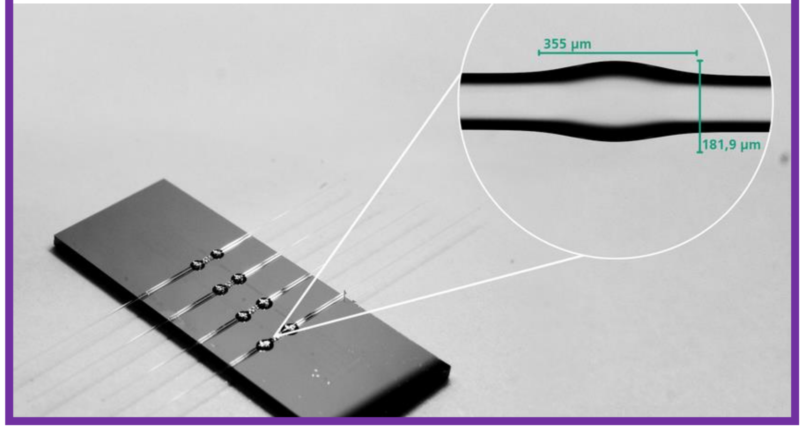

Oliver Kirsch



FOIS

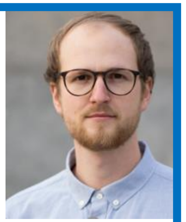
Fiber Optical Interconnects & Sensors

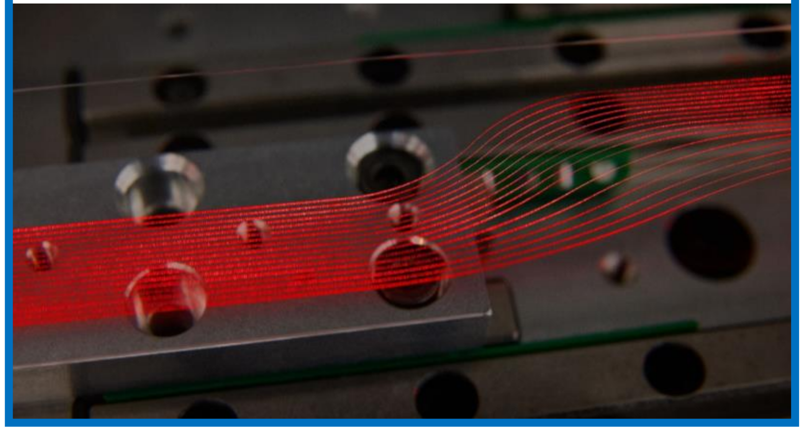

Vanessa Zamora Gómez



EOCB

Electrical Optical Circuit Board


Julian Schwietering



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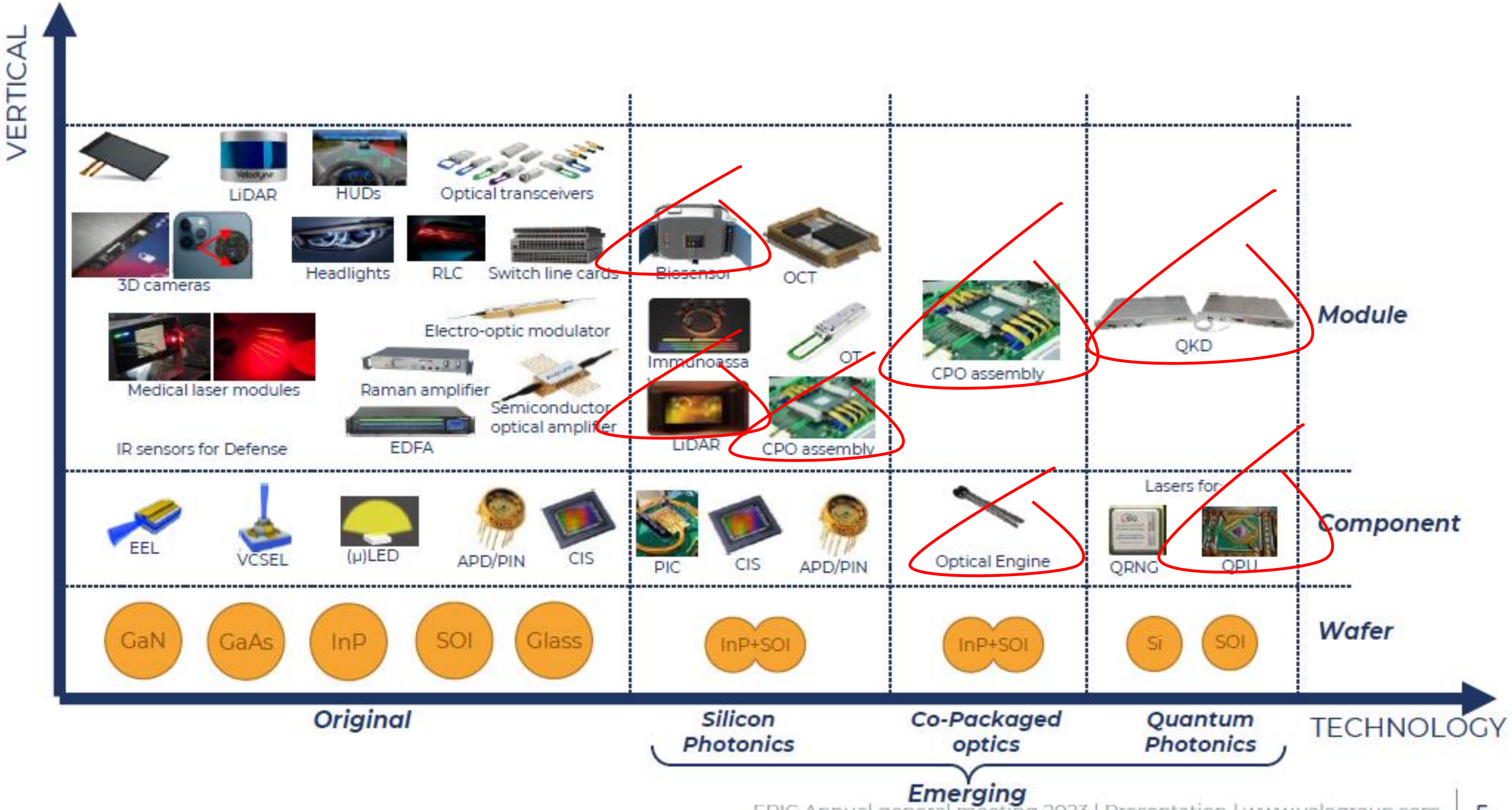
PHOTONICS

Original Photonics Technologies and value chain

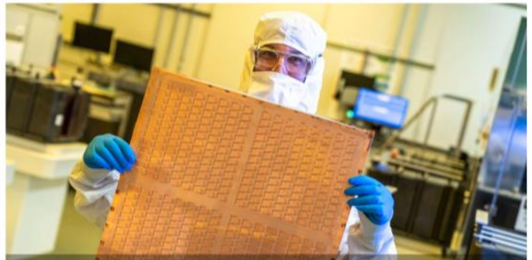
The emerging technology is not new but gaining traction in the respective markets



Outline of the talk

- Motivation for „photonic System-in-Package (pSiP)“
- Packaging Concept
- Experimental Results for a MOPA System as an exemple
  - Package Design
  - Glass structuring (metallic wiring, cavities, slids, mirror facets)
  - Layer Stacking and Sealing
  - Automated Assembly
  - Singulation by breakage
- Further building blocks:
  - Integrated optical waveguides and graded index out-of-plane coupling
  - fiber coupling
  - Generic PIC test platforms
  - 2PP for printed micro-optics and Photonic Wire Bonds
- Take Home messages

We are happy to see: In September 2023 Intel has been announced glass for electronic substrates to enable upcoming HPC including photonics



An Intel engineer holds a test glass core substrate panel at Intel's Assembly and Test Technology Development factories in Chandler, Arizona, in July 2023. Intel's advanced packaging technologies come to life at the company's Assembly and Test Technology Development factories. (Credit: Intel Corporation)

Intel Unveils Industry-Leading Glass Substrates to Meet Demand for More Powerful Compute

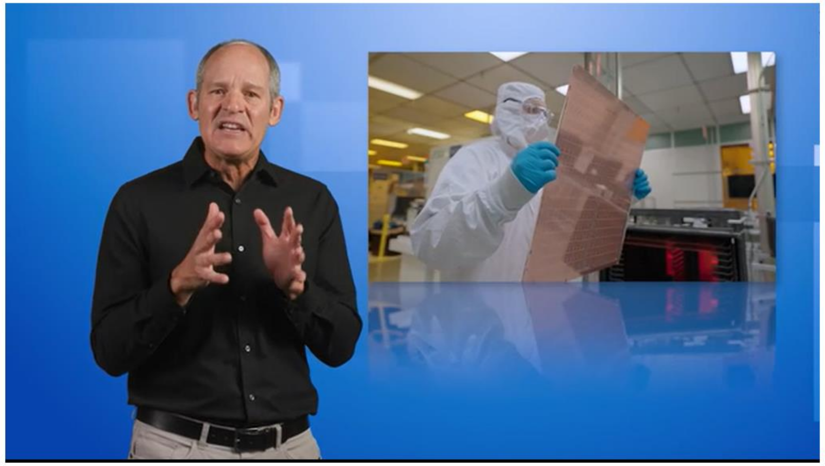
Glass substrates help overcome limitations of organic materials by enabling an order of magnitude improvement in design rules needed for future data centers and AI products.

Glass Core Benefits

		Scaling Enabled by Glass Core	Product Value
1	Feature Scaling	<5/5um Line/Space & <100um TGV* pitch	Reduce metal layer count and/or package size OR add more function/cores
2	Bump Pitch Scaling	Enables D2D bump pitch >36u on substrate and core bump pitch <80um	Reduced die area/power and increased interconnect density
3	More SI Content / Larger Package Size	Enables 50% larger die complex area in same package, >8x reticle Si and package size up to 240x240 mm	Enables scaling of die area complex and package size in HPC
4	High Speed I/O	Smooth Cu + Ultra-low loss dielectric + TGV pitch	Scaling to 448G without the complexity and cost of transitioning to optical**
5	Power Delivery	Advanced IPD	Improved Performance

*Through Glass Via

** With Organic Substrate



What's New: Intel today announced one of the industry's first glass substrates for next-generation advanced packaging, planned for the latter part of this decade. This breakthrough achievement will enable the continued scaling of transistors in a package and advance Moore's Law to deliver data-centric applications.

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Thin glass convinces by superior glass properties for electronics

Excemple: D263Teco, Schott

Mechanical properties

Density ρ	g/cm^3	2.51
Young's modulus E	kN/mm^2	72.9
Poisson's ratio μ		0.21
Knoop hardness	HK 0.1/20	470
Vickers hardness	HV 0.2/25	510
Chemical toughening		possible

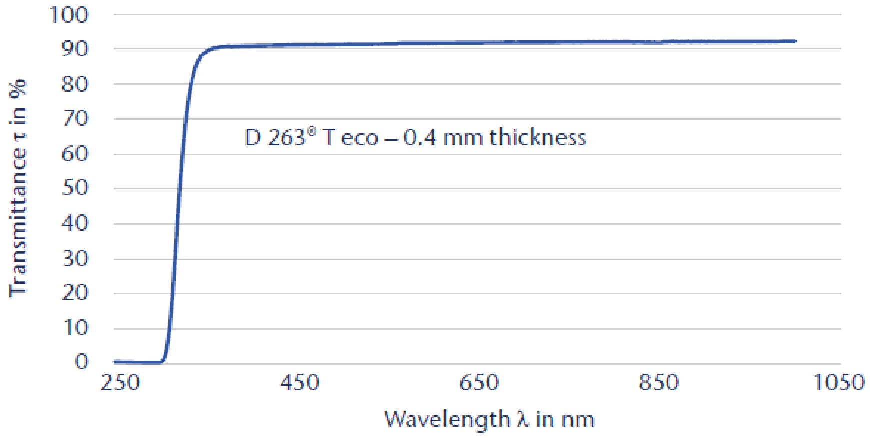
Electrical properties

Frequency in GHz[3) 4)]	1	2	5	24	77
Dielectric constant (permittivity) ε_r[2)]	6.4	6.4	6.3	6.3	6.1
Loss tangent *tan(δ)* in 10^{-4}	74	81	101	210	240

Specific electrical volume resistivity ρ_D at 50 Hz	ρ_D at $\vartheta = 250\,°C$ in Ω·cm	$1.6 \cdot 10^8$
	ρ_D at $\vartheta = 350\,°C$ in Ω·cm	$3.5 \cdot 10^6$

Optical properties

Refractive index n_D	1.5230
Luminous transmittance τ_{vD65} (d = 0.30 mm)	91.7 %



Thermal properties

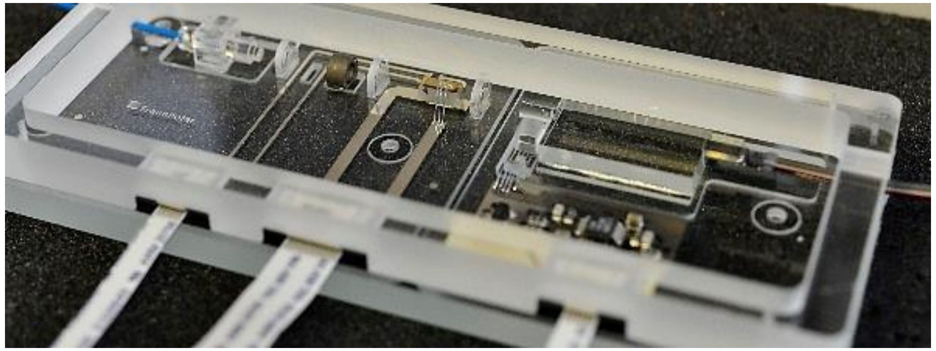
Coefficient of thermal expansion α (20 °C; 300 °C)	$7.2 \cdot 10^{-6}\ K^{-1}$
Transformation temperature T_g	557 °C

https://www.schott.com/de-de/products/d-263-p1000318/downloads

Motivation for the work presented here: Photonic System-in-Package (pSiP) using glass allows both: high design complexity and miniaturisation

- High **design complexity**
- Glass-based electro-optical module for optical spectrum analysis
- Including micro-optics (filters, isolators, lenses)
- assembled by sequential active alignment with temporary fixing of components using integrated vacuum-channels
- metallization (solderable, and wire-bondable) to include electro-optical and electronic features (EOM, TIA, PIC)

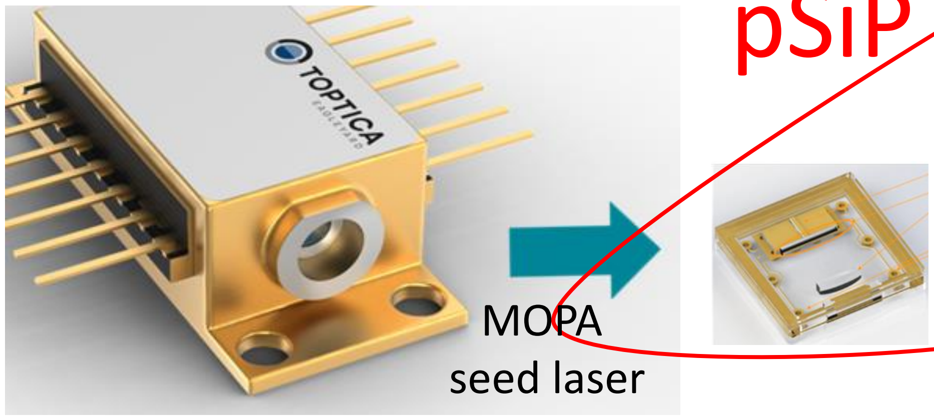
- **Miniaturisation** shown by size comparison of a butterfly package for laser diode, SAC and FAC (left)
- and a glass based photonic **System-in-package (pSiP)** (right) for MOPA seed laser



H. Schröder et al., "Enabling photonic system integration by applying glass based microelectronic packaging approaches", Proc. EOSAM 2022, Porto, Portugal

from cm

to mm



pSiP

9 x 9 x 1,7

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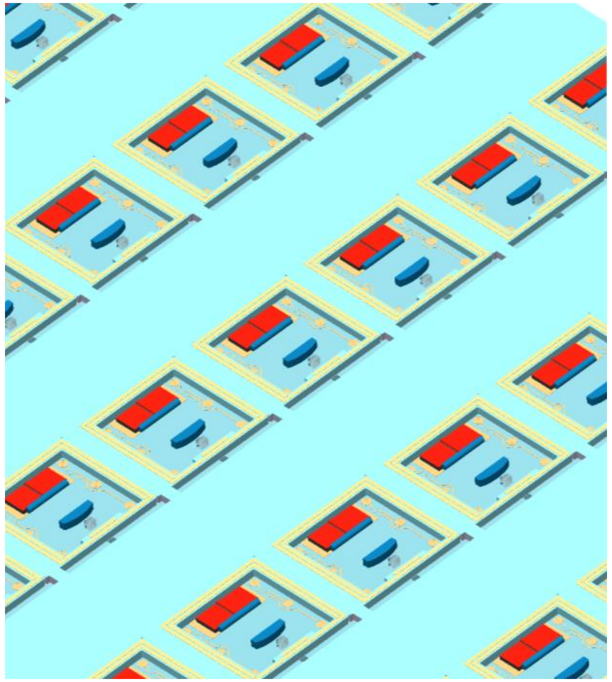
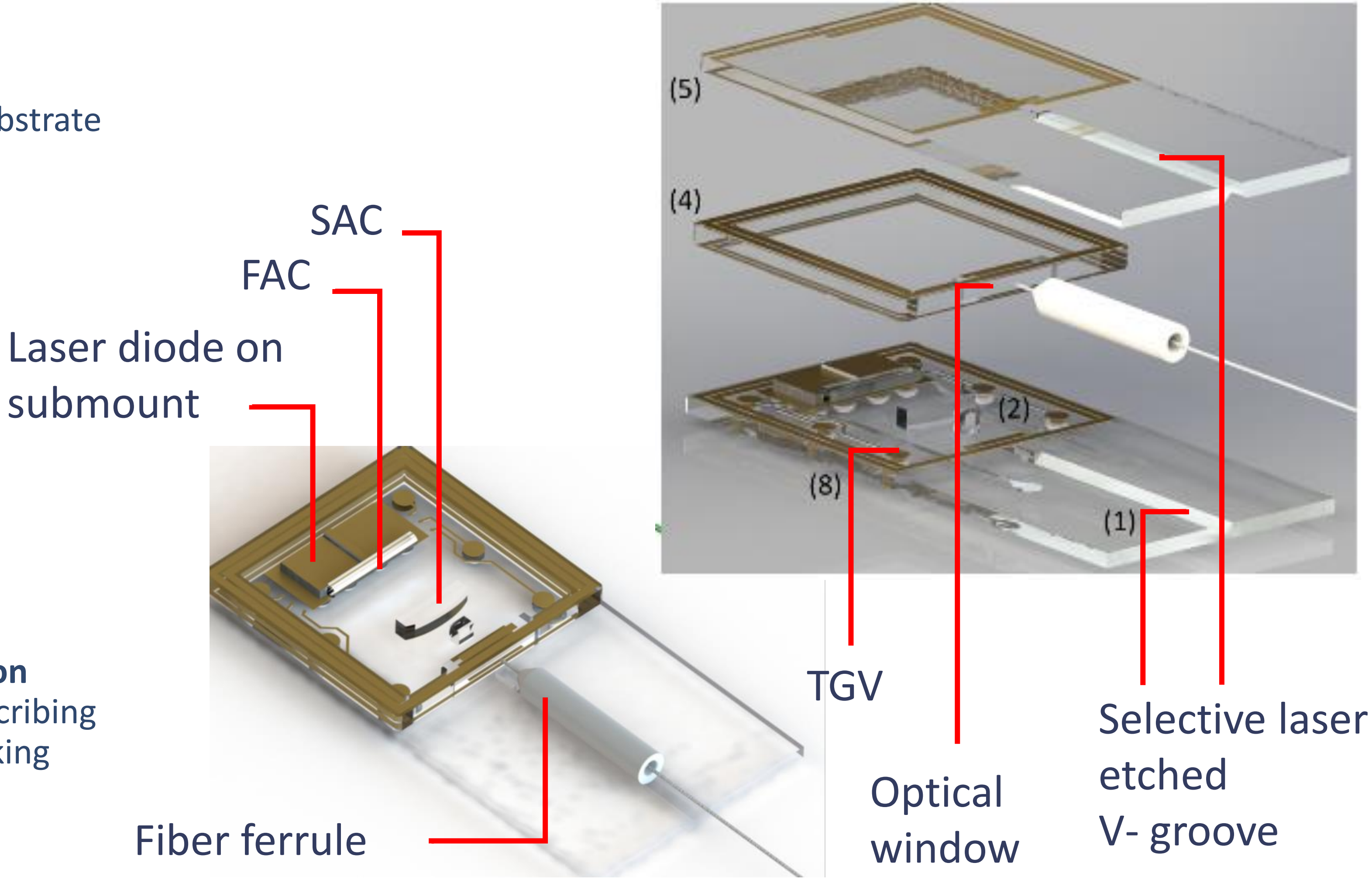
pSiP concept: Glass layer stacking enables panel level assembly and packging before singulation

Stacking of middle frame with optical windows

Panel level component assembly on bottom substrate



Singulation
by laser scribing
and breaking



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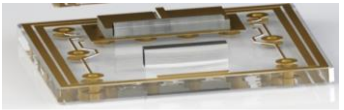
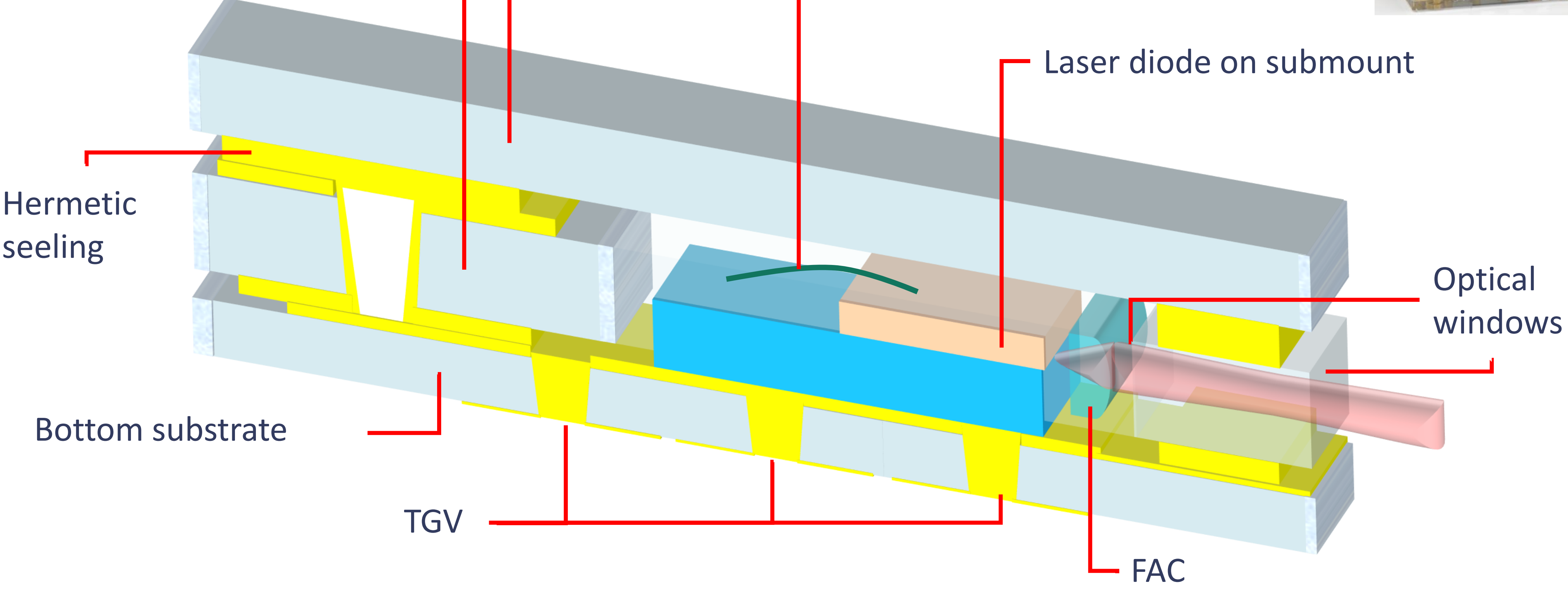
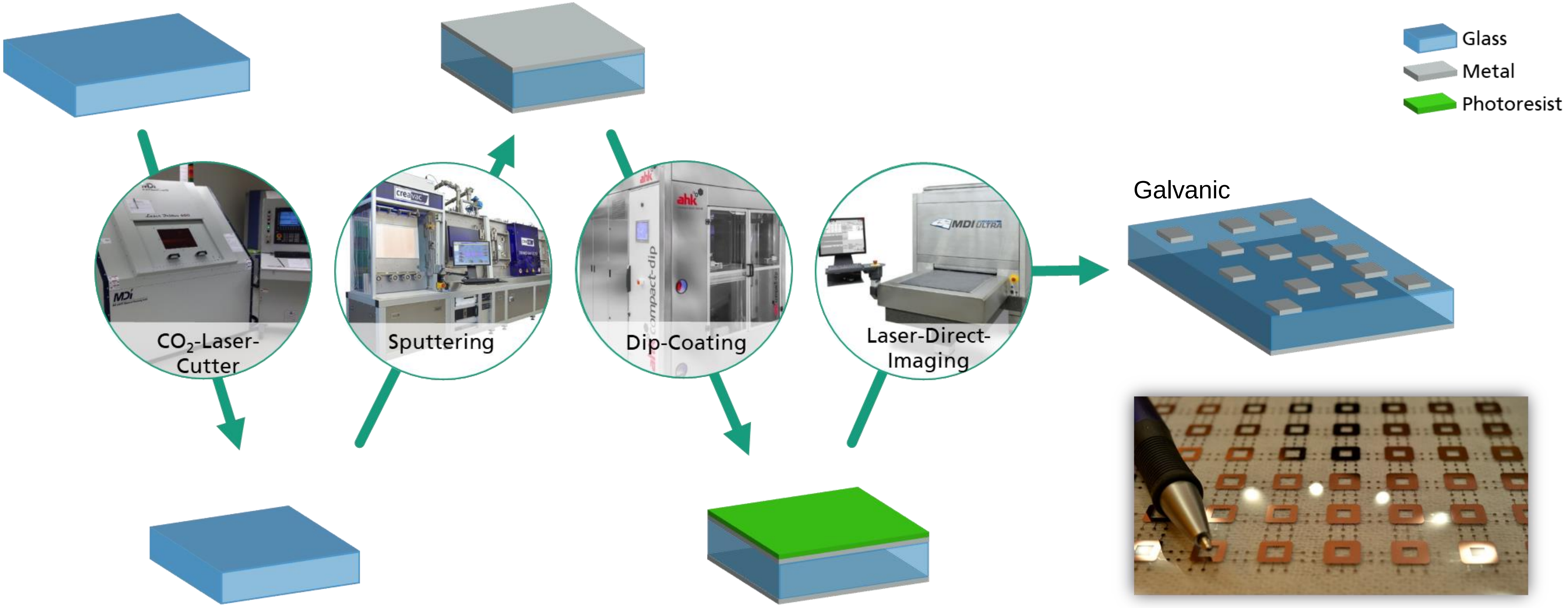
Package design: The cross section shows TGV, hermetic sealing, LD on submount, FAC, and optical window

Seed laser





Electrical wiring and sealing rings are provided by PCB adopted thin film technology, and galvanic processes



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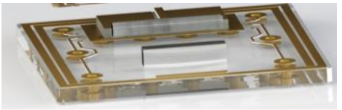
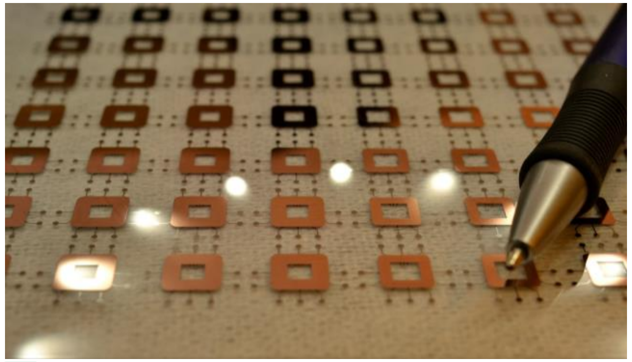
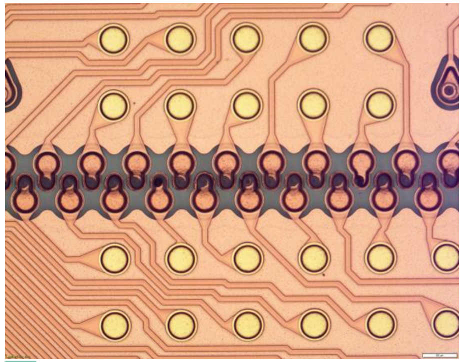
DC & RF interconnects based on RDL, WB and hermetically sealed TGVs enable on board mounting and 3D-Integration

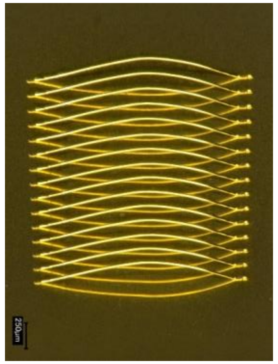
Seed laser



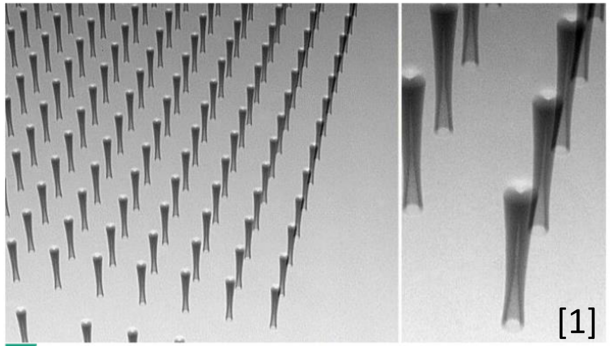
RDL & WB





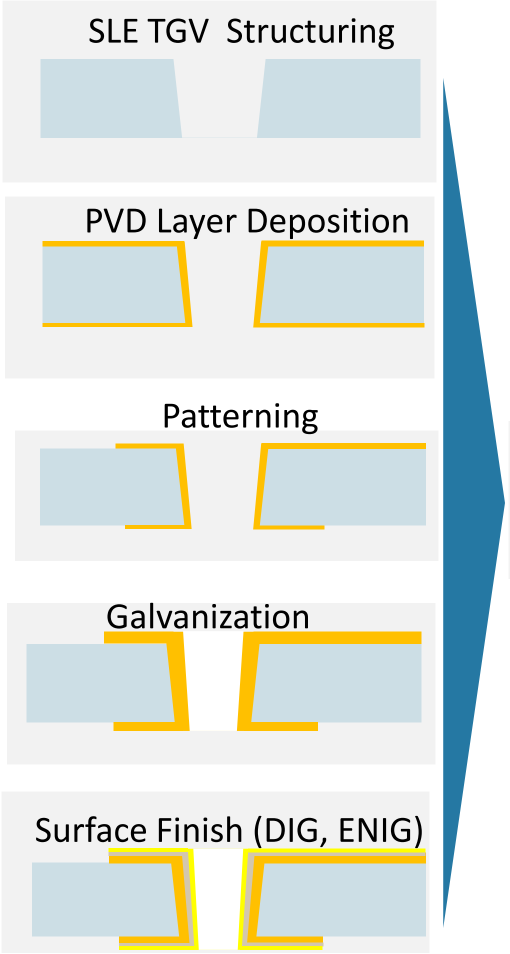


TGV

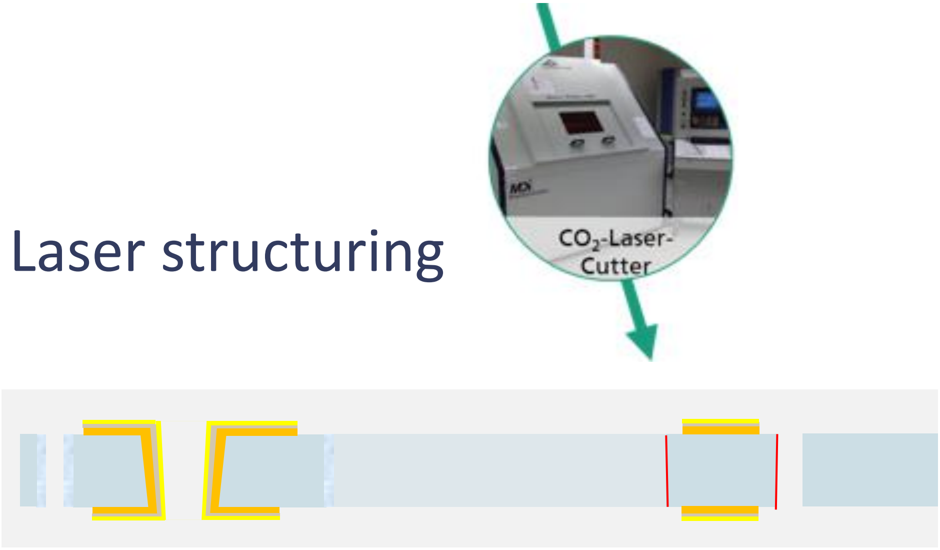


[1] K. Kröhnert et al.: Reliabillity of Through Glass Vias and hermetically sealing for a versatile sensor plattform," IEEE 8th ESTC, 2020.
[2] K. Kröhnert et al.: Through Glass Vias for hermetically sealed High Frequency Application. Additional Conferences (Device Packaging, HiTEC, HiTEN, and CICMT), 2019.
[3] H. Schröder, O. Kirsch, J. Schwietering, K. Kröhnert: Onlinesession "IZM-Photonics: In glass we trust" #2 Online-Seminar: Integrated glass-based electro-optical platform for co-packaging

Thin film technology and galvanic processes gain RDL and TGV, followed by laser structuring, assembly, singulation

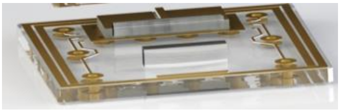


Laser structuring

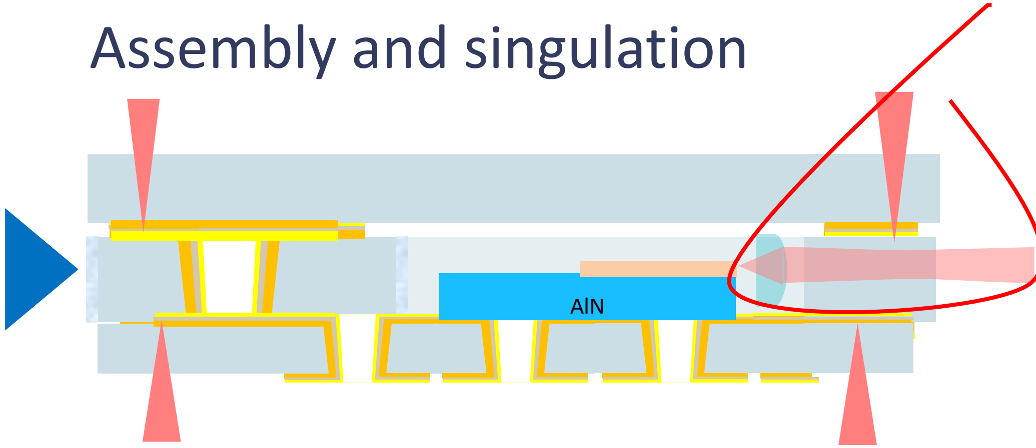


- CO_2-laser scribing of package sidewalls creates an optical window
- 533 nm ps-Laser ablation creates cavities

Seed laser



Assembly and singulation



- Automated Assembly process
- Package sealing using laser
- Singulation from panel

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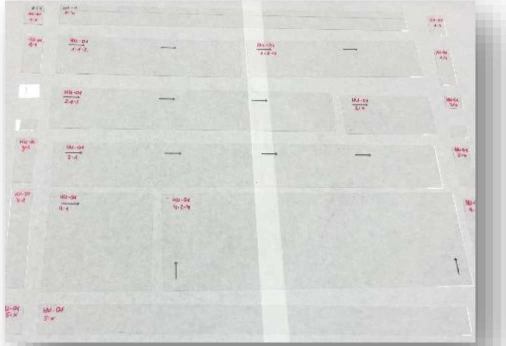
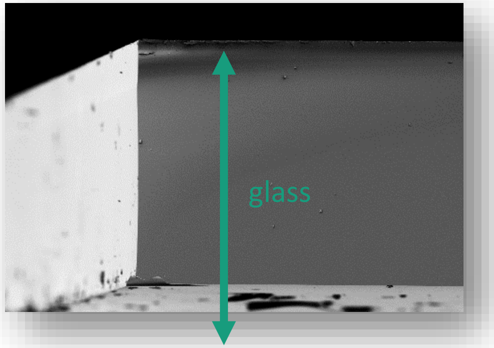
Laser structuring for optical windows and perforation uses 2 different lasers in 1 machine

CO_2 Laser (10600 nm)

- Precise and clean cutting
- ±0.025 mm
- no glass particles
- Optical, crack-free glass edge quality (without grinding)



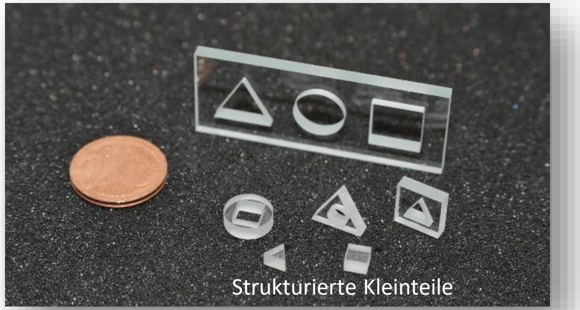
Cutted glass panel

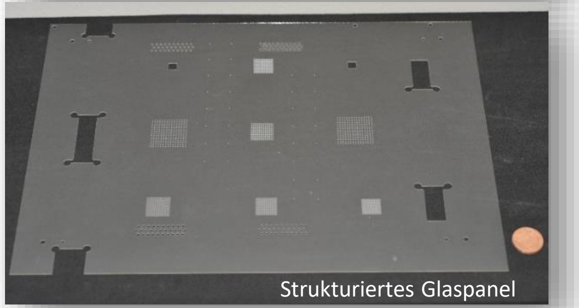


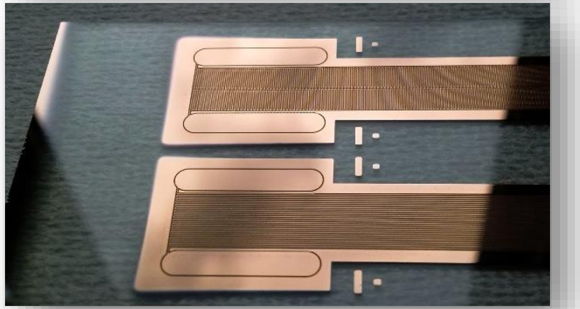
SEM micrograph of optical window

Green Laser (532 nm)

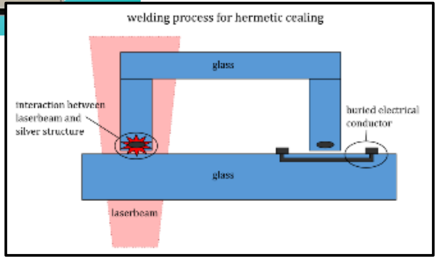
- Manufacturing of glass elements
- Flexible free shape drilling and structuring
- accuracy: <20µm
- Patterning of coatings





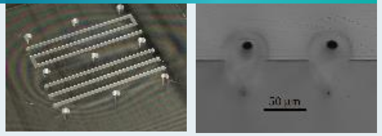


3 glass-glass bonding techniques are in use to be selected according design and component requirements



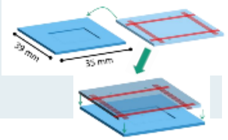
1 **Direct glass-glass bonding - Lightfab**
Direct bonding of glass materials with ultrashort laser pulses
Possible Gap bridging up to 2 µm | minimal thermal stress

Overview and cross-section of welded glass parts © LightFab



2 **IoX enhanced glass-glass bonding**
Laser bonding of two glasses using buried metallic silver as absorbing structures
Large working distance (~cm) | low thermal stress

glass substrate and glass lid with buried structures



3 **Glass-metal-glass bonding**
Laser based hermetic glass bonding using metallic layer for laser absorption
Welding in ultrahigh vacuum (UHV) possible | Metallic layer: Ti,Cr,Cu,Sn, Ti/Au, Al

welded prototype of Glas+FR4

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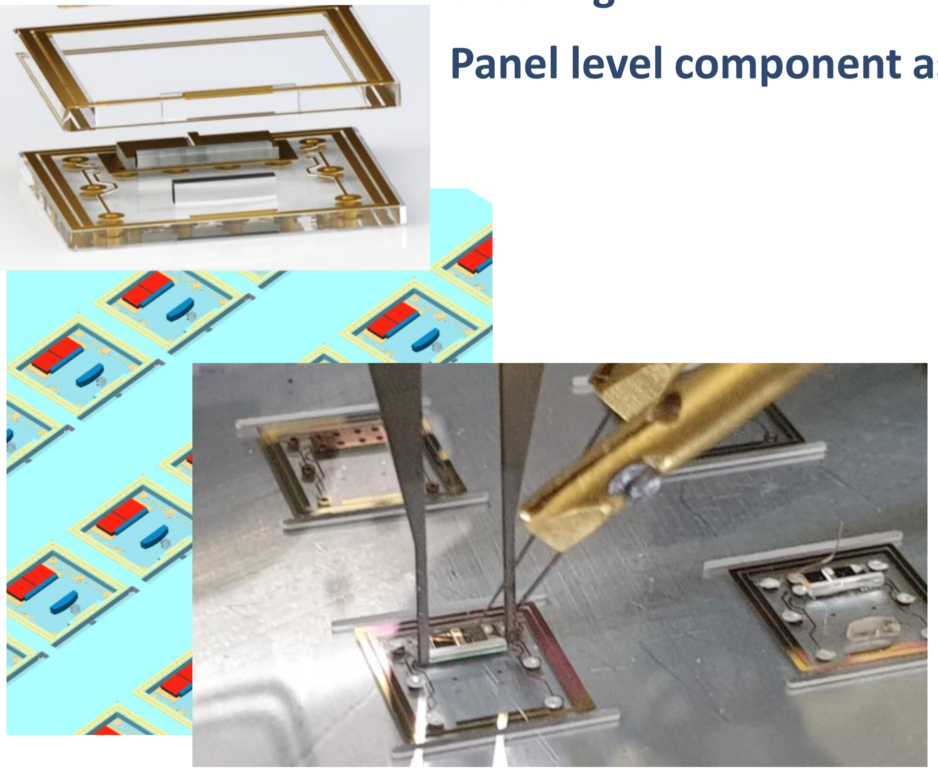
Automated panel level assembly and packging before singulation allows high throughput

Stacking of middle frame panel with optical windows

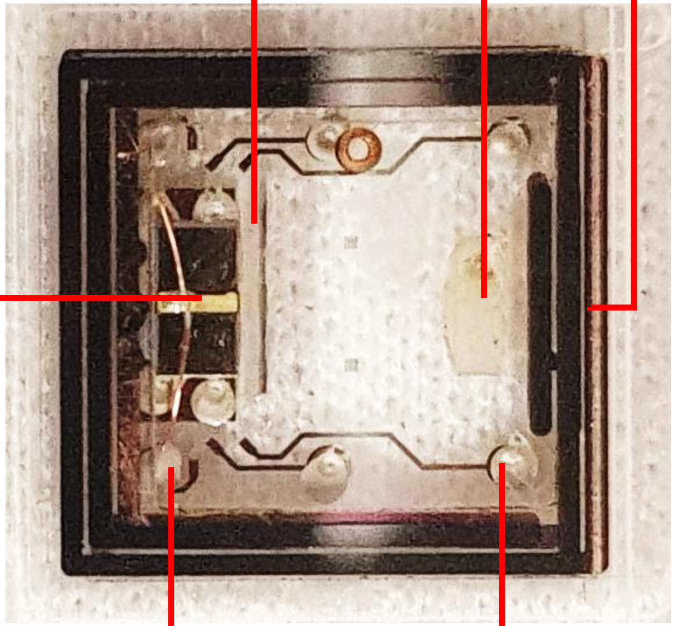
Panel level component assembly on bottom substrate



Singulation
by laser scribing
and breaking

?

Seed laser



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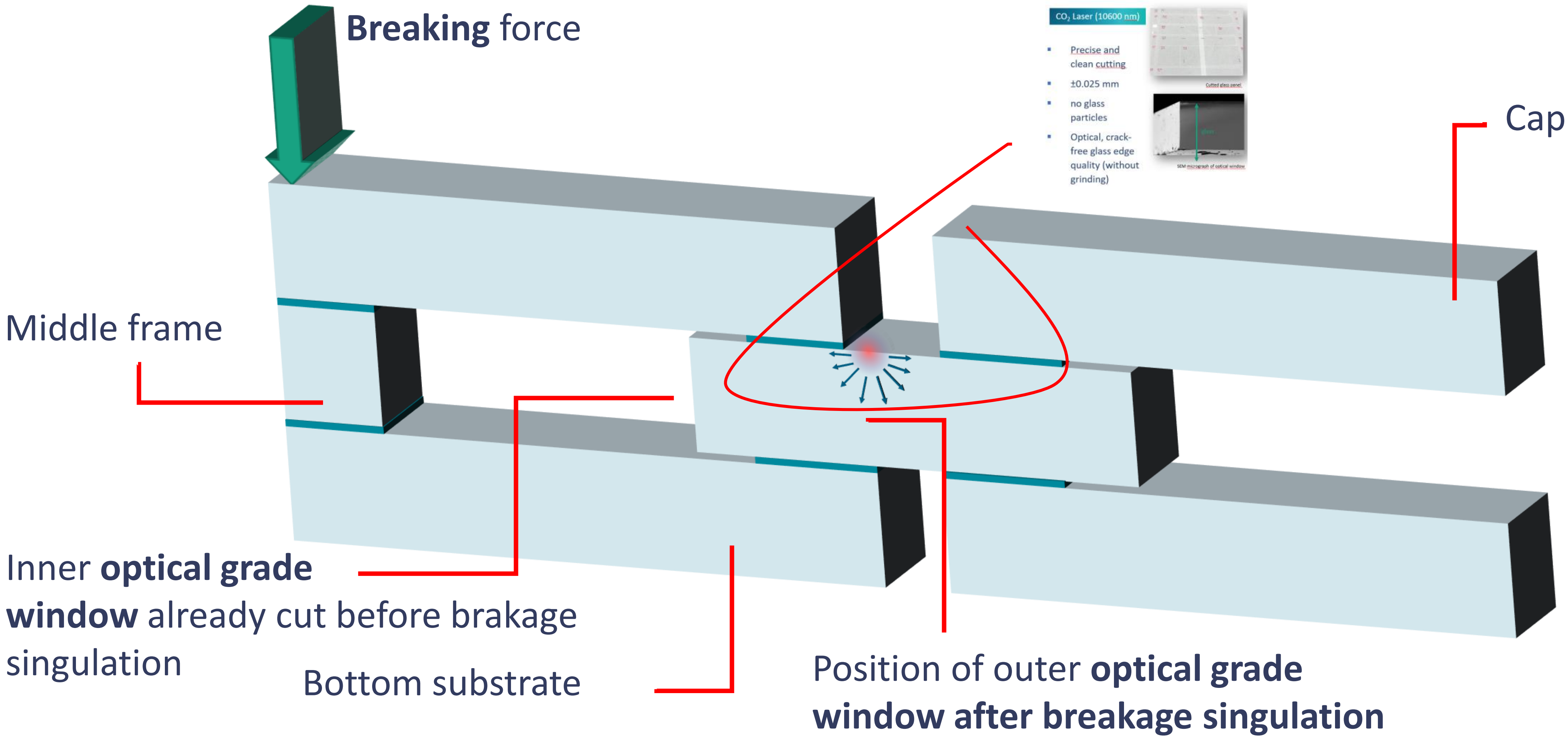
The answer is: Singulation by breakage after panel level assembly at the line of laser induced stress enables optical grade windows w/o polishing



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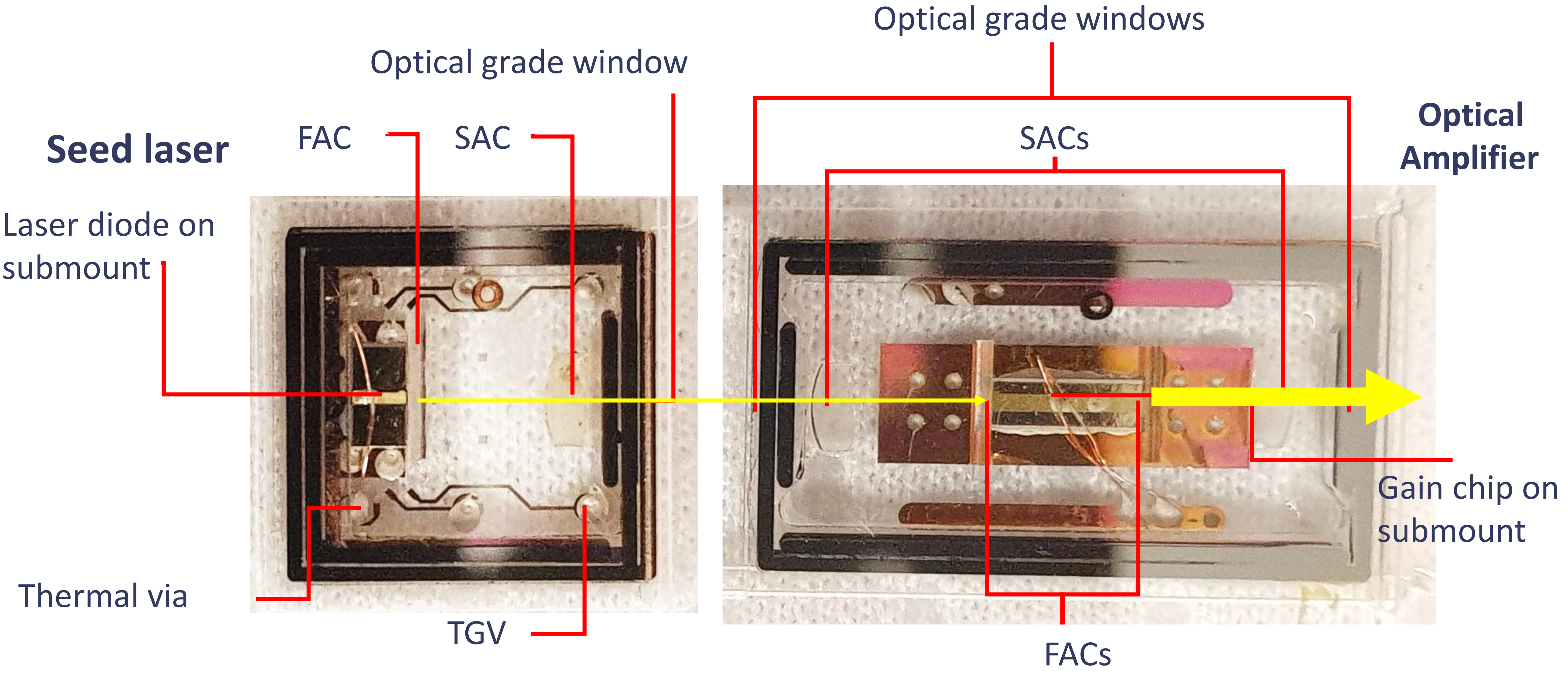
The MOPA system consists of 2 pSiP building blocks: Seed laser and optical amplifier



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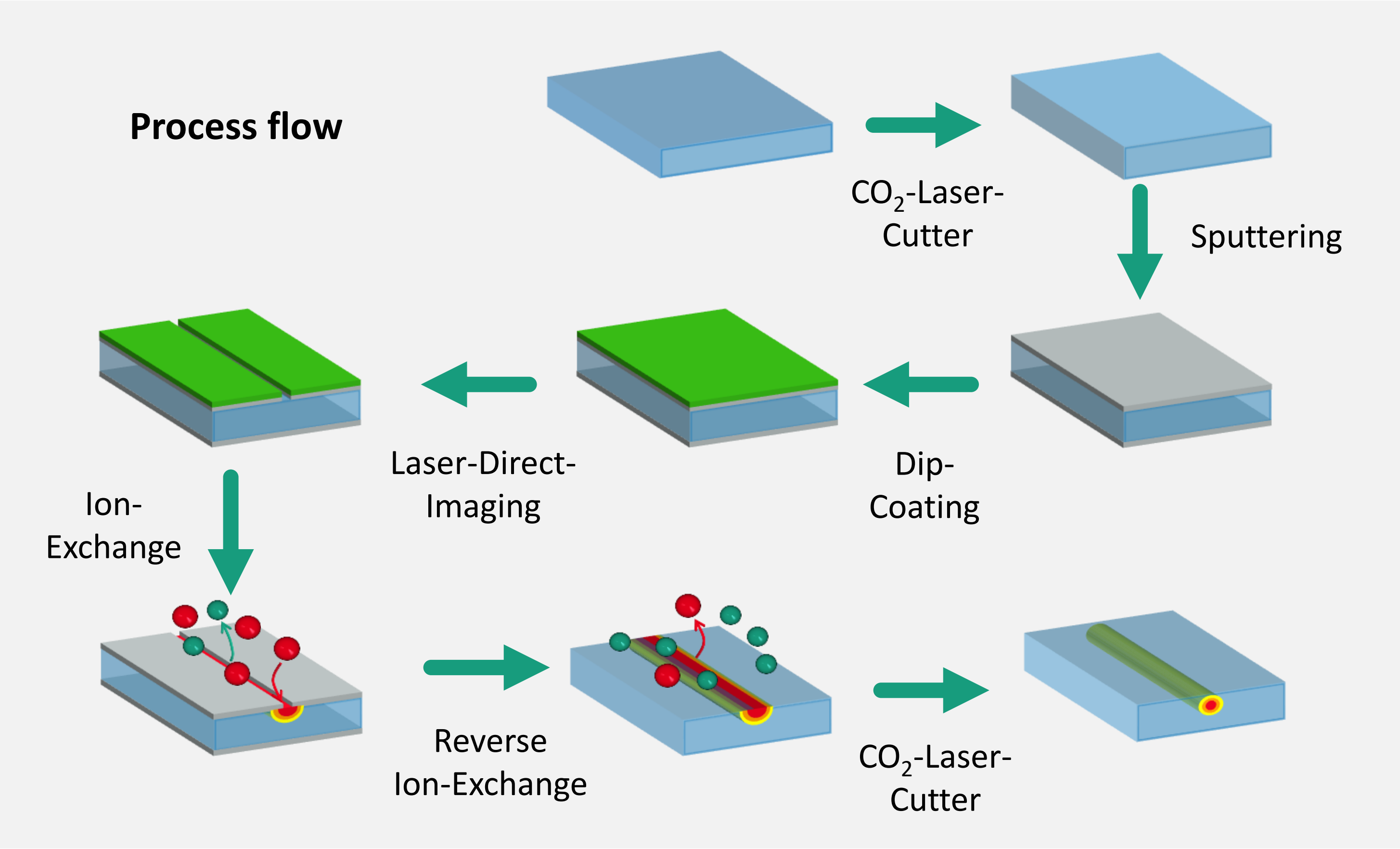
Ion-exchange technology for package integrated optical waveguides

Process flow and optical characteristics



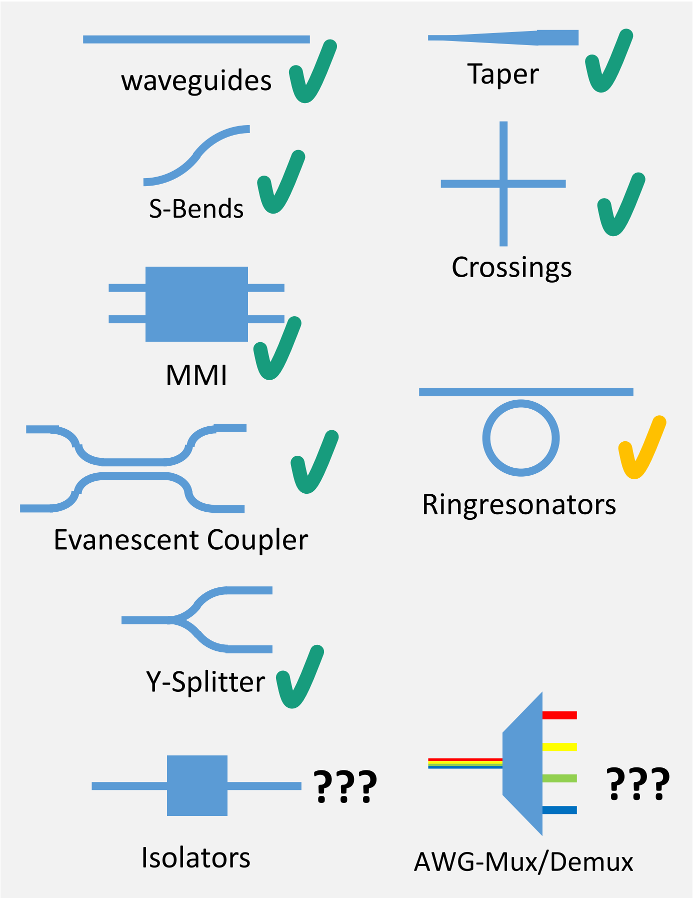
Properties

- Single-mode (λ>1060 nm) and multi-mode operation
- Large optical bandwidth:
  - 400 – 2000 nm
- Ultra-low propagation losses:
  - 0.059 ± 0.001 dB/cm @ 1550 nm
- Low PDL and temperature dependence
- Thin glass down to 300 µm thickness and format up to 440 x 305 mm²
- Mode field of integrated waveguides can be well adjusted to optical fibers

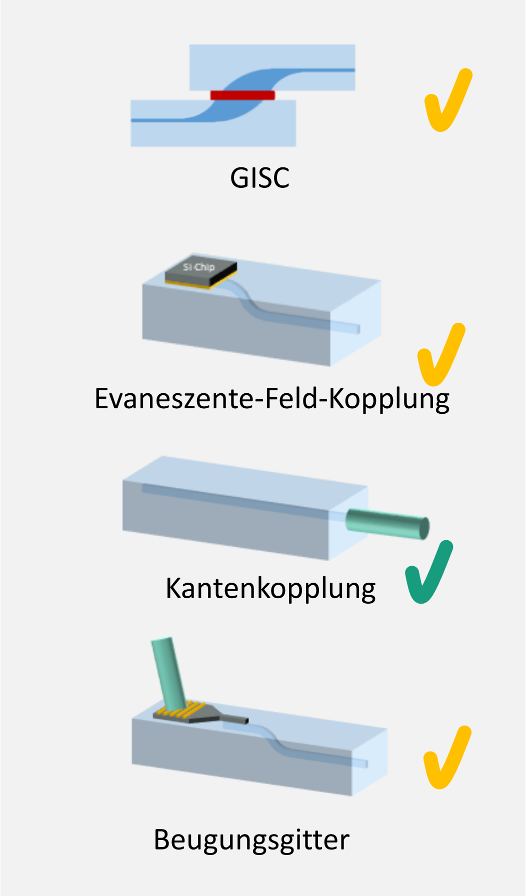
IOX in Glass – much more than simply optical waveguides

Acive and passive functions are added

Passive Components



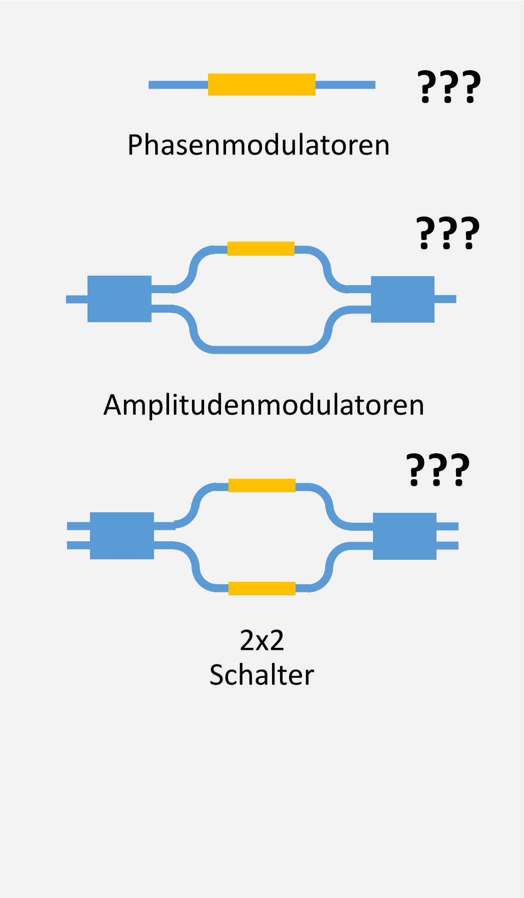
Interconnections



\+

- Semiconductor
- Metal
- Polymer

Active components



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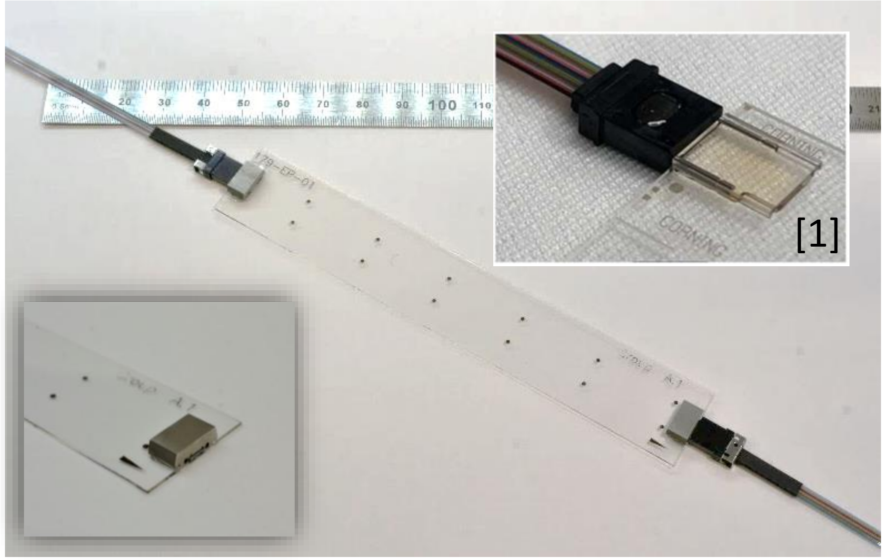
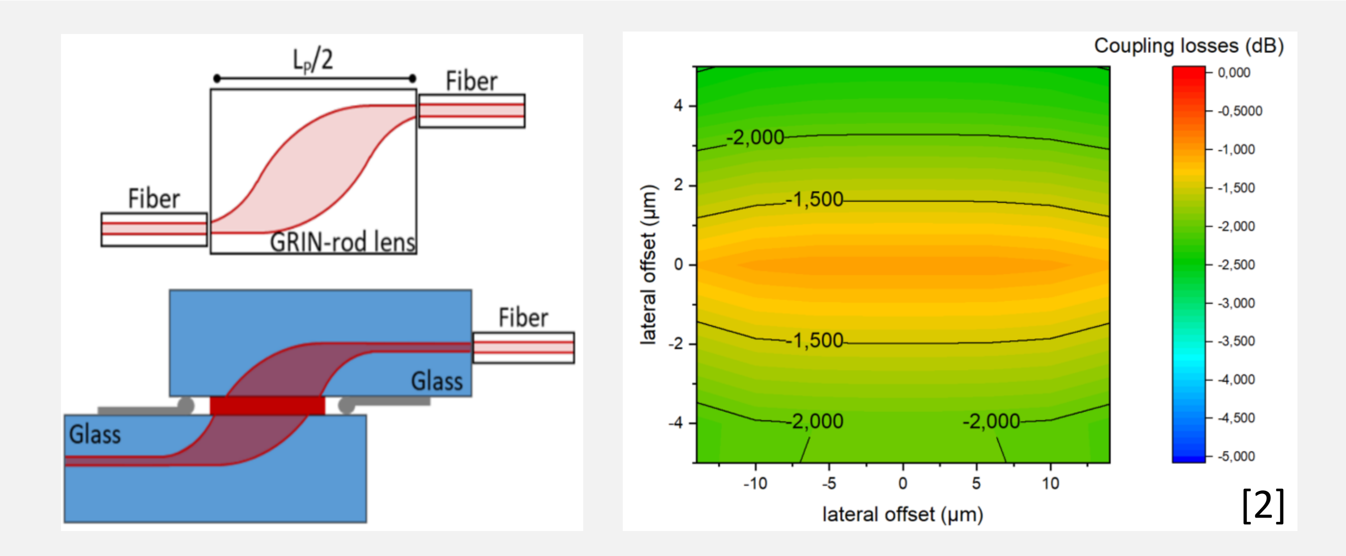
Fiber-to-chip interconnects with high fiber counts and low-cost assembly

Edge coupling and out-of-plane connectors are developed

Edge coupling based on MTP standard



Gradient-index surface coupling (GISC)

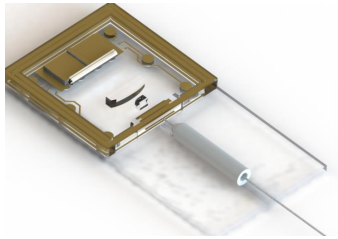


- Fiber-interface at glass interposer can be either based on edge coupling or GISC.
- GISC would allow for a low-profile fiber interface with relaxed alignment tolerances.

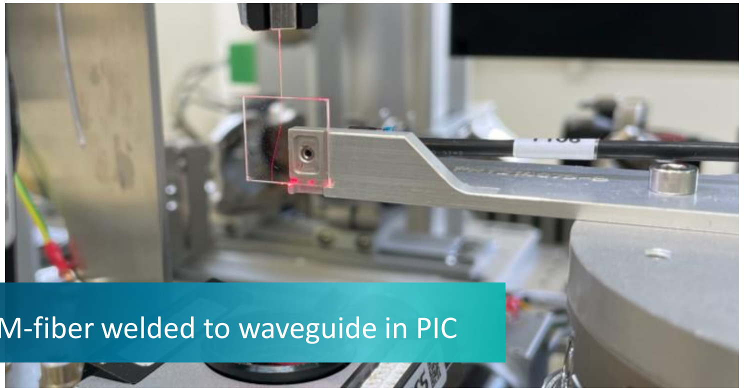
[1]: L. Brusberg et al., "Passive Aligned Glass Waveguide Connector for Co-Packaged Optics," 2021 European Conference on Optical Communication (ECOC), 2021
[2]: Schwietering, Julian et al., „Integrated optical single-mode waveguide structures in thin glass for flip-chip PIC assembly and fiber coupling.“, 2020 IEEE 70th ECTC

Laser welding of optical glass fibers to glass substrates

Adhesive-free interconnection approach



Processing system for laser welding of fibers to substrates



PM-fiber welded to waveguide in PIC

Features:

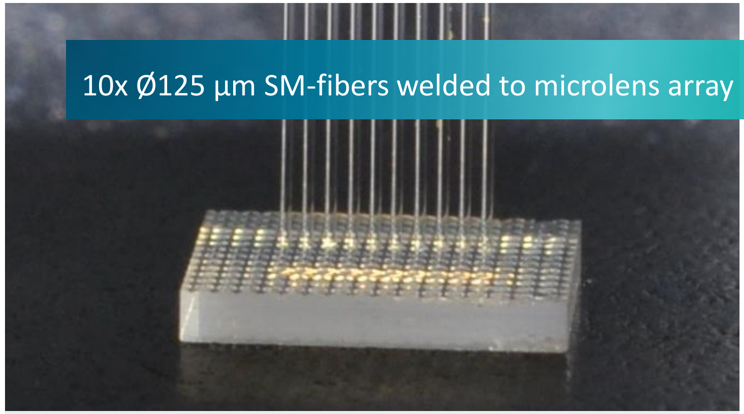
1D and 2D laser-assisted direct glass-to-glass welding, resulting in a position and power stable connection

High-precision linear movement, rotation and angle correction

Active alignment

Monitoring of optical parameters

High automation potential



10x Ø125 µm SM-fibers welded to microlens array

Optical fibres fused on glass integrated waveguides

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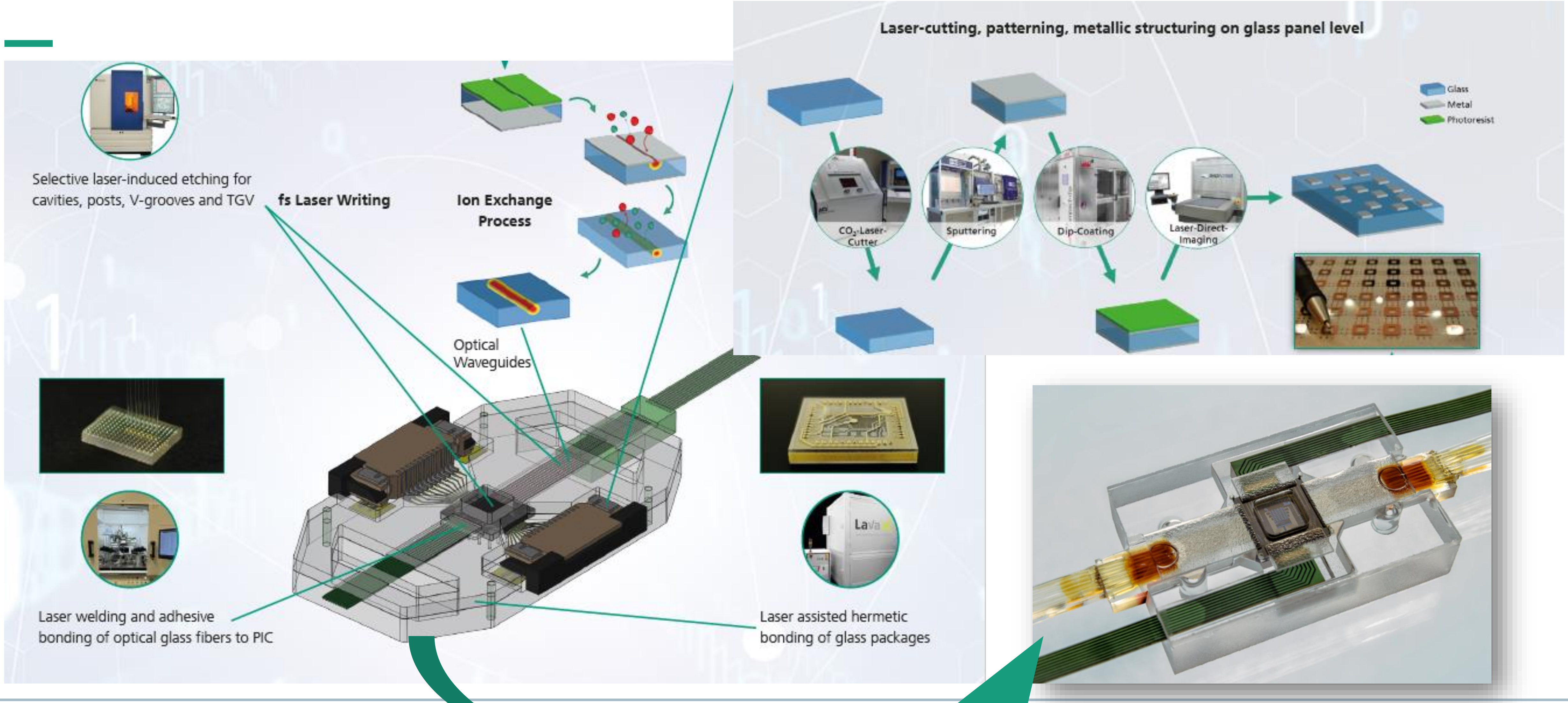
Service offer: generic Packaging Platform for Customized Photonic Integrated Circuits (PICs)

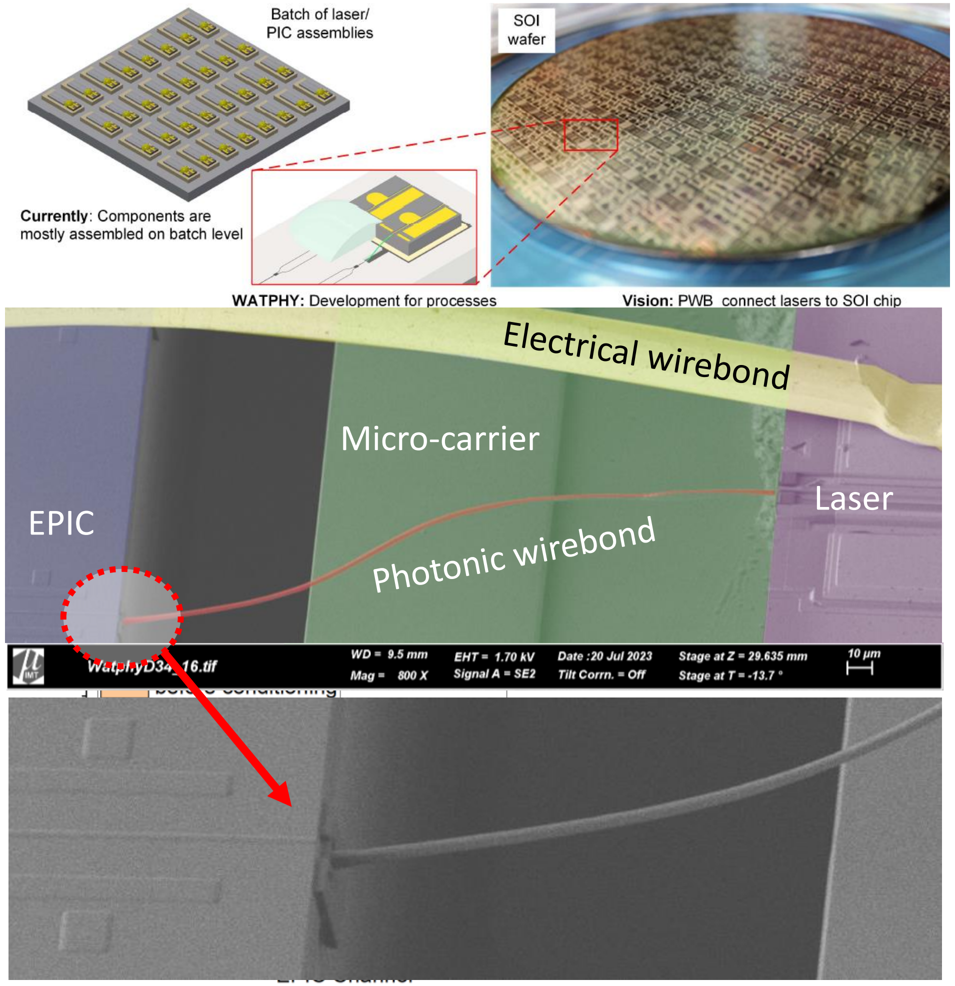


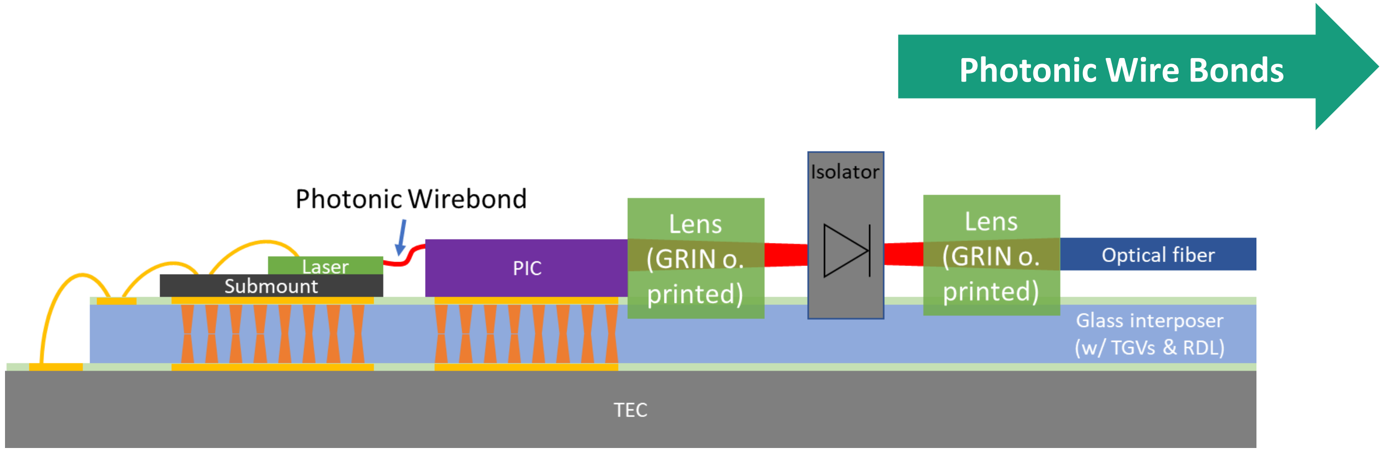
Optical integration of Si photonic circuits and other PIC

Photonic Wire bonding

What is it and what is it about?

- Scalable method to integrate a multitude of lasers to electronic-photonic chips (EPIC) or between PIC, and PIC to fiber
- High-yield optical attach processes exploiting 3D-printed nano-optics, so called photonic wirebonds (with plastic optical fiber properties)





 06.06.2024

Projektträger AiF Ideen eine Zukunft geben

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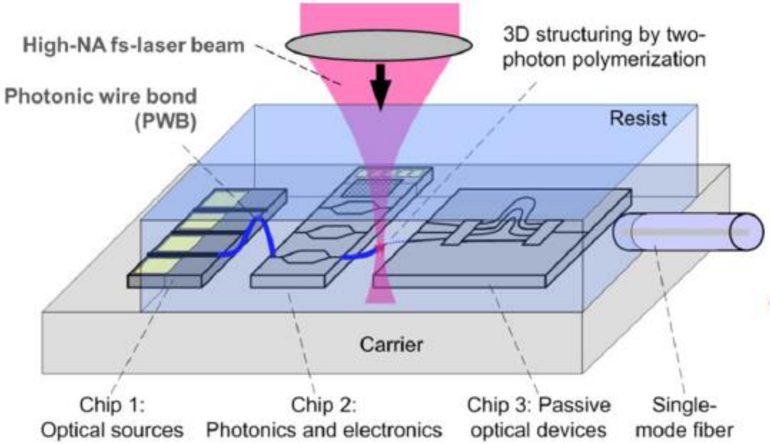
Novel Photonic Wire Bond (PWB) technology

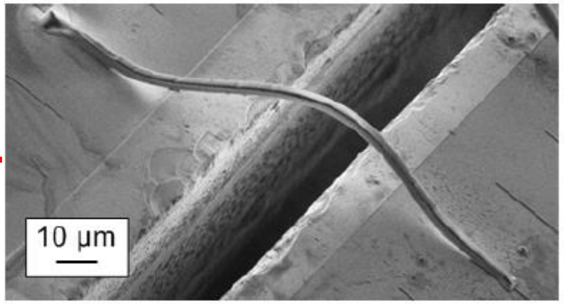
2-Photon-Polymerisation enables flexible photonic integration processes

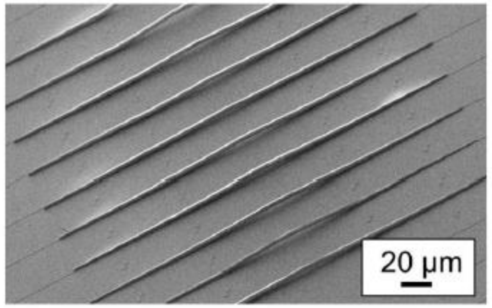
- High-density photonic integration must be complemented by scalable packaging concepts.

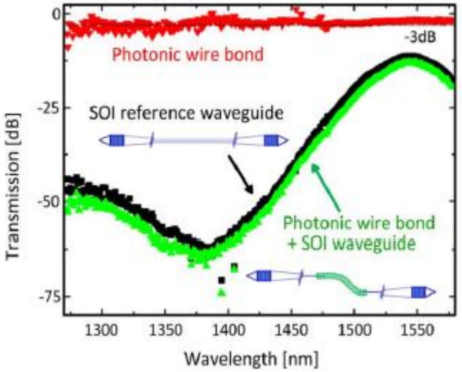


- Photonic wire bonding enables automated fabrication of single-mode chip-chip and fiber-chip connections.

- Experiments demonstrate the viability of the concept for building a universal photonic integration platform.







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Take home

- Motivation for „photonic System-in-Package“:
  - Miniaturization, cost reduction, performance, reliability
- Packaging Concept
  - Display glass: optical transparency, best dielectric properties, thermal management by design (heat spreading and thermal vias)
  - Panel level structuring, hermetic sealing, and assembly
- Experimental Results for a MOPA System for example
  - Package Design: 3 layer stack, perforation to singulate by breackage, frame layer w/ side optical window
  - Glass structuring (thin film, galvanic, cavities, slids, holes, optical grade facets): electrical wiring, TGV, thermal management, windows
  - Layer stacking and sealing: diffusion bonding and fs-direct glass-glass welding
  - Automated assembly: active alignment on panel level
  - Singulation by breackage of perforated zones
- Integrated optical waveguide, fiber coupling, and 2PP have been presented as additional building blocks
  - Ion-exchange can be used to realize surface optical coupling interfaces for integrated waverguides in glass layers
  - Adhesive-free optical fiber welding to integrated waverguides in glass layers
  - 2PP enables micro-optics printed on component facets and photonic wire bonds
- *→ the pSiP-packaging concept is open for other form factors, components, horizontal and vertical beam coupling, higher complexity or, vice versa, for optical CSP*

More Information

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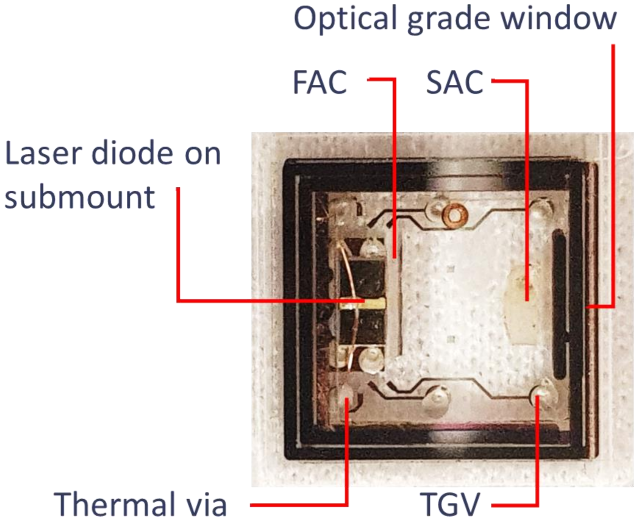
Thermal performance of filled TGVs enables stable DFB-Laser operation close to manufacturer specification

Seed laser



Technical Specifcation:

Laser Type: Edge Emitter DFB

Package Volume 8 x 8 x 0,7mm ~ 45mm³

Glas Layer Thickness: 300 - 700µm

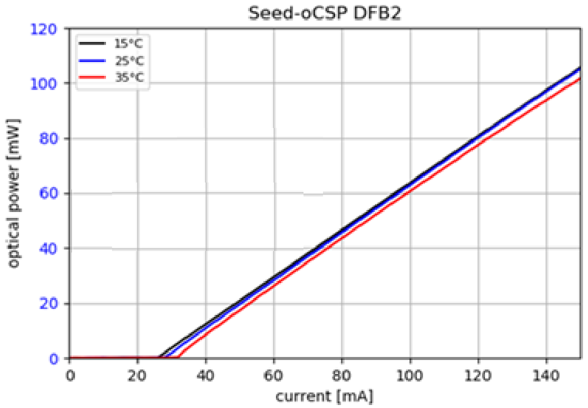
Metallization System Thickness <1µm -10µm Copper

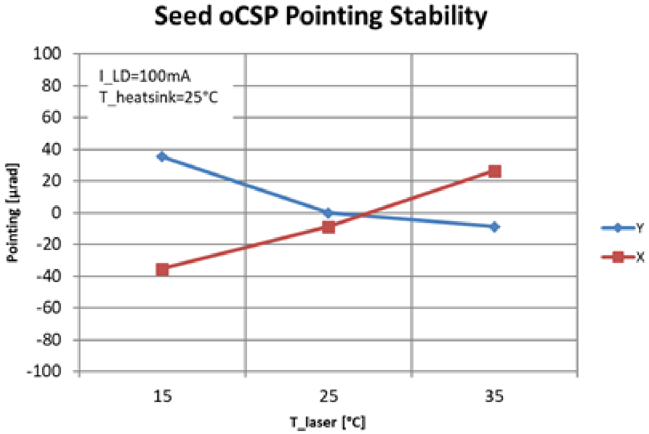
Metallization Finishes Available: Direct Immersion/ Gold & ENIG

Output Beam Diameter ~420µm

Stable Optical Output Power: >100mW

Therm. Induced Beam Pointing Stab.: ~8 $*10^{-6}$ deg/K

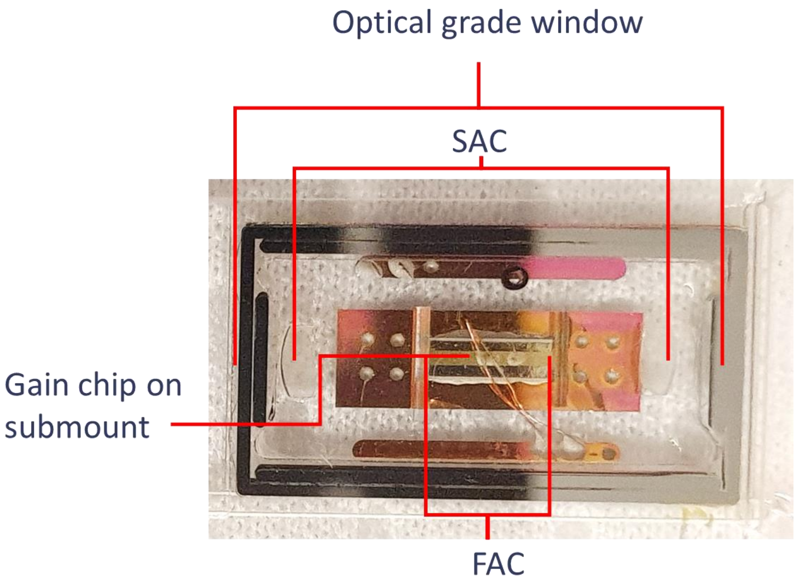


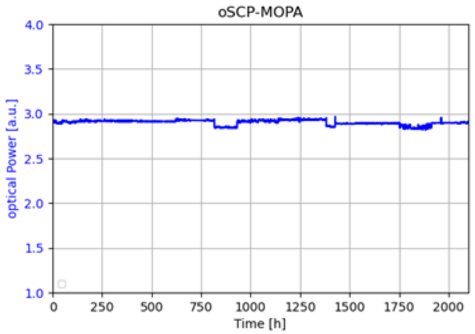


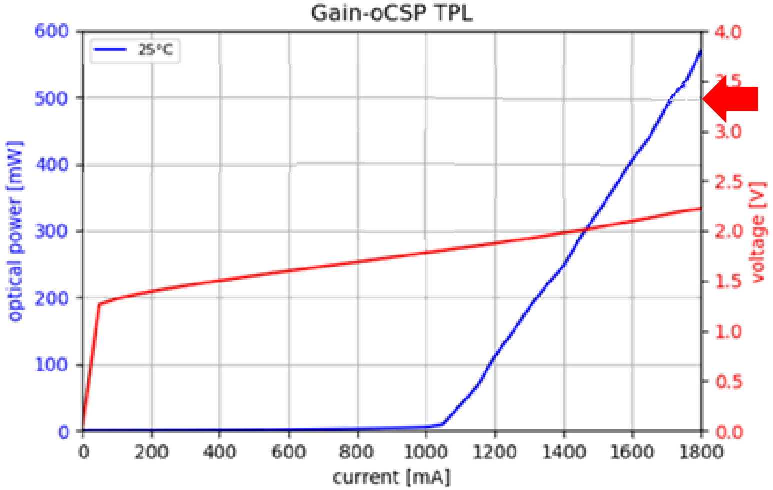
Top: Birds View on Seed laser pSiP with integrated DFB on Submount with FAC and SAC lenses
Bottom: pSiP thermomechanical stability of packaged assembly

pSiP is scalable to higher complexity assemblies with thermal loads up to 3W and multiple optical I/Os

Optical Amplifier







Technical Specfcations:

Laser Type: Tapered Amplifier

Package Volume 19 x 8 x 0,7mm ~ 106mm³

Glas Layer Thickness: 300 - 700µm

Metallization System Thickness <1µm -10µm Copper

Metallization Finishes Available: Direct Immersion Gold & ENIG

Wavelength: 780nm

Output Beam Diameter ~420µm

Stable Optical Output Power: > 500mW

Top: Tapered Amplifier pSiP
Bottom Right: P-I-V Measurement of TPA Performance
Bottom Left: Longterm Stabilitytest of MOPA Assembly

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