

Photonics Integration on Silicon

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ECTC 2012 Plenary session

Photonics: Expanding Markets and Emerging Technologies

Outline

Introduction to silicon photonics

VTT's activities in Si photonics and photonics packaging

Packaging challenges and opportunities in Si photonics

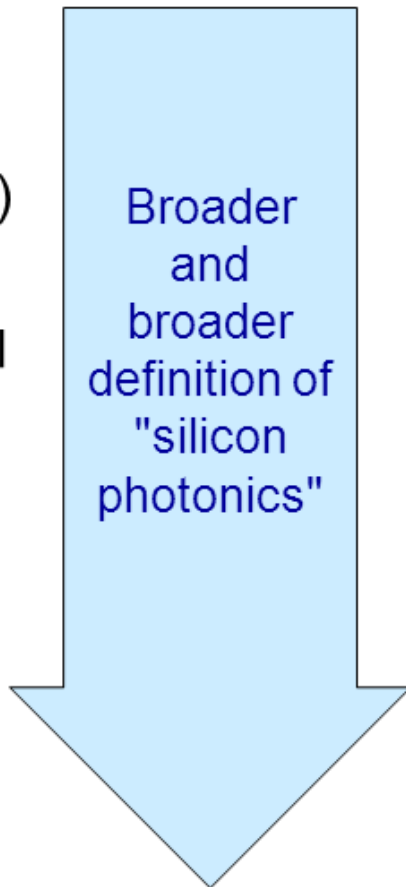


What is silicon photonics?

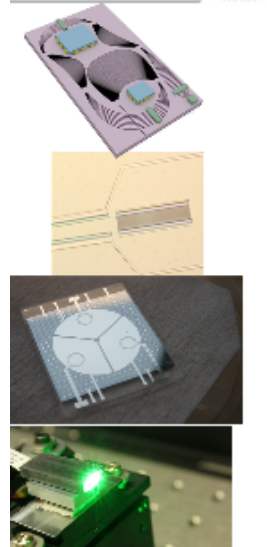
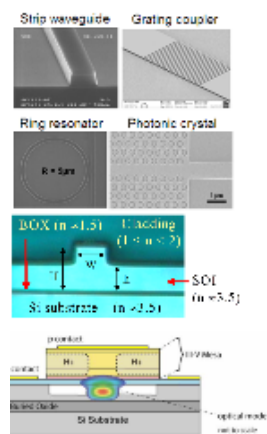
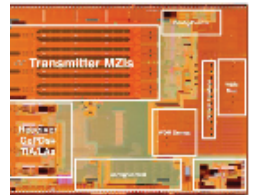
"Generation, manipulation and detection of photons on silicon chips"

Varieties of the Si photonics scope:

- Monolithic photonics-electronics integration
- Silicon-on-insulator (SOI) waveguides:
 - SOI strip & PhC waveguides (e.g. 220 nm thick)
 - SOI rib waveguides (typically 1-10 μm thick)
- Heterogeneous integration of other materials on SOI
- Hybrid integration of other chips on SOI
- SiN_x , glass and polymer waveguides on Si wafers
 - Single-moded (SM)
 - Multi-moded (MM)
- Optical MEMS on Si
- Hybrid integration of non-Si photonics on Si (excluding SOI)



Broader
and
broader
definition of
"silicon
photonics"

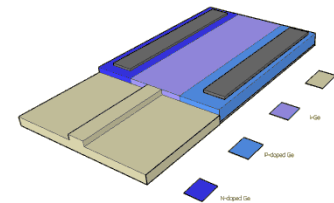
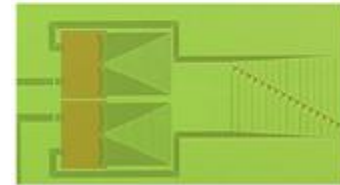
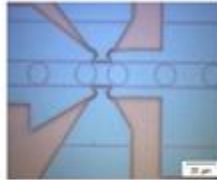


What are the applications for silicon photonics?



How to get feasibility studies and Si photonics prototypes?

- ePIXfab is the European R&D foundry initiative for silicon photonic ICs (www.epixfab.eu)
 - Cost-effective prototyping for R&D with multi-project wafer runs (MPW)
 - Passive and active devices
 - Training and design kits
 - Free feasibility studies for SMEs
- FP7 support action ESSenTIAL expands the offering with integration and packaging services



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**Packaging challenges and
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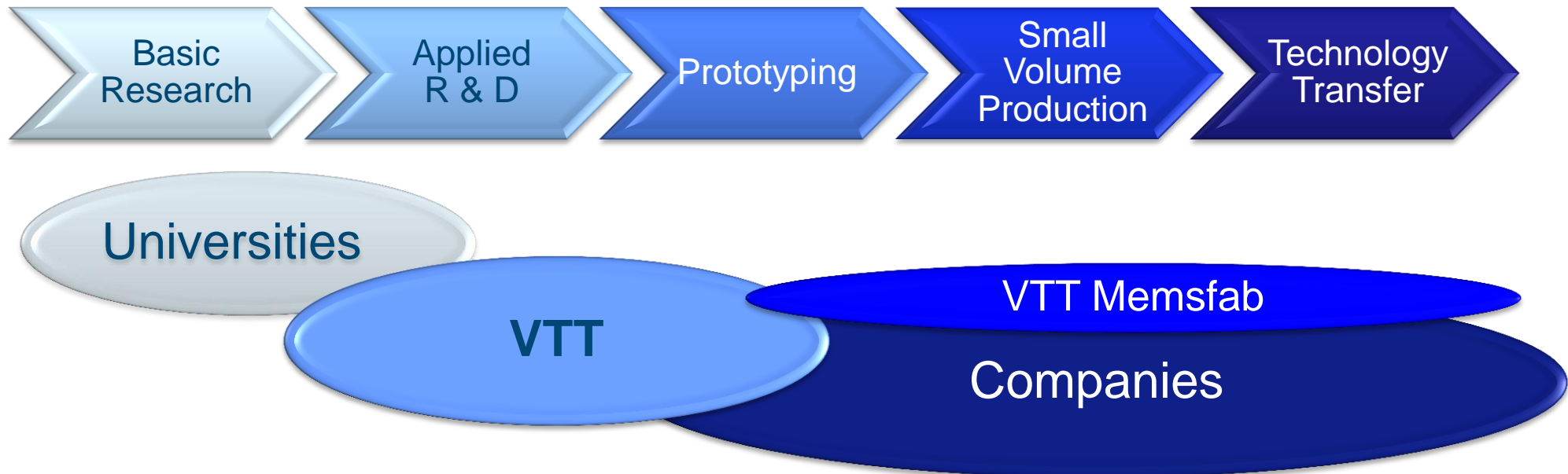


VTT Technical Research Centre of Finland

VTT is a globally networked multi-technological applied research organisation

- Extensive technological and business expertise
- Unique research infrastructure
- Not-for-profit organisation

VTT in the innovation chain:



VTT in brief 2011

- Turnover 278 M€
- Personnel 2,818 (31.12.2011)
- Established 1942
- VTT has been granted ISO9001:2008 certificate.



Customer sectors

- Biotechnology, pharmaceutical and food industries
- Electronics
- Energy
- ICT
- Real estate and construction
- Machines and vehicles
- Services and logistics
- Forest industry
- Process industry and environment



Focus areas of research

- Applied materials
- Bio- and chemical processes
- Energy
- Information and communication technologies
- Industrial systems management
- Microtechnologies and electronics
- Services and the built environment
- Business research



VTT's operations

- Research and Development
- Strategic Research
- Business Solutions
- Business Development
- Group Services

VTT's companies

- VTT Expert Services Ltd (incl. Labtium Ltd, Enas Ltd)
- VTT Ventures Ltd
- VTT International Ltd (incl. VTT Brasil LTDA)
- VTT Memsfab Ltd

Photonics technologies and applications

Process
control



Optical
Communication
& processing



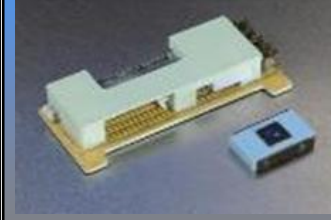
Lighting
&
Displays



Life Sciences



Safety
&
Security



Energy
&
Environment



Optical measurement & sensor technologies: Spectroscopy, machine vision, imaging, interferometry etc.

Design: 1/2/3D optics design, integrated optics, thermal management, electronics

Precision mechanics: CNC machining, 3D optics

3D LTCC & metallic modules: LTCC substrates, assembly, hermetic sealing

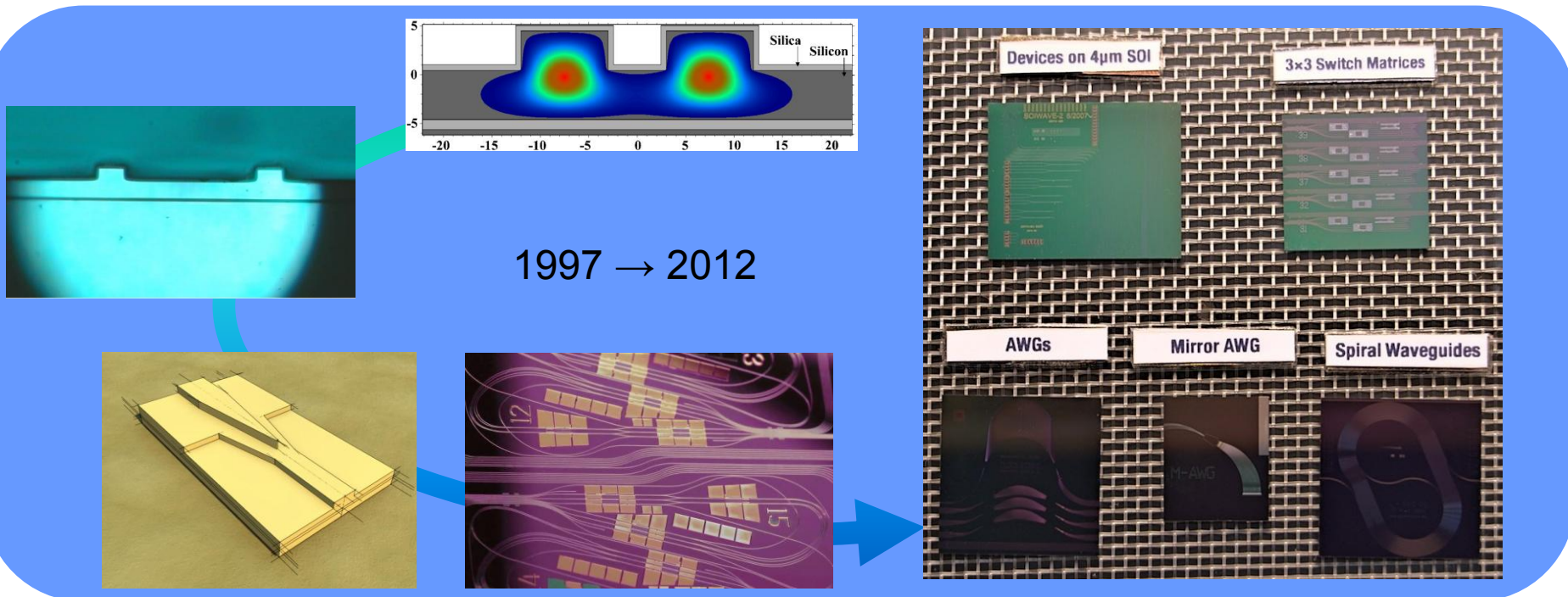
Polymer Integration: Multi-layer lamination, assembled foil over-molding, nanoimprinting

Si technology: MEMS/MOEMS, SOI waveguide circuits, hybrid integration on SOI

Printing technologies: R2R, UV imprinting, printing processes, materials, devices

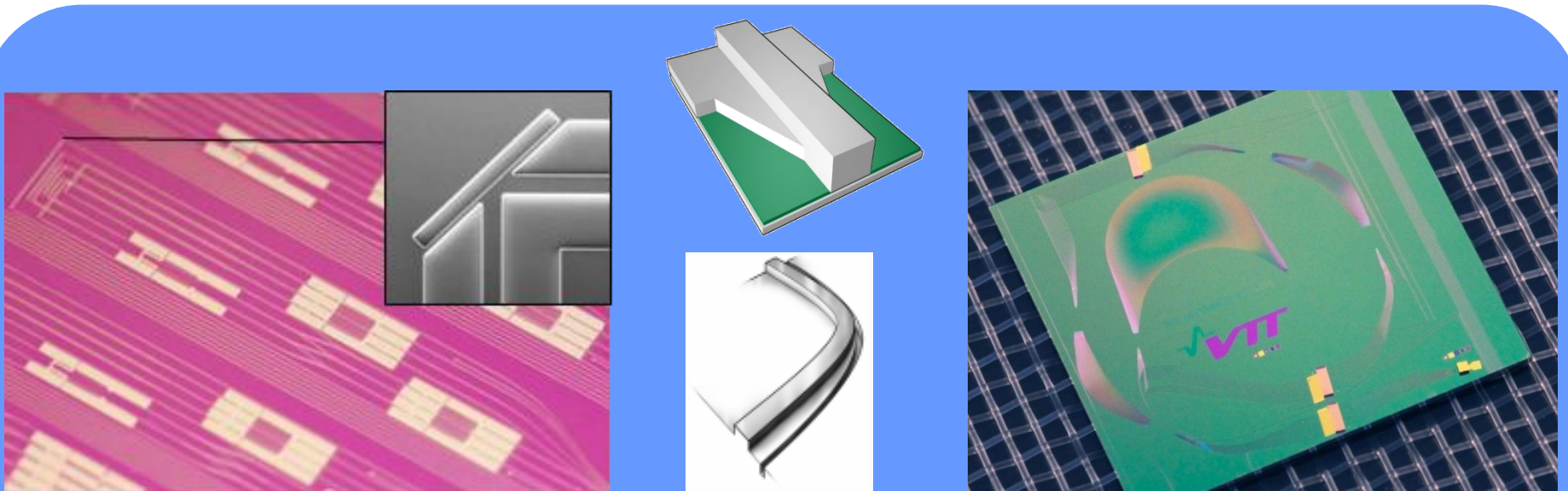
Silicon photonics (1)

SOI waveguides developed at VTT since 1997. Various photonic integrated circuits have been realised into 2–10 μm thick SOI. Single mode SOI rib waveguides have 0.1 dB/cm propagation loss and small polarisation dependency.



Silicon photonics (2)

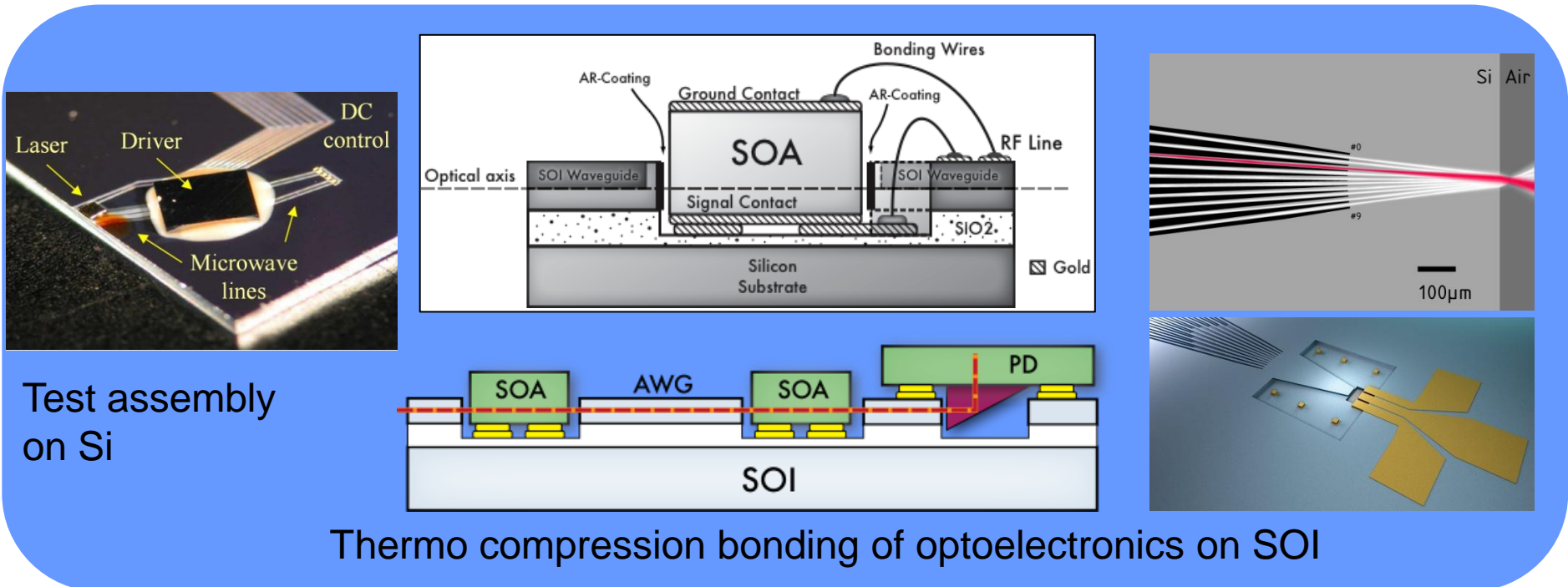
Footprint is reduced by using special mirrors, bends and couplers. Also vertical tapers and fast thermo-optic switching/tuning (700 ns rise/fall time) have been developed.



Multi-step patterning used for compact SOI circuits

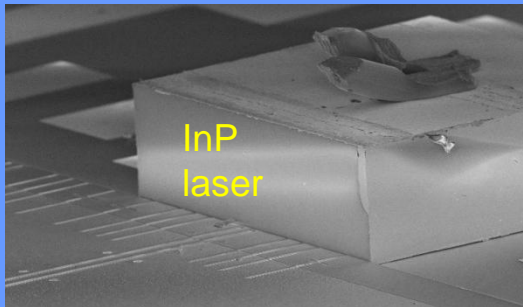
Silicon photonics (3)

DC and RF lines integrated on SOI for controlling optoelectronic chips and heaters. Up-reflecting mirrors/prisms realised on SOI and on PDs. Thermo compression bonding of optoelectronics using passive vertical alignment (± 100 nm).

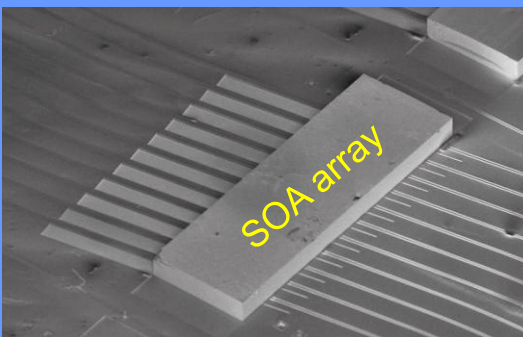
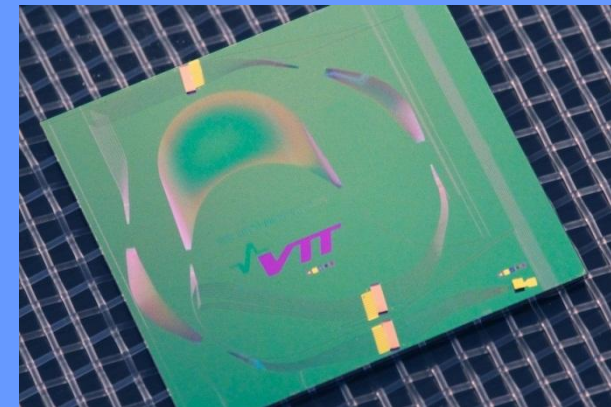
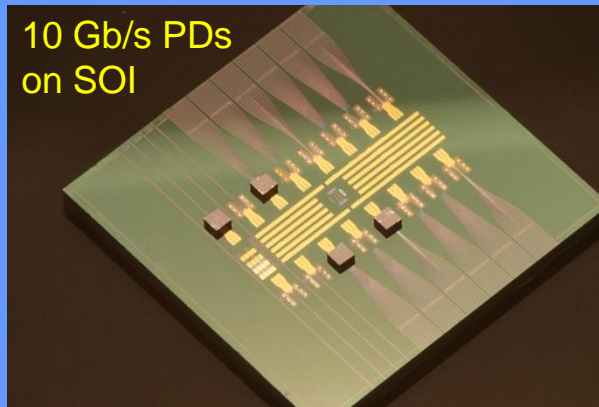


Flip-chip and die bonding

Bonding tools with automated alignment accuracy up to $0.5 \mu\text{m}$.



10 Gb/s PDs
on SOI



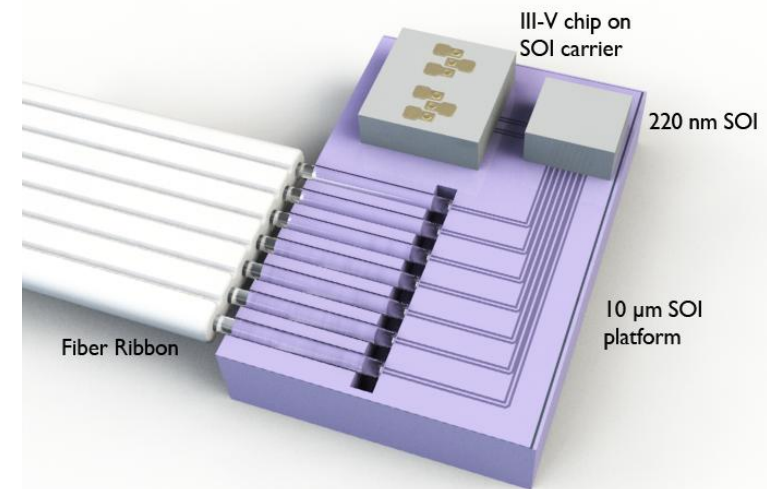
Lasers, amplifiers and photo detectors thermo compression bonded on the SOI waveguide platform using passive vertical alignment ($\pm 100 \text{ nm}$)

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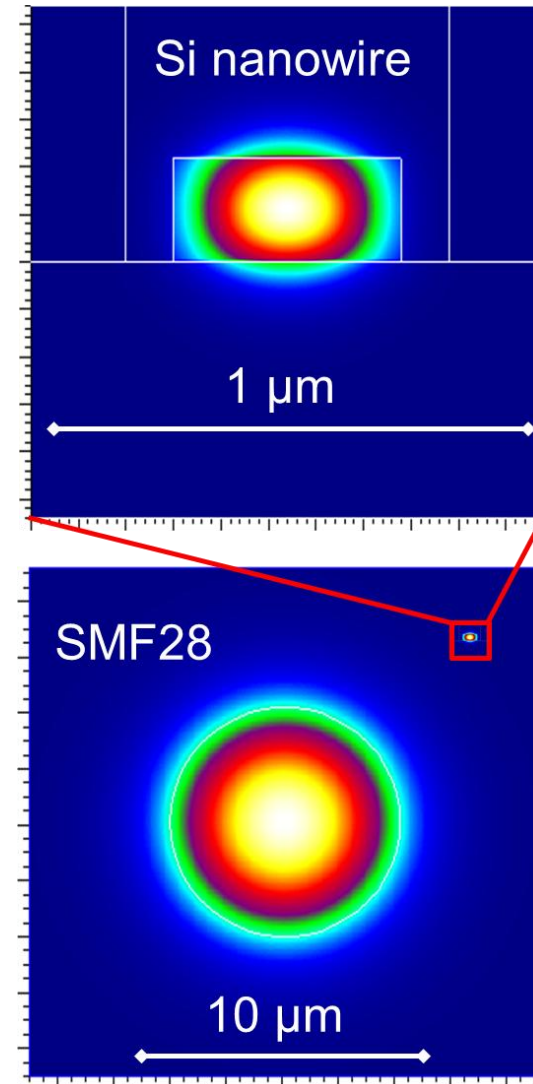
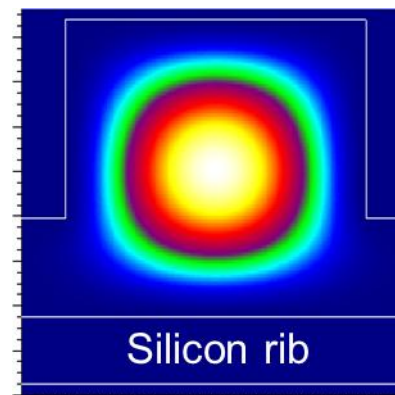
VTT's activities in Si photonics
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Packaging challenges and
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Main challenges in Si photonics

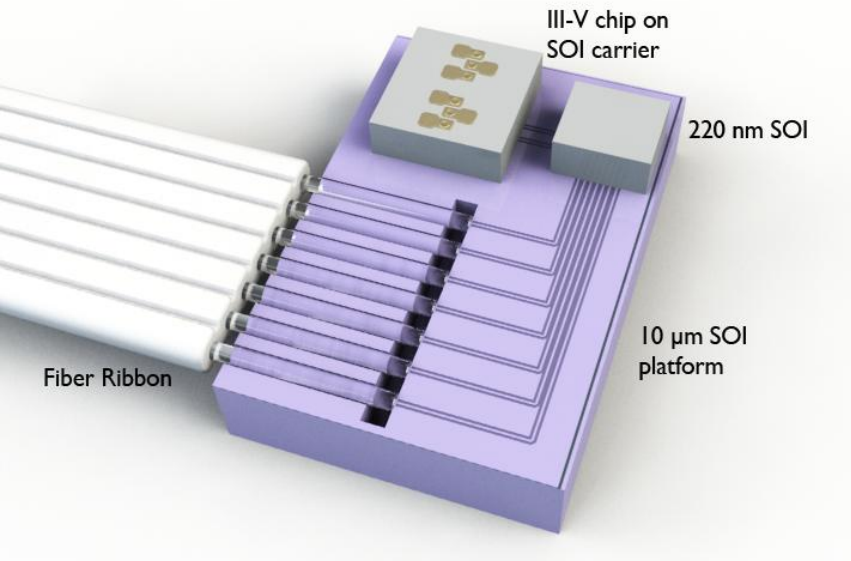
- Lack of silicon-based light sources
- Optical I/O coupling
 - Reflections
 - Mode field mismatch (size, shape)
 - Alignment accuracy ($\pm 0.1 \dots 1 \mu\text{m}$)
 - Polarisation dependency
- Temperature dependence of Si
- Killer application not yet found
- Lack of standardized technology
 - Wafer processing
 - Heterogeneous/hybrid integration
 - Packaging



Main opportunities in Si photonics

- Exploiting the knowledge and facilities built for microelectronics
- Possibility for photonics-electronics integration in some applications
- Increased level of integration compared to discrete components and non-silicon waveguide circuits
 - Lower cost
 - Higher yield
 - Smaller size
 - New functionalities
- Higher data rate, longer links and less power per bit compared to electrical interconnects
 - Card-to-card...chip-to-chip...on-chip
- High-performance sensors at low cost
- Optical computing (?)

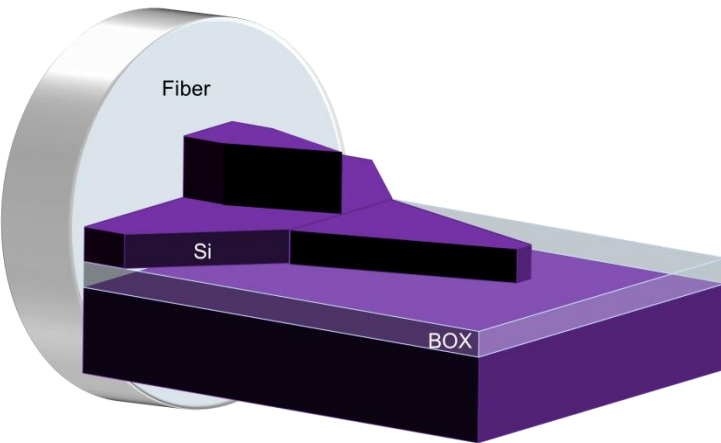
VTT's vision for silicon photonics packaging



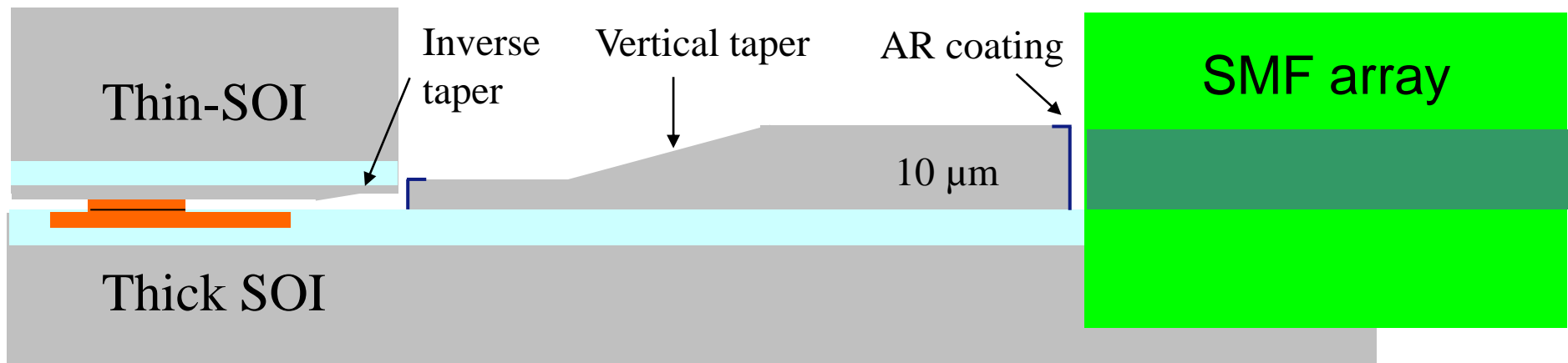
- 10 µm SOI as a generic integration and packaging platform (or interposer)
- Hybrid integration
 - Optoelectronic III-V chips
 - Thin-SOI chips
 - IC chips for control and readout
- Passive fiber alignment into V-grooves

- Packaging of ePIXfab chips (www.epixfab.eu) planned to be offered in 2013 by VTT

VTT's vision for solving the I/O coupling challenge

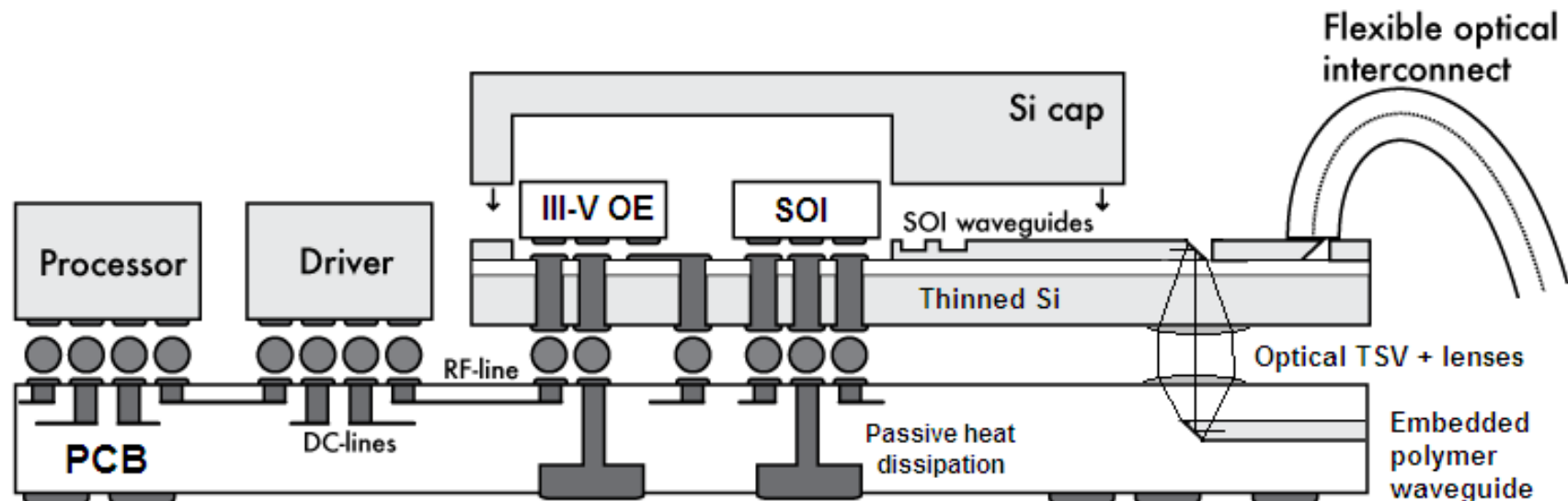


- Spot-size conversions on both SOI chips
- Horizontal end-fire coupling between both SOI chips and standard SM fibers
- Reflections minimised with AR coatings



VTT's vision for SOI module integration on PCB

- Low cost SOI modules with embedded optoelectronics/electronic chips mounted directly on PCB (or similar)
- Wafer level packaging and TSVs enable hermetic sealing
- Efficient heat dissipation through the thinned SOI substrate/interposer
- Several I/O coupling alternatives



Acknowledgments

The work presented here has been funded by the European Commission, Tekes, Academy of Finland, European Space Agency and a large number of companies

VTT's partners and collaborators related to silicon photonics:





VTT - 70 years of
**technology for business
and society**