WTMF 2019 workshop

Outcome from the 10 Technical Working Groups on Friday Morning - **video**

Driving Photonics Manufacturing

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Wednesday workshop charge [1/3]

Overview

- 01. Datacenters – Timo Aalto, Finland
- 02. Telecom - Michael Robertson, UK
- 03. Communication Space & 5/6G - Martijn Heck, Denmark.
- 04. Sensor Spectroscopy – Richard Otte, USA
- 05. Sensor Imaging – Jeroen Duis, Netherlands.
- 06. Silicon Photonics - Lionel Kimerling, USA
- 07. Silicon Nitride and Indium Phosphide – Luc Augustin, NL
- 08. Packaging - Jeroen Duis, Netherlands.
- 09. Assembly - Dan Evans, USA
- 10. Testing - Sylwester Latkowski, Netherlands

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01. Datacenters – Timo Aalto, Finland

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Wednesday workshop charge [1/3]

Define the main functional & performance requirements for the application areas in 2020, 2025, 2030, 2040?

- With which components can these requirements be met?

- Txrx/chiplet data rate: 400 Gbps in 2020 → 4 Tbps in 2030
  - Up to 4 fiber channels for 4 Tbps
- Total link power: 25 mW/Gbps (25 pJ/bit) in 2020 → 2.5 mW/Gbps (2.5 pJ/bit) in 2030
  - Modulator voltage needs to be reduced/kept well below 1 V since total power consumption depends strongly on IC output voltage
- Bandwidth density: Electronic signal from the switch chip 5 Tbps/mm by 2030, e.g. 20x20 mm ASIC (80 mm edge length) surrounded by 400 Tbps aggregate I/O data rate

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Wednesday workshop charge [2/3]

Which PIC technology routes are possible?
- *what are the (dis)advantages of these routes?*

- Faster modulators are needed, which is non-trivial
  - Mature technologies InP and SiPh need new innovation to go >100 GHz
  - New potential PIC technologies are thin film lithium niobate (TFLN) and other ferro electric materials, as well as plasmonic and polymer devices
- Scalable SDM I/O needed: Multicore fiber and high-capacity connectors/interface units
- Hybrid & heterogeneous integration
  - Interposers, co-packaged (multi-chip) modules, chips on board etc.
  - III-V on SiPh integration
  - Dielectric waveguide layers on SOI wafers
- Non-pluggable chip solutions for line card
  - Permanent fiber pigtail for PIC or a PIC-integrated fiber connector

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Wednesday workshop charge [3/3]

What are the main roadblocks/challenges that are foreseen within these technology routes?

- Heat generated on line card: Specified temperature range from 40 to 80°C in 2030
- Power consumed by electronics and electronic interconnect dominates total power consumption (RF/microwave designers need to be involved)
- How to increase device analog bandwidth above >100GHz?
- Transducing E→O and O→E close to the electronic switch chip
- How to handle Tbps signals (only ~100 GHz electrical, but >100 GHz optical)
- Low cost optical chip-to-fiber coupling (active or passive alignment)
- New form factors for line cards in 2030? (front plate or rack size changes?)
- Electronic package evolution over the next decade (involving PIC integration)
- Involving electronics industry and engineers in photonics design (RF, packaging, testing etc.)
- Integrated light source in SiPh with open access industrial supply chain
- Integrated optical isolator or circulator on PIC
- Reduction of optical and electrical parasitic parameters (noise, light scattering etc.)
- Assembly design kits (ADKs) needed

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02. Telecom - Michael Robertson, UK

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Telecom

- Started with review of last year's conclusions on Telecom
- Decided to focus on long haul coherent – short haul and access being close to datacoms

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Topics

- PICs Telecom Focus:
  - Long distance
  - Less electrical power consumption
  - More data
  - Less cost
  - Decrease size
  - Increase reliability
  - Packaging (simplicity/cost)

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Future requirements

- Whats required for the future
  - Low latency
  - High bandwidth
- Future Requirements
  - 2020
    - 400 Gbit/s/lambda
    - current standard
  - 2025
    - 1600 Gbit/s/lambda
    - Try to keep power consumption as currently
  - 2030
    - 12.8 Tbit/s/lambda (needs to be confirmed by market analysis/ fibre limitation ?)

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Future transceiver components

- 2030
  - Modulator bandwidth of 120 GHz, low Vpi < 1 V
  - New reliable material systems and integration platforms
  - Driver-modulator Co-design, integration
  - Matching detectors high responsivity, low dark currents across L and C band
  - High optical power narrow linewidth lasers for multiple bands
  - High operating temperature (150° C) lasers
  - stable lasers with WL-locking
  - polarization rotators and isolators > 30 dB ER (integrated components)
  - low NF-Amplifiers < 5 dB (integrated components)
  - small footprint electro-optical packaging (DCO-like)
  - low IL, low crosstalk, pol-independant MUX / DEMUX

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Which PIC technology routes

- 2025
  - InP alone might suffice
  - Combination of Si and InP photonics
    - Si passives and InP active components
  - Electronics needs to be close to the photonic components
    - Waferbonding?
    - Flip-chip?
- 2030
  - New material integration platform for lasers
    - Quantum dots?
    - Hybridly-Intergrated External/extended cavity
    - More efficient TEC
  - Polymer modulators?
    - Stable and reliable polymer required
    - Non hermetic seal
  - Integration with diamond as heatsink
  - LiNb modulators? Ok if integration suceeds
  - Si-modulators? May be fundamentaly challenging to reach high bandwidth and low loss
  - InP-modulators? May be fundamentaly challenging to reach high bandwidth and low loss

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Roadblocks

- 2030
  - Size-Footprint
  - Modulation speed
  - Power consumption
  - High Temperature performance
  - Phase/amplitude noise
- 2040
  - Technology development highly speculative for this time

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Wednesday workshop – 03 - Space communications and 5/6G

03. Communication Space & 5/6G - Martijn Heck, Denmark.

Katarzyna Balakier, Martijn Heck, Peter Maat

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Some functional requirements discussed

- Satellite communication
  - GEO – 36000km to ground;
  - LEO – 200 – 1000 km;
  - RF to RF
  - **FSO**
  - **Intra-satellite, on-board;**
  - SKA telescope signal transmission;
  - Tethers (fiber links) between Photonic Swarm, 10-100 Gbps plus clock distr.; 100k pieces; ADCs integrated;
- Signal processing
  - ADC
  - **Filtering**
  - Frequency conversion
  - channelization
- Beam forming

Underlined bold selected for break-out sessions

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Fiber optic links for space (1)

Radio-over-fiber

- Now: coax, 1 – 40 GHz (above 10 GHz $$$), EM interference, weight, distance (~1m @ 10GHz)
  - Telescope: analog for telescopes (<1 GHz), phase and amplitude (baseband)
  - Communications, remote sensing: satellite (~10 GHz), broadband (< 10 GHz)
- Future: req. <1W, SFDR 40 dB, 1 GHz (now), (future, 2030 50 dB over 20 GHz), link gain 0 dB;
  - USB connector now is defined for RF; attractive for power supply to connector;
  - 40-GHz analog bandwidth with USB-like connector (communications, repeater, remote sensing)

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Fiber optic links for space (2)

- (electronics →) laser (+ modulator) + fiber coupler + fiber + fiber coupler + detector + electronics
- Issues:
  - Cost of modulators → target €10 per mod
  - Cost of high-bandwidth DMLs
  - Get rid of TEC
    - Temperature stability of amplitude (0.001 dB/K) required
  - >40-GHz component bandwidth

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RF Filter (1)

Filter (RF filter)	Related attributes of photonics platform (StotA)
- Frequency range Ku/ Ka	- 10-13GHz /20-30GHz (depends on the Mod and PD)
- Configurability and speed	- Configurability and speed .. Continuous/microsec
- Bandwidth	- ESA req: 36, 72, 108 (72 MHz in photonics shown), China req: 120 MHz
- Rejection ratio	- ...??see reference
- Ripple	- ..?? See reference
- Power consumption	- Power consumption...200mW, 4uW (heater/PZT(future)), tune and set
- Insertion loss IL	- Insertion loss IL ..... propagation loss x distance
- Crosstalk	- Crosstalk < 60 dB
- Order: (8th order)	- 8th order
- Size	- Size .....now 30x40 mm 5x5 mm（future）
	- For photonics platform: RF-to Photonics and Photonics to RF = modulator, laser and detector performance:... RF Photonics chapter.

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BENCHMARK: Reference state of the art papers: Taddei et al. 2016 & 2018, ESA Final Presentation Days TAS on 72 MHz & 36 MHz.

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Free-space optical (1)

Define the main functional requirements for the application areas in 2025, 2030, 2040?

- Satellite2satellite
  - 2025 10 Gbps on single wavelength (QPSK)
  - 2030 100 Gbps WDM (PIC)
  - 2040 500 Gbps WDM (PIC)
  - 2040 100 Gbps single wavelength but without cooling
  - 1550 nm
  - MZM / EAM
  - 2030 SOA with 2 W optical power
  - 2040 monolithic integration of laser, modulator and high power amplifier

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Free-space optical (2)

Which possible solution routes are possible? And what are the (dis)advantages of these routes?

- Components without TEC
- Novel packaging techniques, such as ceramic (Adv: lower mass, Dis: long time development)
- BPSK -> QPSK
- Dual polarization and DQPSK

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04. Sensor Spectroscopy – Richard Otte, USA

Richard Otte
José Pozo
Wednesday, June 12, 2019

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Sensors-Spectroscopy Workshop Participants

- Richard Otte otte@Promex-ind.com
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- Peter Goetz peter.goetz@nrl.navy.mil
- John Harvey j.harvey@southernphotonics.com
- Sami Musa sami.musa@va-photonics.com
- Rick Sparks rickface27@gmail.com
- John Eisses j.eisses@berenschot.nl
- Let me know if you are missing !!

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Spectroscopy with Photonic Integrated Circuits

- **Analyzing Multiple Wavelengths of light to determine how some Target media influenced their relative intensity.**
- **So, can these functions be implemented with PICs ??**

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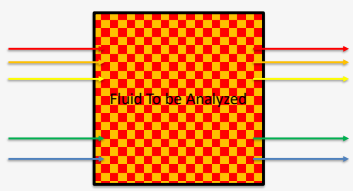
Generic Spectrometer

- Multiple Color Stimulation



- Relative Color Intensity
- Seek Signature Match
- Store Signature

How Can We Implemented This With a PIC or PICs ??

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Needed Functions

- Two Typical sources of light to be analyzed
  - Generating light by stimulating a target
    - an object or fluid
  - Radiation from a source of interest
- Capturing the light to maximize signal strength
- Splitting the light by wavelength (demultiplexing !!)
- Measuring the intensity by wavelength
- Comparing the relative intensities
- Comparing the relative intensities to a "signature"
- **These functions can be done with PICs and electronics !!**

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Workshop Notes #1

- Raman Spectroscopy was discussed a lot
- See Peter Goetz's Presentation from yesterday.
- Implementing Raman spectroscopy requires a lot of filtering to separate the pump wavelength from the Raman signal wavelengths.
- Designing materials to implement this "absorption from a waveguide architecture" that are sensitive to a specific, desired compound is complex.

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Workshop Notes #2

- The requirements and physical architecture for a spectrometer ***depends heavily on the Application!!***
- BUT Basic Functions Needed are:
  - A white light source is the most general and needed stimulator.
    - **A Wideband sharp Tunable laser.**
    - **A high count Comb laser is needed.**
    - **Overlapping LEDs in wavelength.**
- **Wideband demultiplexers** that have sharp wavelength separation and low enough loss to measure intensity by wavelength for each application !
- **Variety of Optical Filters**
- Sensitive Detectors
  - **Broadband: visible through far IR**
  - >2.3 micron wavelength are hard and needed for chemical sensing.
- Appropriate Electronic Signal Processing

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Workshop Notes #3

- Next Steps
  - Develop a List of Potential applications
  - By Application Evaluate the needed:
    - Light source to generate the beam to be analyzed
    - Fluid and sample presentation method
    - Optical stimulation method
    - Macro, Post stimulation beam filtering
    - Wavelength separation sharpness needed
    - Detector sensitivity and wavelength needed
    - Electronic signature processing needed
  - Develop some "Typical (standard ??) Platforms"

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Workshop Notes #4

- Existing and Potential Applications
- Cigarette pack sized spectrometers are available utilizing gratings which controls the size for ~$5K.
- Blood is analyzed to find specific proteins, microrganisms or compounds.
- A Blood Oximeter utilizes 2 wavelengths.
- A commercially available Glucose level monitor utilizes 10 micron wavelength to see deep below the skin.
- A $50 air quality device detects 2.5 micron air particle detectors.
- CO2 sensors might sell in some geographic areas.
- Water quality; nitrate content can be measured at 220 nm but that wavelength is hard to implement. What might enable detecting of nitrates

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WTMF 2019 workshop

05. Sensor Imaging – Jeroen Duis, Netherlands

Jeroen Duis, Erik Teunissen

Arne Bentfeldt
Giuseppe Coppola
Luc Augustin
Daniel Evans
Victor Dolores Calzadilla
Makoto Okano
Axel Schönau

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Sensors – imaging Results

Applications	**OCT**
	Lidar (phased array lidar)
	THz-imaging
	Thermal imaging (bolometers)
	IR-imaging
	Fluorences scanning
	Two-photons imaging
	Night-viewers
	Scanning 2D, 3D, 4D
	Defense (lidar under water)
	X-ray sensors for medical applications
	Shape reconstruction (medical reduction of CT radiation)
	Preasure sensing
	Range finder
	Gas sensing
	Process monitoring (end-point detection)

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Sensors – imaging Results

Properties	**Material dependent**
	Scanning 1D, 2D, 3D
	Multi-wavelengths
	Pulse duration
	Resolution
	Depth penetration
	Power
General requirements	**Regulation**
	Life-time
	Time-to-market
	Safety
	Export regulation

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Top 3 that needs end user input

Lidar, customers: Bosch, Mercedes-Benz, Lumentum, Infineon, Thales, OHB

Functional and performance requirements	2020	2025	2030	2040
	industrial	Aerospace High-end automotive	Mainstream automotive	medical (high-end)
Material dependent				
Scanning 2D, 3D, 4D	2D	2D	2D, 3D, 4D	3D
Multi-wavelengths	1550 nm	1310 nm, 1550 nm		
Pulse duration	0.00001 duty cycle			
Resolution	0.25°	0.1° 30 cm @ 200 m	0.1° 30 cm @ 200 m	
Depth penetration				
Maximum power	1 W (mean power)	3.5 W (mean power)		

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Top 3 that needs end user input

OCT (spectral domain), see p. 14 in Biosensors and Medial Chapter

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Top 3 that needs end user input

Thermal Imaging, customers: Teledyne Dalsa, Brolis, Xenics, Flir

Functional and performance requirements	2020	2025	2030	2040
	industrial			
Material dependent				
Scanning 1D, 2D, 3D				
Multi-wavelengths				
Pulse duration				
Resolution				
Depth penetration				
Power				

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Wednesday workshop charge [3/3]

- What are the main roadblocks/challenges that are foreseen within these technology routes?
  - The scanning method to come to multidimensional images
    - Urgend need of **end user input** and their expertise
    - Eg: how will the multidirectional beam stearing be performed (chip level, assembly level, package level)

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WTMF 2019 workshop 06 – Silicon Photonics

06. Silicon Photonics - Lionel Kimerling, USA

Prof. Lionel Kimerling (AIM Academy – MIT)
Prof. Roel Baets (Ghent University – imec)
Dr. Abdul Rahim (ePIXfab – Ghent University)
Dr. Ajey Jacob (Global Foundries)

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Silicon Photonics Chapter

- Core writing team:
  - Prof. Lionel Kimerling (AIM Academy – MIT)
  - Prof. Roel Baets (Ghent University – imec)
  - Dr. Abdul Rahim (ePIXfab – Ghent University)
  - Dr. Ajey Jacob (Global Foundries)
- List of reviewers of the current chapter: Gunther Roelkens, Ghent University – imec, Philippe Absil, IMEC, Christophe KOPP, CEA-Leti, Stéphane BERNABE, CEA-Leti, Ségolène OLIVIER, CEA-Leti, Bertrand SZELAG, CEA-Leti, Benoit CHARBONNIER, CEA-Leti, Timo Aalto, VTT, Pascual Munoz, VLC Photonics, Cullum Littlejohns (Cornerstone), Eric Mounier (Yole), Kresten Yvind (DTU), Aaron Zilkie (Rockley Photonics), Meint Smit (TU Eindhoven), Benjamin Wohlfeil (ADVA Optical Networking), Anna Lena Giesecke (AMO GmbH), Klaus Petermann (TU Berlin)

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Silicon Photonics Chapter

- Background: The current chapter is a merger of the IPSR Monolithic Integration TWG chapter from 2016 and Photon Delta Roadmap template
- Challenge: The two documents have a different mindset
  - Focus on HPC/DC cabling using monolithic EPICs → Application driven
  - Focus on silicon photonics technology evolution → Technology driven

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Silicon Photonics Chapter

- Strengths:
  - Covers with sufficient details the various flavors of silicon photonics
  - Coherence of the content as the overall chapter is drafted is by a small team
  - Endorsements from academic and industrial stakeholders (but not from all – definitely more is needed)
- Weakness:
  - The document is does not fully fit the roadmap definition
  - The basis for the predictions and what methodologies are required to meet the predicted goals are missing
  - Some key developments are overlooked (for example: silicon plasmonic modulators)

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Thursday workshop charge [1/4]

- What are the strongest and weakers points of the chapter?
  - Weaknesses
    - Implicit marketing
    - Length (20 – 35 pages): make it concise
    - Check table completeness
    - Cohesive tables with other technologies
    - Redundancy removal
    - Check overlap with other chapters and move relevant stuff there
    - Ordering:
  - Strengths
    - Milestones and timelines
    - Coverage is complete

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Thursday workshop charge [2/4] → plenair

- Also based on the Wednesday application sessions and what is already published in the final IPSR-I draft: Key technology development routes for your field for 2025, 2030, 2040?
  - Coupling (loss, bandwidth, PDL)
  - Modulator size, bandwidth, efficiency, loss
  - High power handling
  - Isolator
  - Low PDL architectures
  - Integrated/on-chip laser source and architecture

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Thursday workshop charge [3/4]

- What are the main roadblocks/challenges that are foreseen for your field in each development route and is there much overlap between those?
  - Low cost SOI wafers
  - High resistivity and high thermal conductivity substrate for RF
  - Standardization of the interposer
  - Hybrid integration of electronics and photonics

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Thursday workshop charge [4/4]

- Which possible solution routes are envisioned to tackle these challenges within your technology field for 2025, 2030, 2040?
- Routes to meet challenges
  - High bandwidth density → smaller modulators → WDM

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07. Silicon Nitride and Indium Phosphide – Luc Augustin, NL

Luc Augustin
Sami Musa

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Thursday workshop charge [1/4]

- What are the strongest and weakest points of the chapter?
- Alignment with other technology chapters:
  - Short introduction
  - Need to quantify parameters
  - Not application specific
    - Bussiness decision to go for application critical parameters/requirements
  - Review of the chapter:

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Thursday workshop charge [2/4]

- Also based on the Wednesday application sessions and what is already published in the final IPSR-I draft: What are the key technology development routes for your field for 2025, 2030, 2040?

- Operating temperature 150°C
- Low-linewidth laser, feedback insensitive
- Polarization rotator>30dB
- Isolator >30dB
- Higher integration density

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Thursday workshop charge [3/4]

- What are the main roadblocks/challenges that are foreseen for your field in each development route and is there much overlap between those?

- Integrated isolator
- Higher integration density
- Larger wafersize (6" - 8") required for future applications (e.g. Lidar) → significant investments in existing infrastructure

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Thursday workshop charge [4/4]

- Which possible solution routes are envisioned to tackle these challenges within your technology field for 2025, 2030, 2040?

- Yield increase → ability to remove test as much as possible
- Membranes as route to increase integration density
- InP on GaAs electronics for high speed

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WTMF 2019 workshop SiN

07. Silicon Nitride and Indium Phosphide – Luc Augustin, NL

Luc Augustin
Sami Musa

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Challenges

1. The extension of the guiding range from 0.4-7 µm by means of Si3N4 membranes.
2. The adoption of mix & match lithographies, combining stepper photo-lithography with wafer scale Electron-Beam Lithographies (EBL)
3. Further development of process allowing for a) power-efficient tuning mechanisms, such as piezo and MEMS actuators and b) the co-integration with other CMOS compatible materials for high speed electro-optical modulation [29]
4. The development of transfer printing processes for the hybrid integration of sources and detectors, at the different wavelength ranges in 0.4-7 µm [20]
5. To increase level of integration Light sources and detectors need to be heterogeneously integrated onto the SiN platform.

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Overlaps

- Overlaps with chapters on: Substrate, integration of light sources detectors with this platform overlaps with the substrate chapter

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08. Packaging - Jeroen Duis, Netherlands.

Chairs:
Peter O'Brien, Peter Maat, Jeroen Duis

Participants
Michael Lebby
Jan Mink
Michael Robertson
Thomas de Boer
Peter Goetz
Yanfeng Fu
Zhaohan Liu

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Thursday workshop charge [1/4]

- What are the strongest and weaker points of the chapter?
- Unreadable to long document -> not catching the audience with to much information
- Chapters are written in isolation
  - Example -> Spot Size Converter
    - Packaging people require information on the mode size
    - Foundries are not delivering the information to start modeling the interface
- Overlap with other chapters, Packaging, Assembly, Interconnect
- Look at timelines of pictures and references (eg page 360, figure 13)
- List of definitions (packaging, assembly, co-packaging, Hybrid vs Heterogenious integration) should be consitantly used within the chapters
- Put definitions on wikipedia to get better commonality

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Thursday workshop charge [1/4]

- Image (Schematic) with different colours indicating the definitions within the book
- Fiber array variations, true positioning and pitch reduction
- Polarisation Maintaining fiber / properties
- TRL Level for different sections not clear

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Thursday workshop charge [1/4]

- Economic roadmap of packaging: where is the cost of packaging (break down)
- Throughput volumes are missing -> volume to be assembled
- Lower cost hermetic packaging ->
  - Gold box alternatives
  - semi hermetic packaging
- Increased reliability for datacenters is required

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Thursday workshop charge [2/4] → plenair

- Also based on the Wednesday application sessions and what is already published in the final IPSR-I draft: What are the key technology development routes for your field for 2025, 2030, 2040?
  - Hermeticity or not
  - Cost / scalability
  - Fiber coupling (photonic interfaces, fiber development)
  - Active / passive cooling -> thermal stabilisation

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Thursday workshop charge [3/4]

- What are the main roadblocks/challenges that are foreseen for your field in each development route and is there much overlap between those?

- Funding of the development
- Volumes to get the required cost reduction
- Alternative solutions become dominant (lidar / mm wave, photonics / electronics 5G)
- New thermal cooling techniques
- Cleaning methods for the chips

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Thursday workshop charge [4/4]

- Which possible solution routes are envisioned to tackle these challenges within your technology field for 2025, 2030, 2040?

- Economic roadmap of packaging
- Expanded beam -> bringing photonics tolerances to the mechanical fixtures (3 – 5 micron)

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09. Assembly – Dan Evans, USA

Dick Otte – Promex
Paul van Dijk - LionX
Dan Evans - Palomar Technologies (Presenter)

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Workshop Participants

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Assembly Chapter Review

Strong Points:
- Good overview of the state of the art

Weak Points:
- Need to develop research direction in more depth

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Assembly Critical Roadblocks / Challenges and Quantified Values

Feature	A	B	C	D	E
Better optical Coupling efficiency per interface [dB]	5	3	1	0.5	0.1
Tighter assembly tolerances [um]	5	3	1	0.5	0.1
Higher throughputs [min/assy]	3	2	1	0.5	0.1
Fewer parts (assembly steps in a module)	25	15	10	5	3
Smaller parts [umxum]	10000x10000	1000x1000	250x250	100x100	50x50
Reliability (hours) [or failure in Time]	1000	2500	10000	25000	200000

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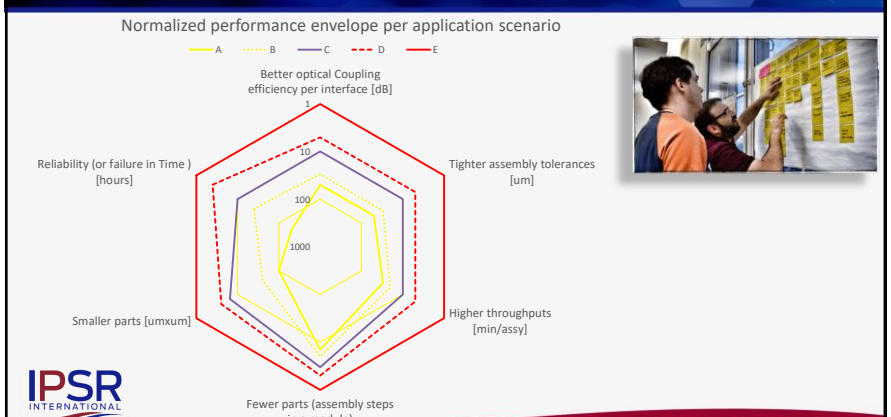
Assembly Critical Roadblocks / Challenges and Visualization



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Possible Solutions

- low cost alignment
- positioning tolerance
- better laser die(e.g. mode field)
- reliability of coupling
- high accuracy of fiber array
- higher throughput

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Next Steps

- Add timing to performance envelopes

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WTMF IPRS-I 2019 workshop

10. Testing – Sylwester Latkowski, Netherlands

Electronic Photonic Test Breakout Session - Highlights
Thursday 13th June, Berlin, Germany

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Driving Photonics Manufacturing

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Participants

- **Martin** Möhrle, HHI , Germany
- **Makoto** Okano, AIST, Japan
- **Tobias** Gnausch, Jenoptik, Germany
- **Erik** Teunissen, Berenschot, The Netherlands
- **Axel**, HHI, Germany
- **Geert**, Fontys, The Netherlands

- **Ignazio** Piacentini, Ficontec, Germany / Ireland ☺ (Chair)
- **Sylwester** Latkowski, PITC - TU/e (Chair, TWG responsible)

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Flavour (Theme)

TEST FOR VOLUME MANUFACTURING

AUTOMATED HIGH VOLUME TEST

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Grand challenge: beauty & the beast

- **Characterization is a 'beauty'**
  - Delivers lots of data and information
  - Good for low volume, MPW,
  - Essential for prototyping, R&D at a 'startup-phase' of a product
  - **Resource demanding, volume 'unfriendly'**
- **Test is the 'beast'**
  - Needs to be swift (s/test = $$$)
  - Essential at early production stages (WLT)
  - A must if volumes are considered seriously

'Characterization ≠ Test', Ignazio

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Test in PIC production - WLT

- **Ideally as much as possible at wafer level**
  - Electrical + optical
  - RF: available but is it really essential here?

'How much time/$ can be dedicated to test?' Sylwester

- **Highly automated**
- **Highly paralleled**
  - Multiple electrical and optical IOs (simultaneously)
  - Multiple-sites

' Table 64 needs to be updated' Makoto
First document update!
~~20 -> 50 ->100~~ 256 -> 512 -> 1024

- **Modular ATE**
  - Tools
  - Test equipment

Dramatically reduced NRE and footprint, S.

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WLT: Hybrid probe-cards

2020: Electrical-optical probe-card
- **Out of plane coupling e.g. gratings**
- Large MFD, alignment tolerant, **tens** of optical IOs
- DC + Optical
- Integration with AT (+1Y?)

'Such solution doesn't exist now and there seems to be a market for', Tobias

2025: Electrical optical probe-card NG
- **In-plane, edge coupling**
- **100+** optical IOs
- Small MFD, thither alignment accuracy
- DC+RF Optical

'Grating couplers... ehmm', Martin & Sylwester
' SiPh folks eventually want them too', Makoto

2030: Optical solder bumps
- **1000+ optical IOs**
- Mixed signals
- Test and assembly suitable (flip-chip?)

How are and when we will get 1000+ optical IOs?
***'Optical Solder bumps' -** IPSR-I Winter 2019, Tokyo*
2040 should be OK...
"I'll be quite advanced in age' then, Ignazio
'Let feel like in SF movie, you all heard John E', Sylwester
"We all seen Vanguard/KIT PHBs' so there is something', Martin
2030 we will have some!

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BIST: Built-In-Self-Test

2025: On-chip diagnostics

- Temperature monitoring
- Open, short CKT

"Chips could test themselves and even more' , Ignazio, Sylwester

2030: Self-calibration

- Parameter monitoring e.g. temp, power, lambda
- Feedback + correction signal
- Somewhat increased El Ph integration would help

'Sylwester and Ignazio possibly have watched too many SiFi movies...' probably all others... in their thoughts

2040: Re-purpose, Adaptive operation modes

- Failure-prevention
- Efficiency management e.g. Energy saving vs Performance
- Adaptive countermeasures
- Advanced logic needed -> Advanced (digital) El-Ph co-integration will be needed

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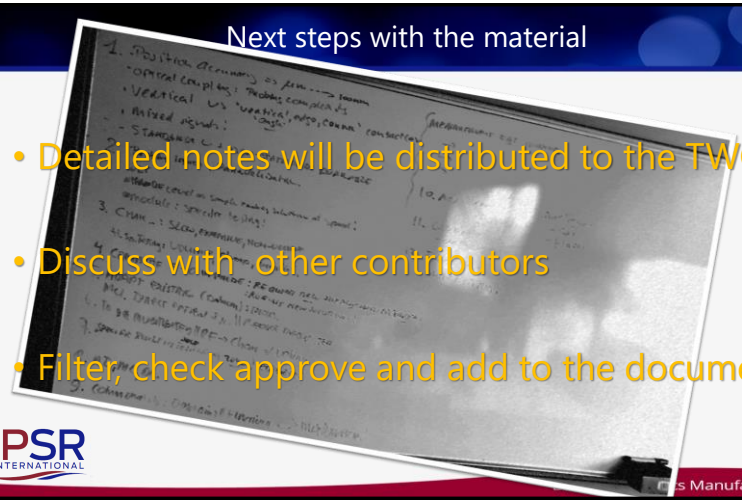
Next steps with the material



- Detailed notes will be distributed to the TWG
- Discuss with other contributors
- Filter, check approve and add to the document

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