Enabling integrated active photonics with transfer printing

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Outline

• Opportunities for photonics
• Integration strategy
• Examples of transfer printing
• Scaling with pilot line
• Outlook
Opportunities for photonics
Opportunities for photonics

- Highly versatile to cover any wavelength from UV to NIR
- Critical element in many everyday applications
  - Communications, illumination, sensing, power, medical,..
  - Only solution for high bandwidth, high density interconnects
- Expanding applications
  - Data centres (communication and storage)
  - Backhaul for 5G
  - LIDAR
- Key technology for Europe
  - Optical components and systems
    - €7.8B which is 32% of the global market

Optech Consulting, Market Research Study Photonics 2017; photonics21.org
Challenges for photonics

• Applications with high volume potential demand low-cost
  – Photonic devices individually packaged comprising 70% of cost
• Applications need sources, waveguiding, modulating, sensing, etc.
• Photonic subsystem
  – Multiplicity of materials and device structures for optimum performance
• Need an effective integration strategy to make un-compromised photonic circuits
• Is there an equivalent platform as CMOS for electronics?
Platforms for photonics (EU)

- InP
- Silicon Photonics (CEA-LETI; imec,..)
- SiN (LioniX, imec)
- Mid infra-red
- Packaging
InP materials for 1550nm light

• Wafer diameter typically 75mm-100mm
  – Quality down to material science and engineering
• No critical imperative to improve (invest)
• Why?
  – One 75mm wafer can deliver ~20,000 lasers
  – Each laser can deliver 10Gbps
    → 200 Tbps available per wafer
• Size mismatch with silicon wafers and other platforms
Integration strategy
Vision for integration strategy

- Produce the optimum components in the most appropriate environment and then heterogeneously integrate with the platform in parallel and scalable manner.

III-V device fabrication

Specialist material preparation

Sensor device fabrication

Platform fabrication (e.g. Si photonics)

Heterogeneously Integrate

Complete subsystem
Transfer print integration

- **Heterogeneous integration** by transfer of devices (or materials) from a native substrate to a chosen new substrate

- Combination of:
  - Inking and printing
  - Substrate separation

- Breakthrough* was the registration of devices and the use of massively parallel, deterministic transfer of the devices

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*E. Menard, R. G. Nuzzo, and J. A. Rogers, Appl. Phys. Lett. 86, 093507 (2005).*
Transfer print steps

Preparation of devices

Pickup of devices

Transfer of devices

Printing devices
Transfer print implementation

• Tools, processes and patent portfolio established by X-Celeprint
• Based at Tyndall and North Carolina
Advantages for micro-Transfer Printing

• Massively parallel (>10,000 devices transferred per 45s cycle)
• Position tolerance of ±1.5μm at 3σ
• Different types of devices or materials can be printed close to each other
• Efficient use of source materials
• Requirements
  – receiving location is locally flat (provide by polymer adhesive)
  – prepare devices with high contrast alignment marks
  – connect up devices
Examples of transfer printing
Example 1: GaAs lasers on ceramic wafers

- Ceramic wafer platform used to produce read-write heads for hard-drive magnetic recording
  - ~5M ‘heads’ produced per day worldwide
- A laser is needed to implement Heat Assisted Magnetic Recording (HAMR) but at minimal additional cost

http://blog.seagate.com/business/seagate-continues-to-lead-as-hamr-technology-advances/
Integrate laser directly on head

- Print coupons of laser material to target
- Post-process into lasers on new substrate

Example 2: InP lasers for Silicon Photonics

• Hybrid circuits based on Si Photonics
  – Complexity growing massively on 200mm wafers
  – Pilot lines at imec, CEA-LETI, AIM, A*STAR-IME,
  – Multiple commercial foundries

• Clear solution for manufacturing photonic integrated circuits in a similar manner to electronic circuits

• Crux – how to include amplification
  – Laser as power source (external)
  – Laser as oscillator (on chip)
Example 2: InP lasers for Silicon Photonics

- Lasers can be integrated by:
  - evanescent coupling
  - butt coupling
Transfer print project (TOP HIT)

- H2020 EU funded project in Smart System Integration

Transfer-print OPERations for Heterogeneous INtegration (TOP-HIT)

www.tophit-ssi.eu
InP laser preparation

Tethered lasers on InP substrate

Tether

Bottom of released coupon

Lasers on Si substrate

Laser on Si

Laser cross-section

1550nm laser integration

- 1550nm laser integration
- Buried Oxide
- Silicon substrate
- Silicon device layer
- Oxide over-cladding
- III-V laser
- Laser
- Si waveguide
- Laser Si photonics facet
- Out-coupled spectrum
- Waveguide modes
- Aligned laser
- SEMICON EUROPA
- 14-17 NOV 2017 MUNICH GERMANY
Integrating silicon electronics

- Circuits design on X-FAB foundry process

Positional accuracy better than ±1μm in x and y

Silicon IC printed on a functional substrate
**Example 3: Display concept**

**Plastic or glass substrate:**
Light, flexible, robust

**R/G/B µLEDs:**
Low power consumption and bright, defect tolerance

**µICs:**
CMOS performance, embedded memory and novel design concepts
* the printed µIC should control a cluster of pixels

**Transparent**
* Fine and/or transparent wiring level

**Room to do more!**
The sparsely integrated µLEDs allow for new functions: µ-sensors, power harvest, gesture sense, image capture, RF, etc...

Passive Matrix MicroLED Display

8 x 15 µm MicroLED

30,000 MicroLEDs on glass

Flexible Plastic Micro LED Displays

- 100 BBB x 100 pixels
- (3 blue LEDs per pixel)
- 100 µm pixel
- 10,000 posts on stamp
- 3 print operations

Prototype display with microscale 180nm CMOS LED drivers within each pixel.

six µ-iLEDs and two µ-ICs in each pixel.
412 transistors per pixel; 1.8V & 5V, 180 nm CMOS.
Digital row and column inputs; current set in µ-ICs.

Scaling with pilot line
Making the technology foundry accessible

• Transfer the µTP-technology to an industrial environment
  – Bridging the “Valley-of-Death” to industrialization

• µTP pilot line in manufacturing environment for open access
  – Development of design rules (DR) and its implementation in Process-Design-Kits (PDK)

• Development of processes for heterogeneous system integration for CMOS and MEMS wafers
  – Realization of processes for source wafer preparation, transfer printing and post-processing on 200mm silicon wafers

MICROPRINCE Grant Agreement No. 737465
Microprince project

- Technology demonstration for five defined target applications for magnetic and optical sensing and photonic systems

WP7: Dissemination, Communication, Exploitation and Standardization (Lead: IMWS)

WP2: Micro-Transfer-Printing for High Sensitivity Magnetic Sensors
   (Lead: MLX TLO)

WP3: Micro-Transfer-Printing for Optical Sensors
   (Lead: XFAB)

WP4: Micro-Transfer-Printing for Silicon Photonics
   (Lead: HUA)

WP5: Micro-Transfer-Printing of LED Devices
   (Lead: MLX DE)

WP6: Micro-Transfer-Printing for Biomedical Implant Applications
   (Lead: IMEC)

Strengthen European Electronics and MEMS Industry

Key Application Areas
- Smart Mobility
- Smart Society
- Smart Energy
- Smart Health
- Smart Production

WP1: Design and installation of the µTP pilot line (Lead: XMIF)

- Specification, set-up and installation of the pilot line for high volume production in a MEMS foundry environment
- Development and providing of general process for manufacturing

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The future with micro transfer printing

• Enabling low-cost, user-designed photonic sub-systems
  – No need to be an expert in semiconductor physics or device technology
  – Verification software
• Applicability and versatility of photonics maintained
• Compatibility with existing platforms
• Photonics not a stand-alone technology
• Vast range of new opportunities for photonics by using transfer printing
Thanks to you for listening our collaborators our funders