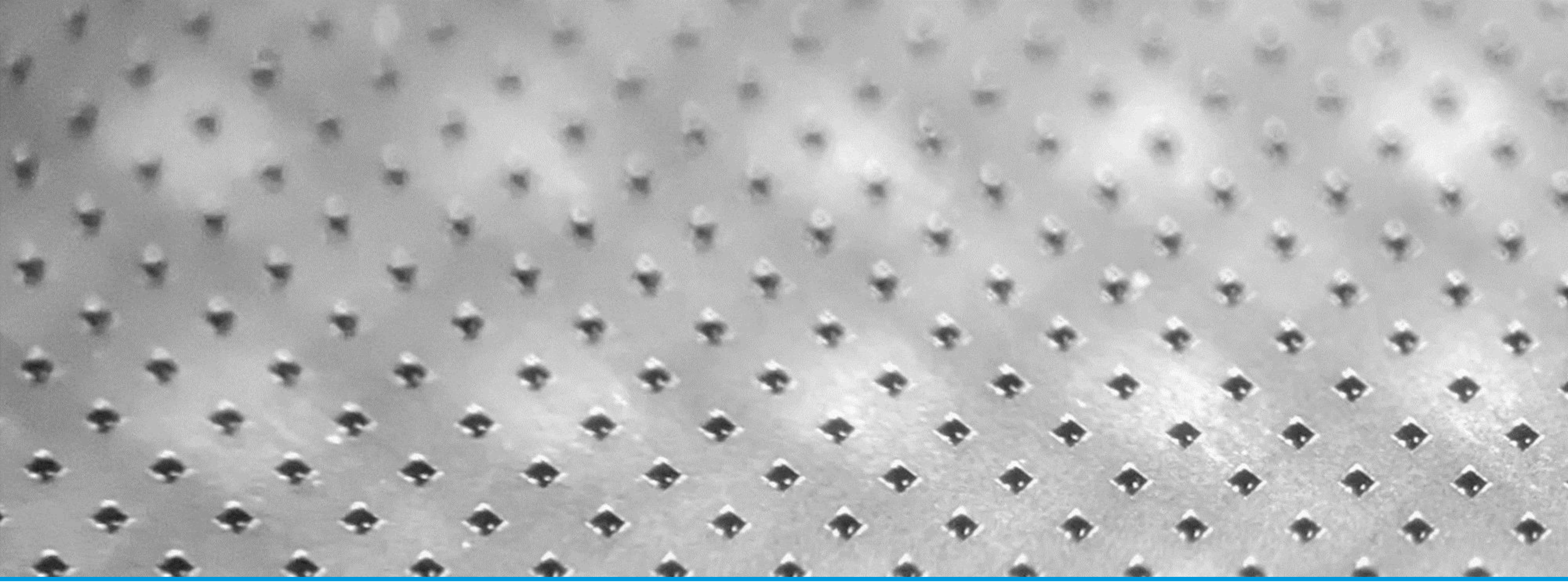


High Precision at Light Speed: Laser-Assisted Die-to-Wafer Assembly for MicroLEDs and Integrated Photonics

Akchheta Karki
Researcher

MicroLED & AR/VR Connect
September 24th, 2025

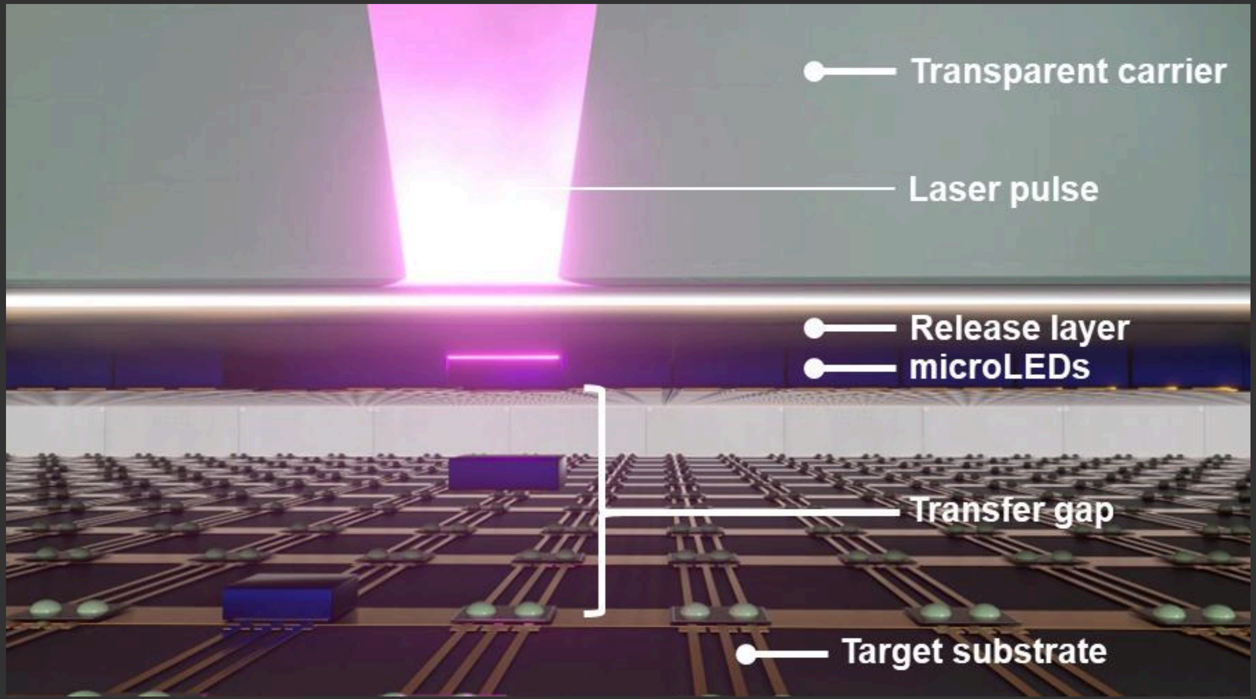
Holst Centre
powered by imec & TNO

LIFT Assembly: *Technology Toolbox*

***LIFT** (**L**aser **I**nduced **F**orward **T**ransfer) of materials and components between substrates in proximity*

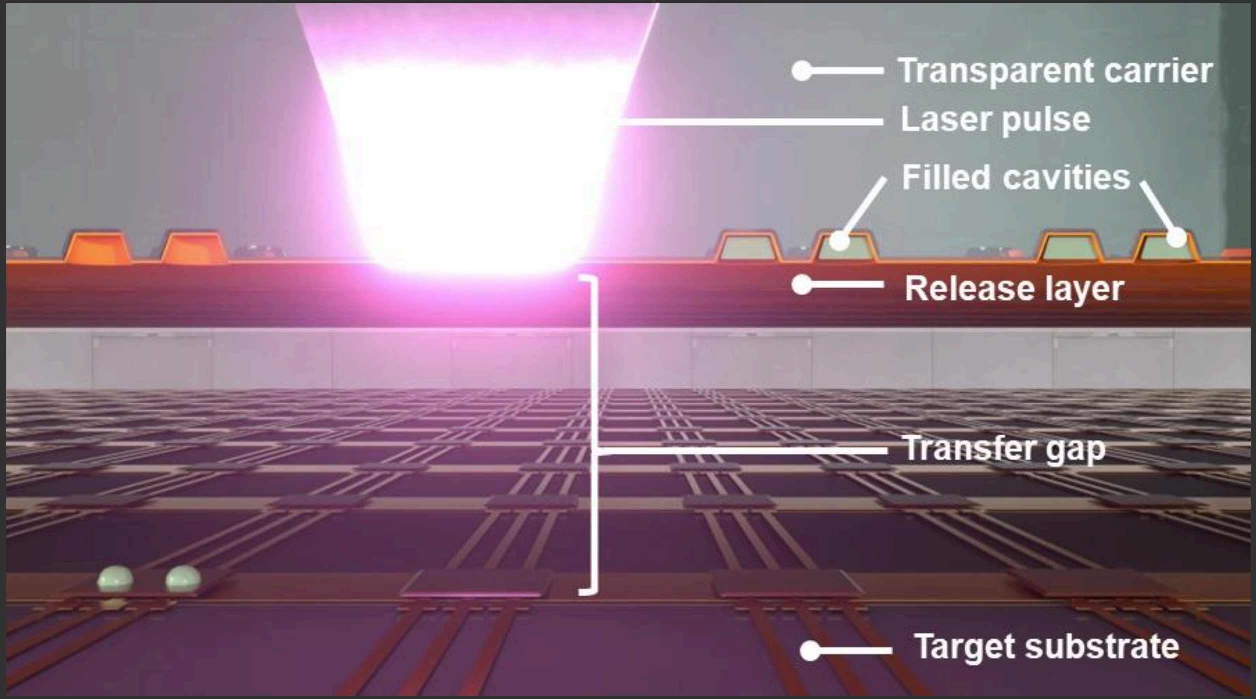
At Holst Centre: Proprietary release stacks used to transfer components and interconnect materials via a low-cost laser source

Component Transfer



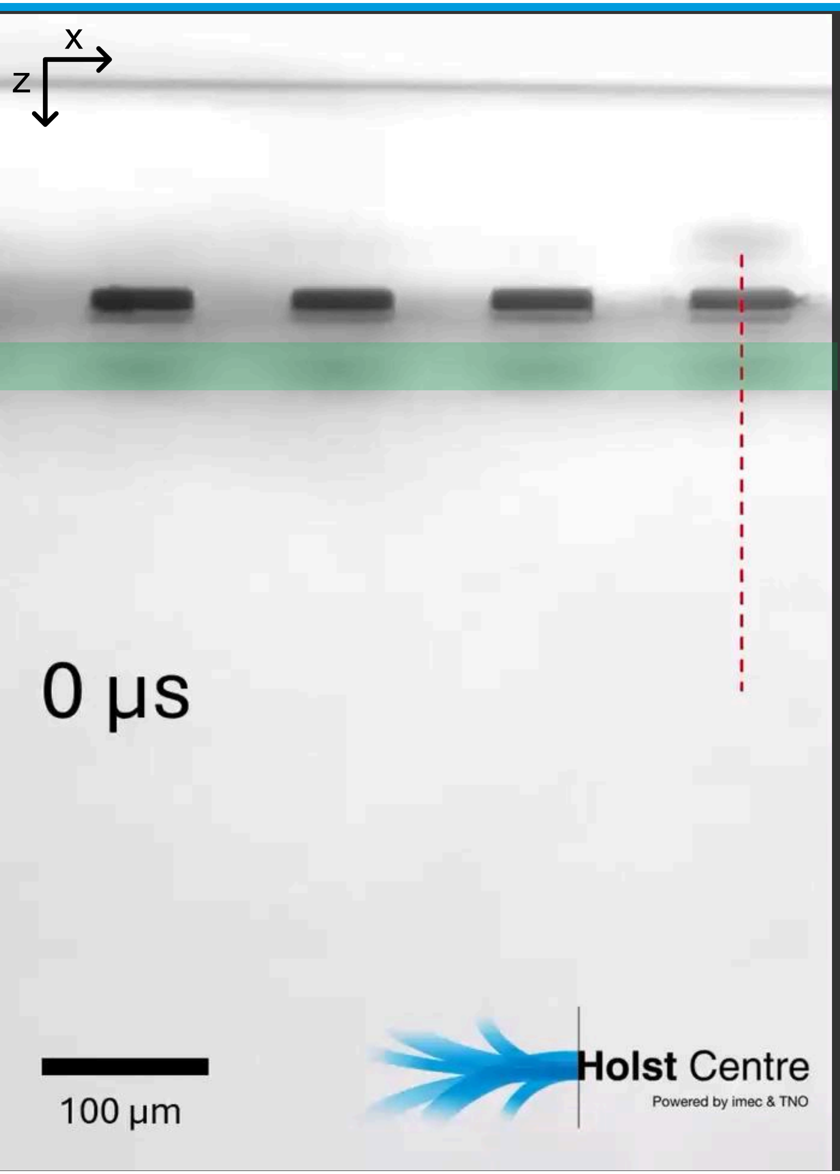
non-explosive | accurate | high-throughput | noncontact | die-on-demand

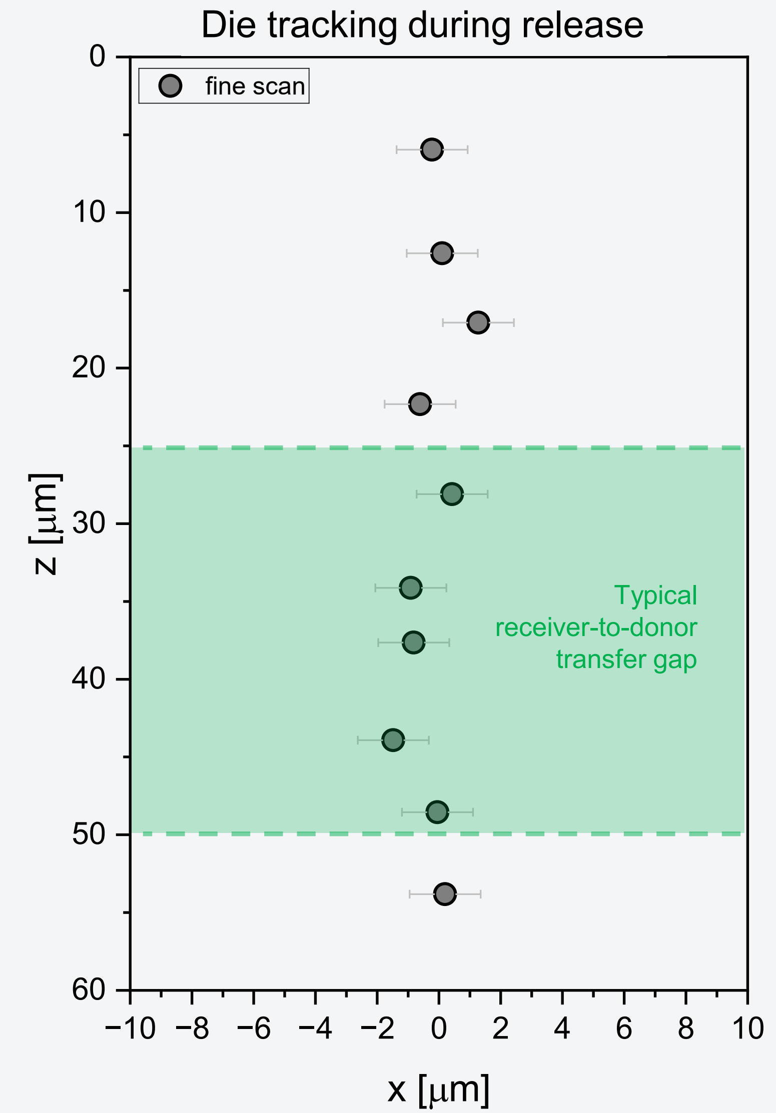
Interconnect Printing



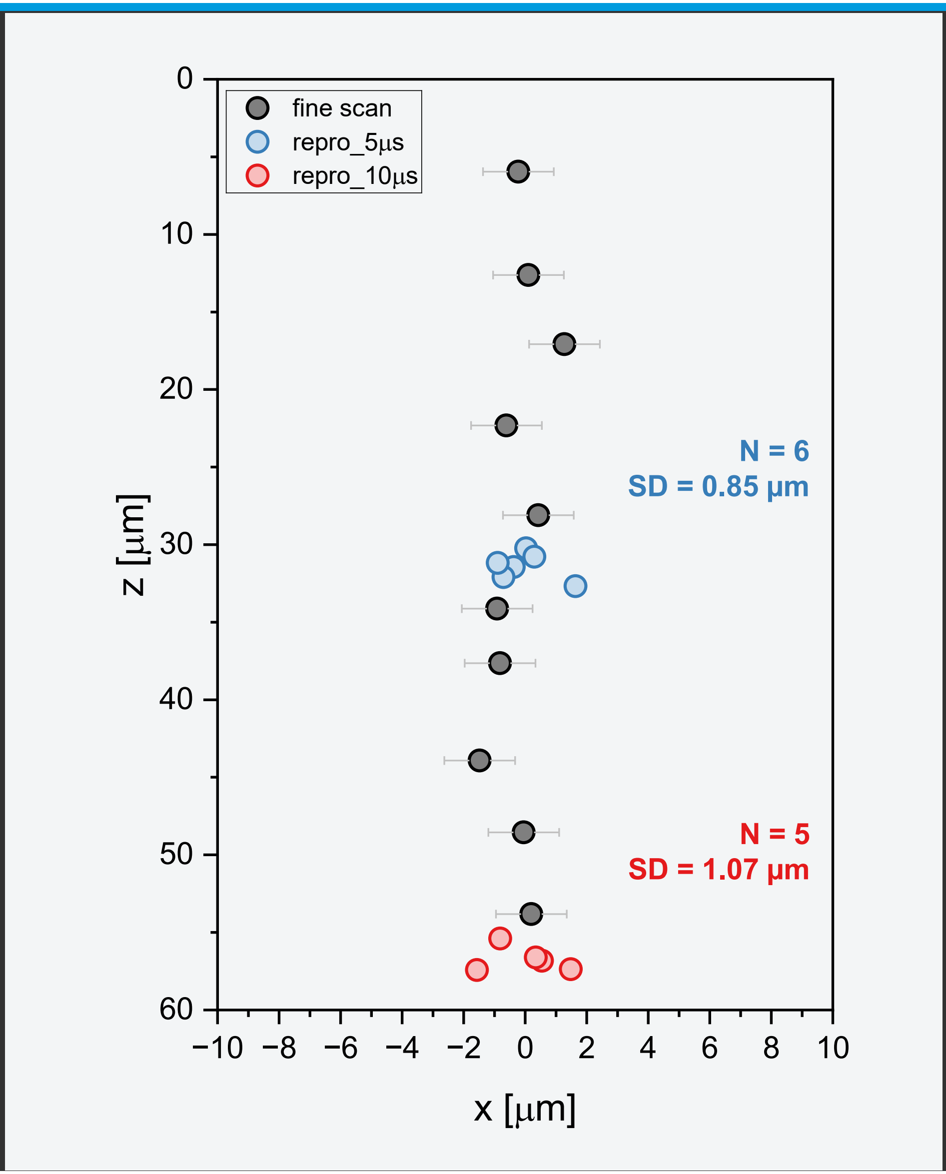
high-throughput | noncontact | digital | **permanent release layer** | **high resolution**

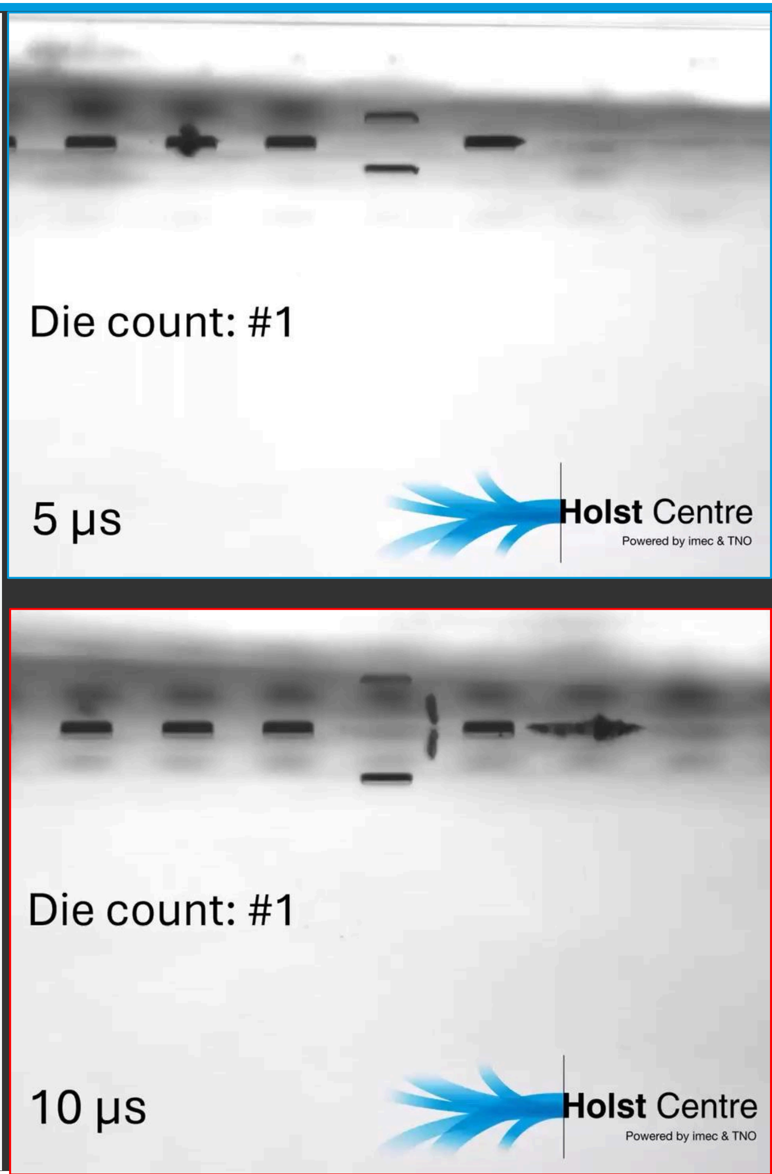
Component release: *controlled speed and stability*





Component release: *reproducibility*



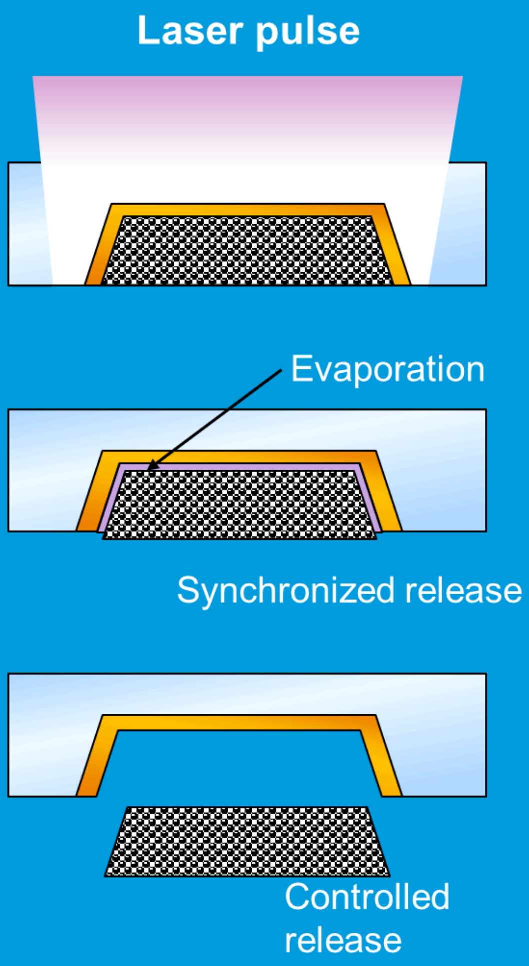


Interconnect printing

Print on TARGET

Printing process: how it works

- A heat pulse is given by a laser pulse
- The solvent in the interconnect material starts to evaporate and a thin vapor film is formed between the release stack and the ink
- The build-up of pressure accelerates the ink
- A homogeneous pressure distribution can cause controlled release of interconnect materials



Real-time visualization snapshot (40µm dot of solder paste)

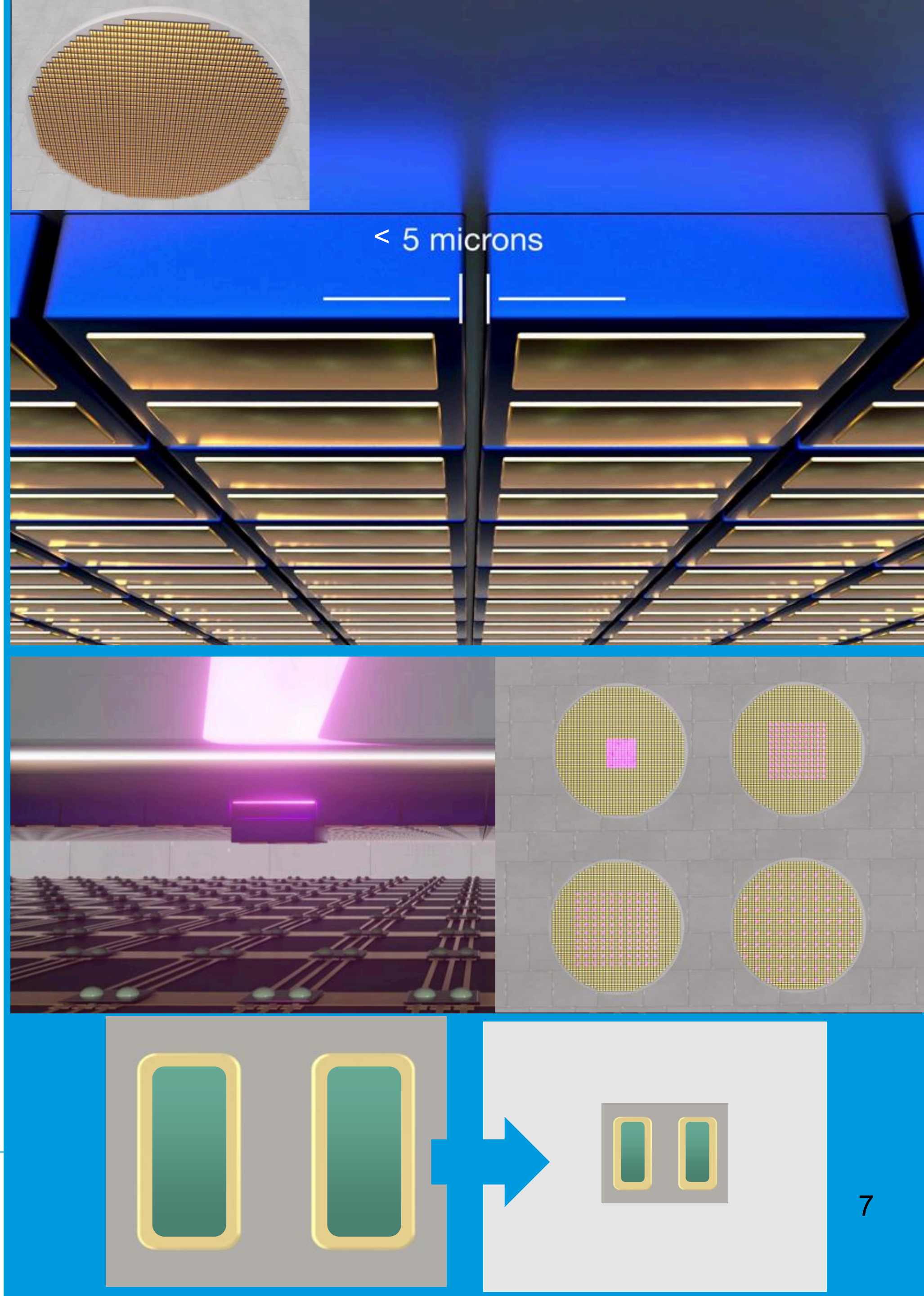
LIFT Assembly: *application domains*

	MicroLEDs	Photonics	Semicon
Component Transfer	• Commercial flip chip microLEDs • Ultrasmall dies down to 10 µm • Efficient Repair	• Photonics Components • III-Vs onto Si photonics • InP coupons	• RFID dies • Power dies • Chiplets
Interconnect Printing	• Fine Solder Paste & Flux • High viscous conductive glues (ICA and ACA)	• Optical adhesives • Solder paste & Flux • Acceptor materials	• High viscous conductive glues (ICA and ACA) • Solder paste • Acceptor materials

microLED assembly challenges

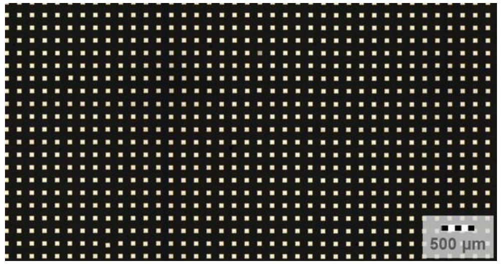
- **Component transfer:**
  - **Small dies:** ~ 50µm (signage), down to 10µm (display)
  - ***Assembly speed:*** *At least 1M UPH*
  - ***Assembly precision:*** *<5µm*
  - **Different product pitch** depending on the application
  - **Efficient repair via single die-on-demand**
    - *Repair process can be as time-consuming as for a full wafer (e.g. pick & place)*

- **Interconnect printing:**
  - **Bond pad dimensions shrink**
    with the miniaturization of LEDs
    - Requires **printing ultrafine deposits of interconnect features**
    - Conventional high-throughout printing technologies
      fail to meet microLED requirements

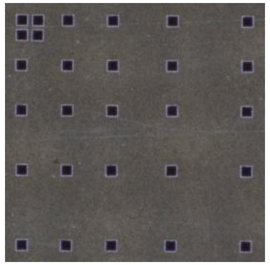


LIFT for microLED assembly

- **Very fast release**: <1 µs
- **Expected assembly speed (per tile):** >10M UPH
- **Highly selective**: adaptive pitch, die-on-demand from a wafer
- **Efficient and fast repair of single die possible**

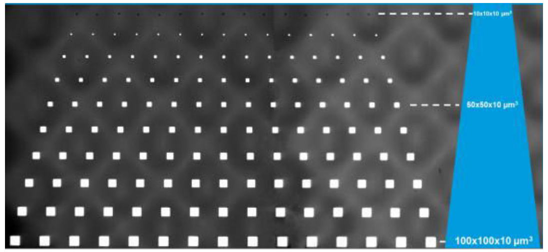


microLEDs



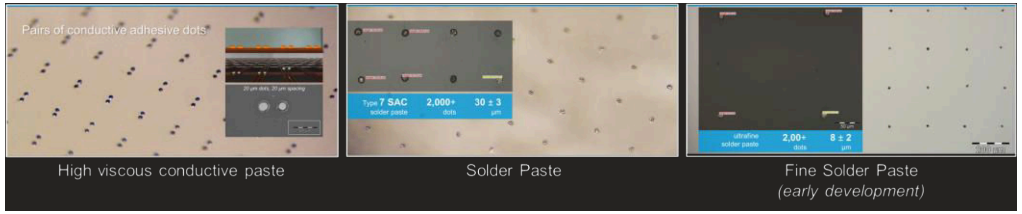
Adaptive pitch

- **Scalable and flexible**: from mini- to microLEDs
  - demonstrated 1 µm transfer reproducibility and >99.9% yield for components from 200µm down to 10µm
  - no fundamental limit to downscale to <10µm components

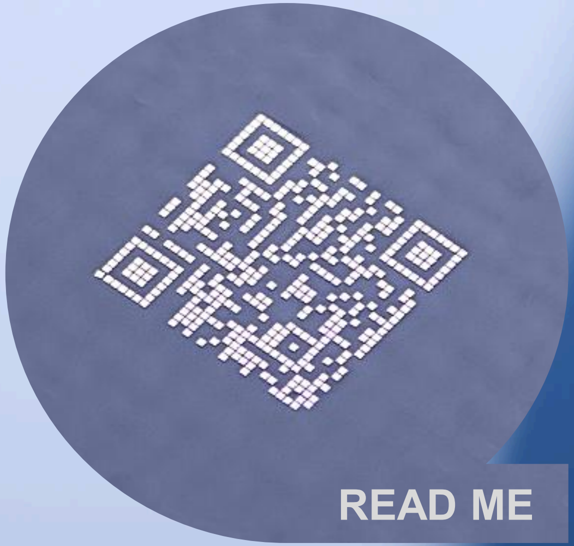


Dummy dies: from 100 µm down to 10µm

- **Printing ultrafine interconnect dots**:
  - Highly viscous conductive pastes, solder pastes, fine solder pastes, and flux
  - Dot diameters ranging from 100 µm down to 10µm



Selectivity

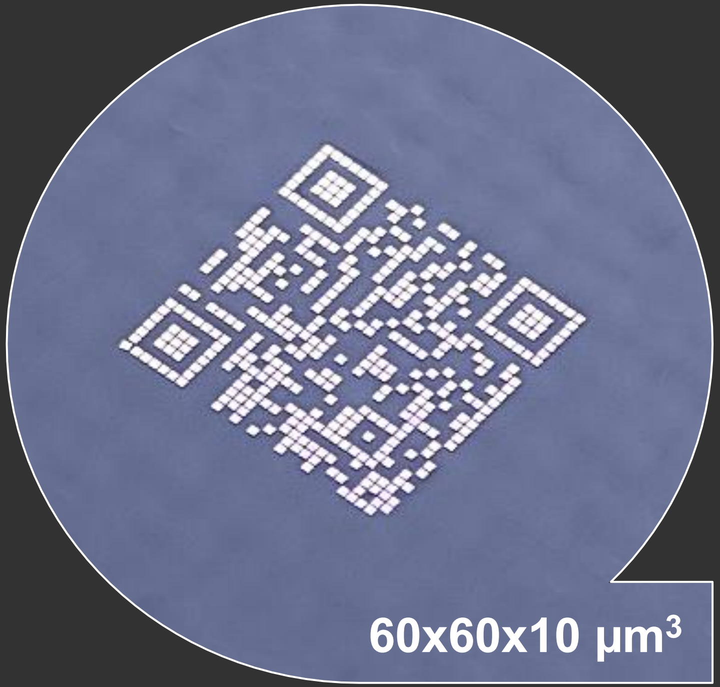


Component size:
60x60x10 μm^3

Edge-to-edge spacing:
20 μm

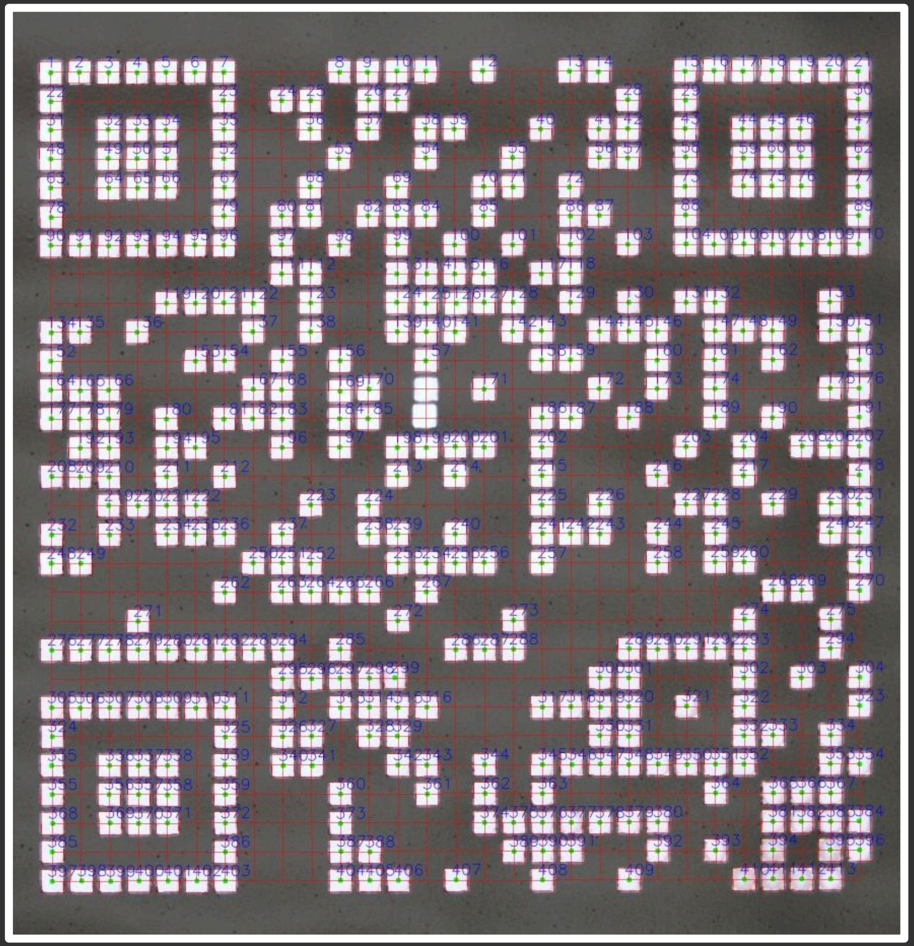
Transfer gap:
50 μm

Placement reproducibility

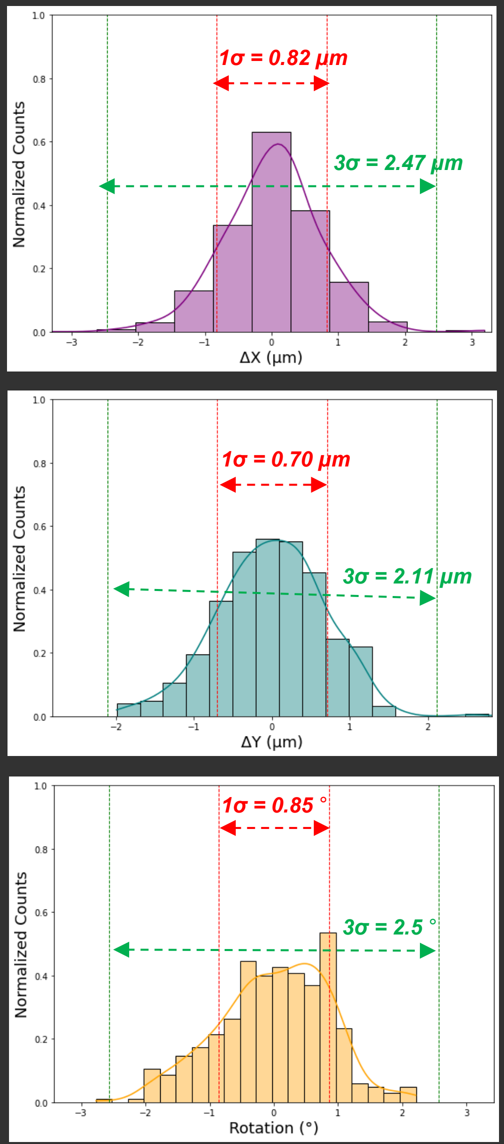


~800 nm displacement

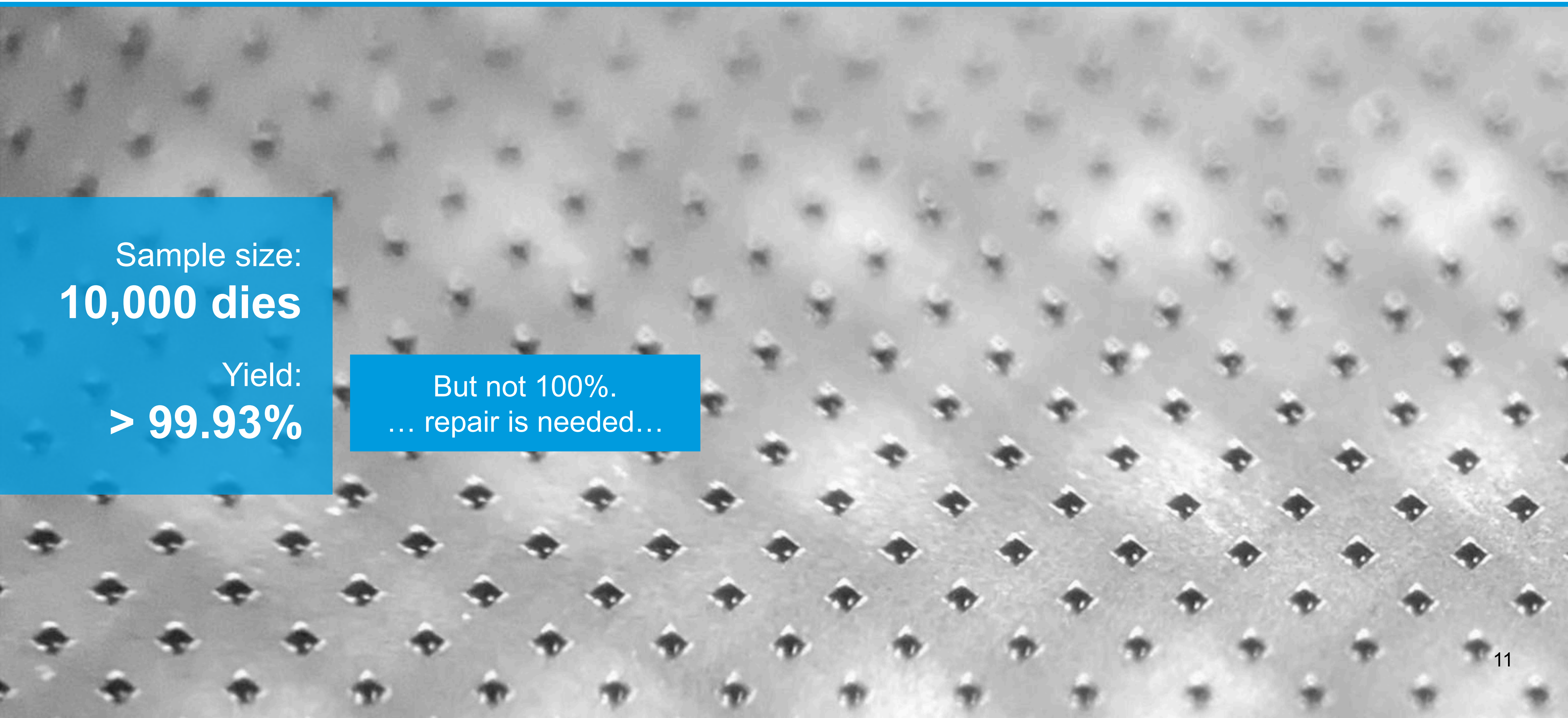
both in x and y (Stdev, 1σ)



*Note: Values are plotted with corrected offsets



Transfer yield

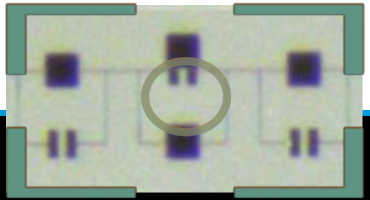


Sample size:
10,000 dies

Yield:
> 99.93%

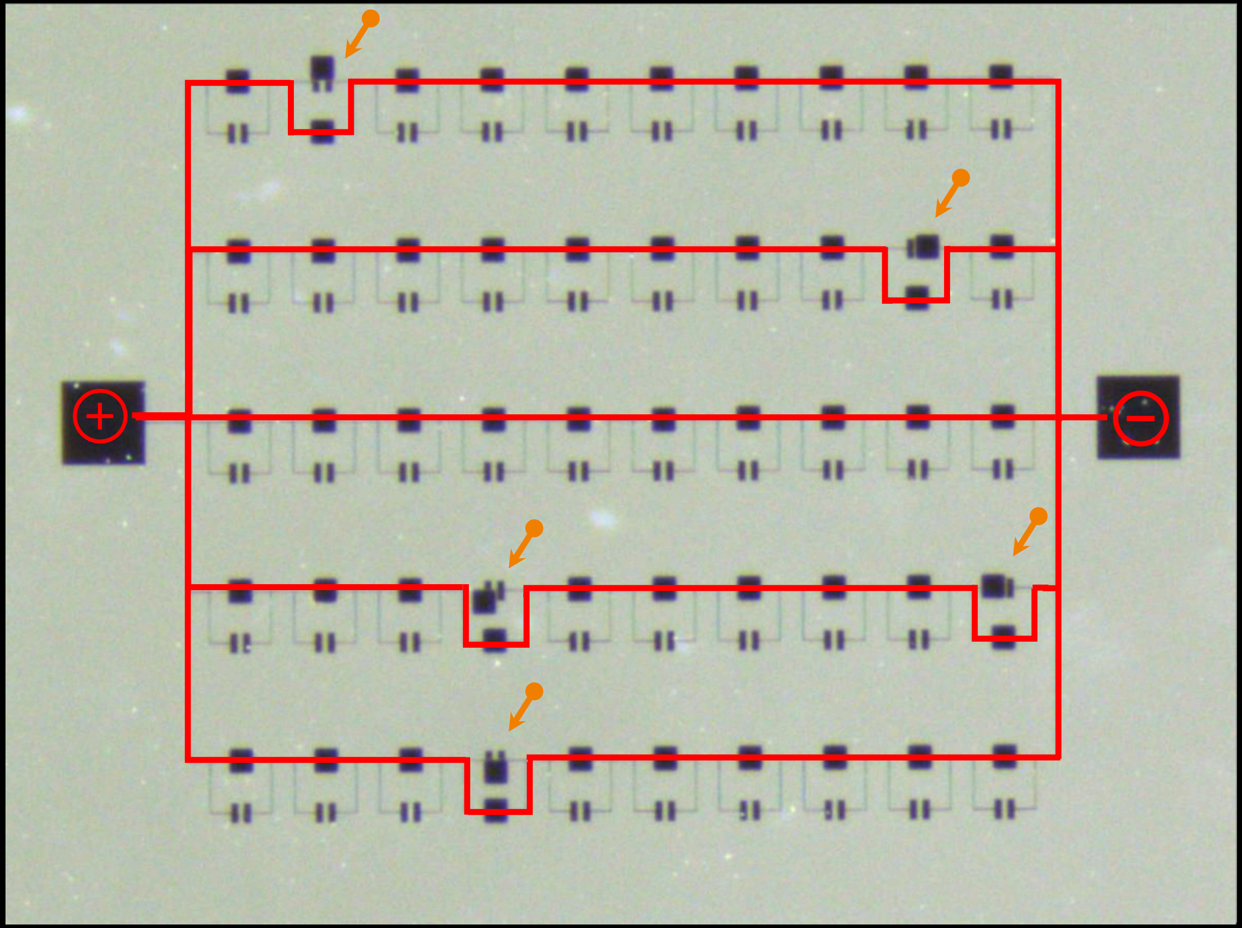
But not 100%.
… repair is needed…

Efficient Repair: *towards 100%*



Repair needed

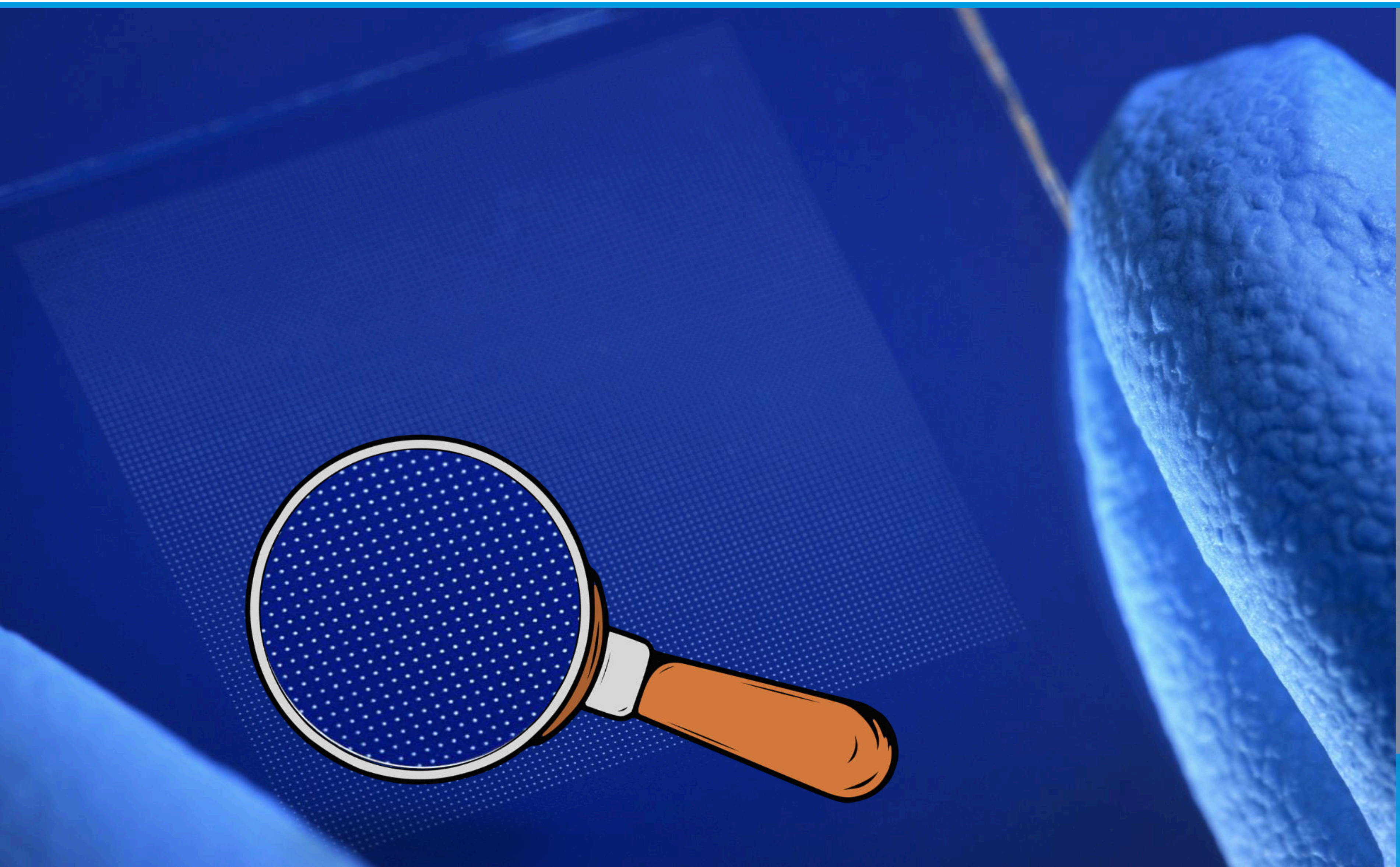
Yield after repair: 100%

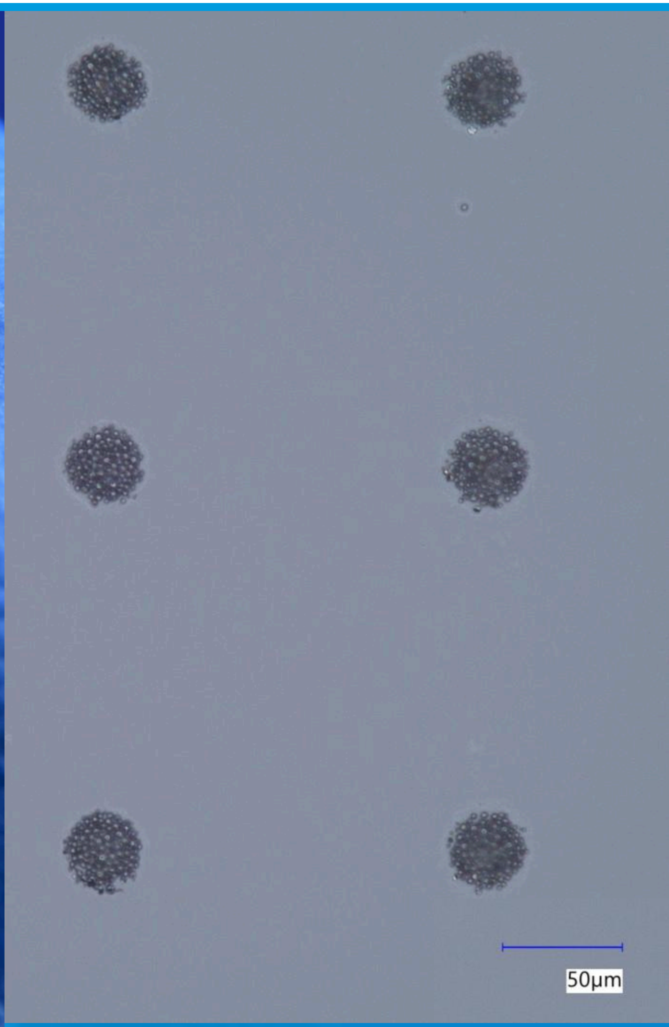


- Highlighted dies (shown with orange arrows) are intentionally misplaced and transferred using LIFT
- We can LIFT print the dies that are misplaced onto the redundant connection for efficient repair
- Repair process via transferring dies on demand with a laser is much faster than using stamp-based pick and place methods

Interconnect printing: *solder paste printing of 10,000 dots*

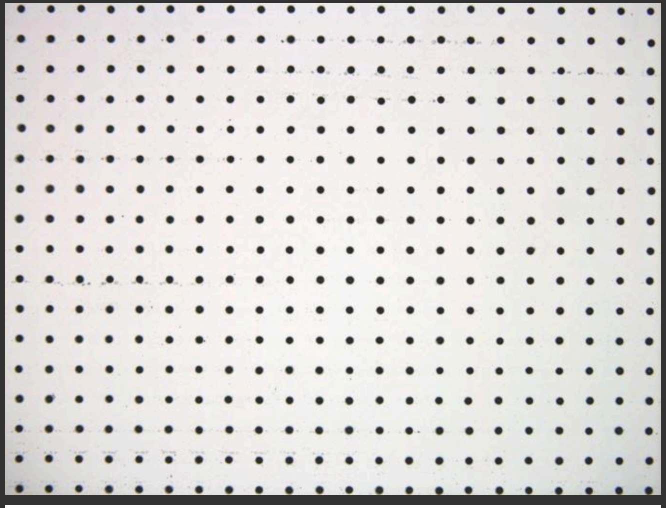
Holst Centre
powered by imec & TNO

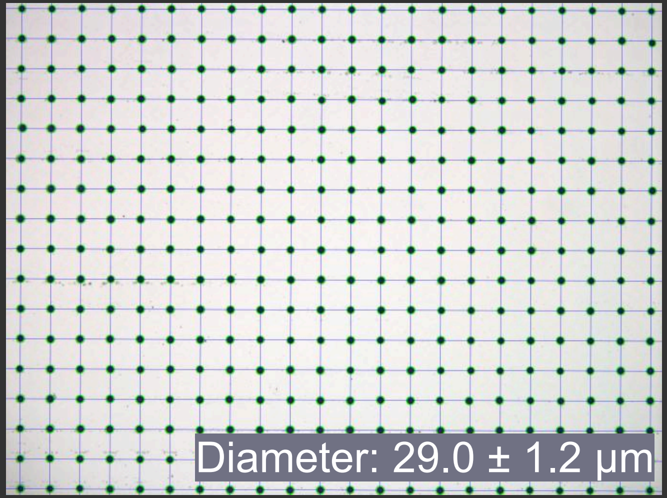


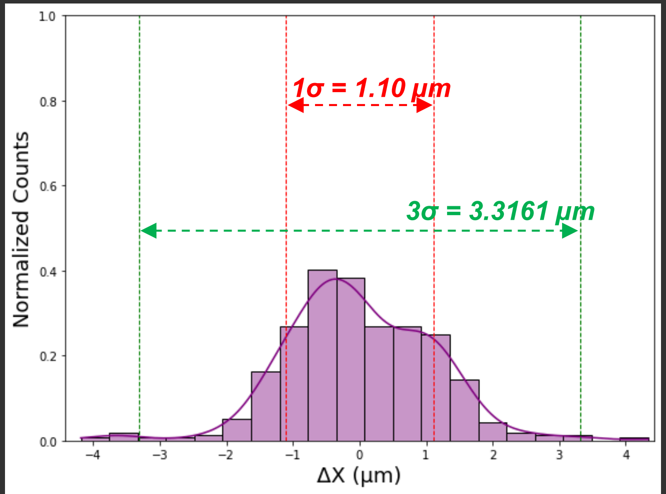


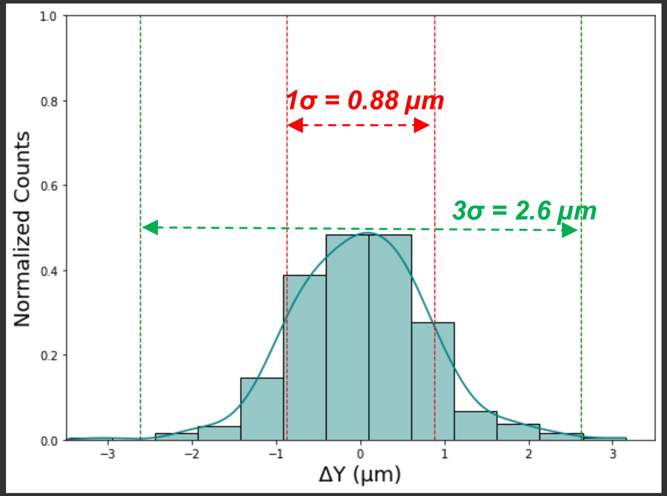
Diameter: 29.0 ± 1.2 µm

Printing placement reproducibility









~1 µm displacement both in x and y (stdev, 1σ)

*Note: Values are plotted with corrected offsets

LIFT Assembly: *application domains*

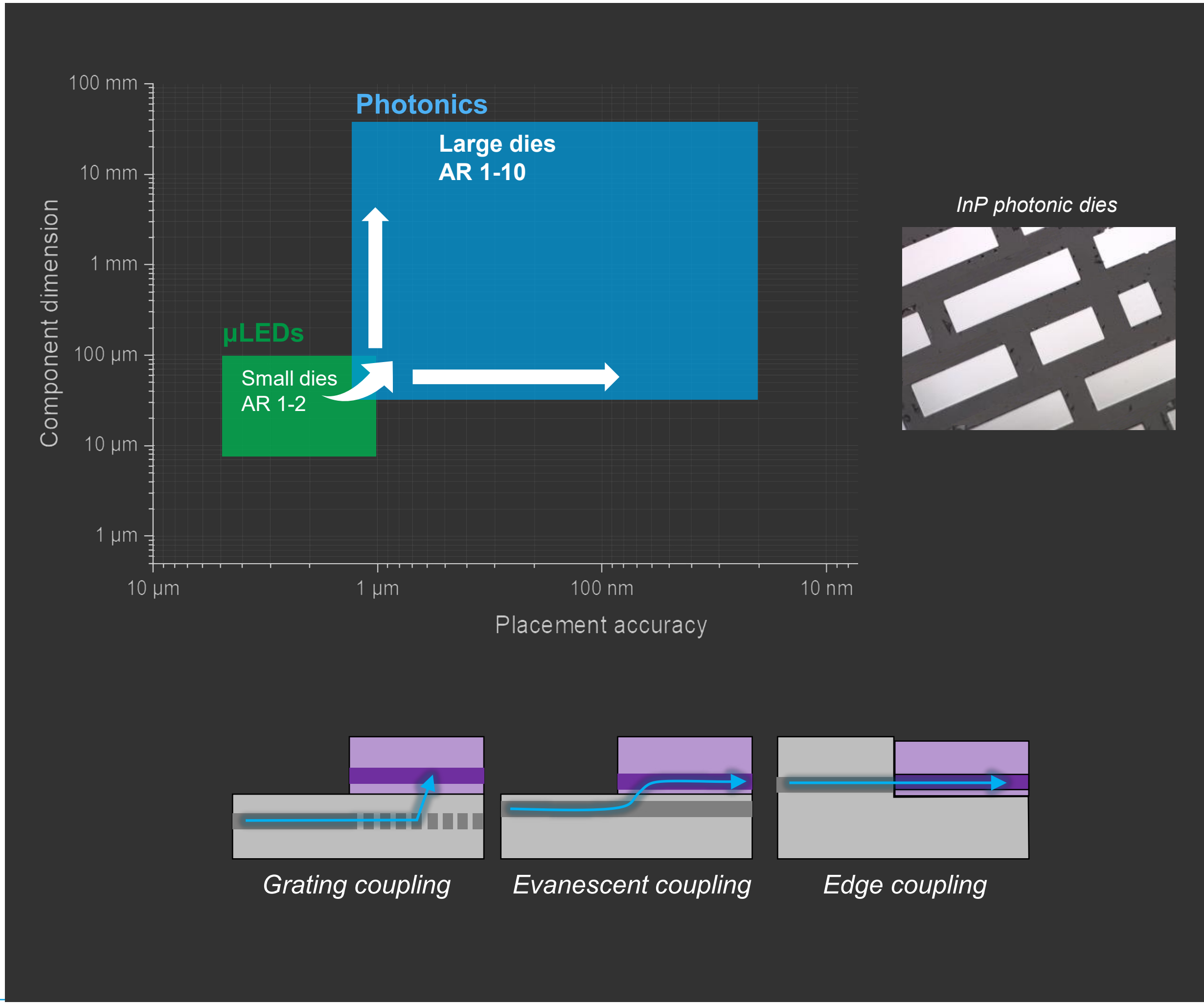
Holst Centre
powered by imec & TNO

	MicroLEDs	Photoni PITC Photonic Integration Technology Center	Semicon
Component Transfer	• Commercial flip chip microLEDs • Ultrasmall dies down to 10 µm • Efficient Repair	• Photonics Components • III-Vs onto Si photonics • InP coupons	• RFID dies • Power dies • Chiplets
Interconnect Printing	• Fine Solder Paste & Flux • High viscous conductive glues (ICA and ACA)	• Optical adhesives • Solder paste & Flux • Acceptor materials	• High viscous conductive glues (ICA and ACA) • Solder paste • Acceptor materials

Integrated Photonics assembly challenges

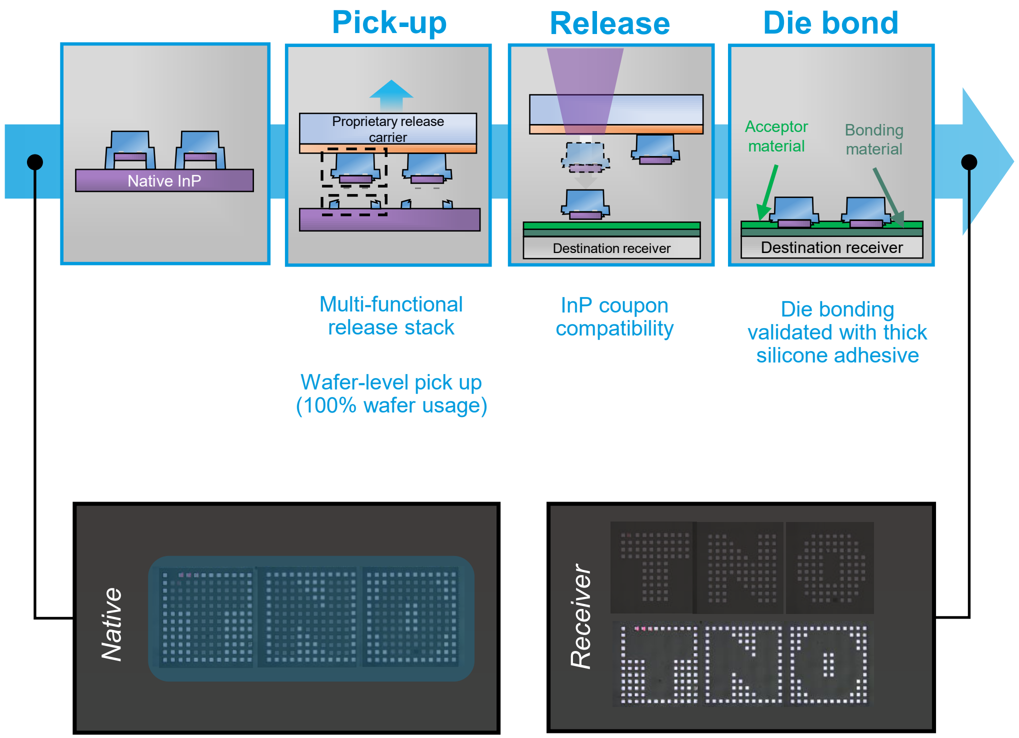
- **Component transfer:**
  - **Handling thin and fragile dies**
  - **Rectangular, elongated dies:**
    - Dimensions: from µm to mm and beyond
    - Aspect ratio: 1:1 to >1:10
    - Thickness: few µm to sub- µm

  - **Optical coupling between photonic platforms:**
    - **InP/Si-PIC interface** needs to be pristine
    - **Sub-micron accuracy** (< 1µm) required for
      - Grating (→ micron)
      - Evanescent (→ sub-micron)
      - Edge (<200 nm)



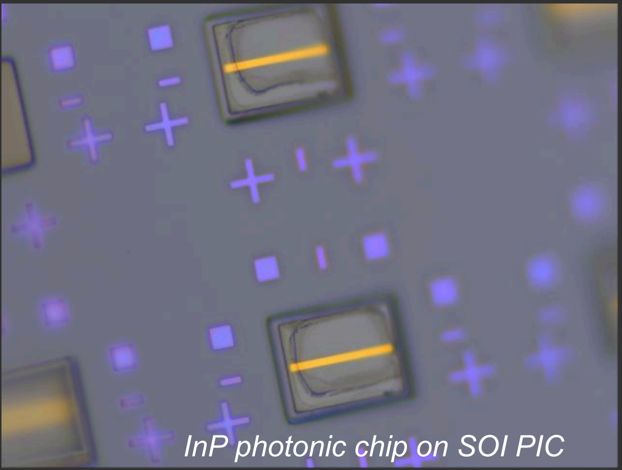
LIFT for Integrated Photonics assembly

- **Compatibility of handling and transferring thin and fragile components**
  - Adapted release stack for multi-functional all-in-one release and pickup, compatible with existing InP foundry fabrication technologies (e.g. coupons)
- **Sub-micron accuracy required for optical coupling to PIC interface:**
  - Development of an acceptor technology that allows for accurate positioning of photonic dies (e.g. InP) on PIC receivers
- **Transferring high AR elongated dies (1:5 to >1:10)**
  - Laser optics modification combined with dedicated release stack to allow transfer without needing to scale up energy and affecting close neighboring dies

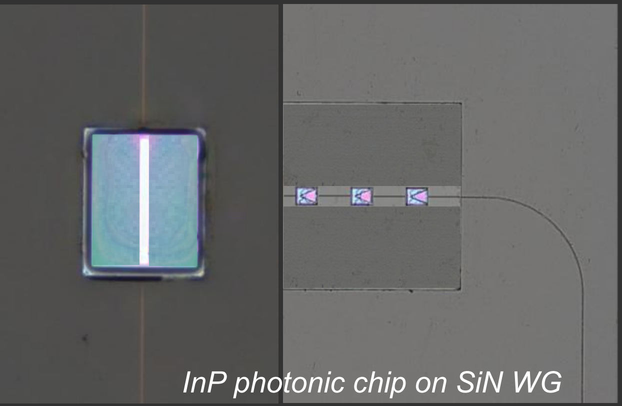


Optical coupling: *route to <200 nm accuracy*

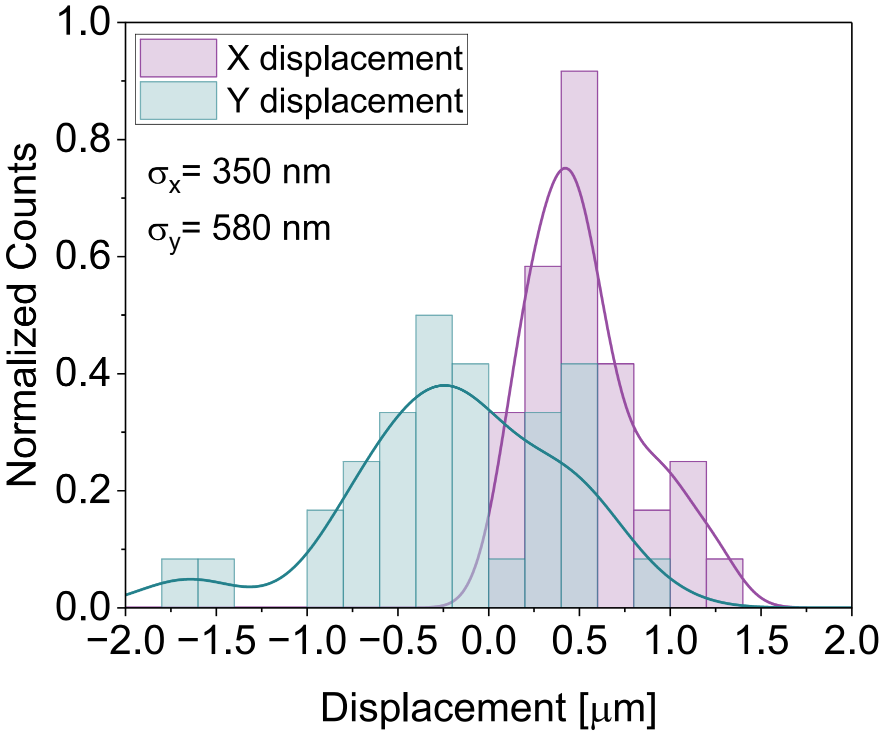
Development of an acceptor technology that allows for accurate positioning of photonic dies (e.g. InP) on PICs



InP photonic chip on SOI PIC



InP photonic chip on SiN WG



Die type:
InP coupons

Die size:
40x50x3.5 µm³
120×120×3.5 µm³

Adhesive-less interface

Compatible with direct bonding for enhanced optical coupling efficiency

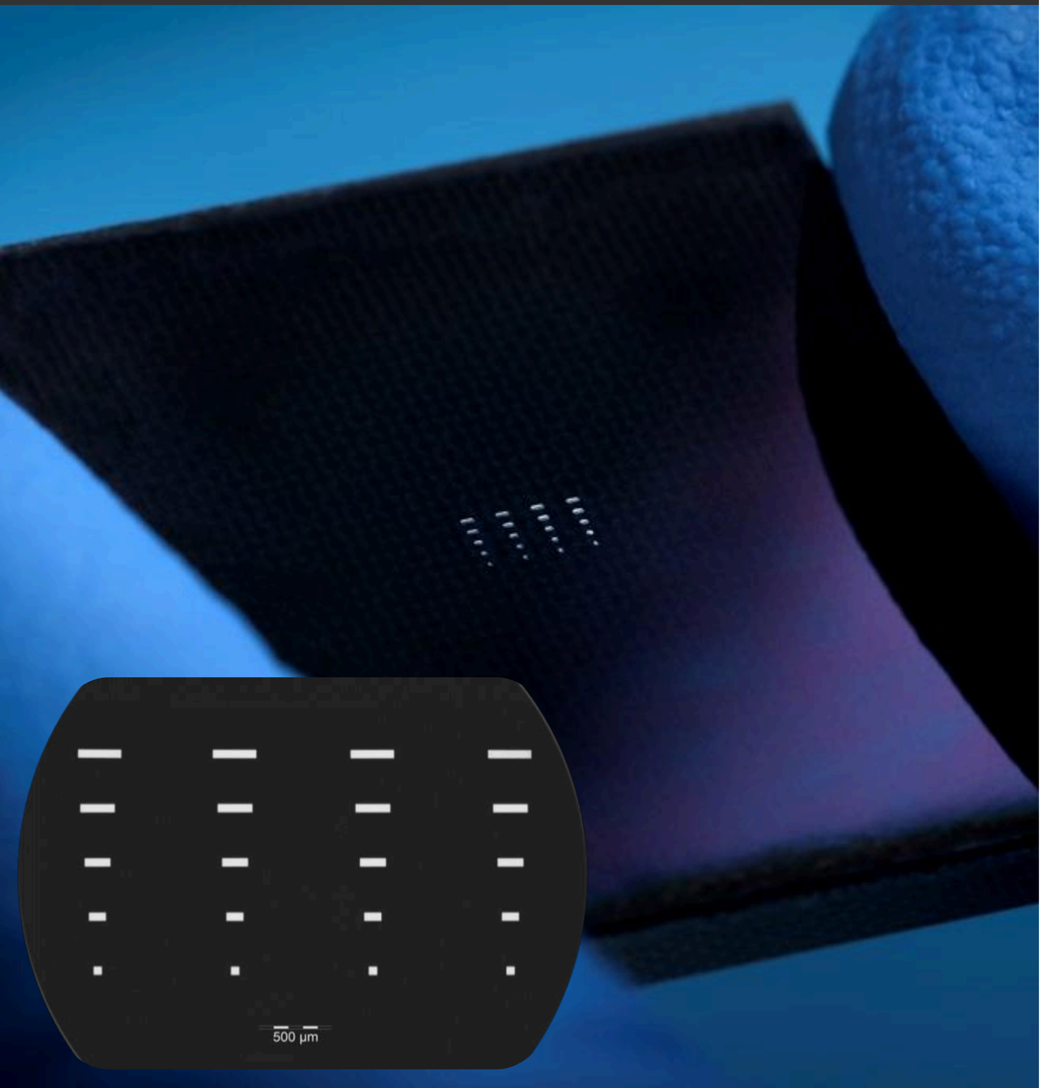
Sub-µm placement precision

Rotation: <1 ° (80%), <2 ° (95%)
X,Y displacement: < 600 nm (1σ)
Roadmap: <200 nm

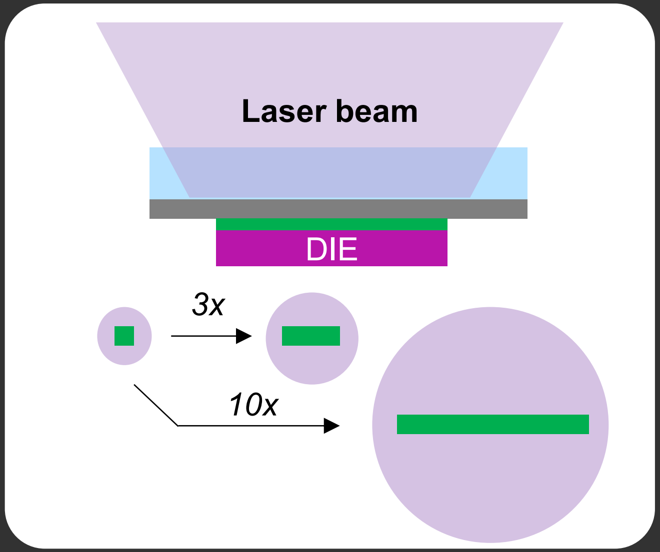
Simulated optical coupling

(for UTC PDs on SOI PIC)
<0.6 dB loss (>85% coupling efficiency)

Transfer of *high* AR components

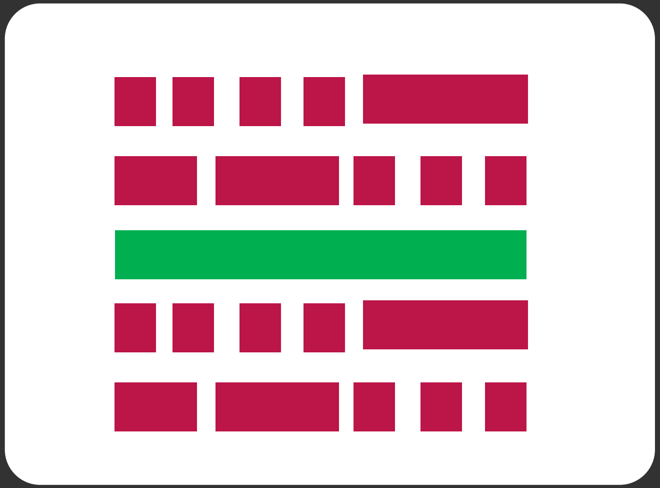


Maximum die size **300µm** and **AR of 5 (60×300 µm²)**



Conventional approach:

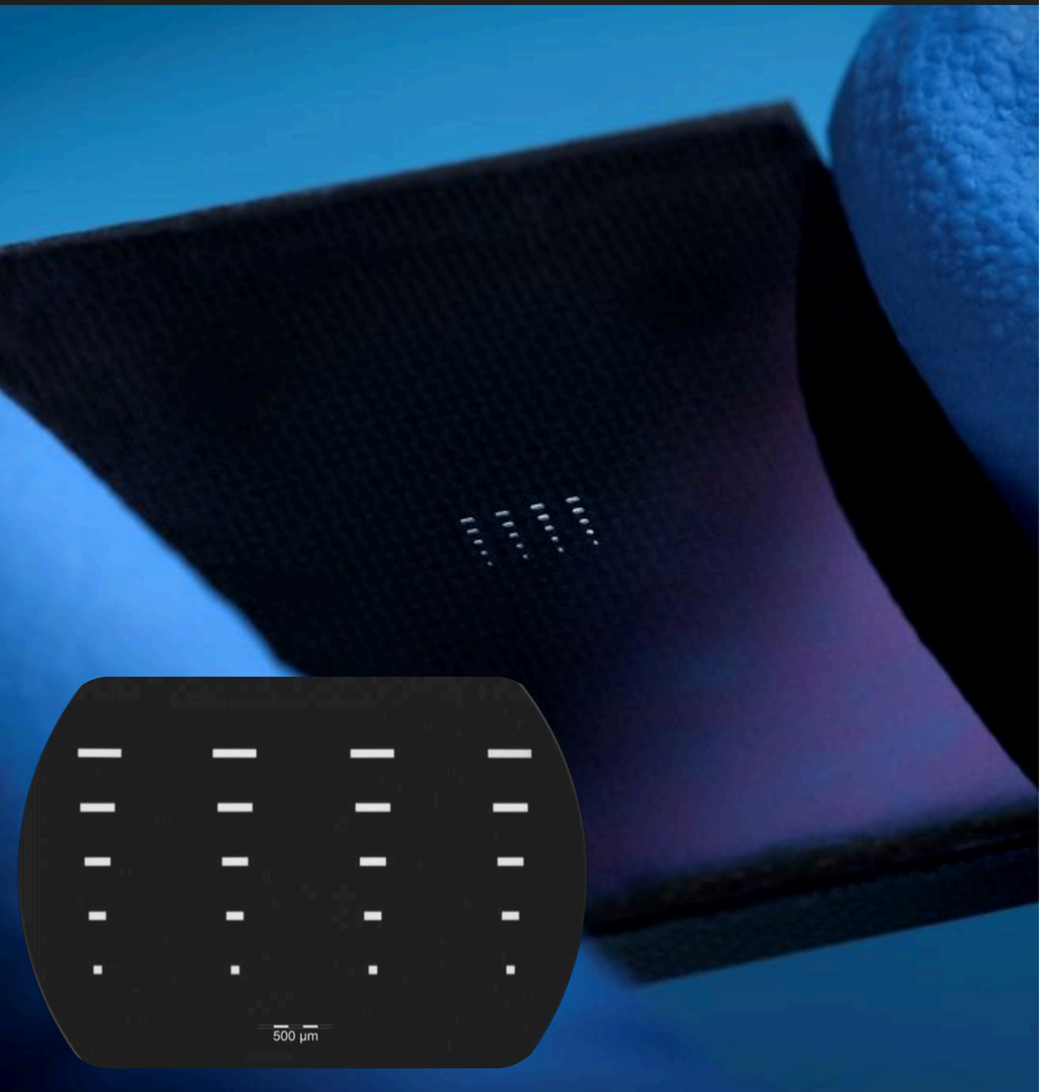
- **Scale the beam spot size to illuminate increasingly larger components**
- **Associated limitations and risks**:
  - Increasing laser energy - inefficiency
  - Limited selectivity



A novel approach based on special laser optics and release stack:

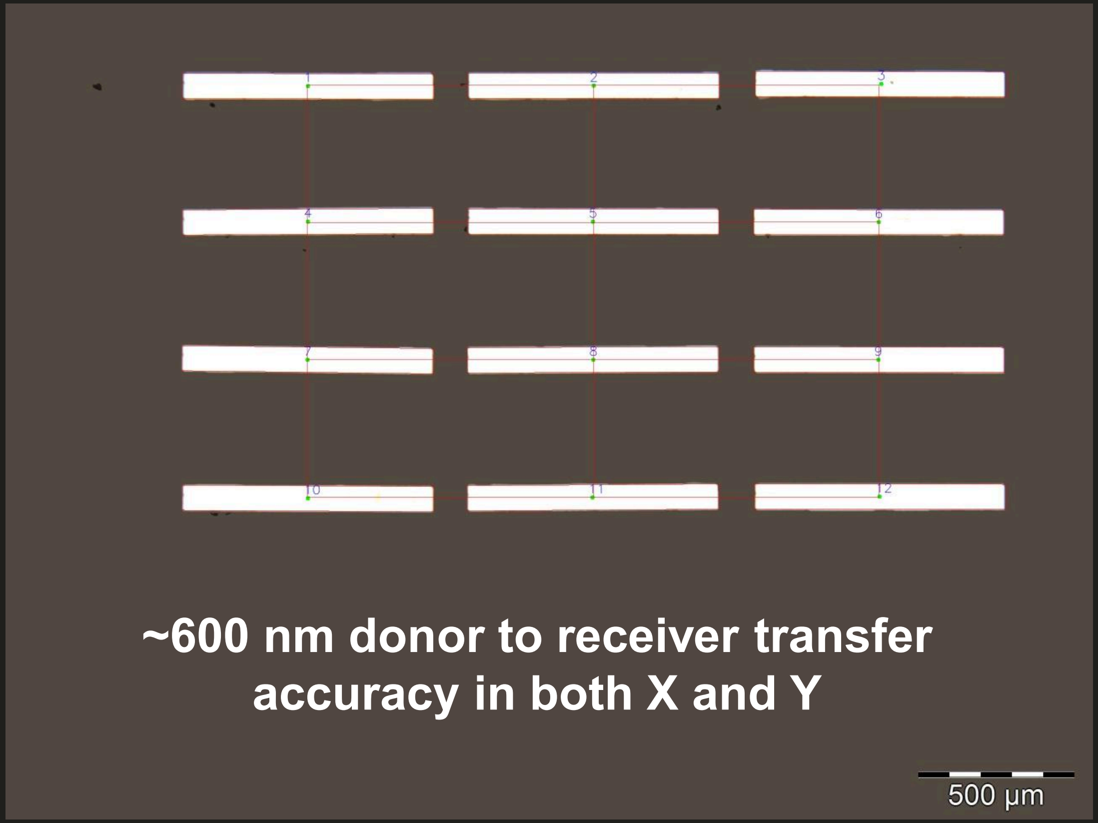
- Small to large AR component transfer, µm to beyond mm-sized components (in the same system)
- Lower energy demand
- **Unaffected neighboring dies**
  - Densely packed components with varying high ARs

Transfer of *high* AR components



Maximum die size **300µm** and **AR of 5 (60×300 µm²)**

80×800 µm² InP dies (AR 1:10)

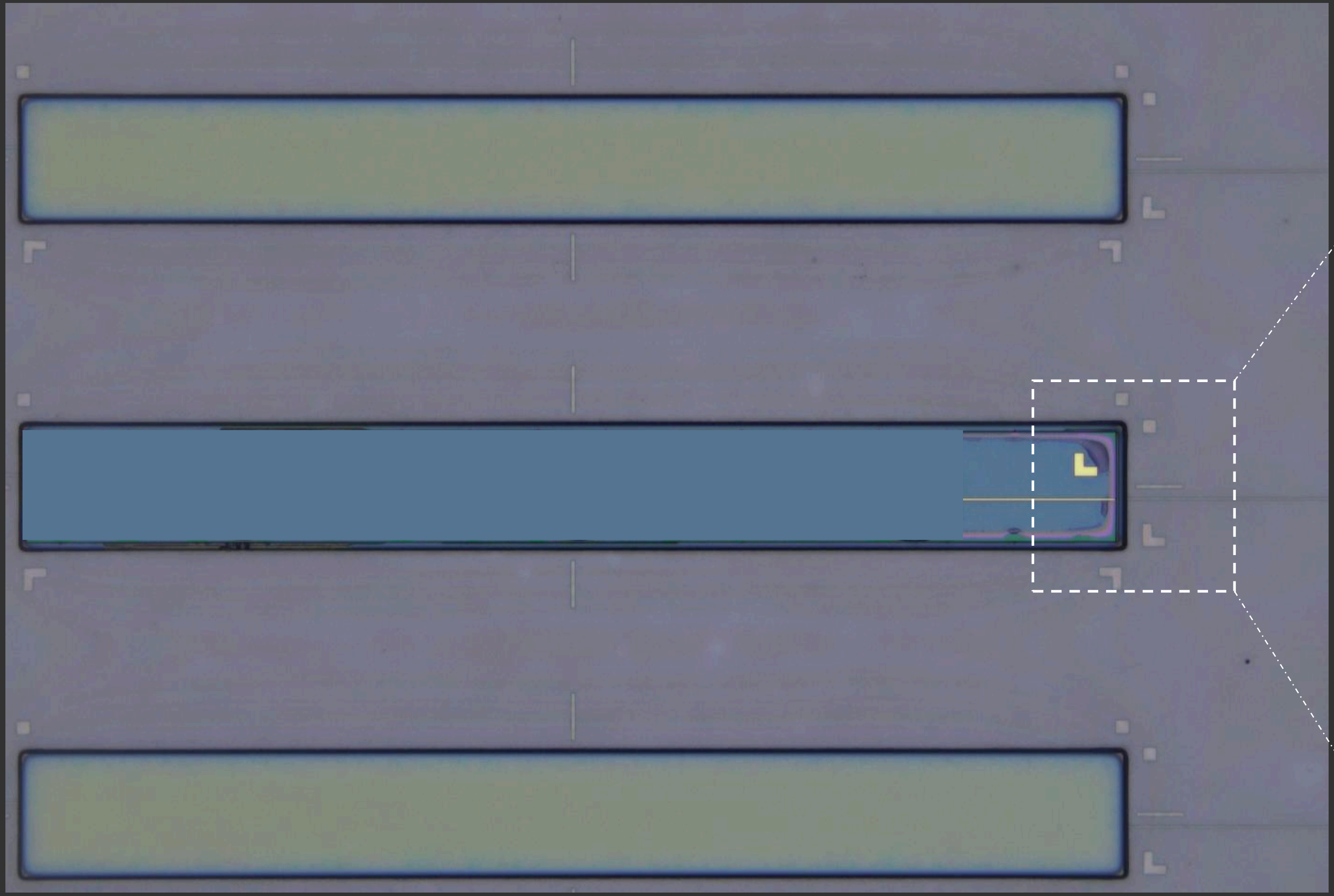


Optical coupling of *high* AR components

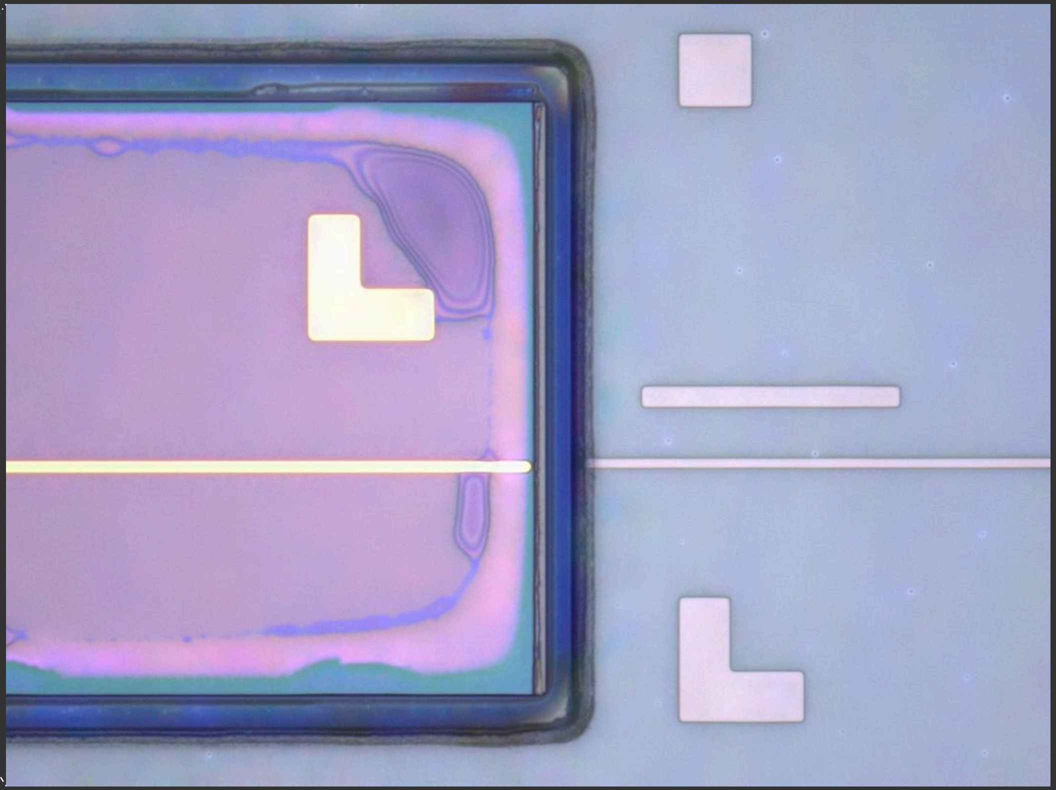
Holst Centre powered by imec & TNO

PITC Photonic Integration Technology Center

80×800 µm² InP chip assembled on SOI PIC



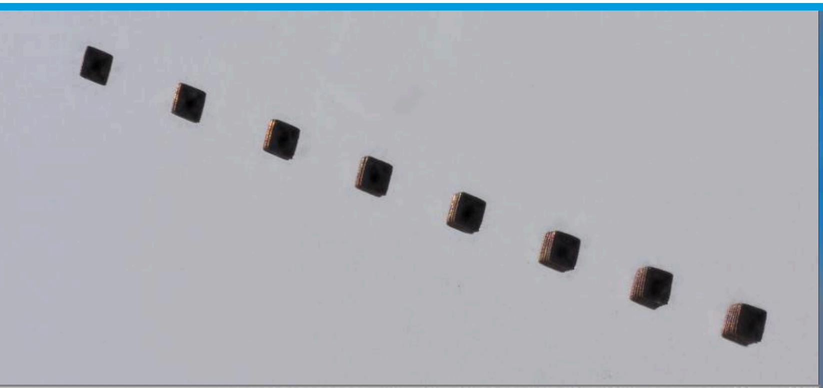
Sub-µm placement precision Y displacement: < 300 nm

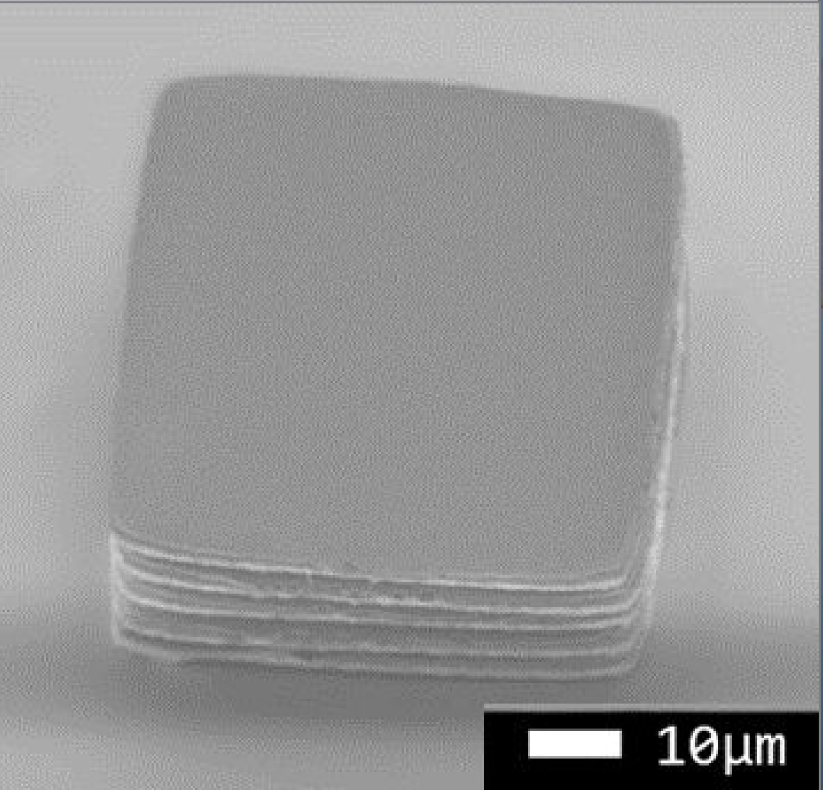


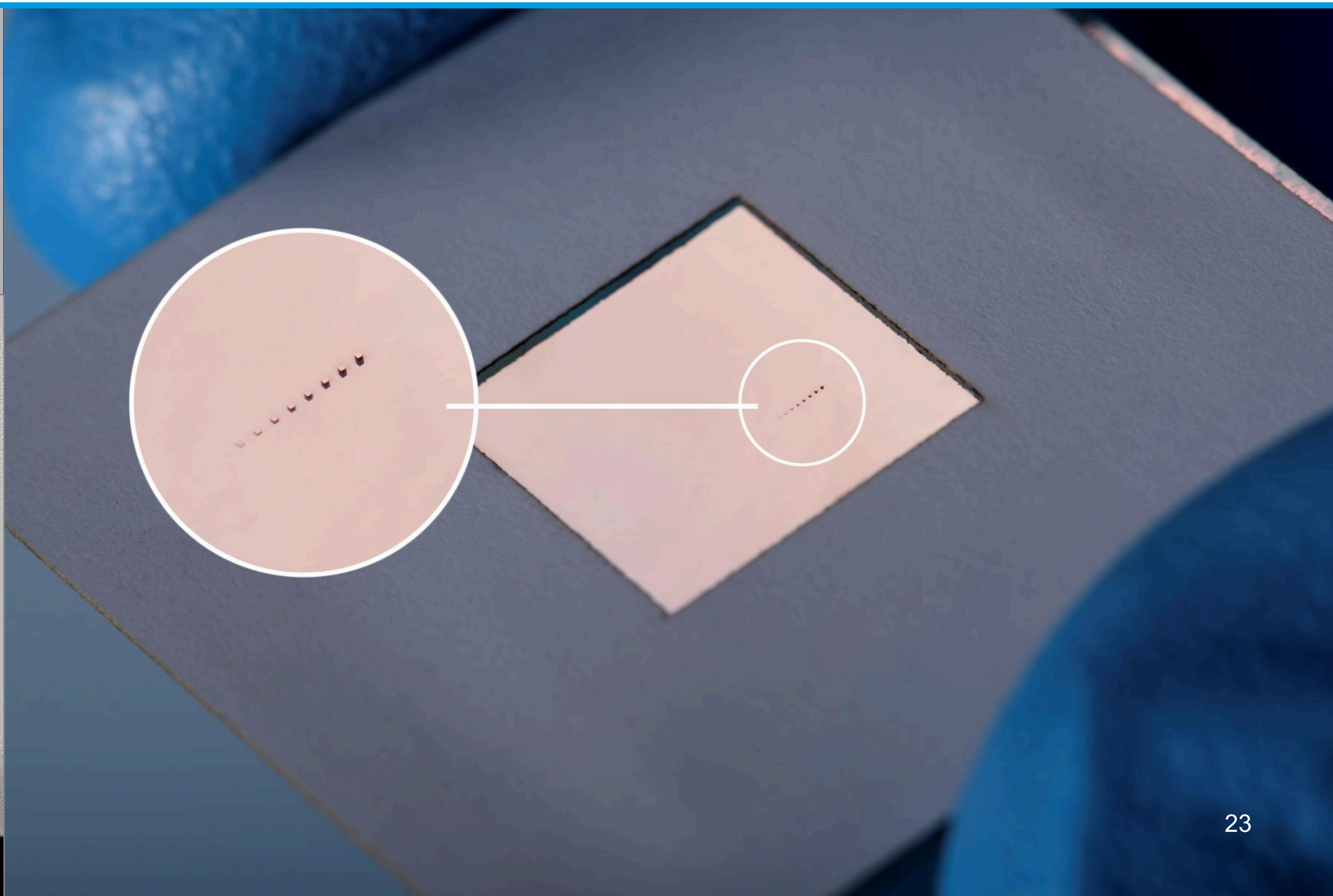
LIFT Assembly: *application domains*

	MicroLEDs	Photonics	Semicon
Component Transfer	• Commercial flip chip microLEDs • Ultrasmall dies down to 10 µm • Efficient Repair	• Photonics Components • III-Vs onto Si photonics • InP coupons	• RFID dies • Power dies • Chiplets
Interconnect Printing	• Fine Solder Paste & Flux • High viscous conductive glues (ICA and ACA)	• Optical adhesives • Solder paste & Flux • Acceptor materials	• High viscous conductive glues (ICA and ACA) • Solder paste • Acceptor materials

LIFT Assembly: *3D die stacking*

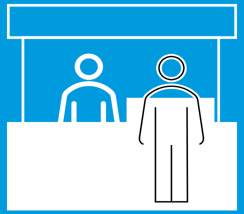






LIFT Team at Holst Centre

Jacqueline van Driel
Henri Fledderus
Merijn Giesbers
Dolf Klomp
Dorothee Hermes
Sergio Roso
Nick de Louw



Visit us at our booth #5!

Thank you for your attention!

Holst Centre
powered by imec & TNO

Questions?

We are happy to help!

Just send us an email.

Gari Arutinov
LIFT Program Manager
gari.arutinov@tno.nl

Riccardo Ollearo
LIFT4Photonics Project Lead
riccardo.ollearo@tno.nl

Akchheta Karki
Researcher
akchheta.karki@tno.nl