PHOTONICS PACKAGING FOR CHIP TO CHIP COMMUNICATION

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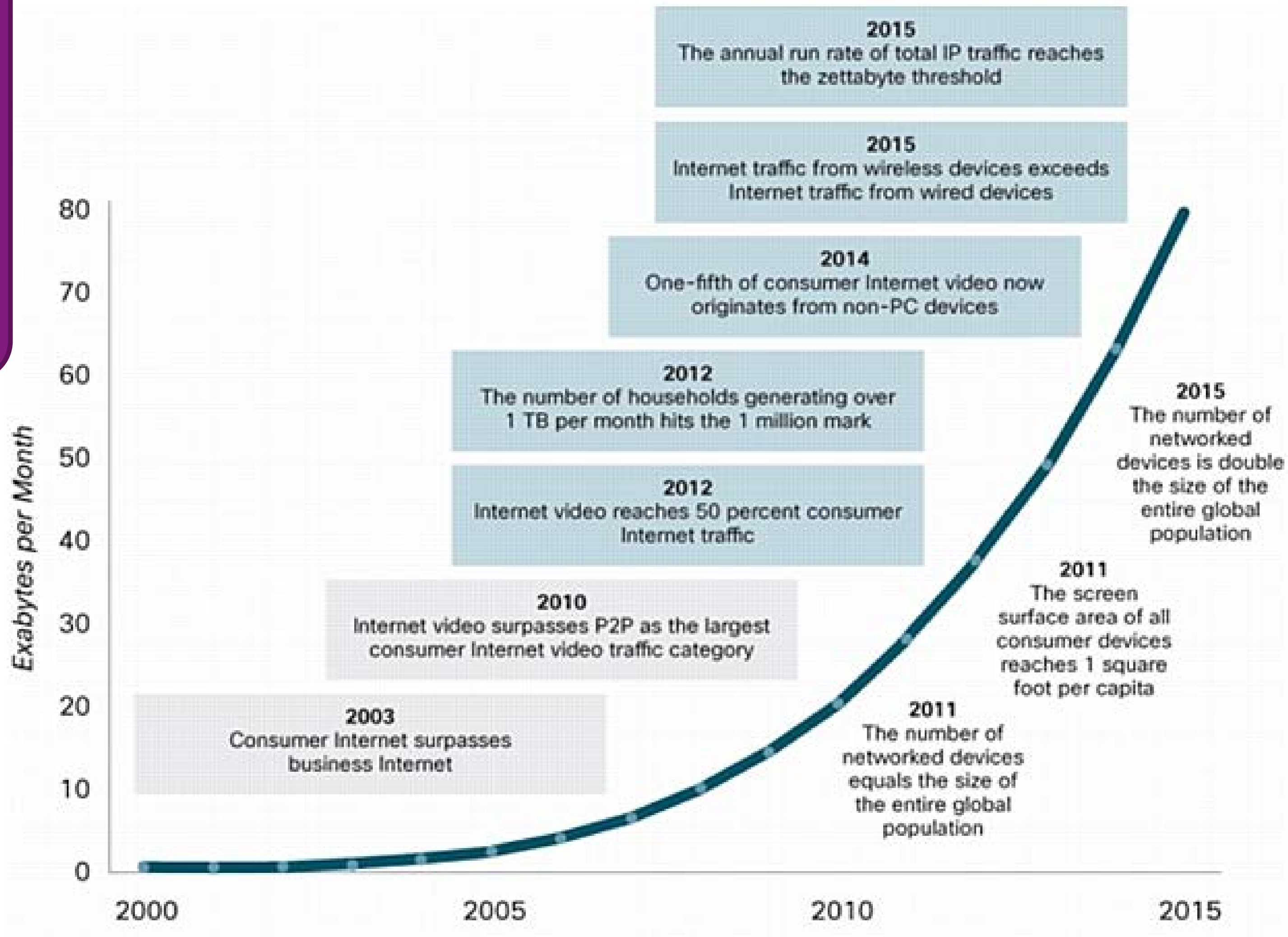
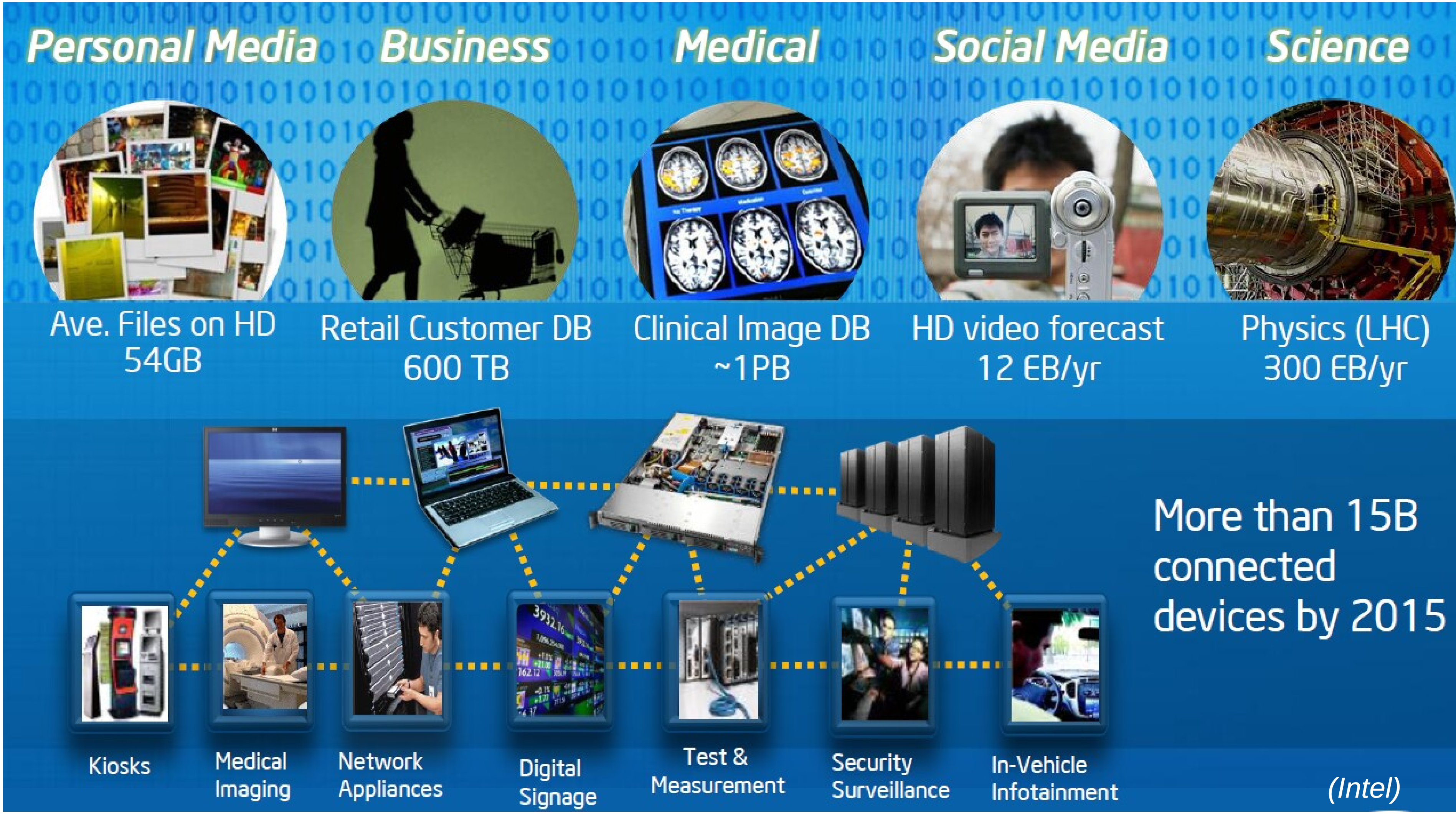
REQUEST FOR BANDWIDTH KEEPS RISING EXPONENTIALLY

Kilo
Mega
Giga
Tera
Peta
Exa
Zetta

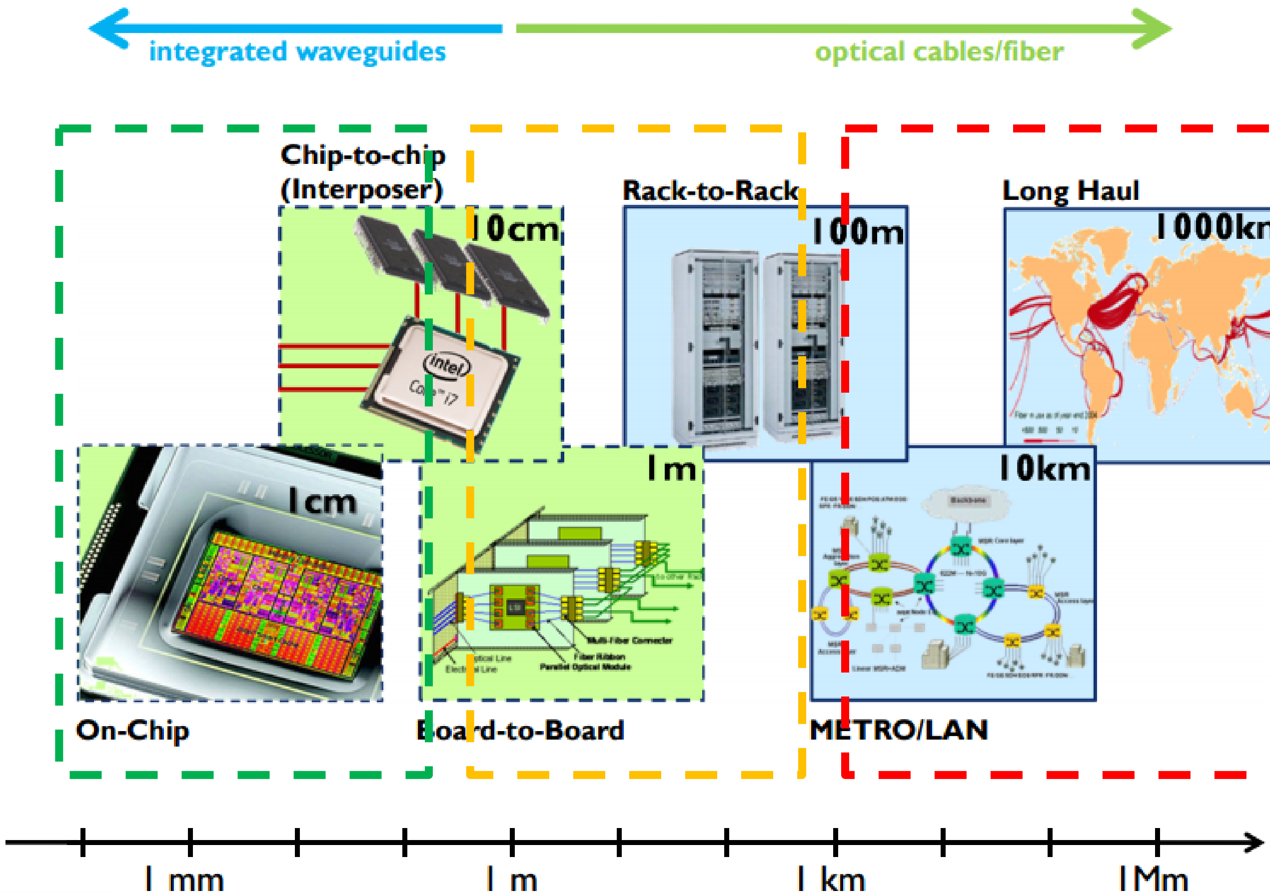


(Cisco)

LOTS OF BANDWIDTH HUNGRY APPLICATIONS



OPTICAL I/O WON THE RACK NOW THE SHELF AND NEXT THE PCB



INTEGRATED

DISCRETE AND INTEGRATED

DISCRETE

(UGent, imec)

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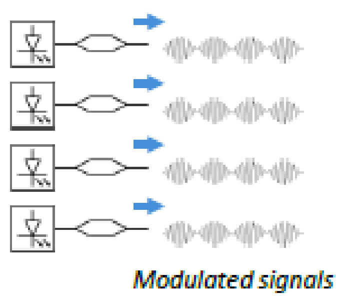
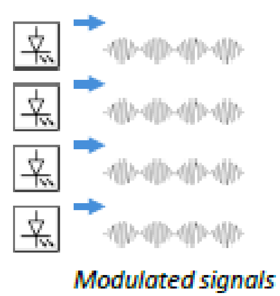
VCSEL VERSUS SILICON PHOTONICS ACTIVE OPTICAL CABLES (AOC)

Molex (Luxtera)* *Silicon photonics*-based 100 Gbps (4 channels @25Gbps) AOC (2014)

4 CW Lasers + 4 external MZI modulators



TE connectivity VCSEL based 100 Gbps (4 channels @25Gbps) AOC (2014)



4 directly modulated VCSELs

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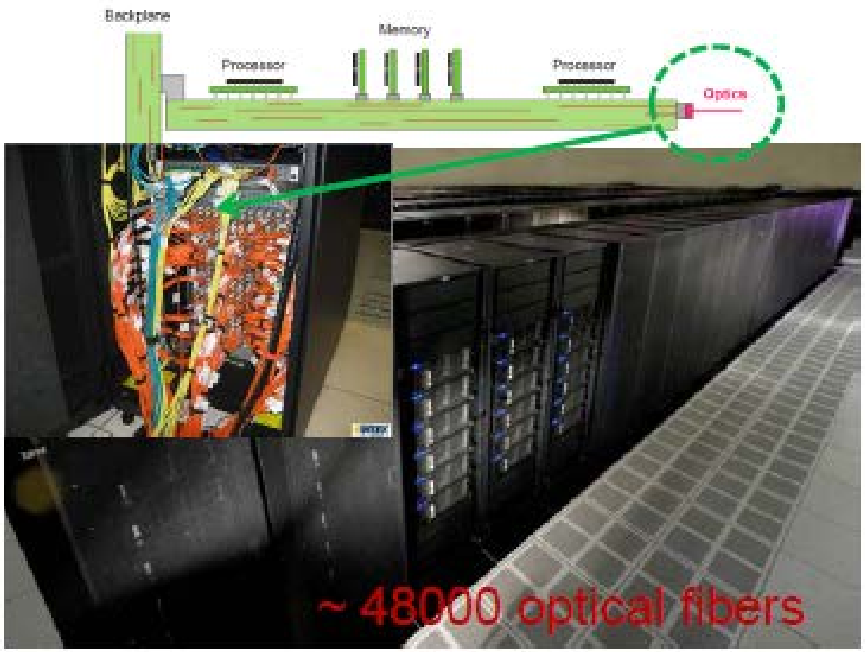
OPTICS AT BOARD-LEVEL IN HIGH PERFORMANCE COMPUTING

- Road Runner 2008, 1 Petaflops,

  Los Alamos National Laboratory, New Mexico

  Inter rack/board optical interconnects



- Blue Waters 2011, 10 Petaflops,

  National Center for Supercomputing applications, Illinois

  Inter rack/board + <u>intra board</u> optical interconnects

Performance increase, but additional assembly effort

(IBM)

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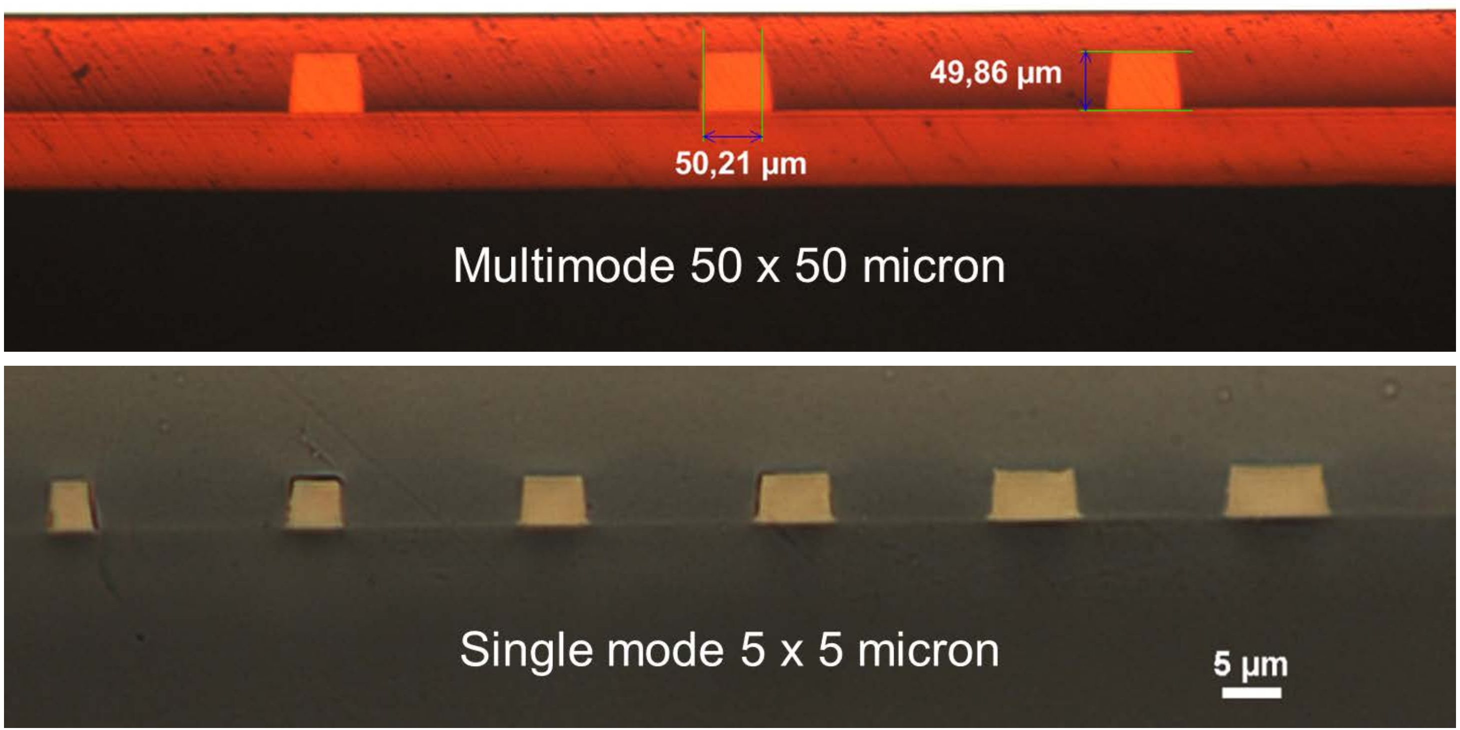
BOARD-LEVEL WAVEGUIDES

- Provide electrical and optical signal routing capability at board-level
- Enable simultaneous interfacing of electrical and optical connections
- Mating of numerous optical interfaces in one assembly step
- Allow close integration of electrical and optical functions
- Avoid cable handling at board-level

(UGent, imec)



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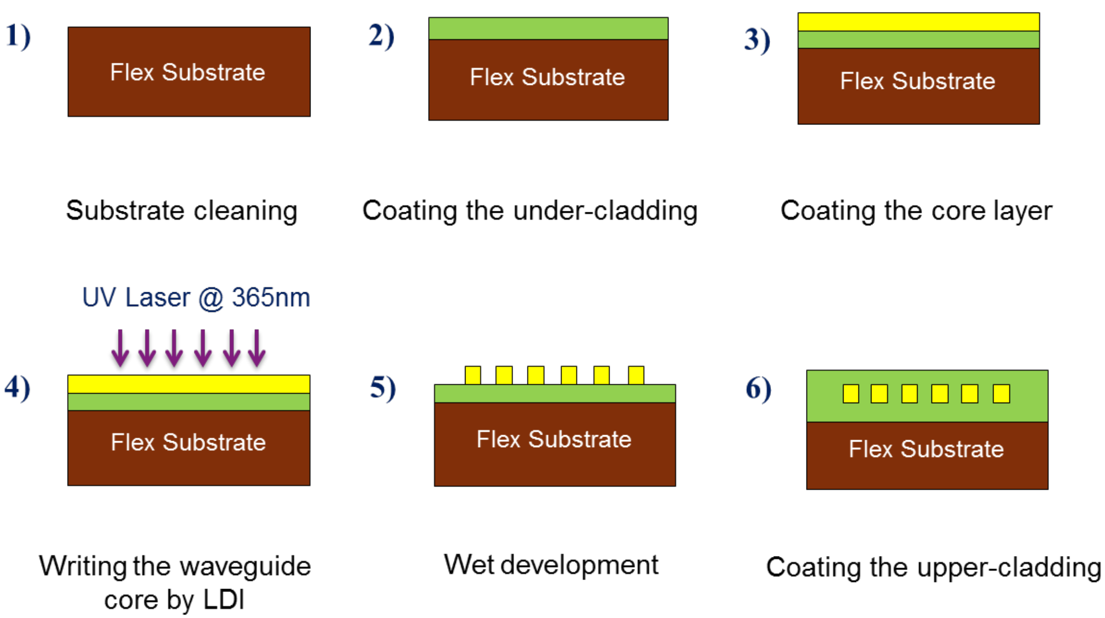
LASER DIRECT IMAGING FOR POLYMER OPTICAL WAVEGUIDE DEFINITION

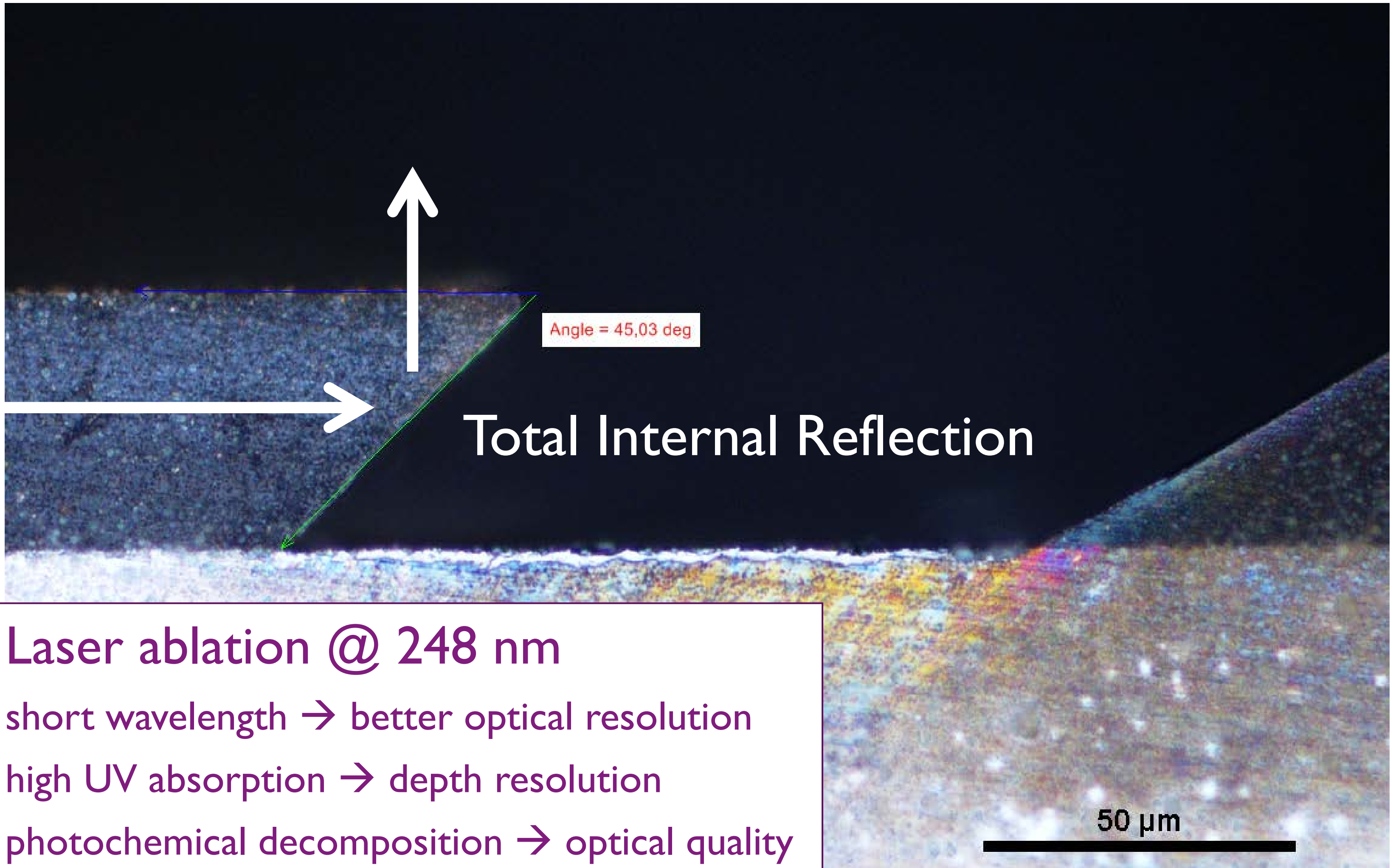
- Mask-less technique
- Flexibility
- Writing over large areas
- Minimum feature size (< 1 micron)



(UGent, imec)

Commercially available polymers

LASER ABLATION
IN- AND OUT-COUPLING STRUCTURES



Laser ablation @ 248 nm

short wavelength → better optical resolution

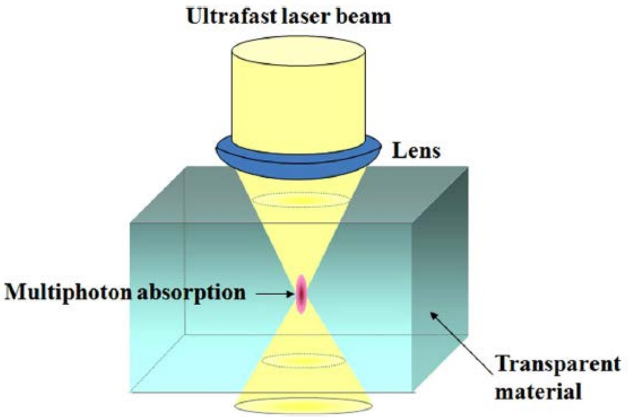
high UV absorption → depth resolution

photochemical decomposition → optical quality (roughness < $\lambda/10$)

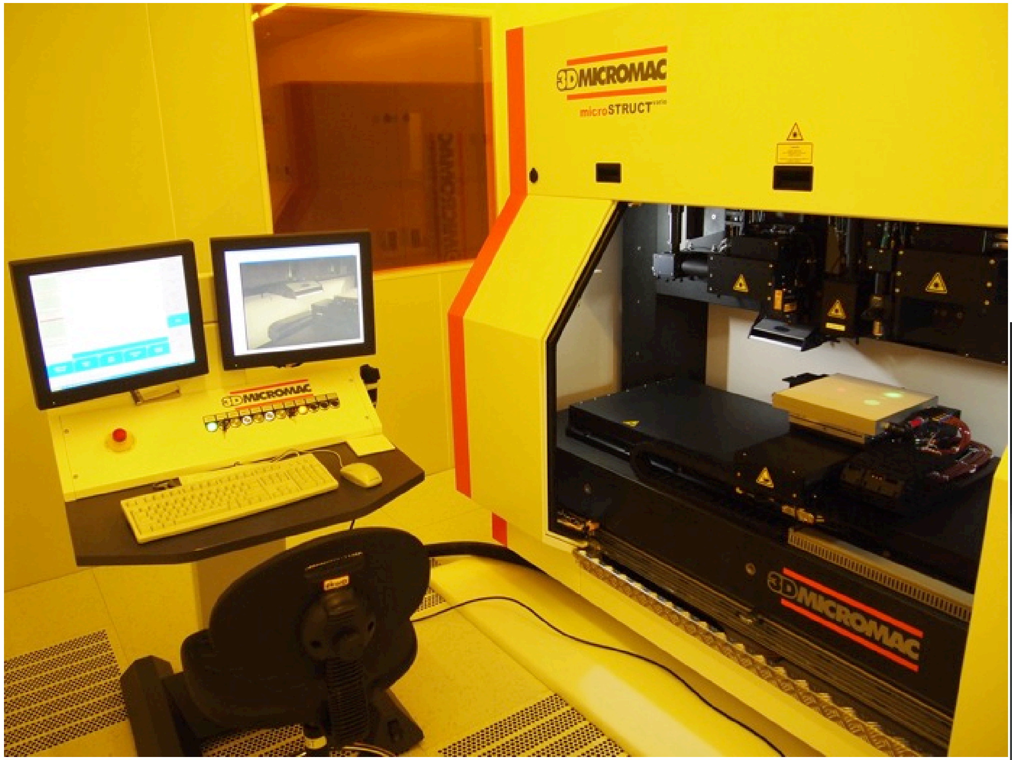
(UGent, imec)

HIGH SPEED 3D LASER DIRECT WRITING OF WAVEGUIDES IN THIN GLASS

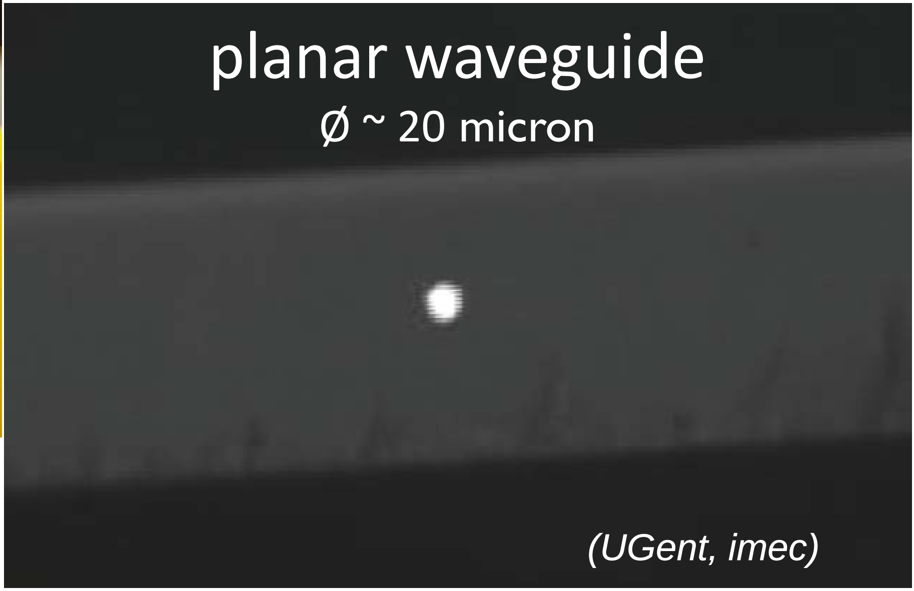
Ultrafast laser beam focused inside a transparent material, with an adequate pulse energy: index modification



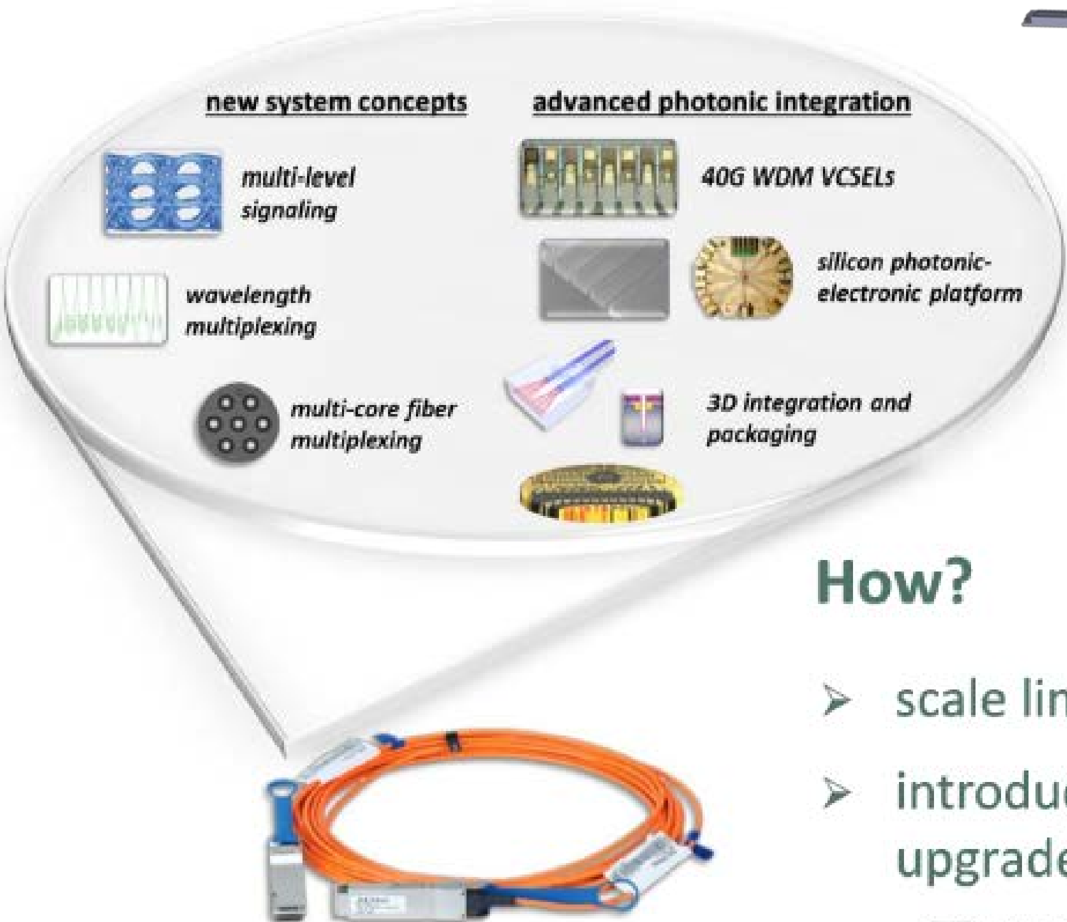
HIGH SPEED 3D LASER DIRECT WRITING OF WAVEGUIDES IN THIN GLASS

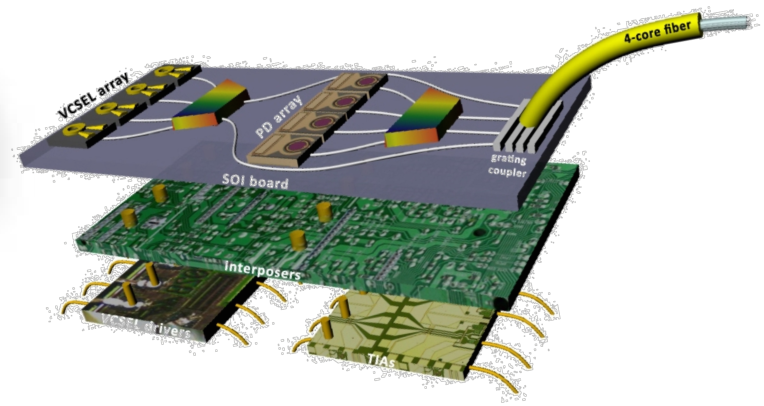


"Dry" process
Writing speeds up to 200 mm/s
Single mode and multi mode
Various wavelength regimes
Harsh environments?



HOW TO ADDRESS TERABIT SCALE INTERCONNECTS





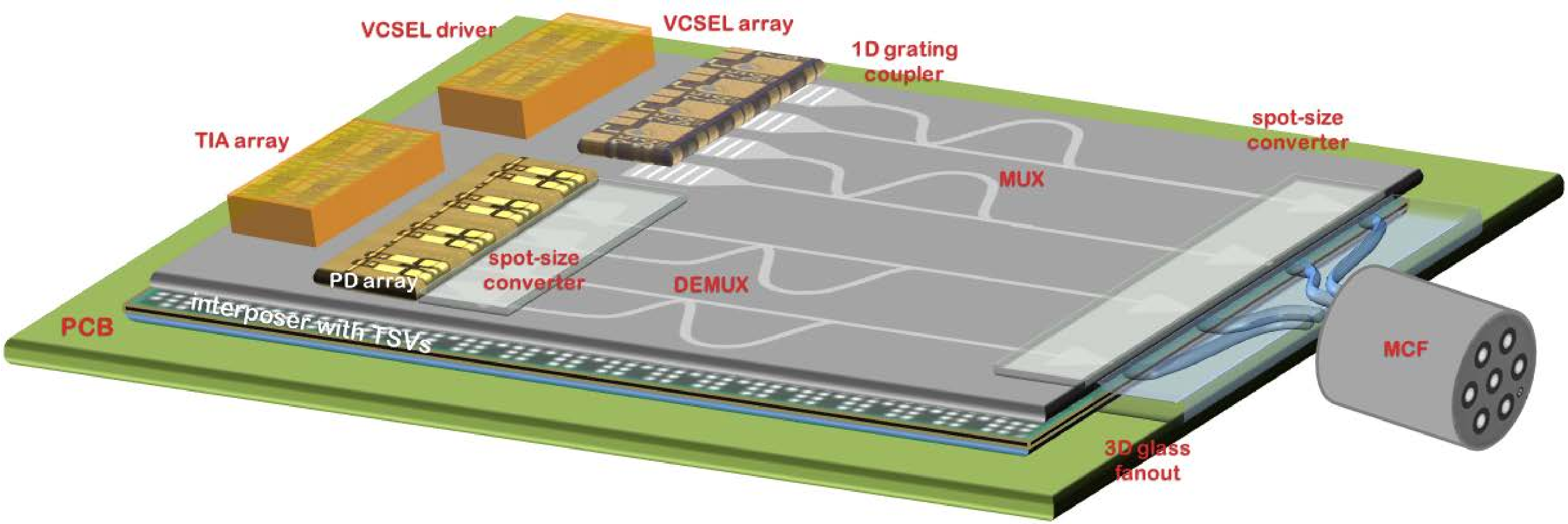
How?

- scale line rate to 40 G
- introduce new multiplexing concepts to upgrade data density

☑ *WDM* ☑ *multi-core* ☑ *multi-level*

NUMEROUS POSSIBILITIES WITH INCREASING COMPLEXITY/FUNCTIONALITY

Multiple photonics packaging challenges



Target: 960 Gb/s
(6-cores, 2 wavelengths, 40GBaud, PAM-4)

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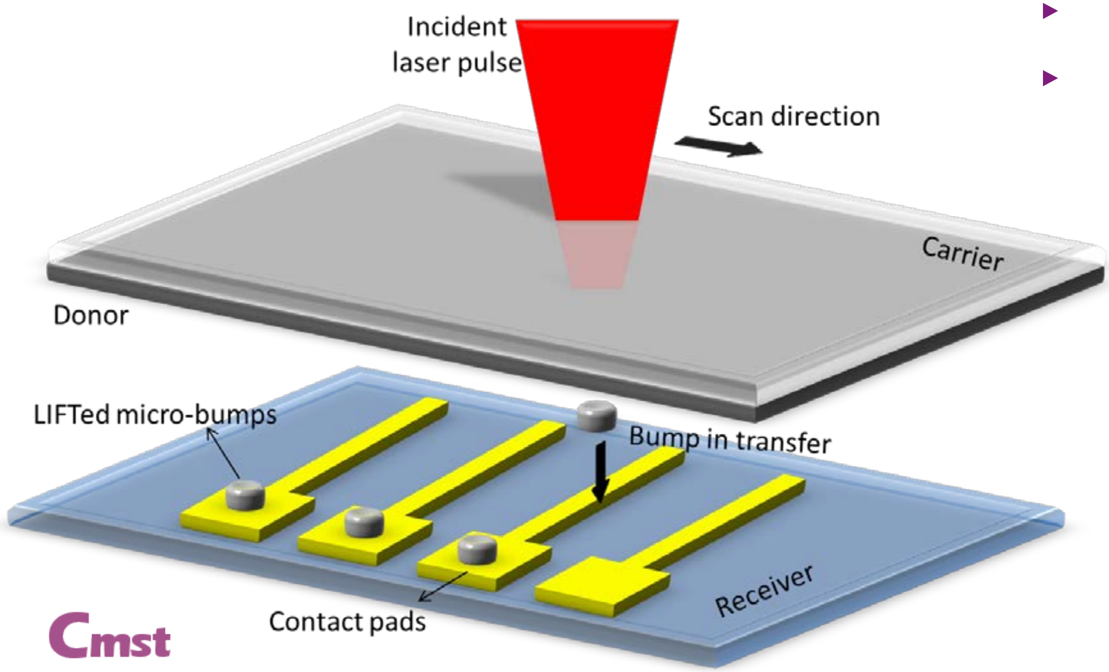
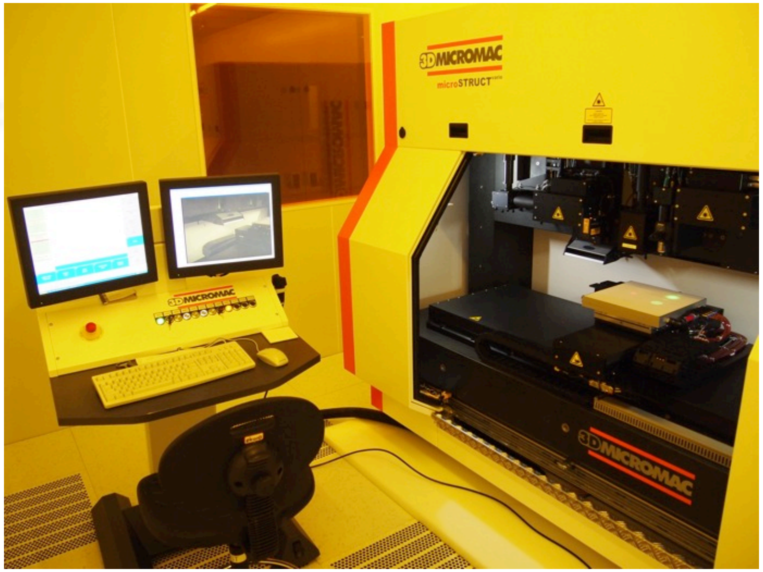
LOW-TEMPERATURE FLIP-CHIP BONDING VCSEL ASSEMBLY

Laser-transfer printing (LIFT) of low-temperature solder (Indium)



- Single step direct-write process
- Rapid, simple, versatile and flexible
- Less stringent experimental conditions
- Able to transfer # materials
- Able to realize complex 3d structures
- Excellent rapid-prototyping tool



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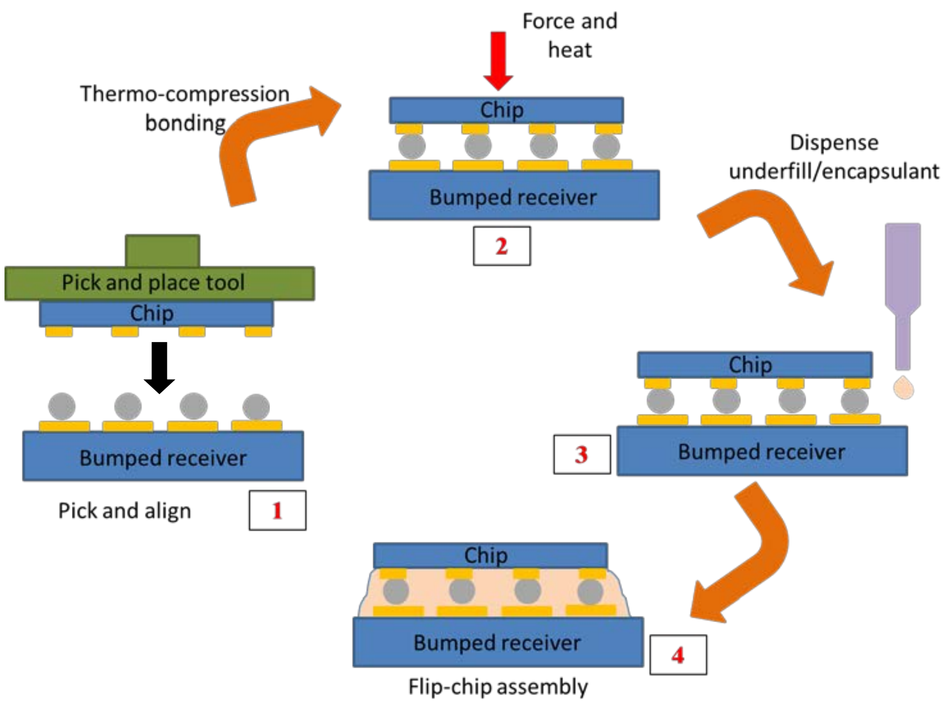
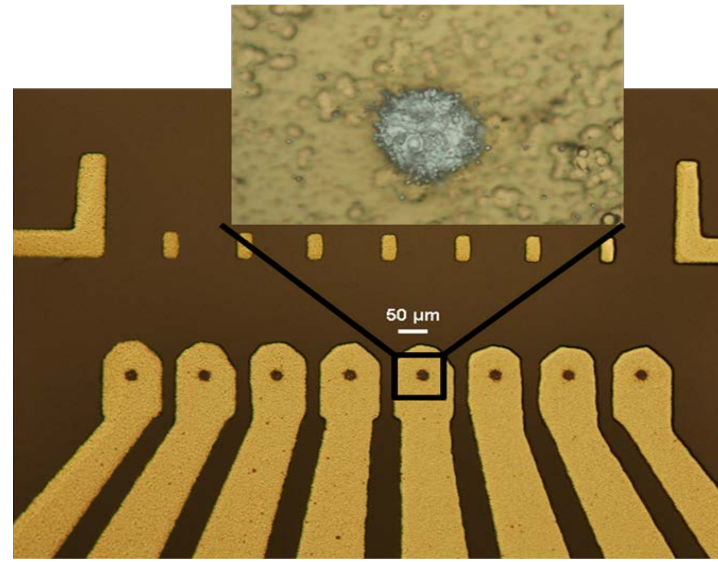
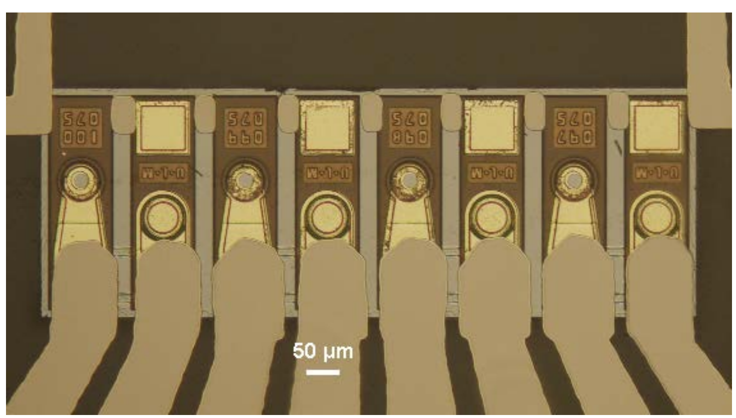
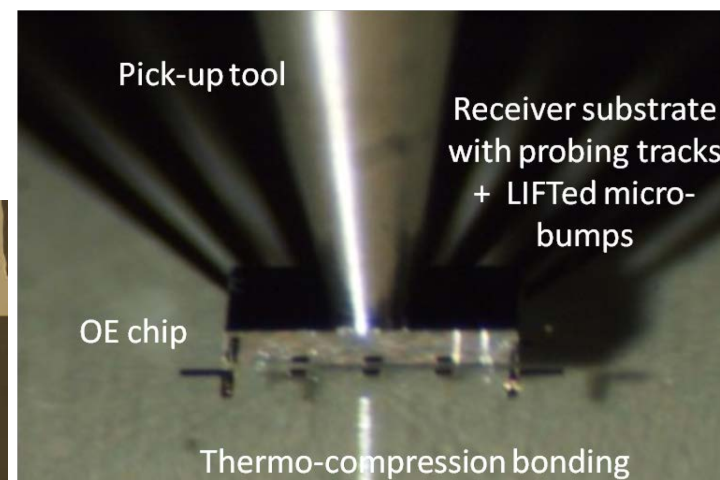
LOW-TEMPERATURE FLIP-CHIP BONDING VCSEL – GLASS









1 x 4 VCSEL array

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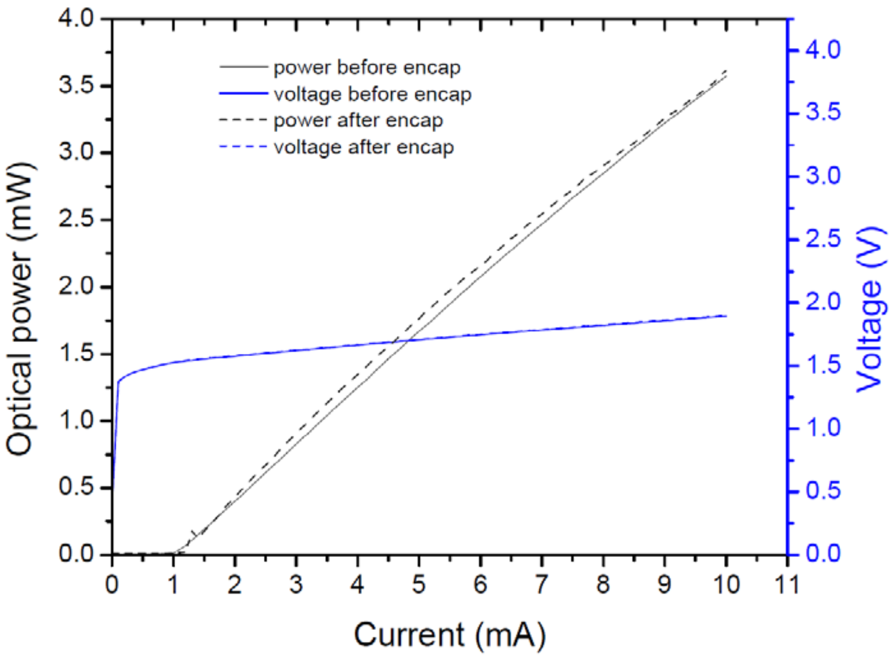
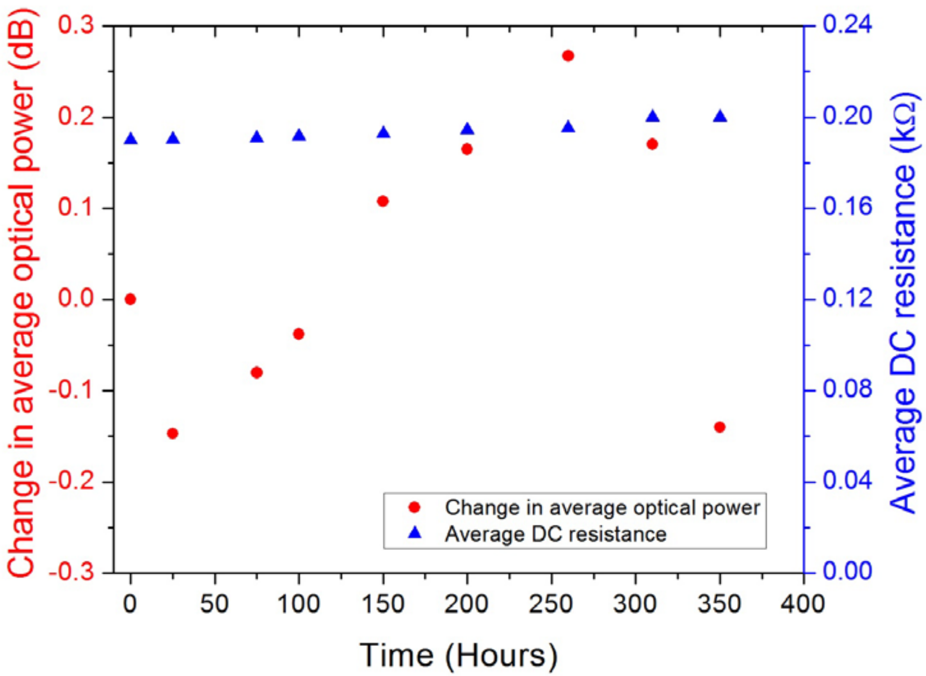
LOW-TEMPERATURE FLIP-CHIP BONDING VCSEL – GLASS

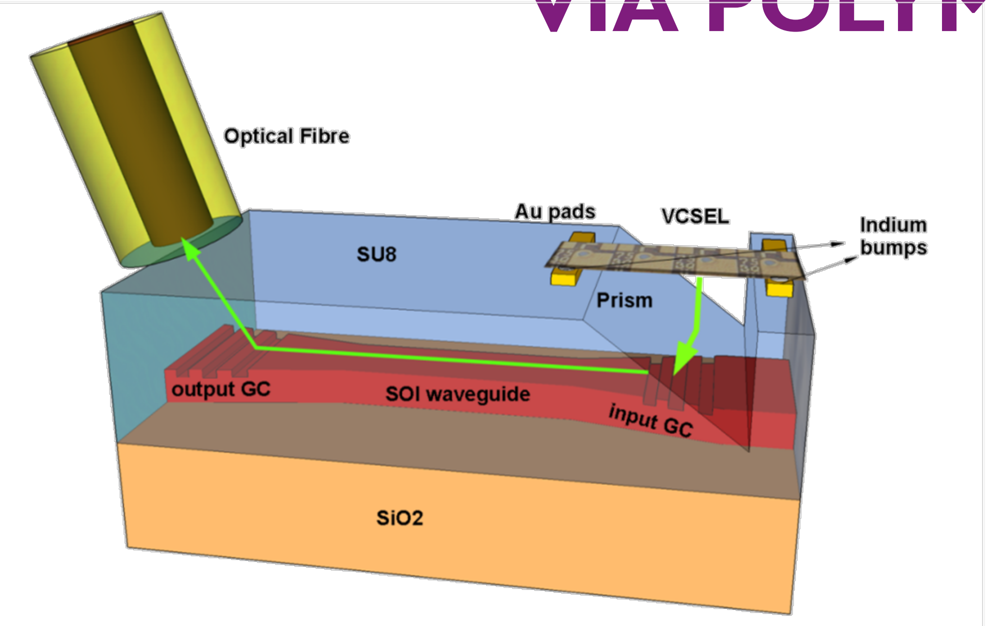


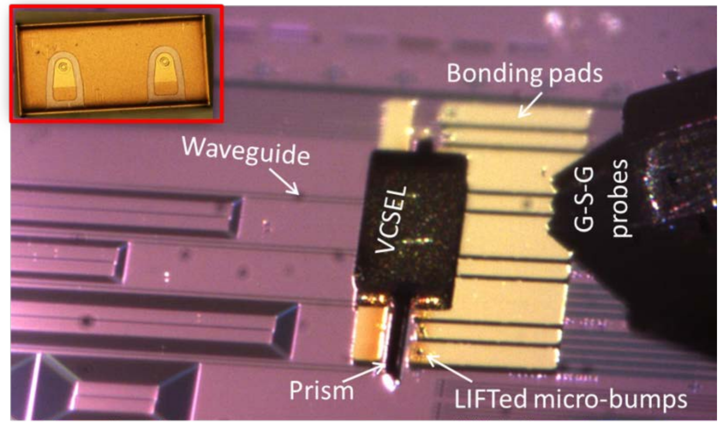


Characterization of flip-chip assembly: VCSEL LVI curves

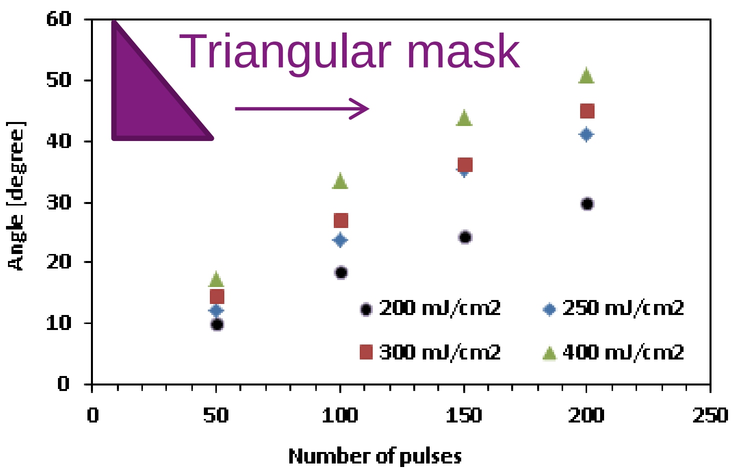
Reliability testing
Accelerated aging @ 85°C
85%RH, > 500 hours

VCSEL – SILICON PHOTONICS VIA POLYMER PRISM





VCSEL assembly on silicon chip



Excimer laser ablation of prism

Fiber-to-waveguide coupling efficiency without prism (10^0, 1550 nm) (dB)	Fiber-to-waveguide coupling efficiency with prism (0^0, 1550 nm) (dB)	VCSEL-to-waveguide coupling efficiency (@ 5 mA) (dB)	Total excess loss (prism+bonding) (dB)
-18.5	-19	-20	**-1.5**
-17	-17.5	-17.7	**-0.7**

Loss measurements

CONCLUSIONS

- VCSEL and Silicon based board level optical interconnects are viable
- Driven by higher BW density, lower power
- Board-level optical building blocks under development
- Lower cost through simplicity and integration
- Industry must optimize mix of solutions and deliver dominant designs
- Role of standards?

RECENT OFC REPORTS ON 1060NM VCSELS

Finisar, Reliability of VCSELs for >25Gb/s

- 25G 980-nm reliability to be even better than 25G 850-nm reliability
- Initial estimates suggest that at 95C the difference could be more than an order of magnitude

IBM, Low power CMOS-driven 1060 nm multimode optical link

- optical link with 90-nm CMOS chips, using a VCSEL bias as low as 2 mA, a 4.9 pJ/bit efficiency is obtained at 20 Gbps

Corning, MMF for High Data Rate and Short Length Applications

- At 1060 nm, both the optical fiber chromatic dispersion and loss are reduced by more than 2 times

GeorgiaTech, 50Gbit/s PAM-4 MMF Transmission Using 1060nm VCSELs with Reach beyond 200m

THANK YOU

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