UNLEASHING THE POWER OF LIGHT
- breakthrough applications enabled by material science -

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Besides life...

- **Light is energy**
  - Harnessing solar power with **high-efficiency solar cells**

- **Light is healing**
  - **Yellow laser** for dermatology

- **Light is information**
  - **Photonic integrated circuits** for ICT

- **Light is security**
  - **Photonic integrated circuits** for advanced sensing

How to make these happen? What materials? What technology?
1. Solar energy harvesting

😊 **Abundant:** The surface of the earth receives 120,000 TW of solar radiation – 20,000 times more power than what is needed to supply the entire world.

😊 **Sustainable, Available all over the world, Many applications …**

😢 **Expensive** (due to technology factors but also political, social, economical etc.)

😢 **Requires space:** maximum power density of 1000 W/m²; global mean power density is 170 W/m² (better than any renewable but small compared to oil). Transportation costs are significant and generate pollution.

**Solution: increase the efficiency of PV conversion**
New materials enabling to increase the number of solar junctions: GaInNAsSb

Key features:
- Lattice matching to GaAs
- Bandgap 1eV - 0.8 eV
- High-quality
Technology: **Molecular Beam Epitaxy** and ... everything else

Synthesis and deposition with atomic-layer precision of III-V crystals

Full-scale development chain from material synthesis to device assembly
Performance outlook

Thin-film light-trapping structures

http://tf2devices.com/
2. Yellow lasers for treatment of vascular lesions and photocoagulation

Established laser solutions for dermatology: expensive, not practical

Pulsed Dye Laser

Synchro VASQ
The Perfect Synergy of Pulsed Dye Laser and the New RightLight™ Technology

Applications
- Vascular Lesions
- Scars
- Porcelain & Vitiligo
- Anti-Aging & Wrinkles
- Pigmented Lesions

Synchro VasQ

Sources
Dye - 595nm
**Vertical External-Cavity Surface-Emitting Lasers (VECSELs)**

- Wavelength coverage from **blue** to **MID-IR**
- Good beam quality with **cw** power scaling to 100W
- Broad tunability (typically tens of nm, record ~ **200 nm**)
- Narrow-linewidth operation, low noise
- Efficient intra-cavity frequency conversion
- Low noise ultrafast pulses at multi-GHz repetition rates
- Compact using low-cost broadband pump laser diodes

SEM micrograph of the gain mirror.
Yellow VECSEL system for dermatology

E. Kantola et al.: OPTICS EXPRESS 6372, 03/2014

5 W prototype on display
3. Photonic integration: enabling optical interconnects and on-chip data highways

Microprocessor and computing challenges

• Transistor miniaturization
  – Lithography and metallic interconnects
  – Power density

• Limitation related to electrical busses
  – Power losses, cross-talks, frequency resonances

• Solution: shifting data busses and logic to optics
  – Lower energy consumption (1 pJ/bit)
  – Faster data processing
  – Different computation paradigms

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2020</th>
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<tbody>
<tr>
<td>Performance</td>
<td>1 PetaFlop</td>
<td>1 ExaFlop</td>
</tr>
<tr>
<td>Cost</td>
<td>150 M$</td>
<td>500 M$</td>
</tr>
<tr>
<td>Energy consumption</td>
<td>2.5 MW</td>
<td>20 MW</td>
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<tr>
<td>Optical bandwidth</td>
<td>0.012 PB/s</td>
<td>400 PB/s</td>
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<tr>
<td># Optical signals</td>
<td>48000 @ 5 Gb/s</td>
<td>320x10^6 @ 25 Gb/s</td>
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<tr>
<td>Optics efficiency</td>
<td>50 mW/Gb/s</td>
<td>1 mW/Gb/s</td>
</tr>
<tr>
<td>Cost of optics</td>
<td>10$ /Gb/s</td>
<td>0.025$ /Gb/s</td>
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IBM Zurich

https://www.ntt-review.jp
Photonics integration platforms

**Silicon Photonics**

- Very mature
- Large scale
- CMOS fabrication compatible
- **Need light source (typically InP)**

**InP**

- Monolithic light source
- Less mature
- Smaller wafer size
- Limited in wavelength coverage (applications)
- Not compatible with CMOS fabrication

Data source: Smit et al., Laser Photon. 6 (2012), updated with Sun et al., Nature 493 (2013), and Summers et al., in Proc. ECOC 2014.

Figure 5 Chip cost (in €/mm²) as a function of yearly fab load for different fab scenarios.
How to generate light in Si? - hybrid integration

Intel InP/Si wafer bonded platform

Hybrid integration of III-V components on SOI platform

First light for Intel’s silicon photonics transceivers
On August 16 at the Intel Developer Forum in San Francisco, Intel announced that its silicon photonics platform is now in volume production and shipping in the form of 100G optical transceivers.

Is there anything but InP/Si?

Wavelength (nanometers)

UV  Visible  Infrared  mid-Infrared

300  400  850  1300  1550  2000  2500  3000  3500

GaAs  AlGaInP  GaInAs  GaInNAsSb

InP  Datacom

GaSb  Sensing

Lifescience
GaInNAs/GaAs active devices for PICs

- GaInNAsSb/GaAs QWs have high band-gap offset → temperature stable
- High quality material for 1.2 µm – 1.3 µm
- Higher absorption (faster modulators)
- GaAs is a volume production technology in microelectronics
- GaAs/Ge compatible to group IV

M. Guina: “MBE of dilute nitride optoelectronic devices” – in Molecular Beam Epitaxy, edited by M. Henini, Elsevier 2013
GaAs nanowires as nanoscale emitters on Si


I. Giuntoni et al. Optics Express Vol. 24,p18417 (2016); https://doi.org/10.1364/OE.24.018417
4. Photonic integration: miniature optical systems for biophotonics, sensing, and security

**Application Specific PICs**
- Much less volume and weight
- Mechanical stability
- Less power consumption
- Lower cost
- New functionality
- Complex architectures
- Higher margin
- Volume manufacturing
  - Increased reliability and yield
  - Easier (automated) assembly and testing

Courtesy of PICs4ALL project and EPIC

Mach-Zehnder interferometer
Michelson interferometer
Integrated OCT system

http://www.biopsypen.eu/
Integrated sensor for CO$_2$ detection

S. Suomalainen et al.: Extending the wavelength of superluminescent LEDs to mid-infrared wavelengths; MIOMD-XIII, Beijing, China, Sept. 18-22, 2016

http://www.h2020-miregas.eu
...some general conclusions

- Light is the engine of a new industrial revolution addressing all key aspects of our activities (e.g. energy, health, information, security, entertainment)
- There is a long way from basic material science to applications
- Photonic materials are multifunctional bringing opportunities for “unexpected”
- Technology acts as a “battery” to accumulate and leverage knowhow creating strong means for differentiation and impact
- Multidisciplinary competences are not an option but a must

TUT vision: “Ahead with Technology enabling great science!”
Mission: “To develop technologies that reshape the competitive landscape of Finnish industry”

Coherent Finland  Non-telecom diode lasers

Modulight  Telecom / Industrial diode lasers

Corelase  Fiber lasers

Ampliconyx
10/2016

EPICRYSTALS

Industrial laser diodes & epiwafers
Coherent Finland Oy

Communication, Industrial, Medical, Security & Defence

Corelase rofin

REFLEKRON ULTRAFAST SEMICONDUCTORS AND LASERS

TUTLI ReLase

Picophotonics

Ultrafast semiconductors (SESAM)

RGB laser sources for pico projectors & displays

CW & pulsed fiber lasers

Laser characterization equipment

brighterwave

... and the story goes on!
Thank you!

www.rapido-project.eu
http://www.h2020-miregas.eu
http://tfqd.eu

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