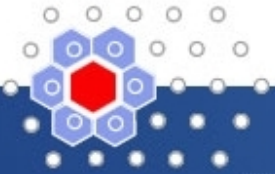


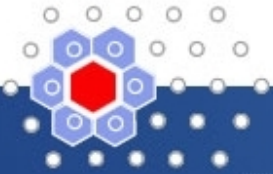
MONA Symposium June 2007, Munich

Report on Materials and Technologies

Roel Baets, Bjorn Maes
IMEC



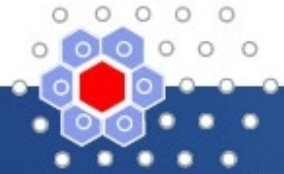
- ◆ Identifying technological breakthroughs, critical issues and potential impact for the different classes of materials
- ◆ Definition of a roadmap for materials and related technologies



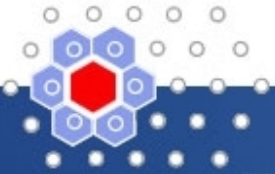
	Optical Interconnects	Datacom/Telecom	Lighting	Data storage	Imaging	Sensors	Displays	Photovoltaics	Instrumentation/metrology
Quantum dots&wires in Si									
Quantum dots&wires in III-V									
Quantum dots&wires in II-VI									
Metallic nanostructures									
High contrast nanostructures in Si									
High contrast nanostructures in III-V									
Microstructured fibers									
Organic nanostructures									
Carbon nanotubes									
Integration photonics/electronics									
Nanoparticles in glass or polymer									
Left-handed metamaterials									

Individual roadmaps established for every segment

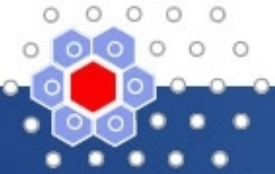
- Input from experts, workshops, personal research etc.



- ◆ All this data is analyzed in several ways
 - Applications, equipment, materials
- ◆ Here we present results from a materials' viewpoint
 - “Horizontal” approach



- ◆ Information used from the roadmaps to obtain
 - For each material:
 - Main application areas and potential impact
 - Challenges
 - European position and recommendations
- ◆ In the following slides we show important aspects per material



Applications:

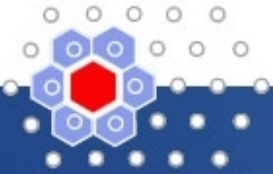
- All-silicon laser for optical interconnects
- Solar cells with nanocrystals

Challenges:

- Basic research stadium
- Role of dopants, in particular rare earths
- Fabrication: size, density control

European position:

- Competitive EU research with respect to QDs in relation to Si photonics
- QD solar cell research lacking in EU



Applications:

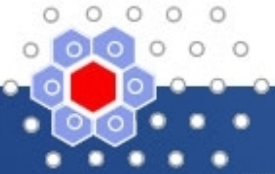
- Wide range of applications: interconnects, datacom/telecom, lighting and data storage, photodetectors (imaging, sensing, photovoltaics)
- Better efficiency, T-stability, lattice mismatched material combinations

Challenges:

- Better fabrication control, novel methods (combination top-down and bottom-up)

European position:

- First devices commercialized now, not much EU industrial involvement however



Applications:

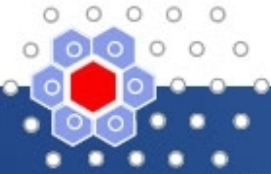
- QD nanophosphor technology rather mature (biosensing)
- Lighting and display phosphors
- Novel: photovoltaics

Challenges:

- Upscaling fabrication processes
- Multi-functional QDs
- Toxicity

European position:

- No QD biosensor companies in EU yet
- More EU R&D for lighting required
- Displays dominated by Asia



Applications:

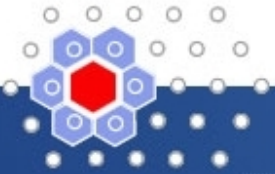
- (Bio)sensing
- Basic research ongoing for: lighting, data storage, lithography, integrated photonics

Challenges:

- Losses
- nm-level fabrication requirements

European position:

- Research level high, more industrial involvement desired
- Competitive EU research for storage, lighting and photovoltaics
- Lithography mainly US or Asia based



Applications:

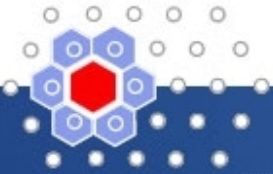
- Very strong potential impact in: telecom, datacom, interconnects, sensors

Challenges:

- Exploit the CMOS technology base
- Low-cost, high-throughput, high-resolution fabrication; packaging & coupling
- Chemical activation for biosensors

European position:

- Many major players are non-EU
- Industrial collaboration required for standards
- Foundry-like access to expensive infrastructure beneficial



Applications:

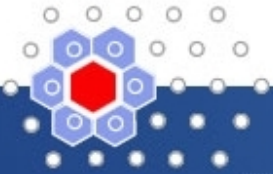
- Lighting: III-V materials broadly used, more efficiency expected with inclusion of nano-features
- Interest for interconnects and datacom/telecom

Challenges:

- Nanopotential e.g. in LEDs needs to be examined
- Photonic chips: competition of Si, useful for hybrid devices
- Similar fabrication challenge as Si, technology less developed however

European position:

- Position in lighting has to be secured
- Chips: foundry-like access beneficial



Applications:

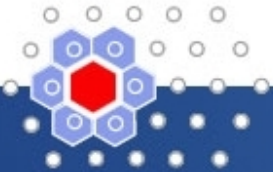
- Datacom/telecom: supercontinuum sources, Raman amplifiers
- Sensors: novel wavelengths, dispersion etc.

Challenges:

- Manufacturing: uniformity, low cost
- Designs and methods for commercialization required

European position:

- Good research position should be extended towards development and production



Applications:

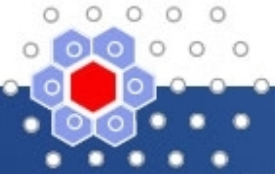
- Lighting (OLEDs), displays, photovoltaics
- Large markets, competition with other technologies
- Next generations may be provided by small organic molecules

Challenges:

- OLEDs: lifetime, efficiency, cost, obtaining flexible, large displays, nanoscale light extraction methods
- Basic research in photovoltaics

European position:

- Imminent OLED commercialization, position of EU OK
- Room for display innovation in flexible displays
- Polymer solar cells attractive R&D opportunity



Applications:

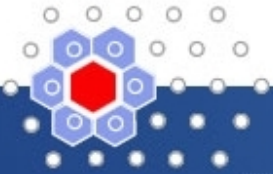
- Main interest: displays
- Additionally: photovoltaics, (datacom/telecom)

Challenges:

- Manufacturing: no conventional low-cost method
- Increasing display size

European position:

- Main players: Asia & US
- Opportunity for EU: support services, R&D and process equipment



Applications:

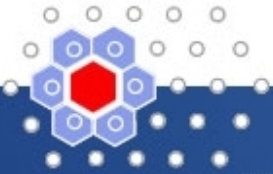
- Strong potential in interconnects and datacom/telecom (FTTH, server interconnects, sensors)
- CMOS: low-cost, mass production environment

Challenges:

- Low-cost packaging and coupling
- CMOS is a thermally hostile environment
- Compatibility of hybrid approaches with CMOS

European position:

- Gap with US industry



Applications:

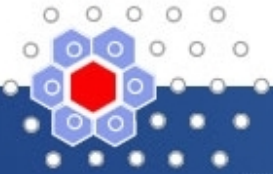
- Large potential in datacom/telecom: doped nanoparticle active fibers
- LED phosphors: basic stadium
- Solar cells

Challenges:

- Active fiber: manufacturing, control of nanoparticle during fiber insertion

European position:

- Not strong for telecom fibers and products
- Potential in the field of lighting



Applications:

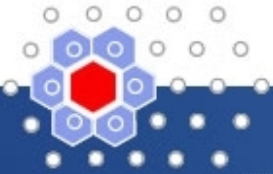
- Superlens: microscopy, data storage, lithography

Challenges:

- Basic research, commercialization difficult to foresee
- Fundamental problems: losses, poor properties of available metals, stringent nano-fabrication

European position:

- Very good research position



◆ A qualitative evolution for each nanomaterial was deduced:

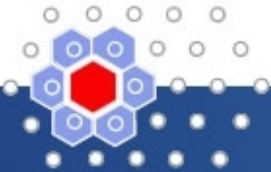
- Research and development effort
- Sales potential

At three times: now, in 2012 and in 2017.

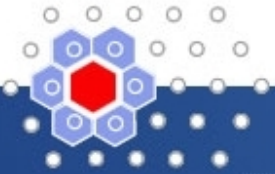
⇒ Allows for comparison between the materials

◆ Qualifiers deduced from previous data:

Timelines, importance (market size/growth) of application areas, impact of the material for key devices, severity of technological challenges, industrial involvement etc.



Material system		2007	2012	2017
Quantum dots and wires in silicon	R&D effort	Medium	Medium	Small
	<i>Sales</i>	<i>None</i>	<i>Small</i>	<i>Medium</i>
Quantum dots and wires in III-V	R&D effort	Large	Large	Medium
	<i>Sales</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>
Quantum dots and wires in II-VI	R&D effort	Large	Large	Medium
	<i>Sales</i>	<i>Medium</i>	<i>Large</i>	<i>Very large</i>
Plasmonic nanostructures	R&D effort	Medium	Medium-large	Medium
	<i>Sales</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>
High contrast Si nanostructures	R&D effort	Large	Large	Medium
	<i>Sales</i>	<i>Small</i>	<i>Medium-large</i>	<i>Very large</i>
High contrast III-V nanostructures	R&D effort	Large	Large	Medium
	<i>Sales</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>
Microstructured fibers	R&D effort	Medium	Medium	Small
	<i>Sales</i>	<i>Small</i>	<i>Small-medium</i>	<i>Medium</i>
Organic nanostructures	R&D effort	Medium	Large	Medium
	<i>Sales</i>	<i>Small</i>	<i>Large</i>	<i>Very large</i>
Carbon nanotubes	R&D effort	Large	Medium	Medium
	<i>Sales</i>	<i>Small</i>	<i>Small-medium</i>	<i>Medium</i>
Integration electronics/photonics	R&D effort	Medium	Large	Large
	<i>Sales</i>	<i>Small</i>	<i>Medium</i>	<i>Medium-large</i>
Nanoparticles in glass or polymer	R&D effort	Medium	Medium	Medium
	<i>Sales</i>	<i>Small</i>	<i>Medium</i>	<i>Large</i>
Left-handed metamaterials	R&D effort	Small-medium	Small-medium	Small-medium
	<i>Sales</i>	<i>None</i>	<i>None</i>	<i>Small</i>



- ◆ Roadmap established per nanomaterial
- ◆ Potentially large impact
 - QDs (II-VI, III-V), Si nanostructures, organic nanostructures
- ◆ Comments, (dis)agree?
 - <http://www.ist-mona.org/roadmaps/>