

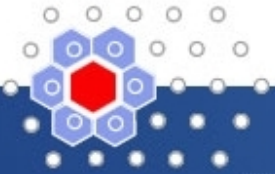
MONA

Merging Optics & Nanotechnologies

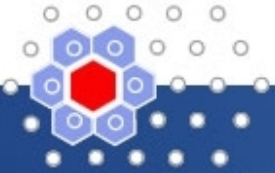
Preliminary synthesis & recommendations



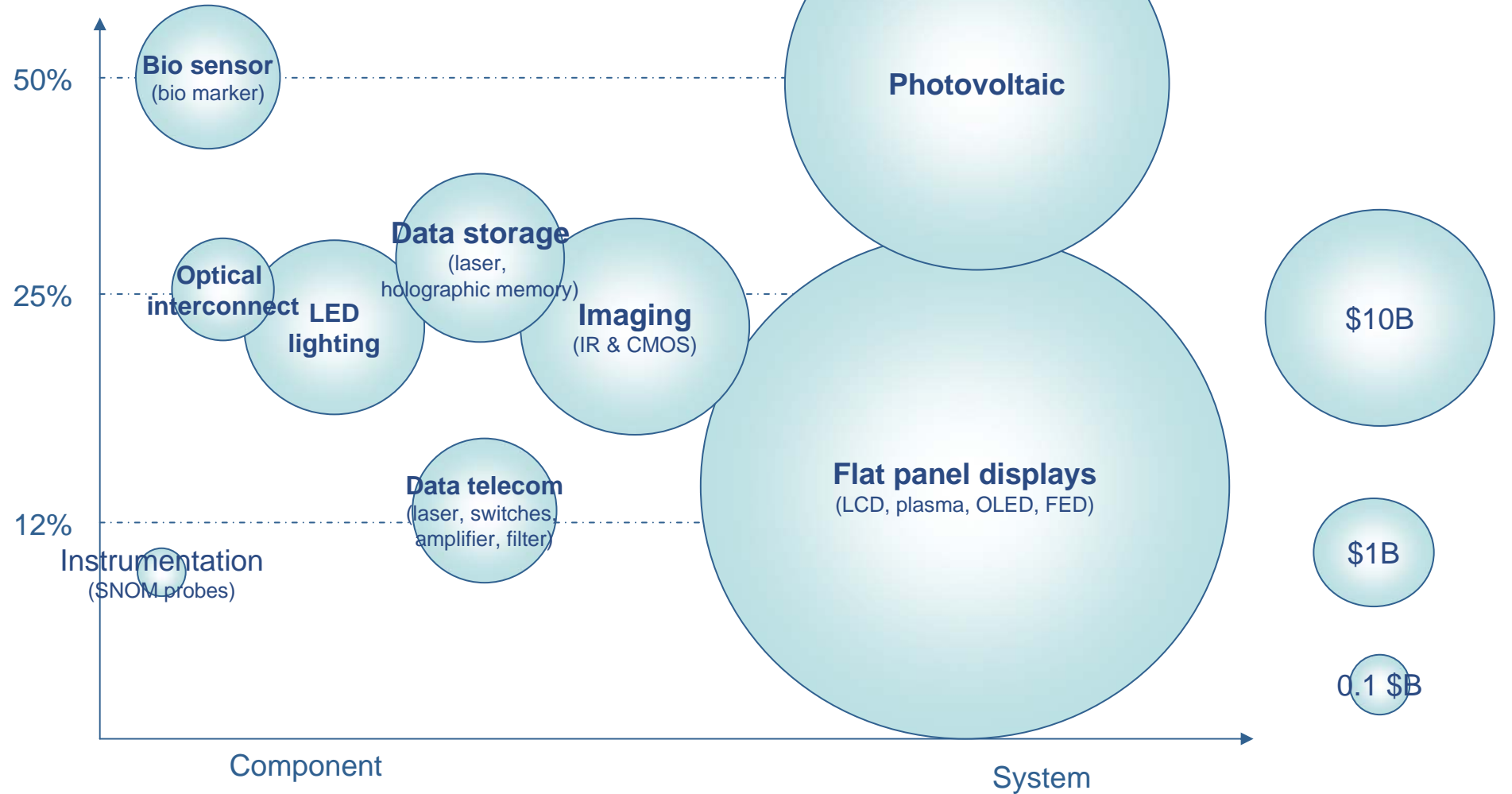
Dr. Eric Mounier
Yole Développement

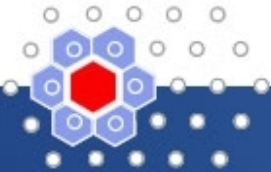


- ◆ Applications and devices
- ◆ Nanomaterials impact and challenges
=> Key nanomaterials
- ◆ Types of equipment with high impact on nanophotonic devices
=> Key equipment
- ◆ Synthesis of key nanomaterials and equipment per applications
- ◆ Recommendations on key nanophotonic devices for Europe



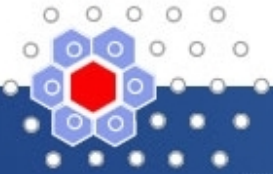
Market growth





Application	Devices
Datacoms/Telecoms	Laser sources Fiber for transmission. Multiplexers, frequency converters, filters, delay lines, switches Modulators Transceiver Waveguides Amplifier Optical buffer Saturable absorber High index contrast devices Detectors
Optical Interconnects	Laser sources modulator, transistor High index contrast waveguide Metallic waveguides Optical gate Couplers (inverse taper or grating) Link (chip to chip, with hybrid, all silicon) Detectors (Ge or III-V based)
Displays	FED (field emission display) LCD backlighting (CNT or LED) SED (surface conduction electron emitter) AR (anti reflective) organic coating Active flat displays Organic Light Emitting Diodes (OLED) Nanophosphors Liquid crystal on Si projection display
Lighting	LED : visible (white, blue, green), UV Organic Light Emitting Diodes (OLED) CNT FE

Application	Devices
Data storage	Optical storage (SIL, superrens) Ultra high density data storage Laser Quantum dot memory
Imaging	Quantum dot infrared photodetector (QDIP) IR imaging device Colour filters Microlens
Photovoltaics	Dye Sensitized Solar Cells (DSSC) Organic solar cells QD based silicon solar cell II VI solar cells
Sensors	Fluorescent marker Bio sensors Strain or pressure, gas, liquid concentration sensors Quantum wire polarization sensor Spectrum analyzer Refractive index sensor
Instrumentation equipment	NSOM (probes, SiC superlens) SP Lithography



● In depth analysis of applications shows common nanophotonic devices and issues to some of the applications fields. For instance:

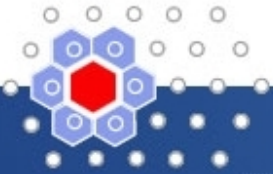
● Display and lighting :

- Issue : Increasing requirement to reduce power consumption and meet Kyoto protocol goals.
- Main devices under development are impacted by nanophotonics :
 - LED
 - LCD backlighting
 - OLED
- Future developments efforts on those 3 devices will benefit to both applications fields.

Application	Devices
Datacoms Telecoms	<p>Laser sources</p> <p>Fiber for transmission.</p> <p>Multiplexers, frequency converters, filters, delay lines, switches</p> <p>Modulators</p> <p>Transceiver</p> <p>Waveguides</p> <p>Amplifier</p> <p>Optical buffer</p> <p>Saturable absorber</p> <p>High index contrast devices</p> <p>Detectors</p>
	<p>Laser sources</p> <p>modulator, transistor</p> <p>High index contrast waveguide</p> <p>Metallic waveguides</p> <p>Optical gate</p> <p>Couplers (inverse taper or grating)</p> <p>Link (chip to chip, with hybrid, all silicon)</p> <p>Detectors (Ge or III-V based)</p>
Displays	<p>FED (field emission display)</p> <p>LCD backlighting (CNT or LED)</p> <p>SED (surface conduction electron emitter)</p> <p>AR (anti reflective) organic coating</p> <p>Active flat displays</p> <p>Organic Light Emitting Diodes (OLED)</p> <p>Nanophosphors</p> <p>Liquid crystal on Si projection display</p>
Lighting	<p>LED : visible (white, blue, green), UV</p> <p>Organic Light Emitting Diodes (OLED)</p> <p>CNT FE</p>

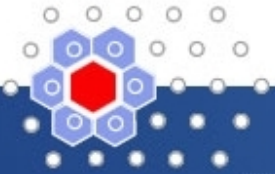
Examples of common devices

Examples of common devices

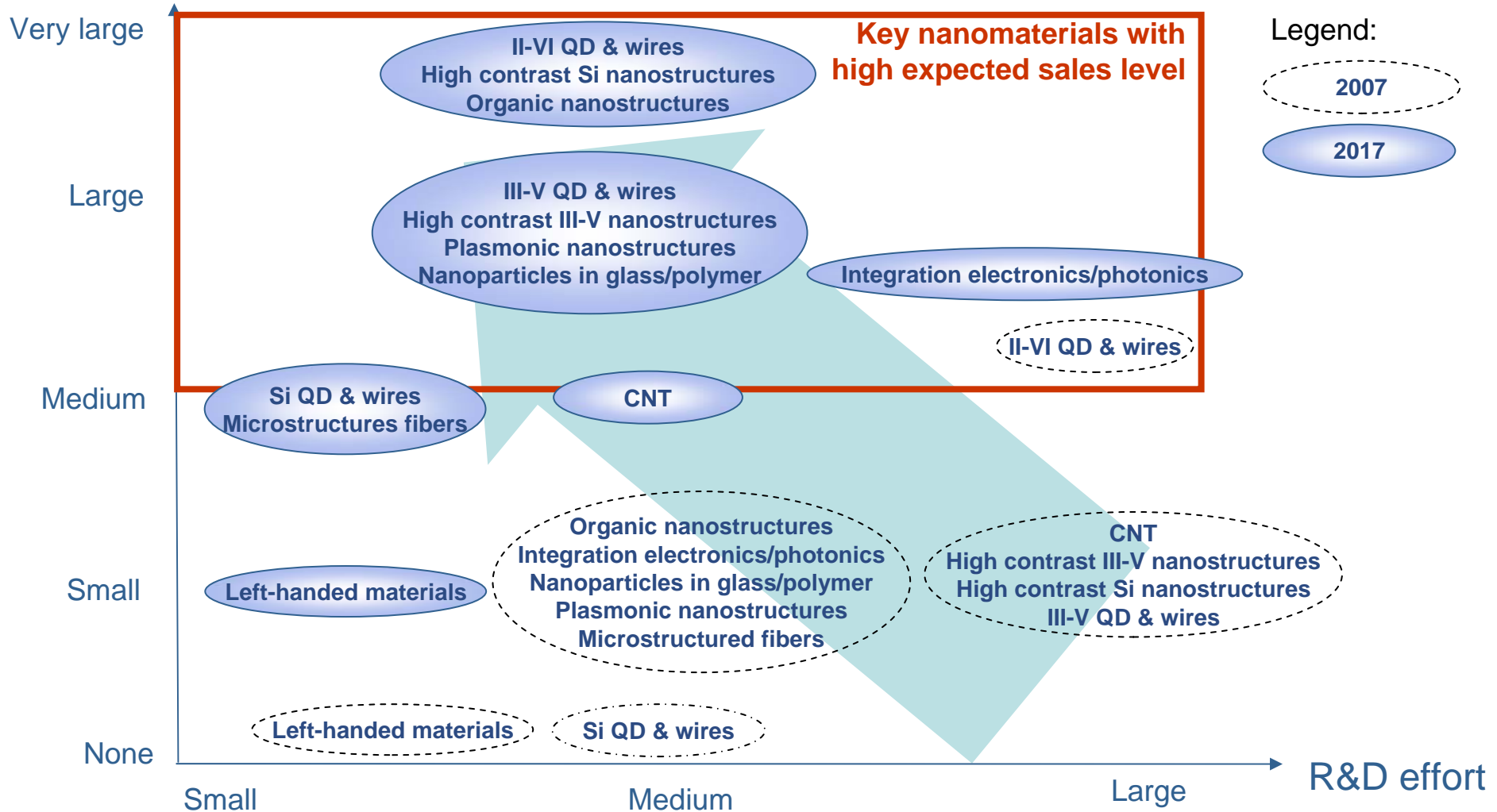


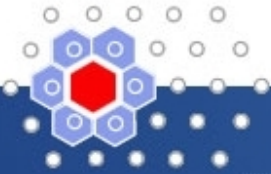
- ◆ For the 10 years to come (2007-2017), the nanomaterials have been classified according to the expected sales for nanophotonics and the level of required R&D effort to attain the objective.

- ◆ It appears that the following nanomaterials will have a large impact on the development of a nanophotonic business:
 - Quantum dots & nanowires (II-VI, III-V)
 - High contrast Si and III-V nanostructures
 - Organic nanostructures
 - Plasmonic nanostructures
 - Integration of electronics with photonics



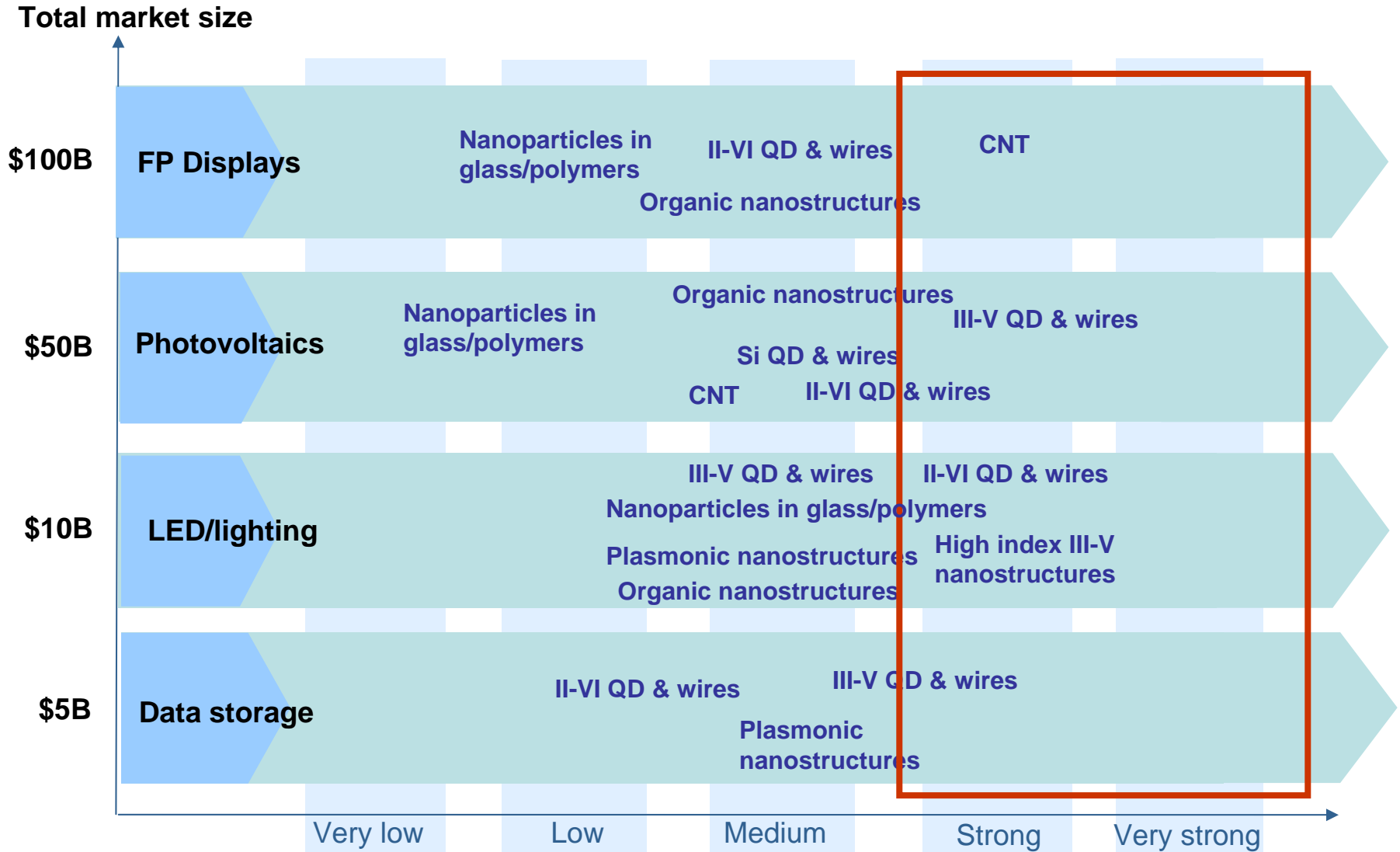
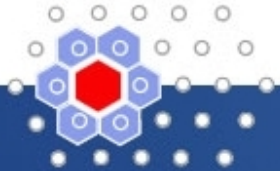
Expected sales level for nanomaterials

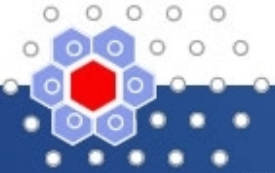




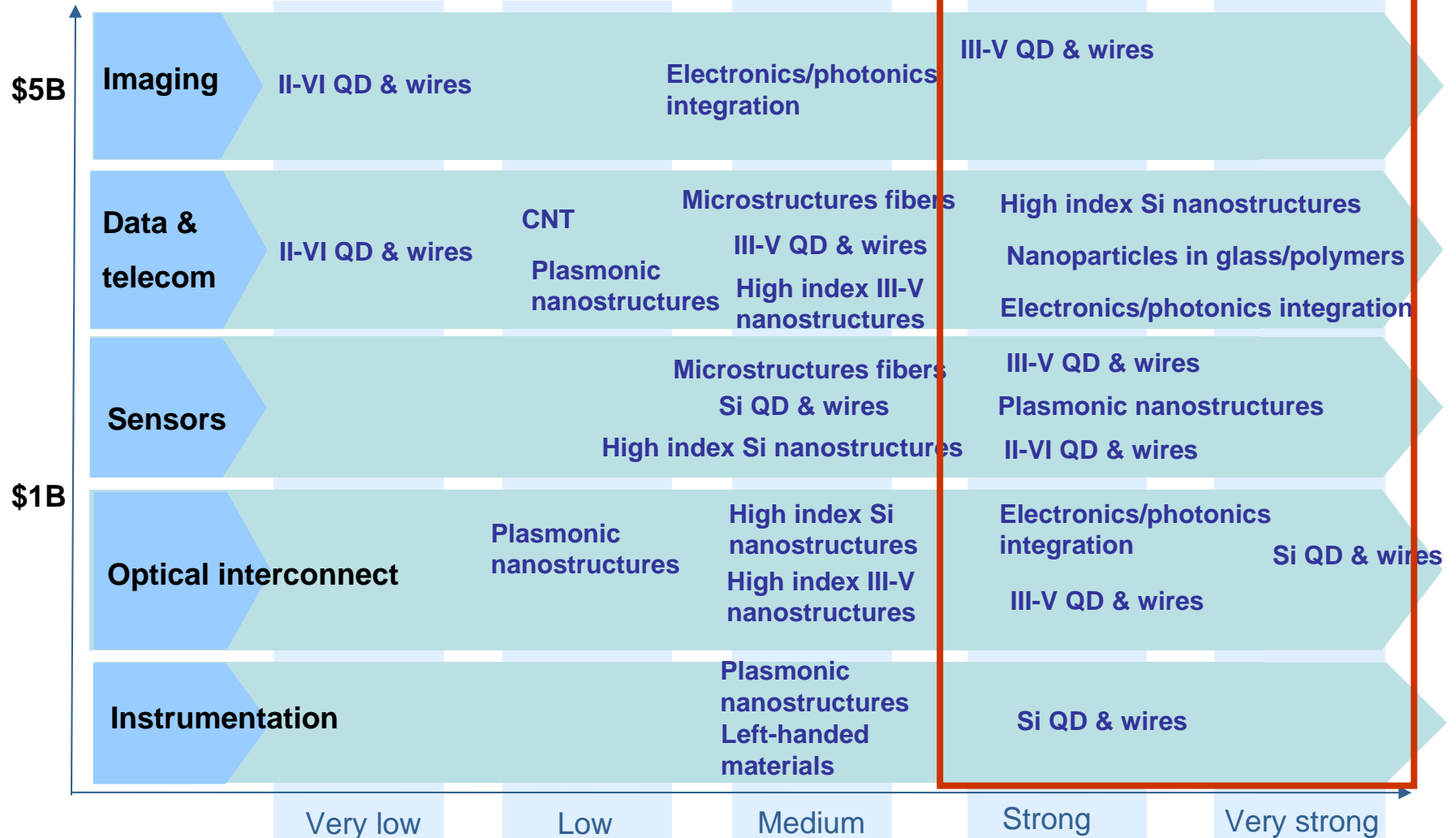
- ◆ Nanomaterials have different impact according to the considered final nanophotonic application.

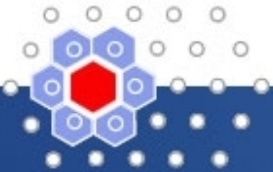
- ◆ The impact level is the contribution of the nanomaterials to the application
 - It could be a better device performance, lower cost, power savings....
 - Impact will be strong if there is a good fit with application issues and needs => strong market driver.
 - e.g. LCD flat panel technology is replacing the classical CRT technology.
 - LCD backlighting power consumption is twice than classical CRT. Hence there is strong concern for energy consumption rise.
 - CNT FE backlighting could provide similar power consumption than CRT => strong market pull for CNT backlighting.



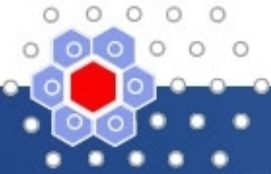


Total market size



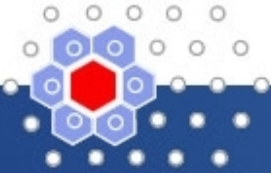


	Fundamental R&D	Production scaling and cost reduction	Toxicity	Foundry access	Industry standards
Semiconductor quantum dots&wires in :					
- silicon in colloidal nanostructures	X				
- III-V including colloidal nanostructures	X				
- II-VI including colloidal nanostructures	X	X	X		
Plasmonics/metallic nanostructures including nanostructures (metal)	X				X
Photonic Crystals/High index contrast nanostructures in :					
- silicon		X		X	X
- III-V		X		X	X
- other materials (microstructured fibers)		X			
Organic nanostructures	X	X			
Carbon Nanotubes (CNT)		X			
Integration of nanophotonic materials/structures with electronic ICs/Silicon Photonics	X	X			
Nanoparticles in glass or polymer		X			
Left-handed metamaterials	X				

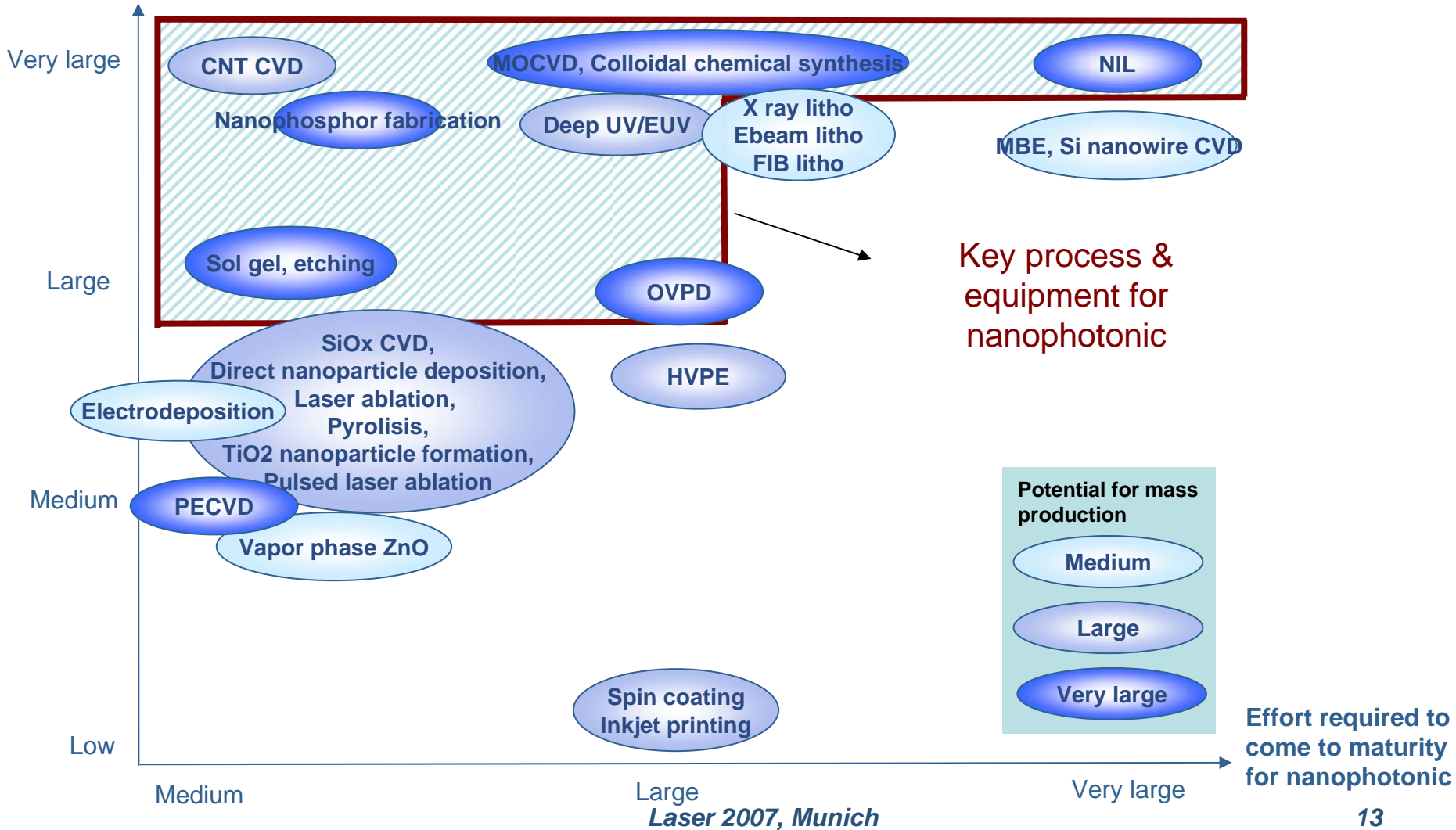


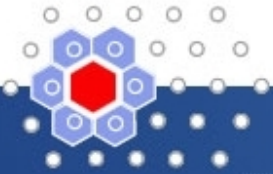
- ◆ The processes and types of equipment have been mapping with 3 criteria:
 - The impact on the nanophotonic devices (e.g., how such equipment will contribute to the final performances of nanophotonic device)
 - The current efforts to mature from R&D to production tool
 - The potential of existing equipment to be used as a mass production tool

- ◆ It highlights that the following types of equipment will have a high level of contribution to the development of nanophotonic devices:
 - CVD (for CNT), nanophosphor fabrication, sol-gel, etching, Deep UV, EUV, MOCVD, colloidal chemistry, NIL



Impact on nanophotonic devices performance

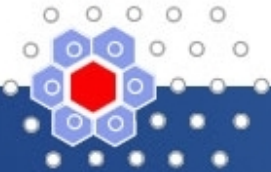




- ◆ In this overview the types of equipment and processes were ranked with respect to:
 1. their maturity
 2. their potential to enter into mass production of nanophotonic devices
 3. the broadness of application fields

- The technologies that have the highest potential impact on nanophotonics and at the same time have potential for mass production are the following: **MOCVD, CNT CVD, colloidal synthesis, nanophosphor fabrication, sol-gel synthesis, OVPD, UV lithography, nanoimprint and etching.**

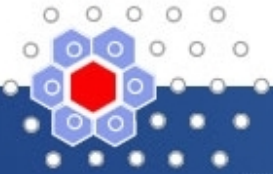
- The types of equipment and processes with the broadest field of applications are the following: **MOCVD, MBE and colloidal chemistry as bottom up technologies and UV litho, e-beam and nanoimprint as top down technologies**



Key nanophotonic devices where Europe should focus on :

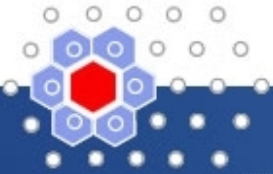
Application (2009 market size)	Devices
Displays (\$ 90 B)	LCD backlighting with CNT or LED
	OLEDs
Lighting (\$6.8B)	LED with Quantum Dots III-V, and PC II-VI
	OLEDs
Datacoms/ Telecoms (\$ 5B)	High contrast Si/ III-V photonic devices (laser, waveguide, switches, detectors)
	Active fiber (amplifier) with nanoparticles
	Nanophotonic devices using CMOS semi conductor process
Optical Interconnects (\$ 0.8 B)	Laser sources and gates with Si nanocrystals
	Nanophotonic devices using CMOS semi conductor process
	Laser with Quantum dots III-V

Application (2009 market size)	Devices
Photovoltaics (\$50B)	Organic solar cells
Imaging (\$10 B)	Infrared photodetector with quantum dot III V (QDIP)
Data storage (\$ 6.5B)	Laser with Quantum dots III V
Sensors (\$4.2 B)	Fluorescent markers with QD II VI
	Biological or refractive index sensors with plasmonic
Instrumentation equipment (\$0.03)	SNOM equipment probes



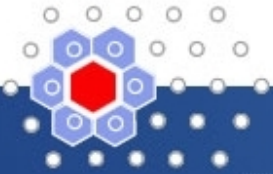
European position on key devices

Application (2009 market size)	Devices	Devices Europe position	
		R&D	Industrial
Displays (\$ 90 B)	LCD backlighting with CNT or LED	•••	•
	OLEDs	••	••
Lighting (\$6.8B)	LED with Quantum Dots III-V, and PC II-VI	•••	•••
	OLEDs	••	••
Datacoms / Telecoms (\$ 5B)	High contrast Si/ III-V photonic devices (laser, waveguide, switches, detectors)	•••	•
	Active fiber (amplifier) with nanoparticles	••	••
	Nanophotonic devices using CMOS semi conductor process	•••	•
Optical Interconnects (\$ 0.8 B)	Laser sources and gates with Si nanocrystals	•••	•
	Nanophotonic devices using CMOS semi conductor process	•••	•
	Laser with Quantum dots III-V	••	••



European position on key devices

Application (2009 market size)	Devices	Devices Europe position	
		R&D	Industrial
Photovoltaics (\$50B)	Organic solar cells	•••	•
Imaging (\$10 B)	Infrared photodetector with Quantum Dots III V (QDIP)	•••	•••
Data storage (\$ 6.5B)	Laser with Quantum dots III V	••	••
Sensors (\$4.2 B)	Fluorescent markers with Quantum Dots II VI	••	•
	Biological or refractive index sensors with plasmonic	••	•
Instrumentation equipment (\$0.03)	SNOM equipment probes	••	••



◆ For each of the key devices, actions would need to be taken to :

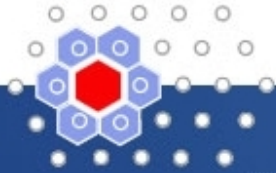
- Support the technological transfer from labs to industry (start-up support, funding of device development projects with R&D labs, SME, large companies....).

Answer to nanomaterial challenges: Fundamental research, production scaling, toxicity, foundry access, industry standard.

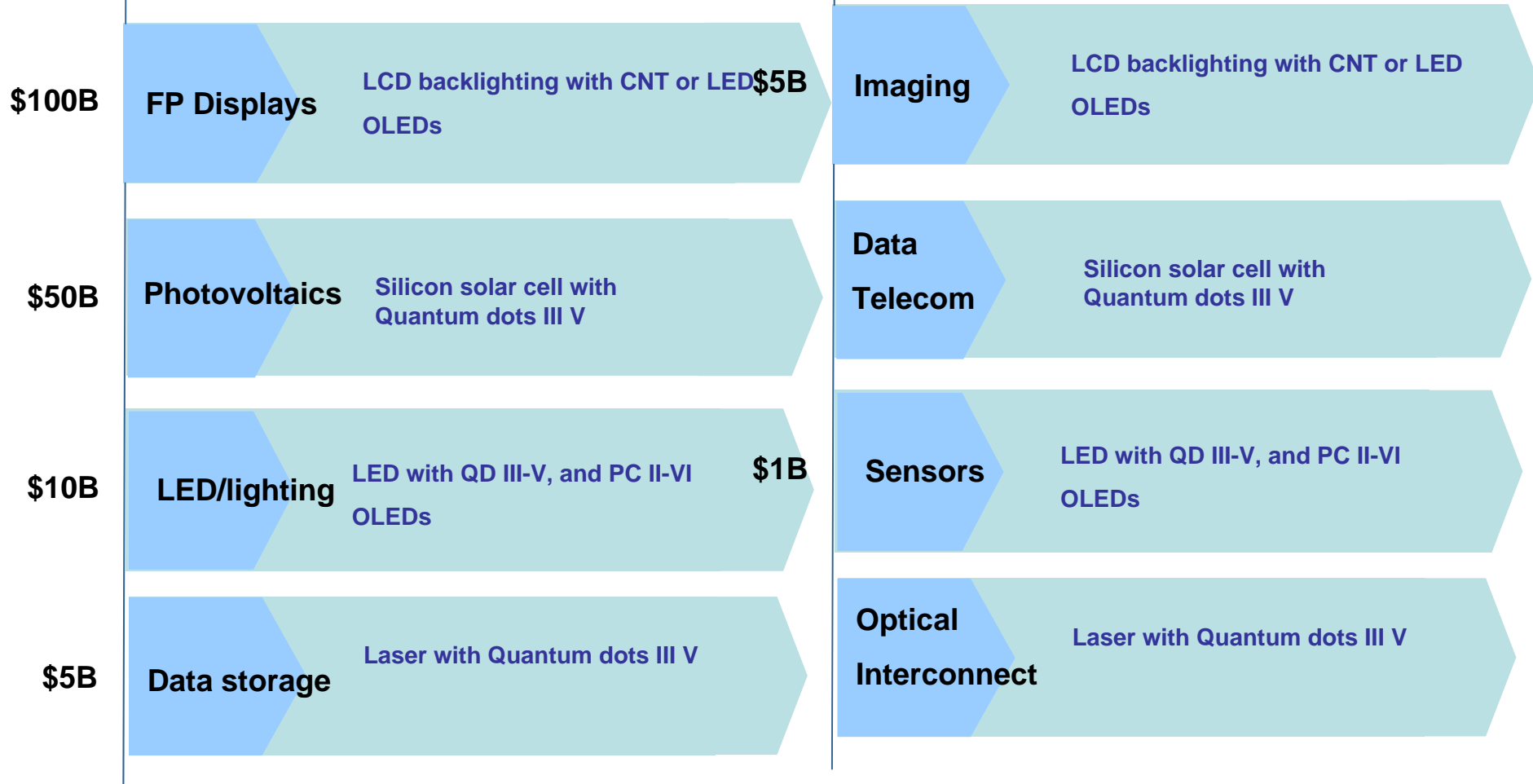
- Support the key related equipment.

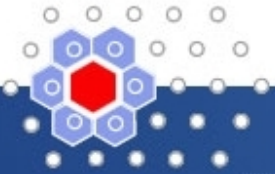
◆ A common approach should be adopted for the following applications which have common issues and some common devices :

- Display and lighting
- Optical interconnect and Data telecom



Total market size





- ◆ Questions on roadmapping process?
- ◆ Do you agree on key nanophotonic devices?
- ◆ Do you agree on position of Europe?
- ◆ What is your expected outcome?
- ◆ ...