MONA
Merging Optics & Nanotechnologies

# Applications and Markets

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# Questionnaire

- Materials and Applications
  - Describe your applications
  - What are in your view the limitations and bottlenecks in 5-10 coming years in your area?
  - In your view, could nanophotonics and nanotechnologies overcome some of these limitations.
  - In which type of field/product/technology/industry are you seeing a development of the use of nanotechnologies in your area/domain?
  - Do you already use nanophotonics concepts/nanomaterials in your devices/applications ?
  - What do you expect from the use of nanoscale materials:new functions, lower cost, higher performance/integration
- Equipment and Processes
  - In your view, are nanomaterials or/and nanophotonic related fabrication processes compatible with current processes and equipment?
  - In your view, what are the main difficulties for the fabrication of nanophotonic devices current equipment?
  - Is there any need for the development of any new equipment?
- European Context
  - In your view what are the strength/weakness of the European industry in the area of nanophotonics and nanotechnologies and what are the possible directions of improvement

**→15 filled questionnaires received**

# Overview

- Optical Interconnects
- Datacoms/Telecoms
- Lighting/Displays
- Data Storage
- Image sensors
- Photovoltaics

# Optical Interconnects level

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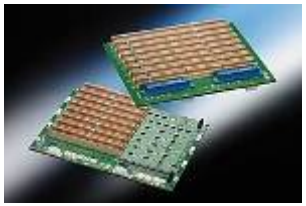
Market launch

Box-to-box interconnects (> 10 m): optical fiber

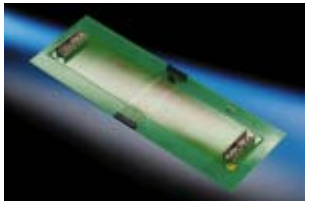
***Used today***



Board-to-board interconnects (1 -10 m); backplanes are potential applications for optical interconnects as bandwidth is increasing

Many technologies have been used (polymer WG, fiber ribbon with VCSELs …): only niche market today (aeronautics)

***> 2006 (current developments for datacom, switches … FCI)***



Chip-to-chip interconnects (1 - 10s cm): density of Cu traces on FR4 is constrained by EMI and crosstalk problems. Solutions have been tested but unsuitable for mass production. Polymer strips and VCSELs have been demonstrated (Intel)

***2010***

On-chip interconnects (< 1 cm): from Al to Cu interconnect to photonic ? CMOS-compatible materials: Si, SiO2, Si3N4 and SiOxNy could be used as waveguides and cladding.

***2010 - 2015***

# Optical Interconnects: challenges

- Objective is to have a high level of integration
- This is today a niche market for board-to-board (aeronautics)
  - Market is planned to take off in 2012 for chip-to-chip @ 22 nm node (but will price be competitive?)
- Bottlenecks in 5-10 years:
  - Propagation performance limitations: signal propagation delay time, power consumption, bandwidth
  - Cu metallization (electro-migration)
- Nanophotonics should answer to higher performance of signal propagation and Ultra Large System Integration (ULSI)
  - Issues are: coupling/decoupling light, alignment precision, temperature resistance …
- Nanophotonics is only a concept for this application so far
- Compatibility w/ existing equipments and processes are highly desirable.
- European context: limited support from applied R&D and industry

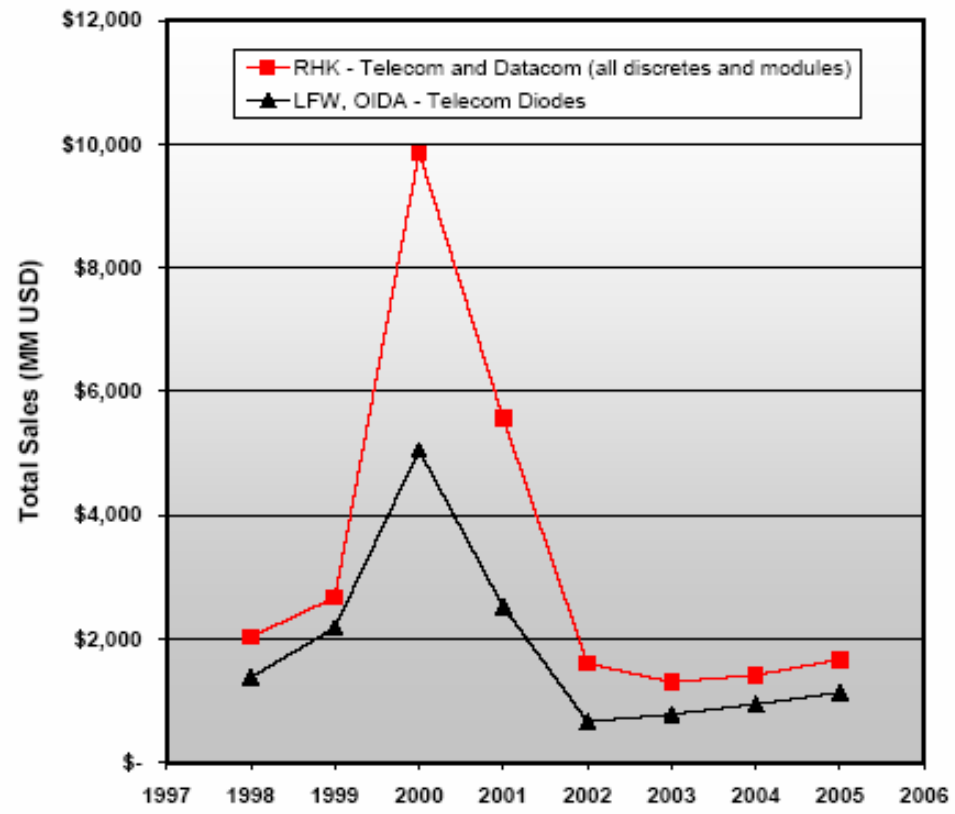
# Datacom/Telecom

"TAM for all photonics components in the communications (telecom/datacom) industry: $2B USD in 2003 and $2.5B USD in 2004.

$10.7B USD in 2000!

This aftermath of the internet bubble burst resulted in anywhere from a 4x to a 10x reduction in the TAM, and is just now growing back to late-1990's level market sizing ."

(MIT source)




Annual sales for discrete photonic components and modules, and for telecom lasers.

# Telecommunications/Datacom

- Limitations and bottlenecks in 5-10 coming years
  - InP processing

- Could nanophotonics and nanotechnologies overcome some of these limitations.
  - Moving further down the nano route blurs the boundaries between semiconductor materials, allowing synthetic bandgaps and wavelength scale beam manipulation.

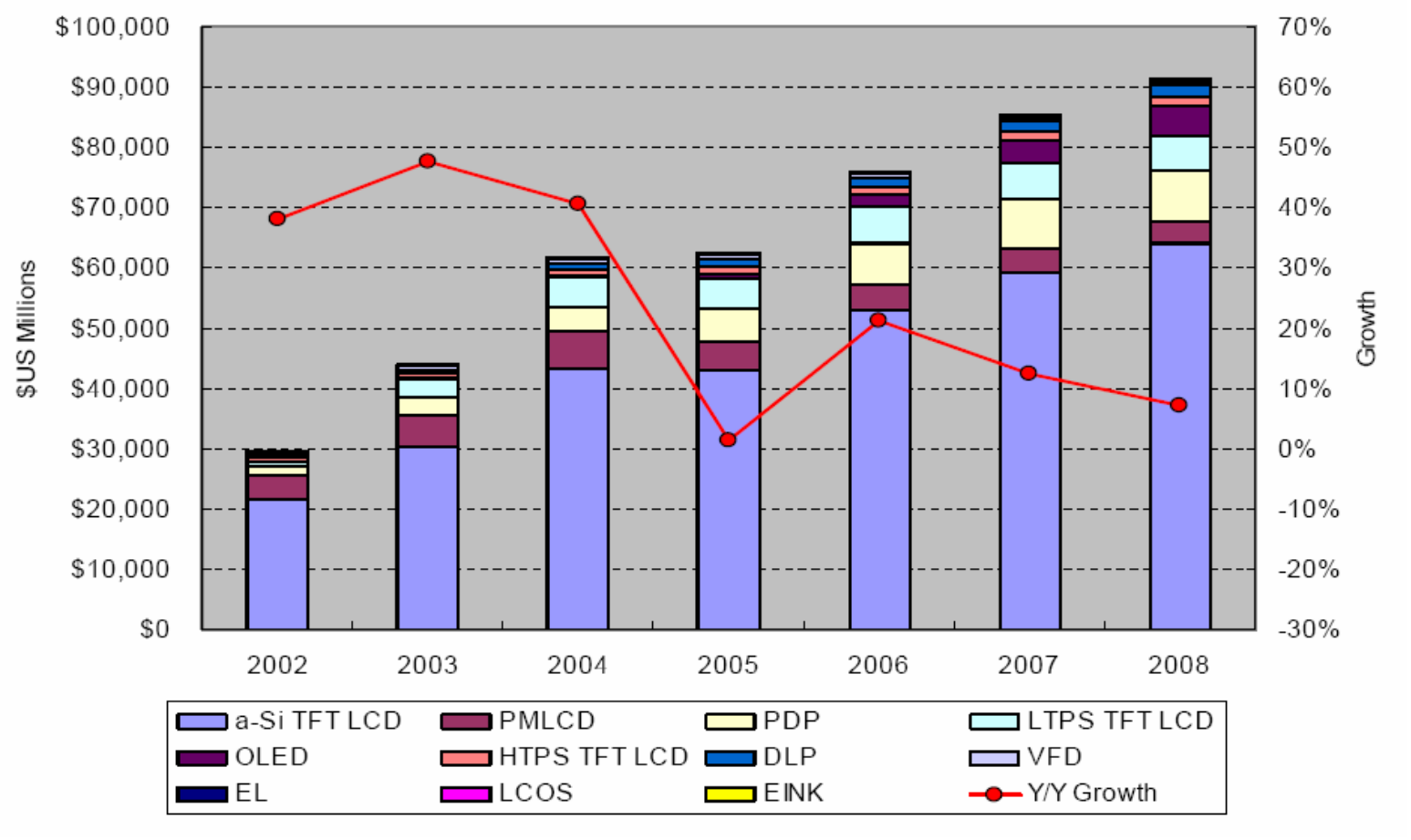
  - The field of PBGs (Photonic Band Gap) will have impact on wavelength/ subwavelength scale beam manipulation/ switching

  - It moves away from the macro scale devices such as AWGs.
    - PGB is key enabler for future high level integration, potentially 3D.

  - Industrial laser design – a key driver is maximising power without too much compromise to brightness so integration methods for array beamforming, mutiwavelength beam combining etc… will be very important.
    - nano technologies such as QD's should help drive fundamental efficiency in industrial lasers – reducing heat, simplifying cooling, overall driving better conversion efficiency and versatility

# Displays: FPD revenues per technology

- Total display revenues are forecast to grow from $59.3 B in 2003 to $103.9B by 2008 (CRT + FPDs)

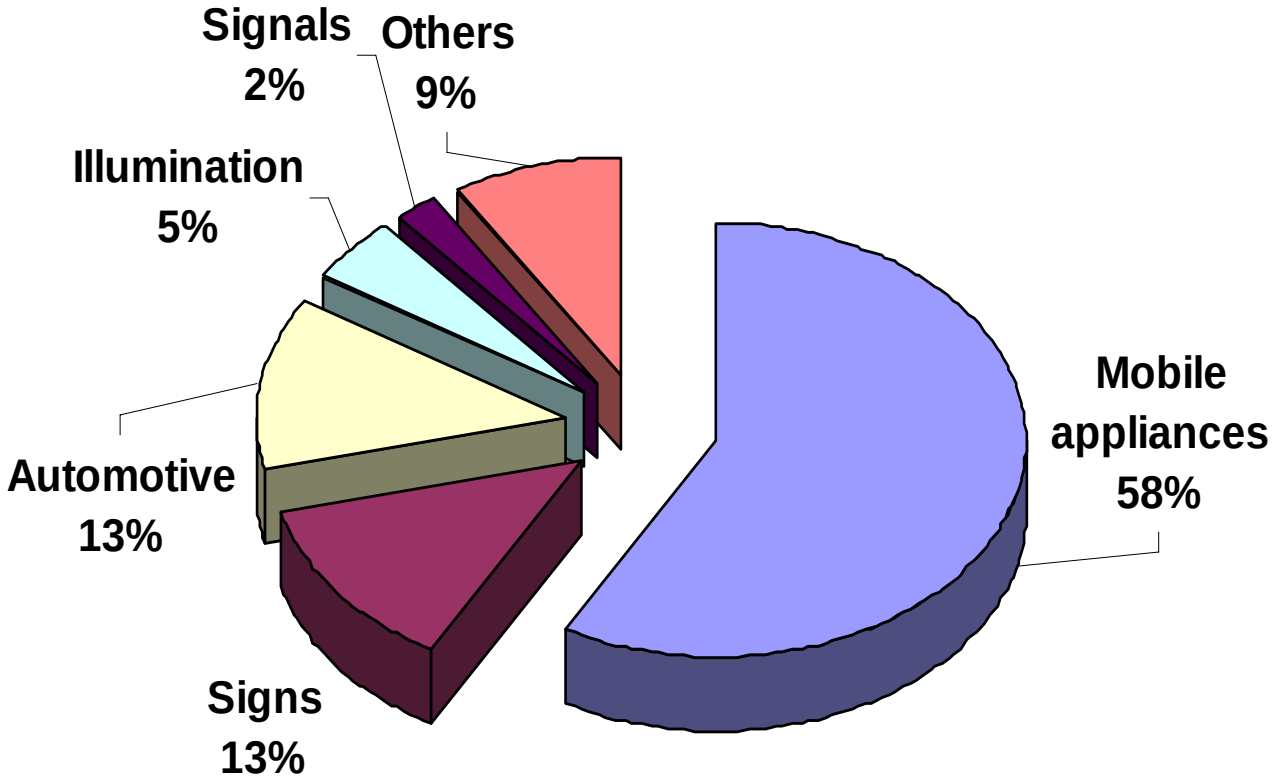


# Displays: technical & economical challenges

- Technical requirements
  - Low thickness
  - Low weight
  - Low power consumption (back-lighting)
  - High contrast (1000:1)
  - Fast response time (in the order of µs)
- Visual comfort
  - Wide viewing angles
  - New design flexibility (wide range of sizes, flexible …)
- Product lifetime
  - Non-decreasing performances over lifetime
  - Long lifetime (10 years)
  - Good resistance to environmental conditions (temperature, moisture, shocks …)

- Nanotechnology could bring CNT instead of µtips:
  - fully compatible fabrication process for large area
  - low cost
  - Low power consumption
- Conventional FEDs are limited to small display
- But no industrial scale fabrication equipment today for CNT.

# Lighting: LED applications breakdown (All colors, all materials, 2004)




*Sources: Strategies unlimited*

New markets are emerging today for LEDs & HBLEDs such as portable projection

# Lighting challenges for LEDs

- Current bottlenecks:
  - Quantum efficiency
  - Light extraction
  - Cooling
  - Packaging
  - Color steering
  - Cost/lumen/W
- Nanophotonics could overcome the above limitations: Photonic Crystals for efficiency and CNT for cooling.
- Nanophotonics concepts such as Quantum Wells are under investigation.
- Using nanoscale materials will improve device characteristics (efficiency, cooling, light extraction) as well as integration
  - Price will be important for market penetration
- Current equipment is not suitable for realizing nanostructures because high precision is needed:
- European industry tends to be a follower instead of an innovator

# OLEDs challenges

- In the 5-10 years to come, bottlenecks are:
  - High efficiency, long lived blue emitting materials, high throughput process, water protection, light distribution control, low cost substrates, large area
- Nanotechnologies could enable:
  - Better light control
  - Low cost substrates
  - Barrier coatings
- Need for equipments able to process large area with high throughput
- The European context:
  - Excellent academic support, strong innovation, broad expertise
  - Lack of coordinated vision, limited risk taking, limited cooperation between different value chains

# Data storage

Global Magnetic and Optical Data Storage Market ($ Billions)

(Source: BCC)

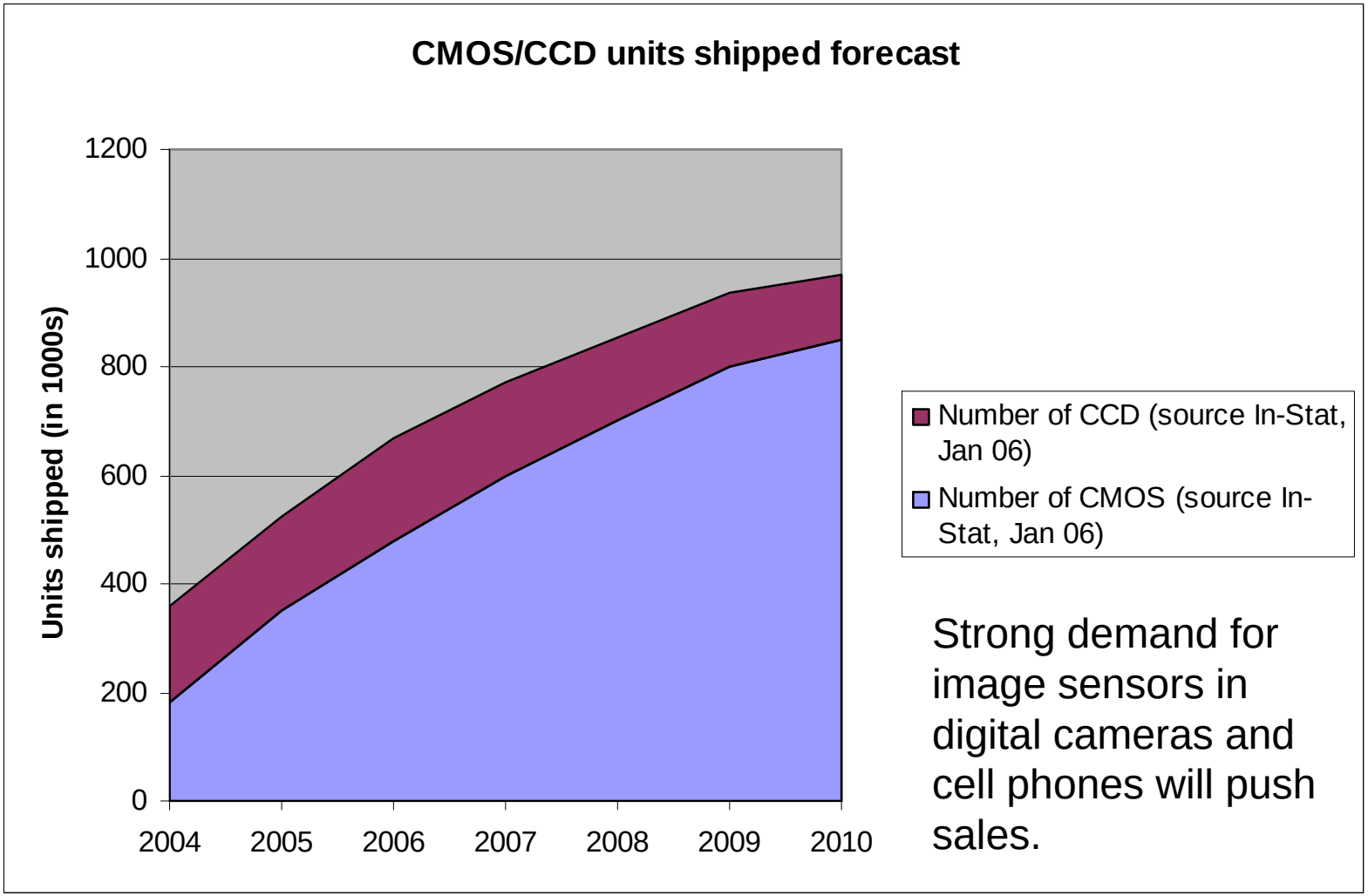
| | 2005 | 2010 | AAGR% 2005-2010 |
|---|---|---|---|
| Magnetic Media (including hard drive heads) | 7.4 | 9.3 | 4.8 |
| Optical Media | 12.4 | 30.6 | 19.8 |
| Total | 19.8 | 39.9 | 15.1 |

- > 60% of the data storage market shares were hold by optical storage media in 2005 and this part is expected to increase to 77% in 2010.
- Emerging optical media (blu-ray and HD-DVD, holographic and near-field storage) are not significant today but are expected to reach 4% market shares in 2010.

# Data storage: technical & economical challenges

- Technical requirements
  - To overcome the physical limit (paramagnetic limit) which is 150 Gbit/in² which could be reached in 2010
  - Product lifetime: no data erased over the time
- Competing technologies:
  - Blue LDs, nano-mechanical storage (IBM) …
    - Philips should launch Blu-Ray disc in 2006
  - Flash RAM technology could gain important market share in data storage

# Image sensors market



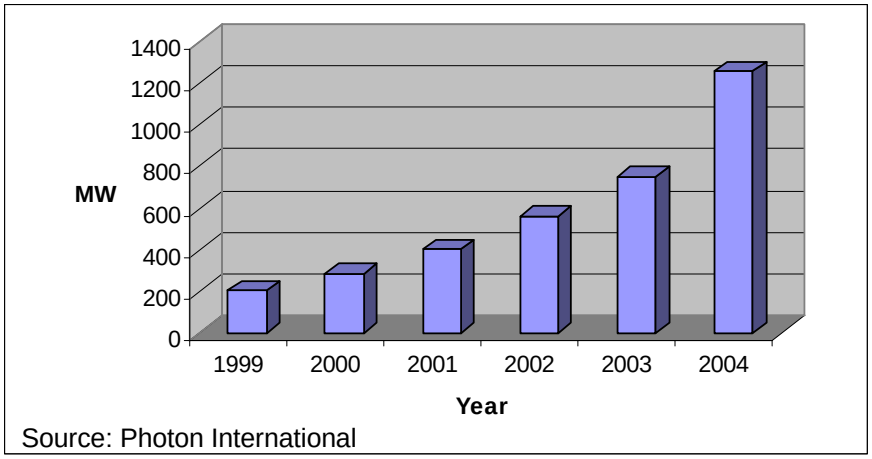

Strong demand for image sensors in digital cameras and cell phones will push sales.

# Image sensors challenges

- Markets targeted are for very small optical products (mobile phones imaging, medical products)
- Limitations and bottlenecks in 5 – 10 coming years:
  - Pixel size (in the 1.5 µm range)
  - High performance classical lenses
  - Accurate mechanical assembly
  - Materials for pixel-sized colour filters
  - On chip image & signal processing
  - Wafer integration of optical functions
- Nanophotonics could allow on-chip integration
- Nanophotonic could bring combination of CMOS process w/ optimized sensitive thin layers and above IC detection.
  - Compatibility with current manufacturing processes is a MUST.
  - No compatibility so far.
- R&D on nanomaterials has started already for filtering
- Benefits from nanoscale materials:
  - Higher pixel density > denser chip integration > lower size > lower cost > larger use.
  - New functions integration on/off chip
- Nanomaterials processing is mostly not compatible with current equipments
- At the European level, more coordination between “photonics” research and other R&D sectors (such as semiconductors) is needed.

# Photovoltaic

- World PV market evolution (what has been sold)



Source: Photon International

- ✓ The production has increased by more than 60% in 2004.
- ✓ Since 1980, it is growing by 25% per year.

- Technology market share in 2004 (conversion photon → energy):
  - Mono-crystalline Si 36%
  - Multi-crystalline Si 54%
  - a-Si 4.4% → First turn-key plant ready in 2006 from Unaxis
  - Ribbon Si 3.3% → Evergreen and Schott Solar are building new plants
  - CIS/CIGS 0.4% → Several pilot plants running, 15 MW and 27MW plants under construction
    (CopperIndiumGalliumSelenium)
  - CdTe 1.1% → First Solar is already mass-producing and expanding production capacity

# Photovoltaic challenges

- Challenges
  - Stability
  - Lifetime
  - Large area processing
  - Efficiency
  - Reducing cost by reducing silicon wafer thickness < 200µm (Si wafer represents about 40% of the module cost)
  - Improving the factory yield and throughput

- Organic PV could overcome some of these limitations: large interface areas with nanostructured surfaces (higher performance, higher integration)
  - C60 is already used