2012

Holland Photonics Roadmap

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Prepared by Core Team Photonics

Hans van den Vlekkert – LioniX bv

Bart Verbeek – Barnel bv

Erik Teunissen – Berenschot

Kemo Agovic – TNO

Frank van den Berg – NWO

Meint Smit – TUEindhoven

Klaus Boller – UTwente

Jaime Gomez Rivas – AMOLF/TUEindhoven

Paul Urbach - TUDelft

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1. Societal and Economic Relevance

1.1 Connection to the key societal themes

The science of Photonics includes the study of the generation, emission, propagation, modulation, signal processing, switching, amplification, detection and sensing of light. Photonics has been recognized by the EU as Key Enabling Technology, allowing major breakthroughs in many application areas because of the unique properties of light. Photonics contributes centrally to the key societal themes that our society has to deal with in the near future:

- In **healthcare** by radical new approaches moving from current, cost-intensive treatment after onset of a disease, to the detection and prevention at the earliest possible stage by new (handheld based) diagnostic instruments*,* which allows to bring these new tools closer to the patient as well as perform remote diagnostics.
- In **energy** saving ("green photonics") by the introduction of very efficient light sources, (O)LED's, and energy *generation* by highly efficient solar cells.
- In **security/safety** by the emerging photonic sensing and imaging technologies for higher levels of security and safety through the use of sophisticated surveillance and encryption technologies both in the field as well as in logistics (e.g. nanodust detection and THz imaging technology).
- In monitoring **climate change** by earth's atmosphere observation using advanced optical pollution (gas-) detection.
- In **mobility** by the development of the future multi-terabit internet fed by full Fiber to the Home (FttH) deployment at ever increasing *capacity* at *lower energy* allowing new economic initiatives and reducing traffic congestions (*less* CO_2) by providing the future proof infrastructure for more homeworking.
- In new **manufacturing processes** with extraordinary quality allowing mass customization, rapid manufacturing, non-destructive testing and zero-fault production (waste reduction).

1.2 Global market size addressed (2012-2020)

The world market for civil photonics products in 2008 was B€256 which, when the defense market is added, results in an overall total of B€277[1],[2] which is significant when compared to other technology sectors and growing fast. From 2005-2008, the global market showed a real annual growth rate of 10% (euro basis), higher than in many other sectors (Food: 2%, Automotive: 3-5%). The photonics supply and demand is global with 30% within the euro zone[3]. Following the Optech study, the Dutch contribution is B€4.4 dominated by production equipment (ASML), lighting (Philips) and printing (OCE/Canon). Medical systems and optical components/systems is estimated to be B€ 0.5. The Netherlands is market leading in the following sectors: production technology in particular lithography, lighting: Solid State Lighting, OLED, Medical Technology with Imaging and diagnostics; Optical Measurement: Machine Vision, CCD/CMOS-detectors; ICT: Printing and FttH equipment; Solar; optical Systems and components. Dutch SMEs target profitable niche segments in all photonic market sectors.

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[1] Optech Consulting, April 2010

[2] The Leverage Effect of Photonics Technologies: the European Perspective March 2011

[3] Photonics21 A Vision for Photonics as a Key Enabling Technology, 2011 www.photonics21.org

1.3 Competitive position of Dutch Industry, total R&D investments

The Netherlands has an excellent position to bring photonics into numerous markets. We have a strong scientific position in important photonic segments (Dutch universities and NWO initiatives) and a highly qualified high-tech industry with specific nano-electronics and mechatronics expertise. Dutch internationals like ASML, Philips and OCE/Canon are big players in the photonics area but the Netherlands has also more than 150 SME's which are already embracing photonics for innovation. A smart photonics ecosystem has been realized in the Netherlands covering the whole value chain.

The photonics industry is still in an early phase but has unique positions in medical diagnostics/therapy, data processing, telecommunication (FttH, interconnect), modern lighting systems, consumer infotainment, sensor/safety, automotive and water. Our strength is in application knowledge and design in high tech systems such as lithography, solid state lighting, generic waferfab processes and platform technologies and the presence of the proper industries to leverage the value chain into a commercial success.

More than 400 M€ (since 1995) has been invested in photonics related infrastructure by industry and government. Knowledge that has been generated by academic groups and R&D institutes is ready for commercialization. The results of the current SmartMix-Memphis project, IOP-Photonic Devices projects, the Perspective programs of STW, the NWO research programs and the Industrial Partnership Programs of FOM and STW sustain and strengthen this position. In addition, the excellent position of Dutch universities is exemplified by covering almost 35% of the 60M€ European photonic projects on photonic integration technologies. A Dutch photonic network has been established that meets once a year at the Fotonica Event (650 participants-2012).

2. Application and technology challenges

2.1 State of the art for industry and science

The strong academic tradition in the Netherlands with several Nobel laureates in optics is the basis for the flourishing applied research in the Dutch high tech industry. Optics has since many years been one of the core disciplines of leading industries such as Philips and ASML. Besides these multinationals, there are many very innovative Dutch SME's active in the field.

During the last decades there is a trend towards miniaturization and integration. The development of optical communication, optical data processing and the growth of the electronics- and ICT industries has led to "integrated optics" and "photonic integration". In this discipline the methodology in IC-manufacturing is applied to realize many optical functions on a single chip.
Photonics spans the entire field from coatings, free forms in imaging and non-imaging systems, fiber optics for communication, integrated optics, (near-field) microscopy, (bio)- medical optics, laser technology, nonlinear optics, (remote) sensing, metrology, spectroscopy, nanophotonics, plasmonics, metamaterials, to quantum optics and quantum communication. Current Dutch academic research is at the fore-front of all these subjects and the Dutch photonics industry is applying their results more and more.

The opportunities of photonics in general and the benefits of generic foundry-based technologies are addressed in three major national R&D-programs: IOP Photonic Devices, Smart-Mix "Memphis" and STW's "Generic Technology for Integrated Photonics" and "Smart Optical Systems" which initiated successful collaborative consortia between industry and universities and have put the Netherlands at the forefront of Photonics technology development. In particular the Memphis project - in which 23 national and international partners join forces in addressing the hybrid and heterogeneous photonic and micro-electronics integration: key to achieve robust, reliable, complex microsystems.

2.2 Future outlook, in present and emerging markets

The Dutch High-Tech industry is increasingly embracing photonics in its innovation[4]. Photonic technology is maturing rapidly. Unique for the Netherlands is that all photonics expertise is available and when matched to our High Tech strength, the industry will become a major player in this field. The enabling character of the photonics industry matches very well with the Top Sectors and is one of the technology "backbones" of the HTSM sector. Although not all devices and functions can be realized on a chip with sufficient performance, we nevertheless expect in the coming years a rapid growth in the development and the application of photonic integration technologies, similar to electronics, where micro and nano-electronic integration technologies have enabled electronics to change our world. Major sectors of activity in the Netherlands[5] where photonics is used are:

- Production technology for semiconductor industry e.g. optical lithography
- Lighting; In the next 3 to 4 decades the demand for artificial light is expected to triple by much more efficient solid state light sources, such as LEDs and OLEDs.
- Information and communication technology: digital photo copiers and printers based on laser and LED technology. Fiber-to-the-Home networks and high speed interconnections.
- Medical technology and life science: advanced microscopy and other emerging tools used in medical and life science research and applications in the clinic.
- Optical components and systems – e.g. fiber based and adaptive optics - will contribute to the development of new photonic based systems..

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[4] Berenschot: IOP Photonic Devices Roadmap 2009.

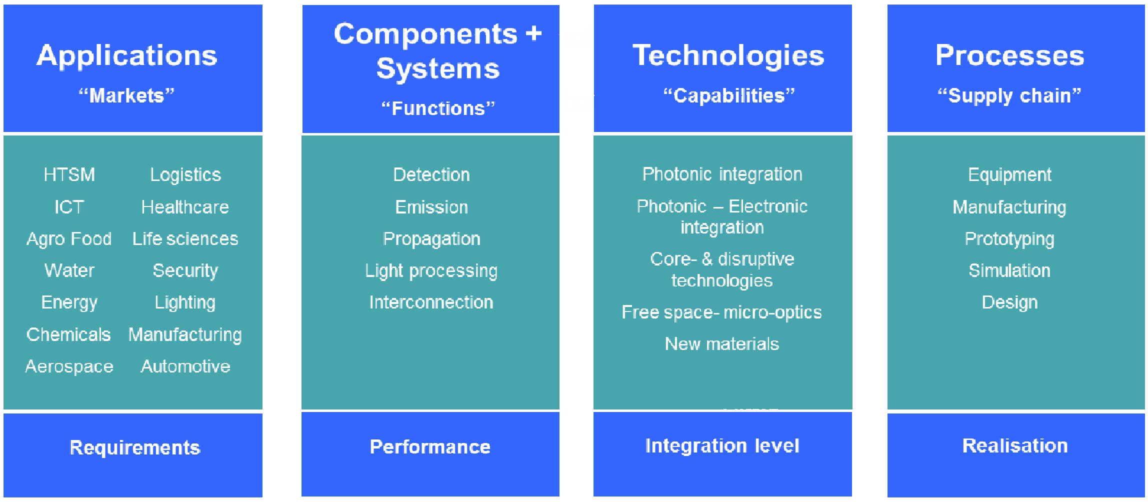
[5] Photonics21: Photonics in Europe, Economic Impact p55 www.photonics21.org

Apart from these areas, we envisage that the Netherlands will be strong in the following fields as well: image technologies, communication, data processing, manufacturing and packaging technologies, security, novel or emerging materials, sensors and bio-sensors which all meet societal challenges.

3. Priorities and programs

3.1 Selected themes from roadmap

In this section an overview is presented of the broad field that is spanned by photonics, with emphasis on activities on running and planned activities in the Netherlands. To provide a guideline, these activities are grouped in four themes: i) **Applications** generating the requirements for the components from the market, ii) **Components and Systems** describe the component performance needed for the applications, iii) **Technologies** provide present and future processing technologies for the components and iv) **Processes** providing the necessary equipment and design for the technologies.



3.1.1 **Applications for Top Sectors**

Photonics in ICT
Novel components, materials and advanced integration technologies for the optical wide-area, access and home networks will enable efficient exploitation of available bandwidth, low-cost network operation, and data security. Optical interconnects will play a key role for future short-haul data communications and all-optical switching fabrics in e.g. data centers.

Photonics for Horticulture and Agro-Food
Growth stimulated lighting in greenhouses, photonic sensors for monitoring of climate and growth conditions in greenhouses, photonic trace gas detection for monitoring of crop conditions in the field and in stores. Monitoring of soil conditions (fertilization) and salt-fresh water ratios. Quality monitoring of packed nutrition and fruit.

Photonics for Water
Photonic sensors for water quality control in distribution networks and reuse facilities and for structural integrity monitoring in large constructions like dikes, bridges and flood control dams. Photonics technology will be used for real time monitoring of water movement, sediment transport and offshore structures e.g. windmills.

Photonics for Energy
Solar cells, solar fuel, energy saving lighting systems, green ICT using energy saving photonics in data transmission and switching, photonic monitoring of mechanical stability in windmill propeller blades.

Photonics for Chemicals
Low cost and high performance spectroscopy of chemicals and pharmaceuticals using integrated photonic devices. Fiber based sensors for temperature measurement and detection of fractures or leakage in processing installations or storage tanks.

Photonics for Logistics.
Photonic devices enabling obstacle detection and position- and speed sensing for vehicles

Photonics in Healthcare and Life Sciences
Medical devices including medical therapeutical systems and systems for in vivo and in vitro diagnostics. Major products include endoscopes, therapeutic laser systems, medical imaging systems, CR systems, ToF-PET and PET-MRI, fluorescence diagnostics systems, coherent detection, optical coherence tomography systems, SPECT, Raman (CARS) based diagnostic systems, Photo Acoustic imaging technologies. All systems comprise a combination of photonic components (lasers, detectors), micro-electronica, mechanics and software. Miniaturization of these systems is often desirable to bring these technologies from the clinic towards the practitioner/patient.

Photonics in Security, Metrology and Sensors
Enhanced sensitivity operation, single-photon detection. Self-sustaining sensors with low ultra-low power consumption. New sensing functionalities, including unexploited wavelengths, active vision, 3D-Vision. The ability to operate sensors in all ambient conditions, including lighting, temperature, pressure, humidity. New applications in the soft X-Ray, VUV and EUV wavelength region (<200 nm) as well as infrared, > 2µm for gas detection).

Photonics in Lighting
New materials and structures targeting performance enhancement. The need for better components and in particular device integration for smart lighting systems, LEDS and OLEDS.

Photonics in Manufacturing
New manufacturing processes and process monitoring with extraordinary quality that will allow mass customization, rapid manufacturing, non-destructive testing via THz imaging and zero-fault production.

Photonics in Automotive
With a focus on intelligent electromechanical systems, the photonics based sensor technology will be integrated in mechanical parts requiring robust components for in-car communications, monitoring, warning and vision.

Photonics in Aerospace
New optical equipment using e.g. radar, LIDAR and space communication.

3.1.2 **Components + Systems**

Photonic components and systems span a broad frequency range from high energies (EUV) to low energies (THz) and can be divided in the following four main topics. However, in most high-tech applications a combination of these topics are present.

Generation of Light
Sources include integrated lasers, solid state green LEDs, photonic crystal lasers and materials for light conversion (such as phosphors and quantum dots), CMOS and other single photon technologies, quantum cascade lasers, VCSELs, plasma sources, ultra-short pulses, high power lasers, THz sources, nano- and, non-linear optical sources, free-electron based sources, broadband VUV sources, fast tunable nanosecond lasers and new scintillation materials. Work on sources includes improved emission by

engineering of optical density of states and/or scattering structures, and by improved excitation mechanisms.

Light propagation and manipulation
Integrated optical circuits, micro resonators, optical fibers, photonic crystal waveguides, plasmonics and metamaterials, spatial modulation by refractive, diffractive and adaptive optical elements, scattering, beam shaping and deflecting, optical cloaking, temporal modulation of light or slowing of light, filters, non-linear optics and switching of light.

Light interaction
Nanostructures for light interaction at sub wavelength scales (nanophotonics), interaction of light with waves, such as with plasmons, phonons, or light waves, coherent control, light for manufacturing (lithography) or data storage, light for medical diagnosis and treatment, optical tweezers, bio-optics, new materials for collecting light and optimizing interactions.

Light detection
Novel types of spectroscopy and microscopy, also with sub-diffraction limited resolution, (remote) sensing, new imaging systems, highly efficient light harvesting structures, optical antennas, optical signal processing, near-field detection, interferometry and metrology, single photon and plasmon detectors.

3.1.3 **Technology**

Photonic integration
Includes the development of generic integration platforms and foundry models. Addressed technologies comprise III-V semiconductors, SOI and TriPleX, CMOS post processing; assembly, alignment and fixation, RF processing in optical domain (microwave photonics). Also photonics technology will be combined with e.g. fluidics and mechatronic technologies.

Photonic-electronic integration
At the chip, board and system levels. Hybrid- and heterogeneous integration. Si-III/V integration; process control/improvement; assembly technologies; pick-and-place tools, optical PCB.

Packaging technologies
Packaging and assembly technologies for low cost sources and detectors, flip-chip optical coupling, combined glass and non-hermetic packaging. Assembly equipment for prototyping of bulk optics with high tolerance requirements.

Core and disruptive technologies
Includes application-specific components and systems such as laser and other light sources, imaging units, transmitters and receivers, detectors and sensors and hybrid integration. Disruptive technologies often exploit effects at the limits of photonic interactions, including nanophotonics, sub-wavelength and near-field effects, plasmonics and quantum effects;

Free space and micro optics
Architecture and assembling of optical components into an advanced photonic device. This includes remote solid state lighting, photovoltaics, microscopy, advanced spectroscopy, health instruments and lithography.

New materials
Includes semiconductors, glasses, plasmonic materials, metamaterials, photonic crystals, nano-(plasmonic) structures, quantum dots, nano-crystals, nonlinear materials, doped materials, magneto optical, electro optical and random materials, organic materials, organic-inorganic combinations and new bio materials.

3.1.4 **Processes**

Equipment
In order to manufacture integrated devices, development of new process equipment for front-end and back-and manufacturing and testing have to be developed. This includes new assembly and packaging processes for 2D and 3D assemblies towards volume production, including novel interconnection techniques for photonic interfaces. Packaging and assembly technologies for low volume, high end optics and micro-optics need to be developed as well. It is worth noting that the world's first ASML DUV scanner (90 nm resolution) for III/V photonic circuits has been installed at the TU Eindhoven in 2011.

Manufacturing and prototyping
The need for cost effective photonic devices drives the need for (standard) technologies for cost-effective high speed manufacturing of these components and subsystems including packaging and assembly processes for volume production and photonic prototyping. Fast time to market is required.

Simulation and design tools
New simulation and design tooling must be developed enabling the designs of new devices and circuits, and link the tooling with the new integration technologies and the manufacturing and prototyping processes (validation). The overall quality of the supply chain will increase by putting more "feedforward" into these tooling, building a living database for further improvements of this supply chain, products and processes.

3.2 Proposed implementation (NWO,TNO/GTI/international R&D, regional, other)

- Photonics is a driving force in the fundamental research programs of NWO, and the EU programs FP7 and Horizon2020[6] with their specific photonic calls and increased budget.
- Dutch R&D is well presented in Photonics21: the European Photonics Industry Association that produce the photonics roadmap for the EU. In particular, LioniX and TUE/COBRA play a very active role.
- Valorization projects will be carried out together with TNO/GTIs including projects with SMEs and links with IPCs and other Innovation Funds to secure commercialization and market introduction for innovative components and systems.
- During 2012 and 2013 follow up programs in Topconsortium Kennis & Innovation (TKI's) will be initiated based on the roadmap e.g Memphis Platform.
- An association will be set up with the following activities: setup, maintain and develop the Photonics roadmap; to coordinate and initiate new collaborative projects; strengthen and maintain national and international contacts; promote Holland Photonics at national and international exhibitions and conferences.
- Furthermore a Photonics Development Lab (GPICSFAB) has been initiated in 2012 by a number of SME's to speed up the availability of integrated photonics chips by a shared wafer approach made at photonic foundries based on market demand.
- Education: SMEs lack sufficiently educated employees skilled in modern photonics and test equipment. Participation of e.g. HBO, WO and graduate schools in collaboration with projects will stimulate students in this field. Support of setting up curricula on photonics at all levels, including business development (Bachelor, Master and Graduate Schools) has a high priority.

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[6] *"Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing Horizon 2020 - The Framework Programme for Research and Innovation (2014-2020)"*. Nov.30, 2011

3.3 Collaboration activities qualifying for TKI

The Netherlands is in an unique position with world leading groups at Universities and Institutes actively researching each of the topics mentioned in 3.1.1. The academic research in support of and in collaboration with Dutch industrial photonics research and development in large companies (e.g. Philips and ASML), Dutch SME's and Institutes such as TNO, ASTRON, SRON and VSL will be continued.

3.4 Engaged partners from industry and science

Industry Partners: Philips, ASML, TE Connectivity, Neways Micro Electronics, BESI, NXP, TOPCON Europe, MicroVision Medical, Dalsa, Esaote Europe, Oldelft, Melles Griot.
SME's: Avantes, EFFECT Photonics, Genexis, SATRAX, Sensor Sense, Technobis, Hybriscan Technologies, RiverDiagnostics International, LioniX, MA3 Solutions, PhoeniX, Bright Photonics, 2M Sensors, Xio Photonics, VTEC, Bruco, Luminostics, Smart Photonics, Lactronic, HEDON, Vermeulen Printservice, Anteryon, 4PICO, Cosine, FTS, Solmates, Unitron, Mach8 Lasers, MILabs, Lambert Instruments, Hemolabs, HQSonics, HollandPTC, Percuros, O2View, IMS, Diagnoptics, PhotonTech, Photonis, OGS Systems, Octoplus, NTS Optel, Lightmotiv, Laprocon, i-Optics, Flexible Optical, Cosine.
Universities and Institutes: TNO, TUE, UTwente, TUDelft, VU, UMC Radboud, AMC, Erasmus MC, AMOLF, ASTRON, SRON, Deltares, NLR, Kavli, Medical Spectrum Twente, Netherlands Cancer Institute, Utrecht Medical Center, VSL.
International partners: IMEC (B), Oclaro (UK), IBM (Switzerland), Fraunhofer-HHI (D), Toptica AG (D), Coherent Europe.

3.5 TKI grant allocation

The TKI grant for 2013 (estimated k€ 50) will be used for networking activities aiming at strenghtening the photonics eco-system in the Netherlands by the newly founded PhotonicsNL organization and partly funding collaborative projects between TNO, NLR and universities with industrial partners submitted to the "Perspectief Program" (Call 2012/2013) that are carried out in the **TKI-Roadmap Program Photonics**.

4. Investments

4.1 Public-private partnership R&D budgets

4.2 Other innovation instrument

Although the government is supporting public-private collaboration by creating attractive fiscal based support measures, these measures are not primarily aimed and applicable for SME's, in particular start-up's which exploit the scientific results of universities/institutes. An alternative method to stimulate SME's to invest directly into innovation at universities/institutes would be an upfront support to be paid back later out of generated profits. In this manner it would be easier for SME's to manage their cash flow, attract investors and for the government it opens up the possibility to create a revolving fund and increase tax income instead of lowering this. Apart from the central government also the provinces could set-up similar instruments to support in particular SME's.