Photonic integrated circuits in biochemical food analysis

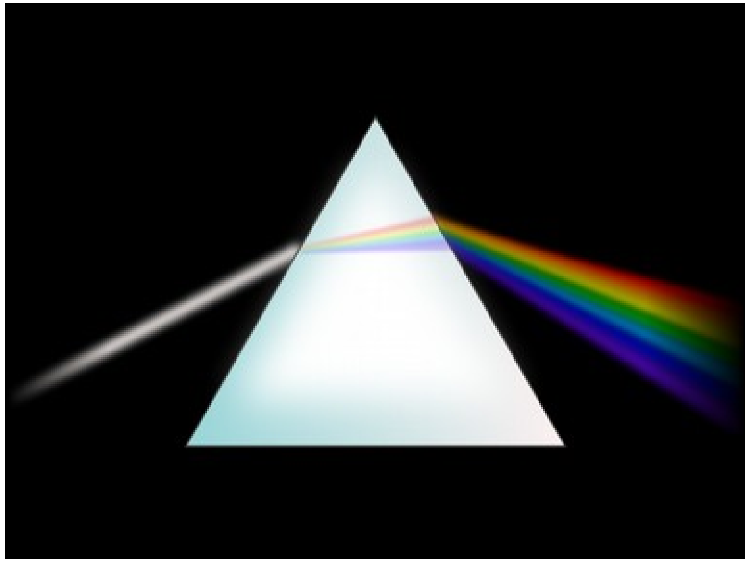
PIX4life – H2020-ICT-2015 – contract 688519

13/06/17

PHOTONICS21
PHOTONICS PUBLIC PRIVATE PARTNERSHIP

What is Photonics?

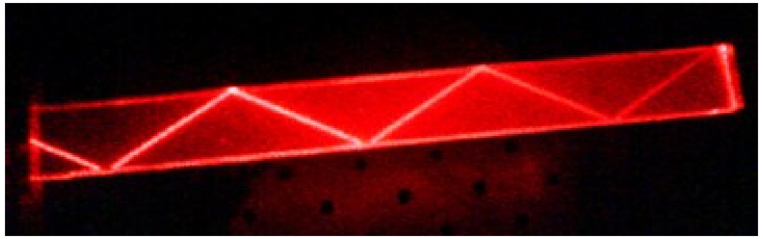
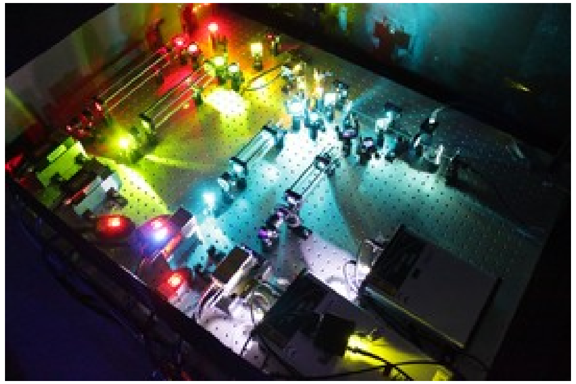
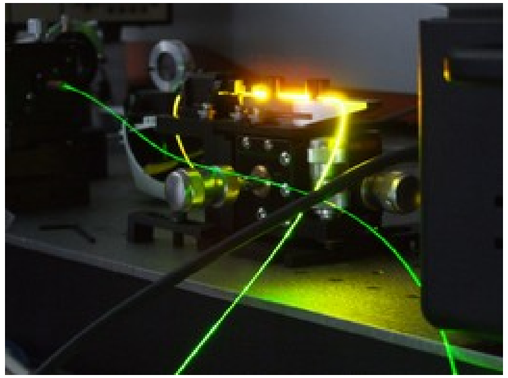
Photonics is the physical science of light generation, detection, and manipulation through e.g. transmission, modulation, filtering, amplification.



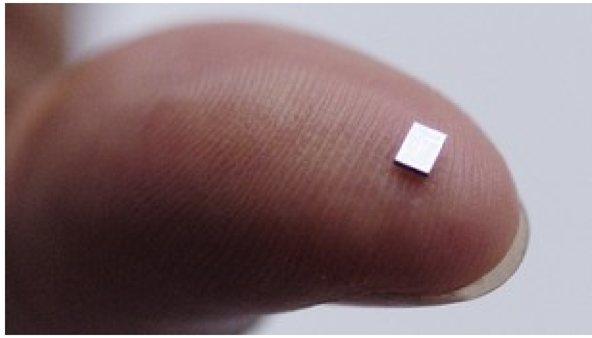
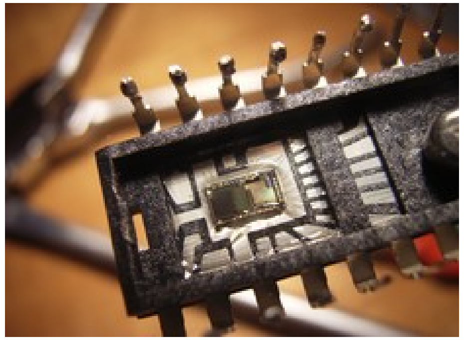
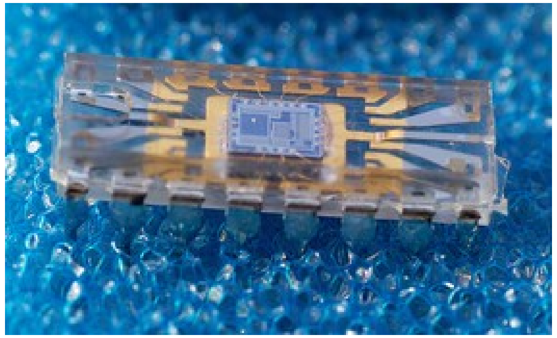
Most photonic applications are in the range of visible and near-infrared light.

What is a PIC?

In optical systems, laser light is generated, transmitted through fibers or waveguides, processed with different elements like filters or modulators, and detected with photodiodes.

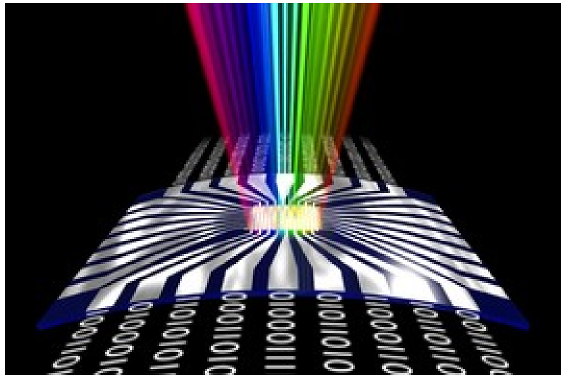




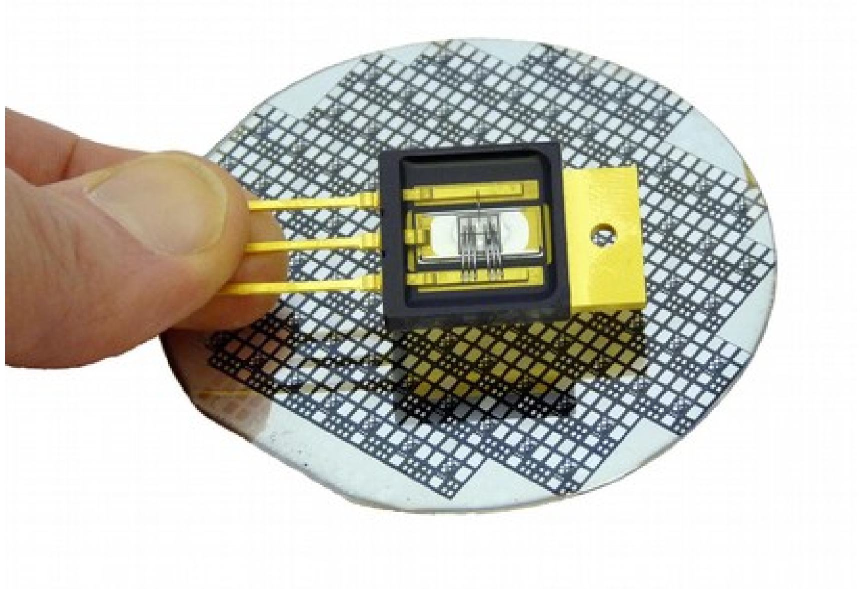
Photonic integration technology allows to miniaturize a complete optical system into a photonic chip (PIC), similar to electronic integration.

Advantages of PICs

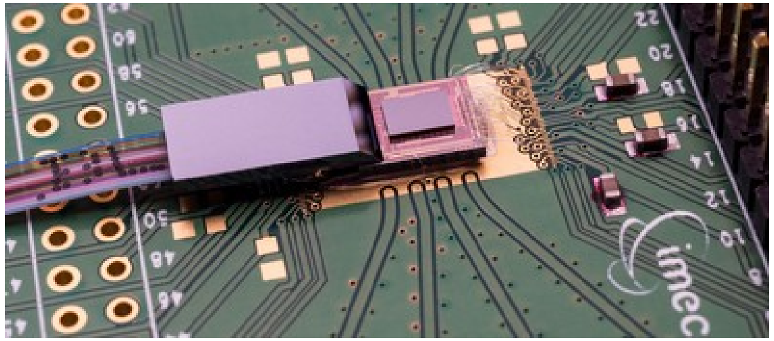
- Smaller size and weight.
- Easier to assembly and package.
- Mechanically more robust.
- Easier to make hermetic and avoid contamination.
- More stable in temperature.
- Able to easily increase number of components in system.
- Able to scale up production to large volumes and lower cost.

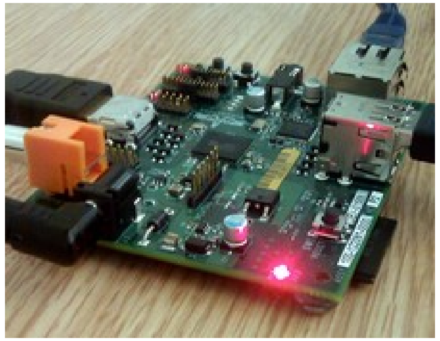
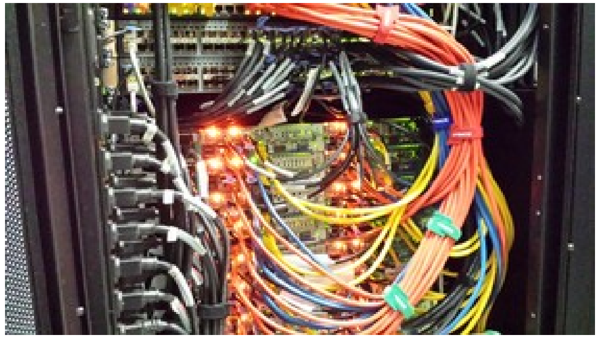




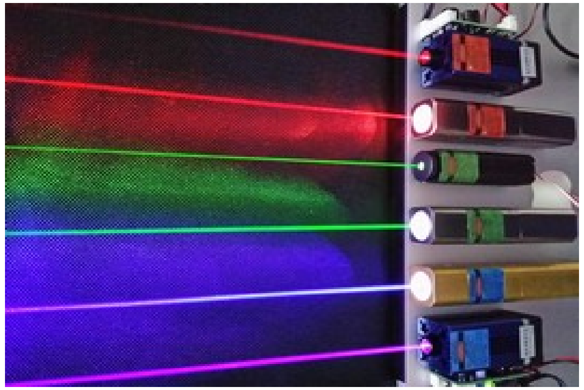
PICs for visible light

- Most of the PICs work with infrared wavelengths of light (~1550 nm), as these are optimal for optical fiber communications, the largest market.



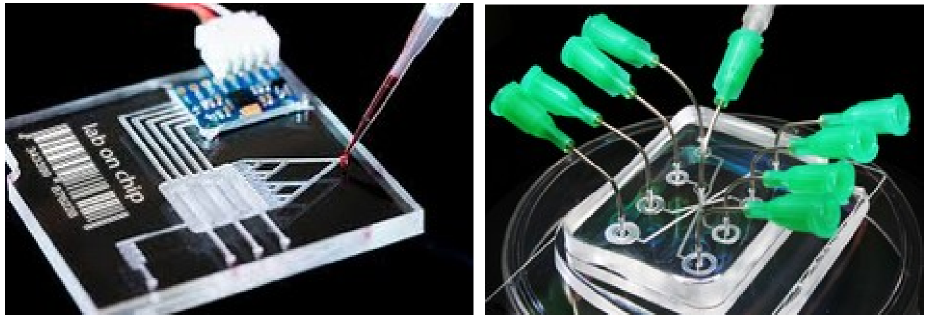



However, sensing for biochemical and medical applications usually requires lower wavelengths of light, in the visible range (400 -900nm).

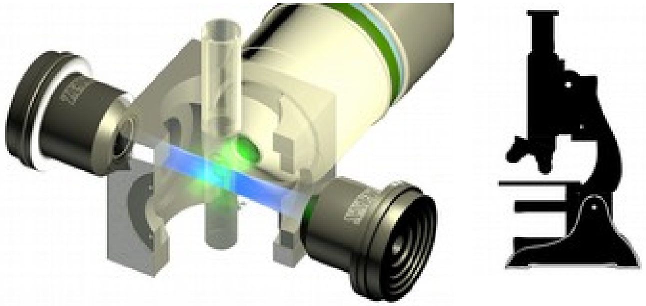
APPLICATIONS for visible light PICs

Diagnostic devices



Lab on a chip

DNA sequencing
& opto-genetics



Microscopy and cytometry

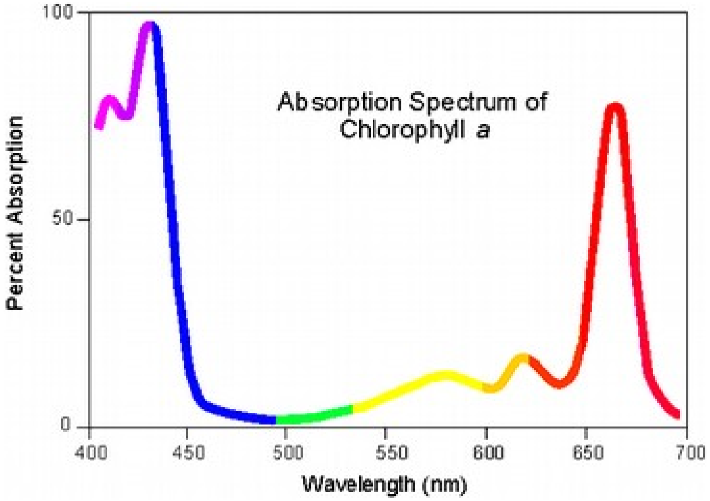
Healthcare &
biochemistry

Medical instrumentation
(e.g. optical tomography, spectroscopy)

Food analysis



- Detection of cross-contamination of ingredients in production lines.
- Detection of toxins and pathogenic agents.
- Food microscopy.
- Industrial spectroscopy and miniaturized spectrometers for biochemical analysis.
- Fluorescence sensing.


Spectroscopy for food analysis

ABSORBANCE

- Explore chemical composition of a food via the wavelengths absorbed when light is transmitted through.
- Mostly used for liquids, but also for inspecting fruit for ripeness, internal rot, pests and defects.
- Examples:
  - <u>Fruit juices:</u> soluble solids content, pH, color, adulteration
  - <u>Milk:</u> fat, protein and casein content
  - <u>Saffron:</u> ISO 3632 quality method to measure crocin, picrocrocin and safranal
  - <u>Vegetable oils:</u> identity, adulteration, acid value, peroxide value
  - <u>Wine:</u> quality, phenols, tannins, methanol content





Spectroscopy for food analysis

REFLECTANCE

- Explore chemical composition of a food via the wavelengths reflected when lighted.
- Penetration depends on wavelength, power, and sample composition.
- Examples:
  - Crabmeat: substitution with surimi-based imitations and lower-grade crabmeat
  - Fruit: variety, ripeness, sugar content, soluble solid content, internal pests
  - Meat: distinguishing pasture-fed from concentrate-fed livestock
  - Purees: adulteration of strawberry or raspberry with lower-cost apple
  - Whole grains: protein, moisture, oil content





Spectroscopy for food analysis

NIR SPECTROSCOPY

- Non-destructive probing of vibrational overtone absorption of chemical bonds, requiring later chemometric analysis for evaluating composition.
- Similar to reflectance and absorbance, but deeper penetration of Near InfraRed (NIR) Light.
- Examples:
  - <u>Adulterated ground beef:</u> detecting mutton, pork, organs and fillers
  - <u>Chicken quality:</u> detecting thawed versus fresh cuts; artificially boosted water content
  - <u>Fraudulent labeling of fish:</u> identification of fish species without DNA testing
  - <u>Fruit quality:</u> screening for core rot, internal pests and ripeness
  - <u>Gluten screening:</u> sorting unprocessed grains with NIR and machine vision





Spectroscopy for food analysis

FLUORESCENCE

- Uses the native fluorophores in food products to detect the presence or concentration of those components.
- Fluorescence spectra are composed of broad, overlapping emission bands containing information about the sample components, and its analysis may look for changes in intensity, wavelength or bandwidth.
- Different excitation wavelengths may be used to build up a fluorescence excitation-emission matrix.
- Examples:
  - <u>Cheese:</u> variety, manufacturing method, geographic origin and degree of aging
  - <u>Eggs:</u> freshness
  - <u>Food and animal feed:</u> mycotoxins in nuts, grains, dried fruits and spices
  - <u>Fruit:</u> fecal matter contamination of peel
  - <u>Meat:</u> quantification of fat, bone, cartilage and connective tissue





Spectroscopy for food analysis

Surface-enhanced Raman spectroscopy (SERS)

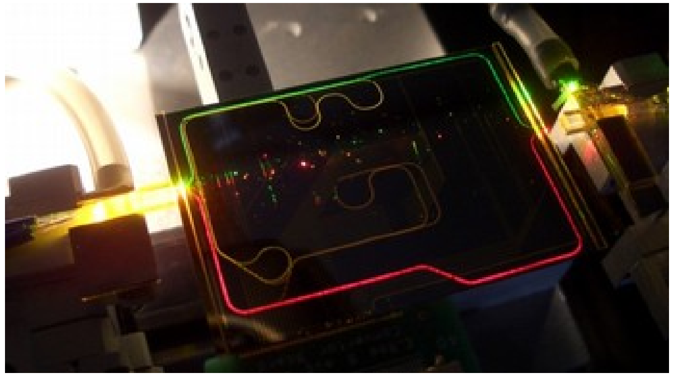
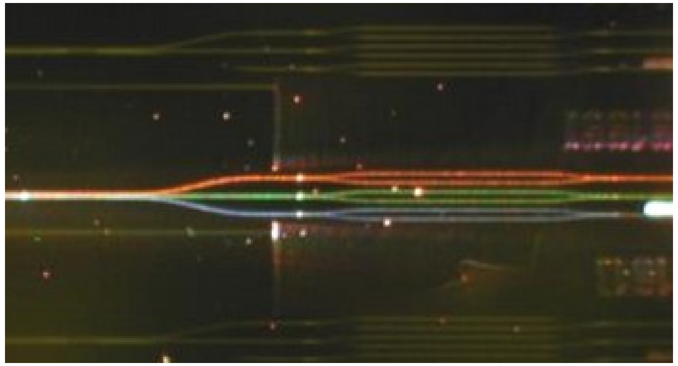
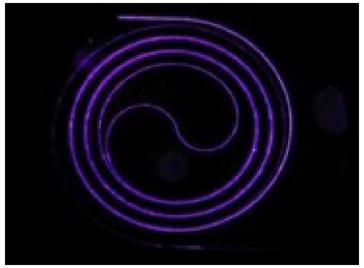
- Used for trace detection of harmful compounds in foods, from pathogens to antifungal dyes, antibiotics and pesticides.
- SERS substrates may be gold, silver or gold-silver alloy-based, and can be made even more specific through functionalizing ligands specific to a particular pathogen.
- Examples:
  - Banned antifungal agents used in aquaculture: crystal violet and malachite green
  - Food dyes: Sudan 1, a carcinogenic, mutagenic dye used to boost color of chili powder
  - Pathogens: Salmonella enterica and Staphylococcus aureus on fresh spinach
  - Pesticides: organophosphorus & sulfur-containing pesticides, tricyclazole, malathion, imidacloprid
  - Restricted antibiotics: enrofloxacin, ciprofloxacin and chloramphenicol

SILICON NITRIDE PICs

- Silicon nitride (Si_3N_4) is an excellent substrate material to build PICs operating with visible light due to its low propagation loss at these wavelengths.

- Si_3N_4 circuits are designed by interconnecting different functional building blocks, and later on fabricated on wafers, a scalable and low-cost manufacturing technique used in CMOS electronics.

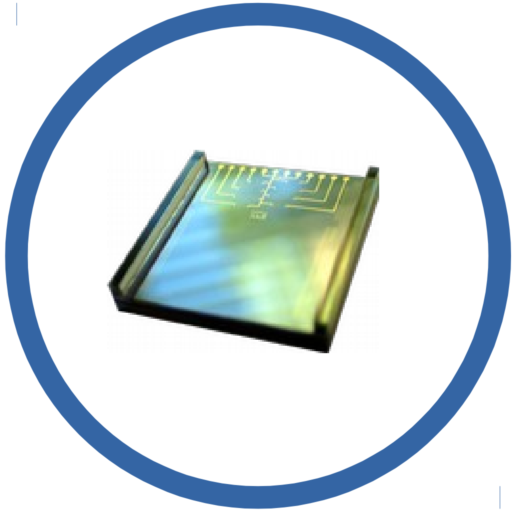
- After fabrication, they are tested and put into a miniaturized assembly, with a housing, optical fibers, electrical interfaces, etc.

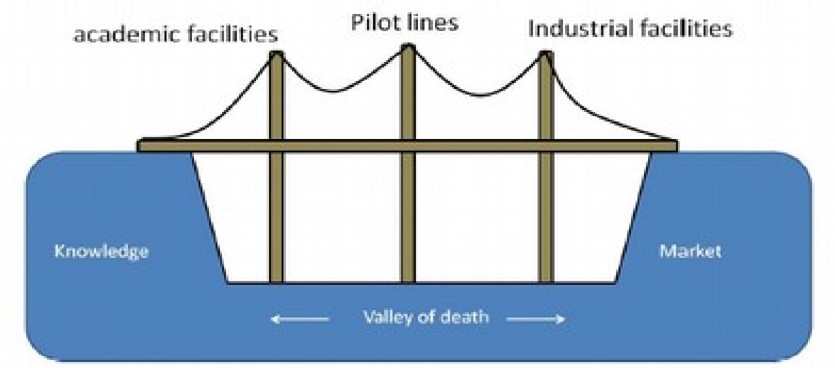

PIX4life

A European Pilot Line 2016-2019

Development of Si_3N_4 Photonic Integrated Circuits



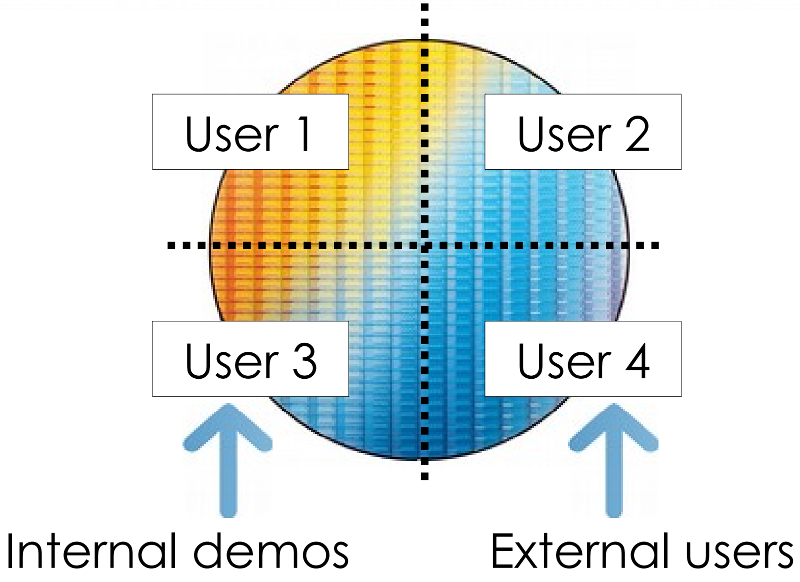
Applied to life sciences applications

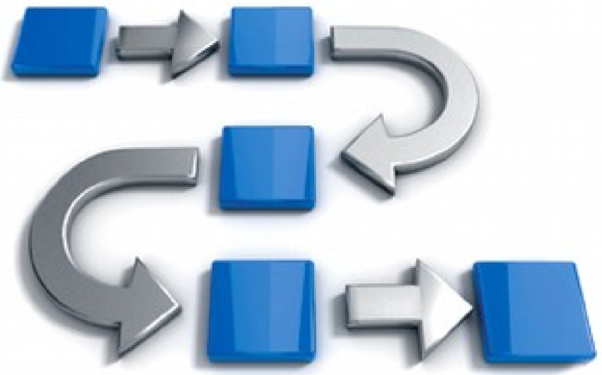


Consortium of 14 European companies and institutions bridging the gap between research and industry.

PIX4life goals

- Mature **Si_3N_4 PIC technology for visible wavelengths,** allowing for low-cost Multi Project Wafers for prototyping with generic building blocks and interfaces.
- Build and validate an **open access** platform and business model, driven both by **internal users and external customer** requirements.
- Develop a **full value chain to develop Si_3N_4 PICs, targeting life sciences applications**: from design to component characterization guided by well chosen demonstrator specifications.





Technology providers

imec
LioniX International

Fabrication of Si_3N_4 PICs

Luceda Photonics
PhoeniX Software — Solutions for Micro and Nano Technologies

Software tools to design PICs

VLC Photonics

Services for designing and testing of PICs

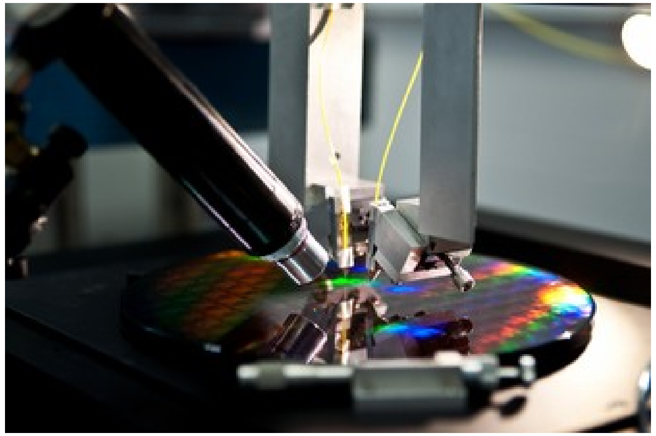
Tyndall National Institute — Institiúid Náisiúnta

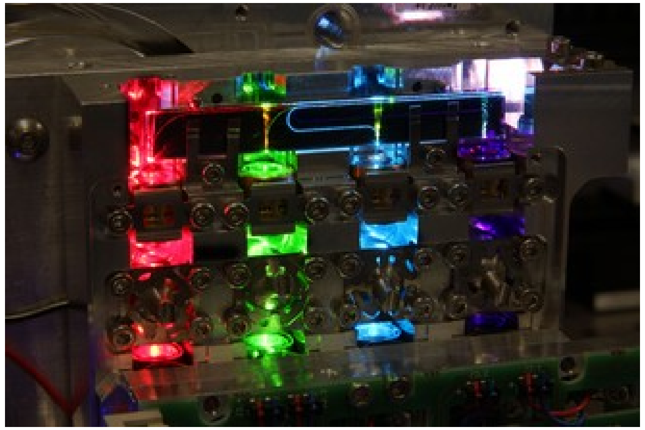
Packaging of PICs

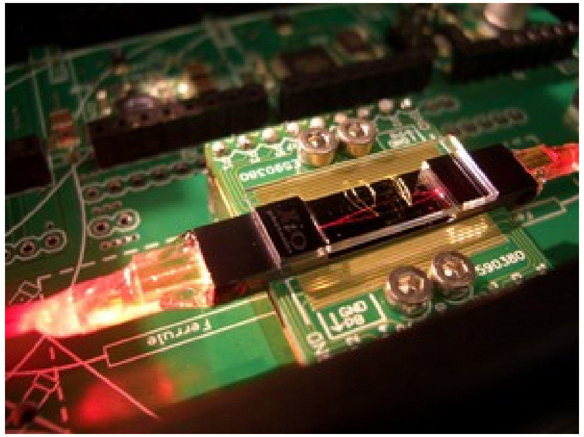
PIXAPP Photonic Packaging Pilot Line

PIX4life internal demos

- Flow cytometer
- OCT imager on chip
- Gas/Bio multi-sensor
- Multispectral light source







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1

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2

Sign a NDA, share the details of your application, and get feedback from the pilot line for its implementation.

3

Engage into a MPW run, with support on software, circuit design, test and assembly.

4

Get your PIC prototypes developed at a subsidized cost, and ready to scale up for production.

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