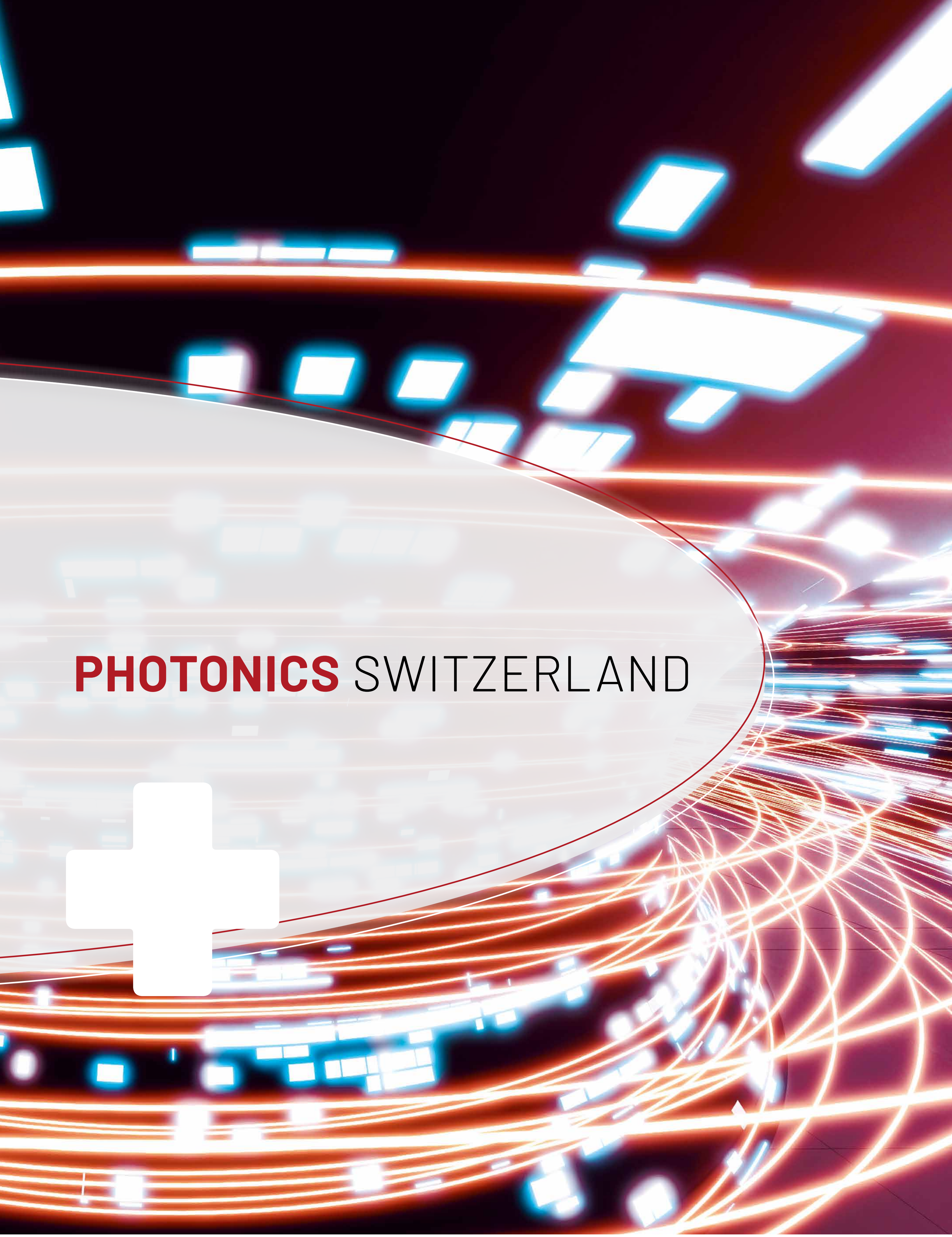
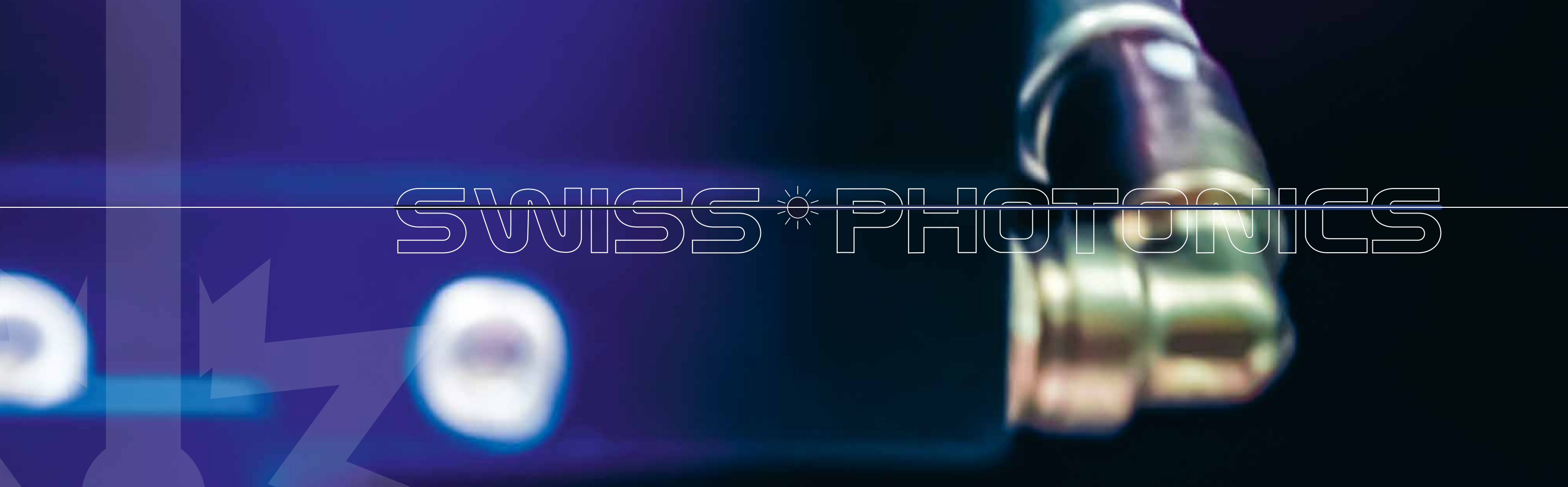
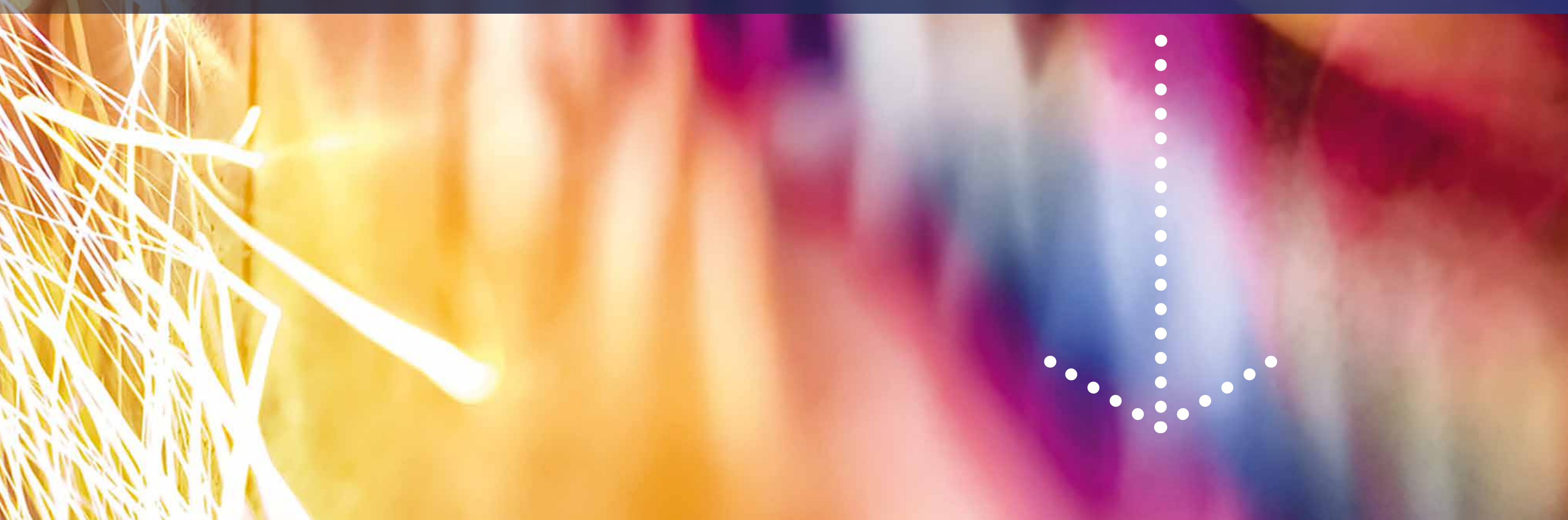


# PHOTONICS SWITZERLAND

SWISS PHOTONICS


SWISS PHOTONICS





# THE SWISS PHOTONICS COMMUNITY

Photonics has a bright future and is key for technical and digital sovereignty, to solve societal problems and to improve prosperity and equality. The offerings of Swiss photonics companies are very diverse, covering a wide range of high technology components . With a 2022 estimated production volume of €5 billion, Switzerland accounted for about 4% of European production of photonics core components and a workforce of around 12'000 employees. It is estimated that the photonics market will have an annual growth of 6% over the coming years. Switzerland has strong actors in Photonics but it suffers from a fragmented ecosystem The association Swissphotonics is providing a base for networking this ecosystem.

Around Switzerland, the support for Photonics is strongly increasing. To name a few, the Photon chip organization PhotonDelta recently secured €1.1 billion for investments on Photonics, AIM Photonics in Albany, USA received $321 billion last year and Germany will invest € 2 billion in quantum technologies. Switzerland certainly needs to strengthen its support for Photonics substantially.

This new brochure is intended to showcase the strength of Switzerland in photonics. It is aimed primarily at members, players in politics and business, and potential new customers. It is vivid and cutting-edge. The online version includes interactive features such as a 360° panorama, cinemagrams and videos. Together with the published topics, this creates an all-around innovative reading experience.

We hope you find this brochure valuable and helpful to promote the Swiss photonics activities in Switzerland, Europe and worldwide.

**Enjoy reading!**

*Christoph Harder*
*President Swissphotonics*

*Christian Bosshard*
*Managing Director Swissphotonics*

WE ARE SWISSPHOTONICS –

# WELCOME

Swissphotonics is a non-profit association with more than 200 members. It is the declared goal of Swissphotonics to improve the competitiveness of its members through the support of innovation forces.

What is it, that we actually do? We organize events such as workshops to foster the interaction within the innovation community, roundtables to address challenges and we support conferences to provide opportunities for communicating leading edge information. Our mission is to support individuals and groups which we can support to pursue their specific innovation efforts.

We support eight clusters which act as center of competence and provide single point of contact service and support to SMEs. Also, we inform about Swiss and European strategic research agendas, research platforms and initiatives and we provide information about funding opportunities as well as the support on how to access them.

Of course, we serve the full field of photonics, starting from materials which convert electricity into light and light into electricity all the way to the application of light such as photonic manufacturing (material processing with a laser beam: cutting, welding and 3D additive), imaging, photonics for life sciences, optical communication, photovoltaics and illumination.

We serve companies, research organisations and universities in the field of photonics in basic and applied science, technology development, manufacturing and selling of photonics components and applications. We support the industry as well as research institutes in finding research partners and the necessary funding.

We support networking within Switzerland and we establish international contacts, within Europe (Photonics21, EPIC, EOS) and worldwide (OPTICA, IOA). We work with Innosuisse, Euresearch, Swissmem and the Innovation Boosters to support innovation in photonics.

Swissphotonics is governed by the yearly general assembly.

*EPIC member run at ECOC 2022 in Basel.*

*Plenary session at ECOC 2022 in Basel.*


*Workshop Photonics 4 Masterpieces at EPHJ 2022 in Geneva.*

# PHOTONICS INDUSTRY

The global photonics market accounted for €690 billion in 2019 and should reach €900 billion in 2025, according to the recent "Market Data and Industry Report 2020" published by Photonics21 (Fig.1).

ongoing products and by the rapid introduction of higher performing components at constant prices which drives our industry ferociously (Fig.2).

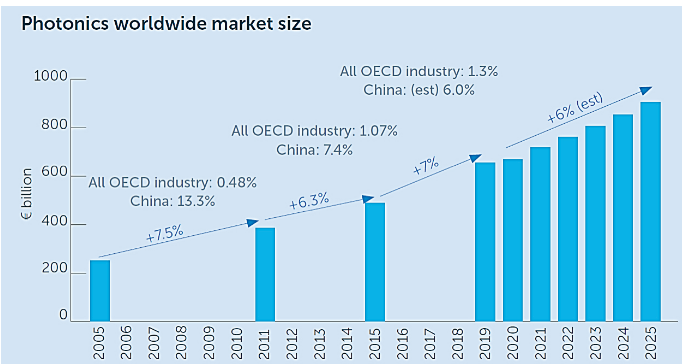



*Figure 1: Photonics worldwide markets size (Source Photonics21/ TEMATYS)*

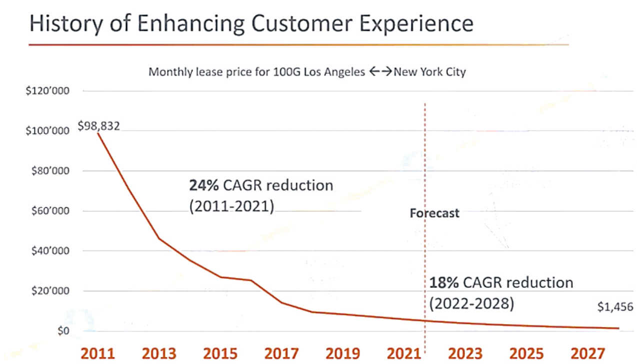



*Figure 2: Price reduction of telecom due to rapid development of photonic components with higher performance at lower cost. (Courtesy David Welch, Infinera, Plenary ECOC2022)*

Photonics is a fast-growing industry compared to the more traditional ones; while these traditional markets were growing at an average of 1.3% per year between 2015 and 2019, the photonics industry showed a CAGR of 7%. It is expected that long-term growth of photonics in € will settle at around 6%/year.

We all witness the ever-increasing performance of photonic consumer goods at steadily reduced prices, be it for flat panel displays, smart phones or data rates of our internet connection. This is made possible by a combination of year-to-year price reduction of

Price reduction, especially for the extremely high-volume markets of photovoltaics, displays and lighting has also been made possible through China, either as companies subsidized by the Chinese government using these products to generate hard currency for China or by offering low wage manual labour opportunities for our companies in the western world driving the offshoring trend.

It is evident from Figure 3 that China is serving big consumer markets whereas Europe is serving highly specialized smaller markets.

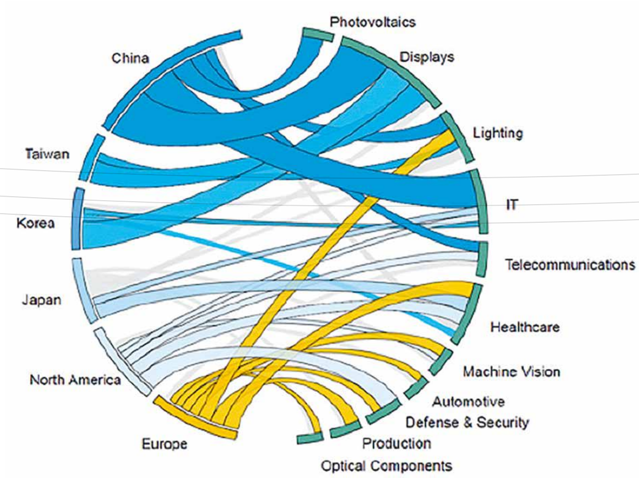



*Figure 3: Global photonic overview on countries serving important markets (Source SPECTARIS/ Süptitz)*

Some are tiny niche markets, whereas others are medium-sized markets with volumes of several thousand, too small for giant companies but still profitable for SMEs. Serving those applications markets, and to remain at the forefront of technological change, requires constant innovation by these SMEs. Thus, research and innovation are key to maintaining competitiveness.

## EUROPEAN INDUSTRY

Due to a strong European research capacity, companies can maintain and expand their businesses and catch their share of this 7%/year fast-growing market.

These European companies are leaders in markets like technologies for Industry 4.0 (laser machining, semiconductor production machines, machine vision…), instrumentation, microscopy, and optical measurement systems, medical and healthcare photonics-based technologies (Fig.3). The European photonics industry revenue was €103 billion in 2019, amounting to 16% of the global market (Fig.4). It creates an employment of more than 390,000 jobs at a very high average of more than €250'000 of revenue per employed person.

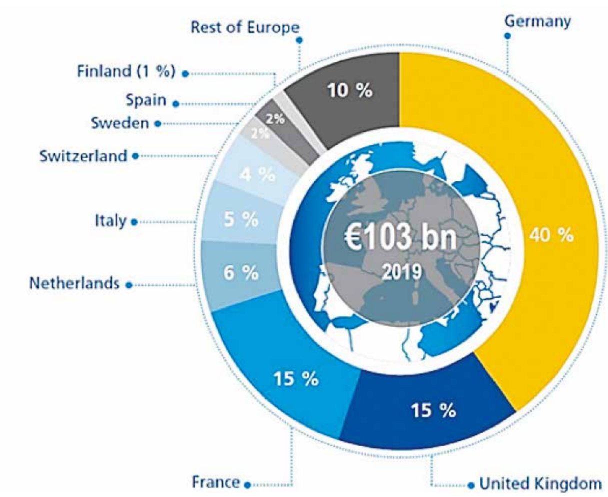



*Figure 4: Photonics revenue distribution across European countries (Source SPECTARIS/ Süptitz)*

## SWISS INDUSTRY

Switzerland has a 4% market share of the European photonics revenue and is in first place with respect to revenue per capita (Fig.5).

| Country | Domestic Production (Bio €) | Inhabitants (Mio) | €/capita |
|---|---|---|---|
| **Switzerland** | **4,3** | **8,6** | **500** |
| Germany | 40,8 | 83,1 | 491 |
| Netherlands | 6,2 | 17,3 | 358 |
| UK | 15,6 | 66,8 | 234 |
| France | 15,3 | 67,1 | 228 |
| Total Europe | 103,3 | 748,7 | 138 |
| Italy | 5,1 | 60,3 | 85 |
| Rest of Europe | 16,0 | 445,5 | 36 |

*Figure 5 Photonics revenue per capita*

Thus, Switzerland is often called a photonics cluster with many agile companies, some of which present their offerings in this brochure.

| Country | Domestic Production (Bio €) | Employment | Revenue €/ employee |
|---|---|---|---|
| Netherlands | 6,2 | 15.590 | 398.000 |
| **Switzerland** | **4,3** | **12.210** | **352.000** |
| Italy | 5,1 | 15.070 | 338.000 |
| Rest of Europe | 16,0 | 56.460 | 283.000 |
| Total Europe | 103,3 | 390.400 | 265.000 |
| Germany | 40,8 | 160.350 | 254.000 |
| France | 15,3 | 60.680 | 252.000 |
| UK | 15,6 | 70.040 | 223.000 |

*Figure 6 Photonics revenue per employee*

It is interesting to note that the employees of Swiss companies rank second with respect to revenue per worker (Fig.6). Both statistics manifest that Swiss companies work in highly paid niches with a high value content.

Swiss companies (not only photonics) participate actively in European programs, however at a waning rate (decrease in funding from Framework 7 to Horizon Europe). We consider it essential that Swiss companies continue to actively participate in the Photonics21 PPP's generation of roadmap and calls through workshops.

Switzerland has a long tradition in producing manufacturing tools, especially for high volume and high precision products. Based on this Switzerland was an early adopter of machining with laser beams and ultra-high precision surface finish of optical lenses. Even today these companies and products represent a major part of the overall revenue and have proven worldwide leadership.

Switzerland has also cutting-edge research institutes, among them EPFL and ETH, which are the bases of start-ups and innovation for companies. Thus, we have prominent companies with leading-edge products in quantum, medical and other markets. These companies profit also from the unique matching-funding support by Innosuisse, which can be obtained for any topic at any time.

Some of these companies do present their products and their company in this brochure.

# CLUSTERS HELP THE CASE – A LOT

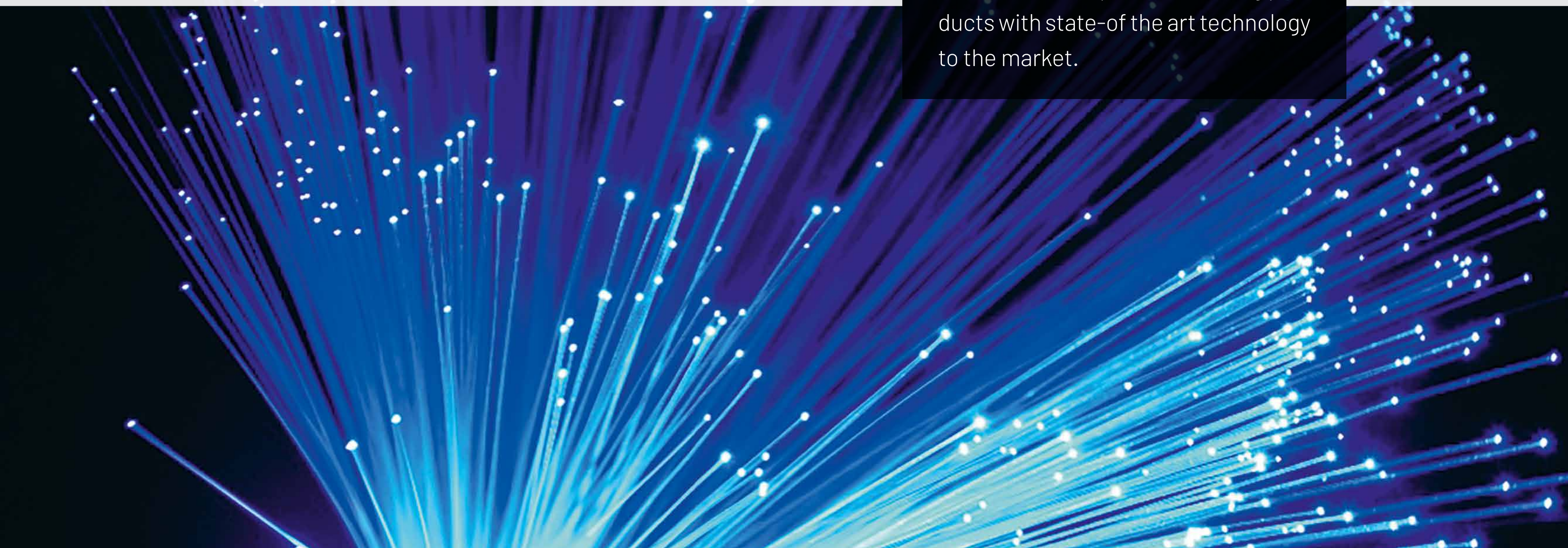
Swiss industry wishes to have a single contact-point at universities to help them connect to the best suitable partner to manage a specific request. Universities are interested in coordinating their activities, especially with respect to infrastructure. Thus, Swissphotonics initiated and supports competence workgroups, so called „Swiss National Photonic Clusters".

To minimize IP and business conflicts participation in these clusters is limited to persons from academia and RTOs who decide to join such a cluster and these clusters combine relevant and interested research organizations for a specific topic. Each Cluster is actively participating in their respective workgroup in the European public private partnership platform „Photonics21" where roadmaps and Horizon calls are prepared and organizes regular meetings for information exchange within the cluster and with customers and collaborators.

AT PRESENT SWISSPHOTONICS SUPPORTS EIGHT CLUSTERS

- Material Processing with Laser Beams (SNAP)
- Optics and Micro-optics Cluster (SNOP)
- Optical Fiber Cluster with Prototyping Facility (SNFL)
- Packaging and integration (SPPL)
- Optical Sensors (SNOS)
- Research in Photovoltaics (SRPV)
- Solid State Lighting (SSSL)
- Education Platform (SEPP)

Clusters are here to bundle the academic and research know-how, distribute it and provide it to start-ups, SMEs and established companies delivering products with state-of the art technology to the market.



axetris

# WAFER-LEVEL µ-OPTICS PAVE THE WAY FOR SCALING UP PIC APPLICATIONS

Photonics technologies cover almost endless aspects of our modern life and wellbeing. The need ranges from information collection with cameras and sensors, to information processing and sharing through all kinds of devices and further to information storage in finally tangible recording means.

Worldwide data volume is expected to multiply incessantly, driven by IoT applications, cloud services and on-site processing that make it really skyrocket. That said, efficient optical signal transmission is a mission critical issue in modern data communication and continuous performance improvement of optical sub-assemblies is a future key success factor.

Nowadays, photonics systems get more and more complex. Often, the required optical setup may require the size of a living room table. No doubt that will work and the desired tasks can be accomplished with such bulky systems. However, you certainly recognize that such a system of highly populated optical components is very difficult to industrialize and to scale up for mass production. So, what could be the solution?

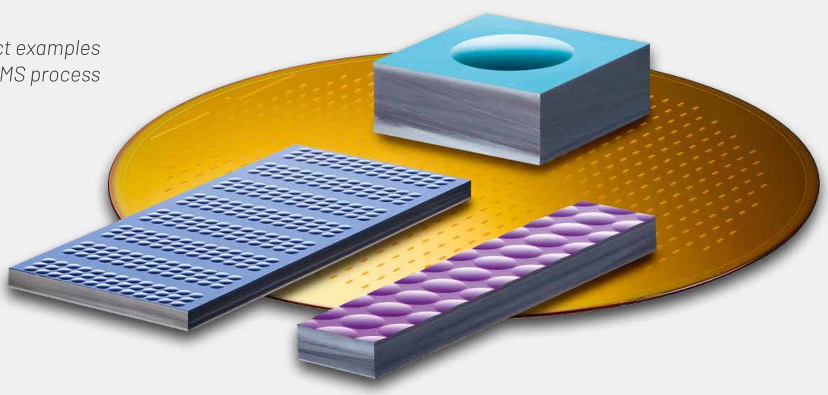
Photonic integrated circuits (PIC) seem to be the best approach among today's state-of-the-art options. When coupling light into- and out of the PIC or other forms of optical circuits, premium quality micro-lenses (shown in Figure 1) can be also the best fit to maintaining high efficiency light coupling on one hand and vast scaling up to mass production requirements on the other.

Let's take a look at proven technologies in Telecom and Datacom, like the 100G to 400G small form factor transceivers. Optical sub-assembly (OSA) consists of the transmitter (TOSA) and the receiver (ROSA) modules, whose exemplary schematic is shown in Figure 2. Silicon micro-lens chip of sub-millimeter dimension empowers those optical sub-assembly modules by coupling light from a laser diode into the optical circuit and further toward optical fibers, see Figure 2. Such an assembly scheme can be adopted wherever PICs employed. For instance, frequency modulated continuous wave (FMCW) light detection and ranging (LIDAR) and Quantum applications need interferometers, splitting optical paths, branching them in multiple outputs. Those optical functions are now all available in PIC circuits of millimeter size chip dimension.

In addition to the optical characteristics, wafer-level MEMS processed micro-optics allow adding a wide range of mechanical structuring and metallization features to facilitate higher integration, smarter embedding and further miniaturization of optical sub-assemblies, see examples in Figure 3. Needless to mention that wafer-level micro-optics manufacturing is probably the smartest way to scale-up production output from prototype to multi-millions, exactly as PIC does.

**Axetris is a leading manufacturer of micro technology based (i.e. MEMS) infrared light sources, laser gas sensors and micro-optical components used for performance critical applications in industrial, telecom, environmental, medical and automotive applications.**

*Figure 1: Micro-optics product examples made by wafer-level MEMS process*



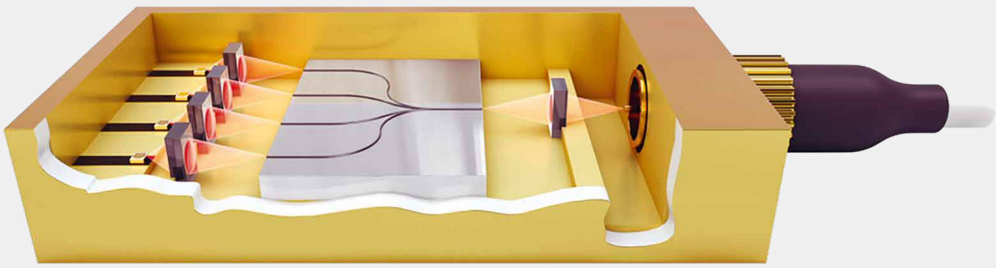


*Figure 2: Transmitter optical sub assembly (TOSA)*

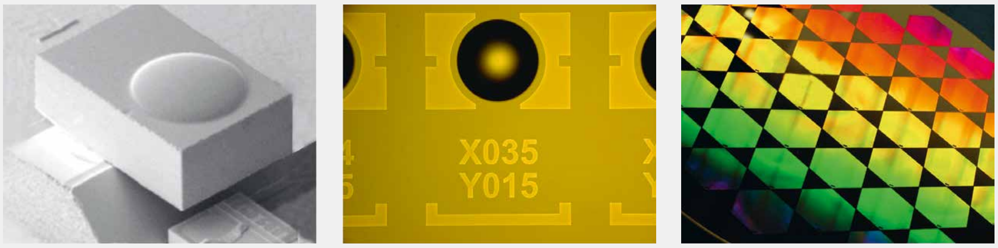
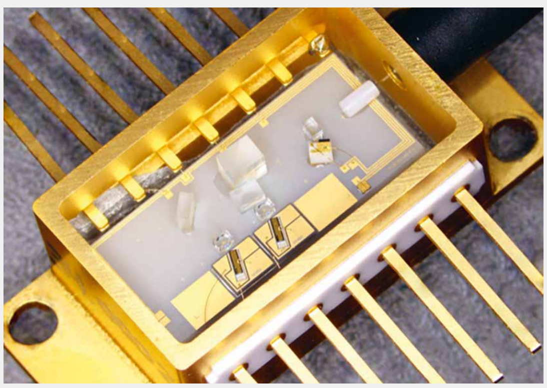


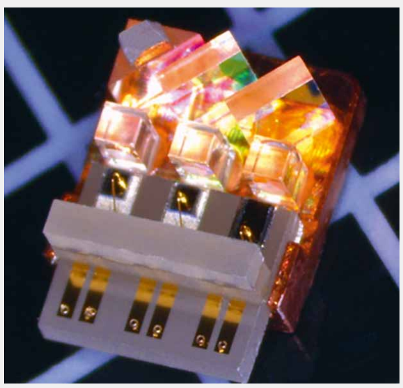

*Figure 3: Examples of additional features, such as mechanical structuring and metalizations*

## AUTOMATED MICRO-OPTICAL INTEGRATION AND PACKAGING

EXALOS is a high-tech SME specializing in broadband, semiconductor-based light sources for the visible or near-infrared wavelength range. These broadband, so-called superluminescent light-emitting diodes (SLEDs) are technology-wise related to laser diodes (LDs) and have similar performance characteristics, for example high brightness, high coupling efficiency to single-mode fibers or high polarization extinction ratio. On the other hand, SLEDs share many aspects of LEDs as they emit a continuous broadband optical spectrum, translating to a short coherence length in the micrometer range. Therefore, SLEDs are preferred light sources for various interferometric applications, for instance optical coherence tomography (OCT) or fiber optic gyroscopes (FOG), or for use in machine vision, metrology or optical fiber sensing.



*Dual-polarization SLED source in 14pin BTF module*



*Micro-RGB LD module with 4 mm x 4 mm footprint*

Optical integration allows for realizing compact modules with a higher functionality, thereby collapsing multiple optical components and devices into one, miniaturized optical light source module that enables smaller system layouts and lower setup costs. EXALOS has developed over the past fifteen years a so-called hybrid optical packaging platform (HOPP) that is based on a fully automated assembly of micro-optical components, including passive devices like lenses, beam splitters, wavelength filters, polarization optics, etc. but also active devices like SLEDs, LDs, MEMS devices, photodiodes and so forth.

All these devices are assembled with sub-micron precision, as shown in the examples below. Advanced optical recognition routines, automated pick-and-place processes in combination with sophisticated active or passive alignment algorithms allow for high-yield and high-volume manufacturing of integrated optical light source engines for next-generation optical systems.

# TURN-KEY, EASY-TO-USE MULTIPHOTON MICROSCOPY FOR 3D DEEP TISSUE IMAGING IN NEUROSCIENCE

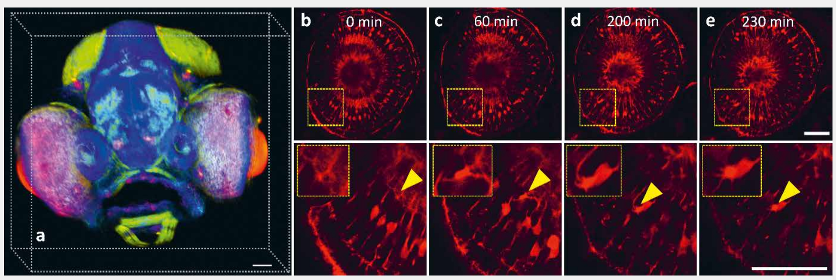
For decades, confocal and widefield microscopy, were used in neuroscience to image 2D samples, like a cellular monolayer or thin tissue sections. However, when imaging deeper into the tissue, multiphoton techniques are mandatory to explore neuroscience in a native 3D context. Excitation with femtosecond-laser in the near infra-red range (NIR), typically between 780 and 1300 nm, produce nonlinear optical effects: the intensity of the generated signal does not increase linearly with the number of photons but rather by the square power (for two-photon effects) or the third power (for three-photon effects). This phenomenon is confined to a very tight focal volume, significantly reducing the absorption cross section from out-of-focus planes. Moreover, using wavelengths in the NIR range leads to lower scattering in tissue and thus yields higher penetration depth and lower photodamage compared to conventional linear confocal techniques. For 3D deep tissue imaging, Prospective's novel turn-key MPX multiphoton microscope combines different imaging techniques in one easy-to-use and portable device: two-photon, higher harmonics and widefield microscopy to maximize informational content originating from any type of sample ranging from singe cells up to living animals.

In the field of neuroscience, one prominent example of using multiphoton microscopy for 3D deep tissue imaging is in-vivo life imaging, like in zebrafish.

The zebrafish model serves as an invaluable subject in the field neuroscience and developmental biology. Its sustained transparency in the larval stage and its fast development within days make it a highly practical and expedient live model for research.

In a research cooperation with the zebrafish-lab of the university of Zurich, living zebrafish specimens, expressing fluorophore-tagged proteins, where imaged to explore migration of neuronal cells in the retina during development of a 3-day old zebrafish larvae. Here, long-term time-lapse imaging over 14 hours allows to visualize cell migration and filopodia over time.

*Figure 1: Multiphoton 3D snapshot image of a fixed (a) and time-lapse imaging of migrating retina cells in an eye of a living zebrafish larvae with respective close-ups (b-e). Scalebar: 50 µm*



SÜSS MicroOptics

# NOVEL MICRO-OPTICS SOLUTIONS

*Monolithical, precisely aligned and highly cost competitive micro scale integration of a lens with a prism, manufactured by SUSS MicroOptics.*

The new trends in micro-optics have been often driven by new light sources. Excimer lasers for photolithography, high power laser bars for industrial manufacturing, laser diodes for fiber communication, VCSEL, LEDs, etc. New light sources often required new types of micro-optics for coupling, collimation, or beam shaping. This trend will certainly continue for the next years and micro-optics will be an enabler for many of the future mega-trends such as edge computing, IoT, autonomous driving and accessible healthcare, which are heavily based on photonics and optical solutions.

The engineering of the often complex and costly optical devices towards mass-market compatible size, weight and power (SWaP) and cost targets drives constant manufacturing innovation. Optical devices constantly shrink and increasingly employ fabrication processes derived from semiconductor technology. Higher integration of functions into single elements, like lenses and prisms at the micro-scale, and the mastery of their design and manufacturing enables technological leadership. Furthermore, beyond microlenses, features such as cavities and optically smooth sidewall surfaces are often required for beam expansion or as coupling facets. SUSS MicroOptics offers processes for both as well as a wide range of AR coating, metallization and glue management options. This comprehensive offering provides a powerful toolbox for miniaturization and integration of scalable optical solutions. These integrated micro-optical components are door opener and key enabler for innovative designs and applications that are driving the future trends, such as photonic integrated circuits (PIC), optical subassemblies and transceivers, environmental sensing, autonomous driving and LiDAR as well as point-of-care solutions in life science and wearable diagnostics.

# BRING REVOLUTIONARY META-LENSES TO THE MASS MARKETS

Miniaturizing components while maintaining high performance is a critical enabler for smartphones, consumer electronics, and AR/VR devices. Flat optics is generating much excitement as a solution that addresses that need. It can disrupt numerous applications, such as simplified Time-of-Flight (ToF) systems, ultra-compact NIR cameras used for eye-tracking and driver monitoring, sensing and machine vision applications, SWIR imaging to detect food freshness and food contamination, medical imaging, LiDAR, presence detection in smart home, object detection/avoidance in robotics, and health/biometric sensing.

A single Metalens can replace multiple refractive lenses while delivering similar or improved performance. The Metalens is typically made using amorphous silicon on a glass substrate, making it mechanically strong, rigid, reliable, and thermally stable. It can be customized for wavelengths in visible, NIR, and SWIR bands.

NIL Technology (NILT), mainly based out of Copenhagen, Denmark, and Horgen, Switzerland, is currently focused on developing and mass-producing meta optics for smartphones, consumer electronics, and AR/VR/MR.

NILT uses high-resolution, high-fidelity E-beam lithography (EBL) with nanoimprint lithography (NIL) to fabricate high-quality, low-cost Meta Optical Elements (MOEs) in batch sizes suitable for mass production. At the end of 2021, extensive experience in EBL and NIL, combined with sophisticated optical design methods and advanced in-house optical characterization, allowed NILT to introduce a single surface metalens with a record-high absolute efficiency of 94%. NILT is currently shipping samples of its Metalens to qualified customers.

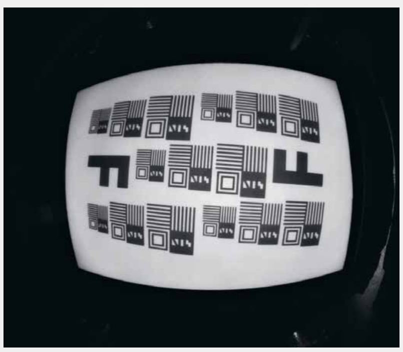
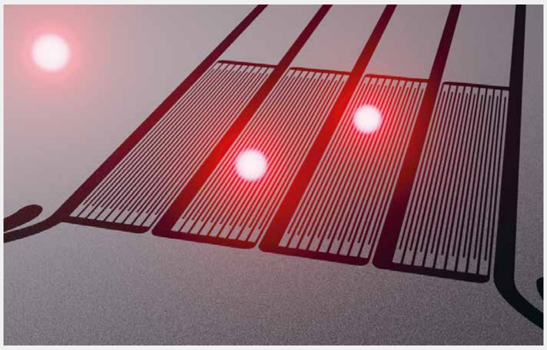


*Image using a single meta optical element surface (1M MOE) designed for 940 nm wavelength. The image has excellent resolution for edge-to-edge NIR imaging and is comparable to images captured with a multi-element refractive lens.*

*An array of Meta optical lenses.*

# STATE OF THE ART IN SINGLE-PHOTON DETECTION



A parallel-pixel SNSPD, capable of ultrafast single-photon detection and discrimination of 4-photon states, manufactured by ID Quantique

Detecting single photons is hard. Not because they are strange wonders of quantum mechanics, but because there are simply too many of them. One has a similar problem counting the number of drops of water in the ocean.

It is a relatively simple matter to turn a single particle of light into a machine-readable signal. Photo-multiplier tubes (PMTs) and single-photon avalanche diodes (SPADs) can rapidly turn a single photon into a large number of electrons, much like the clicks of a Geiger-Mueller tube detecting particles of ionising radiation. The state of the single-photon detection art, however, lies with superconducting nanowire single-photon detectors (SNSPDs).

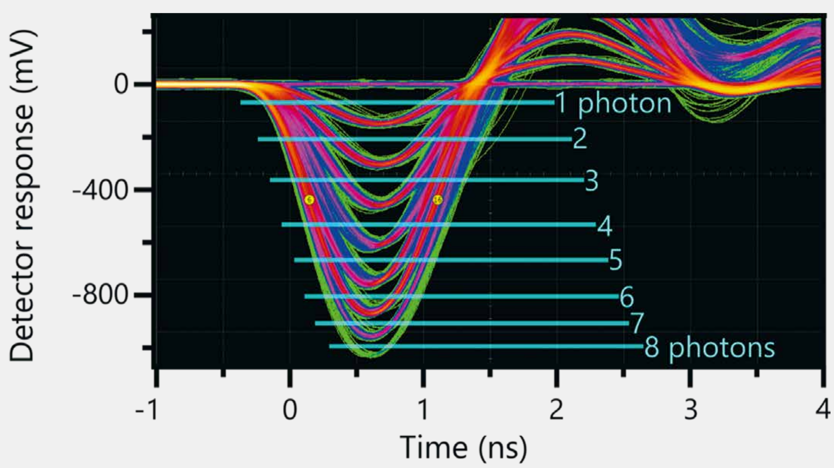
SNSPDs work by holding a single meandering line of superconducting material close to its superconducting threshold. A single incident photon will rapidly create a localised hotspot, and the transition from the superconducting to regular conducting state gives an incredibly sharp and measurable electronic pulse. This technology provides near-ideally high efficiency, super-precise timing and ultra-low noise, allowing researchers to see ever-smaller gaps in space and time, and making previously impossible photonic applications possible.

Standard superconducting nanowire single-photon detector (SNSPD) designs can only detect the presence or absence of photons, and their performance is limited by the photon pile-up effect, often limiting their performance to detection rates of tens of MHz at best. An innovative solution is found in a parallel-pixel SNSPD design. In these devices (patent pending), an array of SNSPDs are connected in parallel to a single readout circuit. Here, single photons are much less likely to pile up at one pixel, with recovery times—the time taken for the detector to exceed and stay above 50% of its maximum efficiency after a detection—comfortably below 10 ns.

In recent collaborations with IDQ, researchers at the University of Geneva were able to demonstrate single-photon detection rates in excess of 200 MHz with such a detector (M. Perrenoud et al., Supercond. Sci. Technol. 34 (2021) 024002). Better yet, this detector design can also discriminate the photon number state, up to n photons for an n-pixel SNSPD, as seen in further recent work (L. Stasi et al., arXiv 2207.14538 (2022). All while benefitting from SNSPDs' near-ideal detection efficiency, unparalleled timing precision, ultra-low noise, and broadband operation.

This high-performance and continually-improving technology promises to enable a plethora of photonic applications, from enhanced-precision metrology for industrial manufacturing, to entirely new uses in the field of photonic quantum computing.

Persistent oscilloscope trace from the output of an 8-pixel parallel SNSPD (manufactured by ID Quantique) under pulsed illumination. The trace demonstrates discrete and highly resolved pulse amplitudes, corresponding to between zero and eight photons being registered in a single detection event.

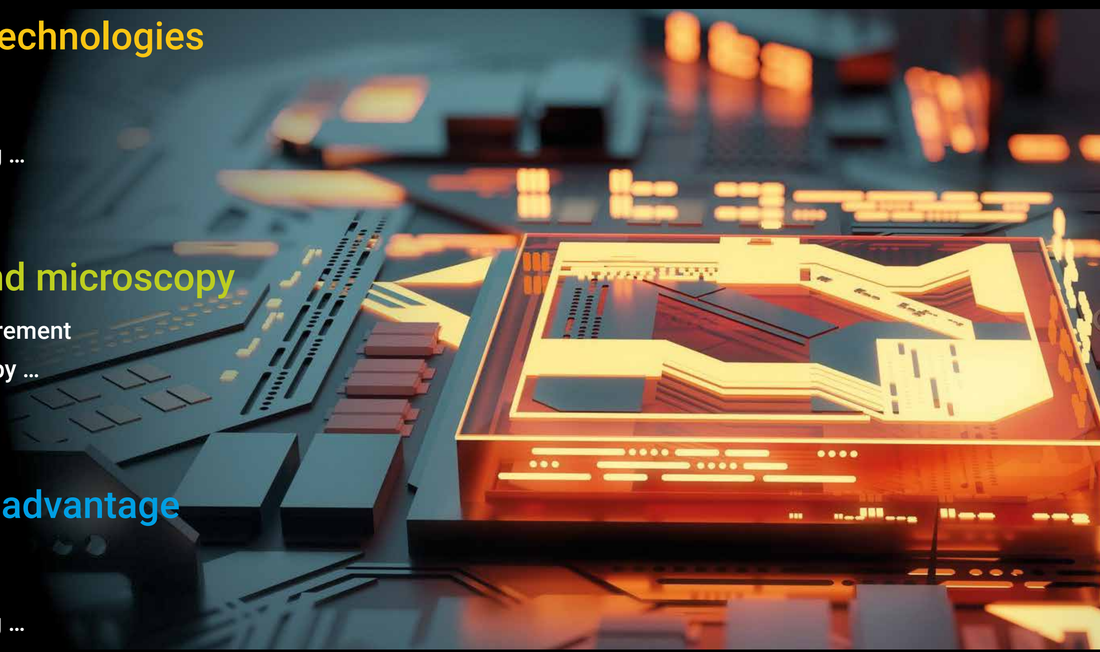



a. M. Perrenoud et al., Supercond. Sci. Technol. 34 (2021) 024002
b. L. Stasi et al., arXiv 2207.14538 (2022)

# Enabling Quantum Technologies through

# Photonic Sensing Solutions

Empowering you to create the building blocks for a Quantum Internet



## Driving emerging technologies

Quantum key distribution
Quantum relays & repeaters
Photonic quantum computing …

## Honing imaging and microscopy

Fluorescence lifetime measurement
VIS, NIR and MIR spectroscopy …

## Enabling quantum advantage

Quantum optics
Single photon sources
Metrology and manufacturing …

SNSPDs: the very best
in single-photon detection

Compact and effective
single-photon avalanche detectors

Picosecond precision
measurement and control

Versatile and easy to use
picosecond lasers

IDQ

Switzerland | USA | South Korea

Talk to us today info@idquantique.com
Find out more www.idquantique.com

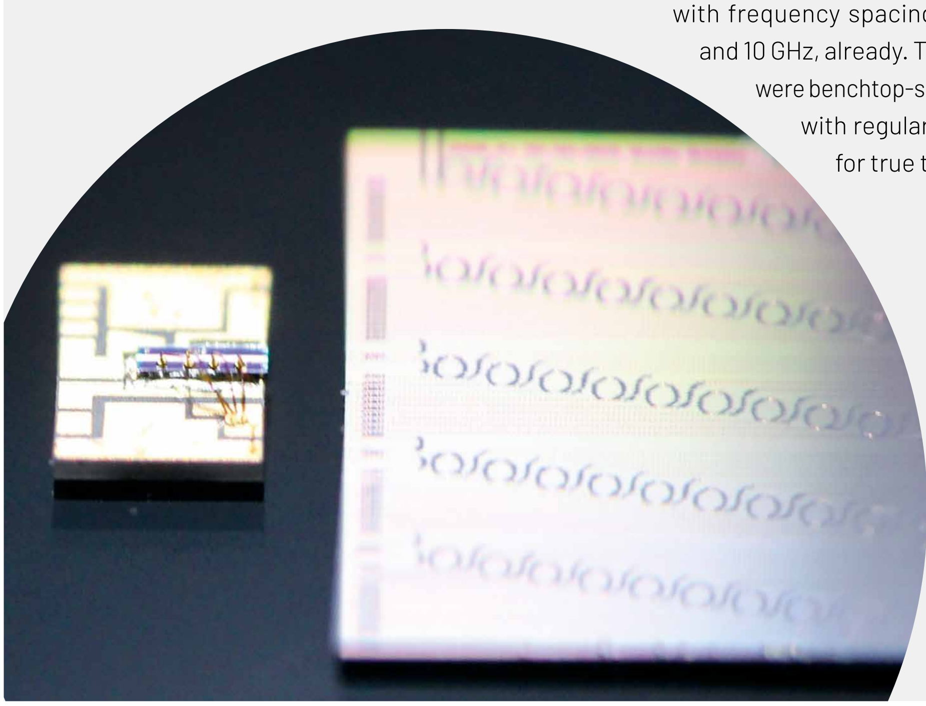
# LASER COMBS IN HIGH VOLUME PRODUCTION

Menhir photonics and Enlightra are two companies which build their products upon essential Swiss traditions: Excellent research and high precision in manufacturing. Excellent research in the field of laser technology has led to the products the two companies sell: Laser frequency combs. Manufacturing with highest precision is their path to mass markets.

Laser combs are multichannel laser sources with an extremely precise spacing between the single channels. The name was coined after their spectrum which looks like the teeth of a comb. Laser combs deliver extremely precise signals as needed in fields such as optical communications, data centers and high-performance computing. Accordingly, applying manufacturing technologies from the telecom industry is the path to achieve volume numbers.

"We use the most advanced pick and place technology for the automated production" says Dr. Florian Emaury, CEO of Menhir Photonics. "This way we can integrate complex optical components in our laser systems and still produce large batch numbers with the needed reproducibility, price and volume." The company started by selling ultra-compact sources for pico- and femtosecond laser pulses with frequency spacings between 1 and 10 GHz, already. Those devices were benchtop-sized and came with regular mail service for true turn-key operation. In the meantime, they went one step further and put the laser source into a butterfly casing, as a regular component.

Enlightra approaches the same challenge from a different angle: "We take technologies which were actually developed for semiconductor chip manufacturing and use them for making photonic integrated circuits" explains Dr. John Jost, Co-CEO of the Lausanne-based Enlightra. As an integrated photonic circuit (or PIC), their devices are made on silicon wafers enabling high-volume manufacturing. In such a PIC, they use a micro-ring resonator to generate laser combs with ultra-pure colors. The small size of the resonator allows them to approach larger frequency spacing for operation: "compared to conventional laser combs,



we push the boundaries of achieved spacings by almost two orders of magnitude, to cover range from 25 GHz up to Terahertz and open the door to optical communications and computing applications for higher speed and energy efficiency" says Dr. Maxim Karpov, the other Co-CEO of Enlightra.

The precision of the laser combs matches with another traditional Swiss product: Clocks. In fact, many of Menhir Photonics' devices have already been used for challenging timing tasks. Those include large accelerator rings, or radar systems, where more precision means a longer range. Together, the two companies cover the full range of laser comb products needed by the market to address its most critical niches. "With the new level of integration being developed by both companies, we can address high-volume markets" says Emaury.

Just recently, scientists at the Danish Technical University have shown a data transmission rate of 1.8 Petabit per second. This is twice the total global Internet traffic (as of 2022). They used one single light source for this experiment – a laser frequency comb. It is only a matter of time that such transmission rates will be introduced at data centers. Then they will need the bandwidth and energy efficiency provided by laser combs. The advanced technologies developed by these Swiss companies, provide the needed solution suitable for mass-manufacturing.

And there is more to come: While quantum computers raise the attention of politicians and investors, it is optical computing that quietly evolves, thanks to demands in artificial intelligence and machine learning. With the development of more and more optical components available on chip level, the building blocks for pure optical data processing are on the table. Laser combs will play a pivotal role here to enable higher-throughput computation and reduced energy consumption. „For both approaches, the path is obvious," says Jost „Upscaling is the way to go." They target five to six digit batch sizes. They can rely upon established processes from semiconductor manufacturing. First shipments for secure data center links are scheduled for 2023. Emaury summarizes the vision: "Within the next five years, we plan to be incorporated into high-volume market data center applications, telecoms, and photonic computing, to introduce a new level of speed and energy efficiency."

# LASER SOLUTIONS FOR HIGH PRODUCTIVITY MICRO- FABRICATION OF HIGH-QUALITY MICRO-MECHANICAL COMPONENTS

LASEA group, with a Swiss branch in Biel/Bienne, is a manufacturer of femtosecond-laser machines. These machines are used for high precision engravings, cutting and drilling applications, decoration and surface texturization in various industries including watches, jewellery, medtech and electronics. For the past ten years, Ultra Short Pulsed lasers (USP or femtosecond lasers) have rapidly penetrated the market, producing more and more quality components with exceptional surface quality, no burr and almost no heat affected zone.

Market analysis shows that the number of femtosecond laser systems used in industrial environments will continue to rise in the years to come. Future industrial applications of USP lasers will require high processing quality, coupled with higher throughput and productivity, by using higher average power lasers. Today's laser sources already offer high average power, but this alone does not guarantee superior results unless all other elements of the laser machine are properly selected and managed. For example, at high average powers, residual thermal effects become significant and can degrade the quality of processing and optical components, posing specific new challenges. Therefore, new machining strategies must be applied including laser beam shaping, high-speed scanning, parallel processing, or a combination thereof.

To address this new market requirement, LASEA has developed a range of new machines, including LASEA NEO and LASEA Flex. To increase the productivity of the machines, the high-power laser beam is split into two beams which are sent to two galvanometer scanners. By doing so, two identical parts are machined simultaneously. This approach of parallel processing is suitable not only for engraving processes, but also for cutting and drilling applications using the precession module LS-Precess, which can provide a 0°-taper angle. Using this technology, functional parts can be fully machined without the need for costly post-processing.

# LASER-BASED GLASS MICRO-MACHINING FOR INTEGRATED PHOTONICS

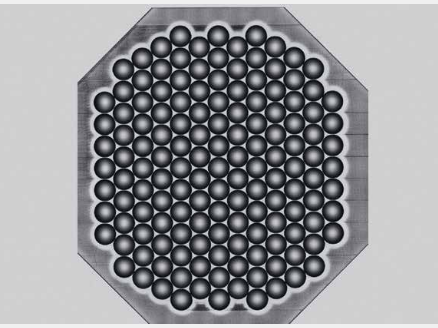


*Fig.1 Detail of a fully processed micro-lens array.*

In the current trend for miniaturization of photonic systems, the FEMTOprint© laser-based glass micro-machining technology allows 3D freedom in design and fabrication, as well as the possibility of monolithically integrating several functionalities within a single photonic system, thus avoiding complex assembly steps, while allowing for a high level of complexity. Moreover, it enables the access to fast prototyping and pilot production, while guaranteeing the possibility of up-scaling to volume production.

In the field of micro-optics, laser-based glass micro-machining represents an innovative manufacturing technique that has proven to be successful in the fabrication of arrays of micro-lenses, which can be used as components or to produce high-quality glass masters to be used in high-volume imprint manufacturing in plastics. Fig.1 shows a micro-lens array manufactured on a fused silica substrate.

The lenses were designed to have a diameter of 500 μm, a nominal radius of curvature (RoC) of 650 μm, and a sagitta (SAG) of 50 μm. The average RoC was measured to be in the order of 625 ± 5 μm, while the SAG matched the nominal value within ± 1.5 μm. The achieved average surface roughness (Sa) was measured to be smaller than 5 nm. Fig.2 shows a miniaturized photonic system combining refractive and reflective optical elements. Using the FEMTOprint© laser-based micro-machining technology, the optical component was fabricated achieving Sa values in the order of 5-15 nm.

In datacom and telecom applications there is a clear trend to move towards 2D fiber arrays, which allow the integration of several channels per surface unit, thus increasing the level of miniaturization. The fabrication of high precision ferrules for 2D fiber arrays still faces important technological challenges and laser-based micro-machining represents a very promising solution, which can effectively handle dimensions in the range of few microns to a few millimeters with resolution and accuracy below 1 μm. The FEMTOprint© technology allows to fabricate high-precision ferrules (Fig.3) in glass with machined surfaces showing a typical average roughness in the order of 100 nm, well below what can be achieved by standard fabrication methods. In particular, 2D fiber hole arrays can be manufactured with a diameter accuracy < 0.5 μm, a position accuracy with respect to fiducials with a maximum deviation of 1.6 μm, and an average hole positioning error of ± 0.7μm and a standard deviation < 0.4 μm.

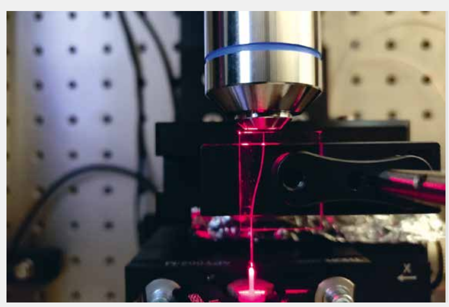
The FEMTOprint© laser-based micro-machining technology can be also used to locally increase the refractive index by a factor of 10-2 to 10-3, thus creating 3D waveguides (Fig.4) within the bulk of the glass. In particular, it is possible to fabricate single mode waveguides at telecom wavelengths (1310nm and 1550nm) with mode field diameters ranging from 3 μm to 12 μm and propagation losses, which can be as low as < 0.7 dB/cm. To keep losses at bends in the order of 1dB or less, the radius of curvature is currently limited to 20-30 mm. However, the possibility of shaping the waveguides in 3D in the glass volume is a unique property for the design of optical circuits, when compared to other technologies.

In conclusion, the possibility of combining waveguides and photonic wire connections with high-precision micro-mechanical alignment elements such as V-grooves and ferrules, as well as with micro-lenses or micro-lens arrays paves the way to the fabrication of fully integrated photonic systems in glass with self-alignment of all elements within +/- 1 μm.

*Fig. 2: Picture and sketch of a miniaturized glass photonic system (courtesy of CEA-LETI).*

*Fig. 3: Ferrules and 2D fiber hole arrays.*

*Fig. 4: Free-form 3D waveguide laser-written within the bulk of the glass.*




The ART of high-precision
µ MANUFACTURING

# The new frontier of laser-based glass-micromachining

FEMTOprint is a Swiss high-tech Contract Development and Manufacturing Organization (CDMO) specialized in high-precision laser-based 3D micro-fabrication in glass.

With the advanced FEMTOPRINT® micro-fabrication technology we serve leading industrial Customers with feasibility, rapid prototyping, pilot, and volume manufacturing at wafer scale.

**APPLICATIONS**

Micro-fluidics | Micro-optics | Photonics | Optical effect | Micro-mechanics | Packaging

**INDUSTRIES**

Life Sciences & Diagnostics | Medical | Watchmaking I Aerospace | Industrial Machinery | Optics | Photonics | Energy | Quantum

The FEMTOPRINT® technology relies on ultrafast, laser-based micro-manufacturing processes, which enable truly free-form surface/volume shaping, welding, surface treatment,and ablative solutions in glass.

With a monolithic approach to avoid challenging assembly and alignment steps, it allows the integration of micro-optical, micro-mechanical, and micro-fluidic functionalities.

The company is certified ISO 13485:2016.

**COMPETENCIES**

- Design for manufacturing
- Rapid prototyping
- Pilot & volume manufacturing
- Structural & functional characterizations
- Quality control

**PERFORMANCE**

- Process resolution ~ 1 µm
- Standard roughness ≤ 100 nm
- Roughness after surface treatment ≤ 10 nm
- Aspect ratio: > 1:500
- Substrate thickness: up to 30 mm
- Working area:  up to 8”

**WHY FEMTOprint**

- Breadth of capabilities
- One-stop shop manufacturing foundry, vertically integrated
- Free-form design at the µm scale
- Fast turnaround time in prototyping
- From proof-of-concept to wafer-scale manufacturing

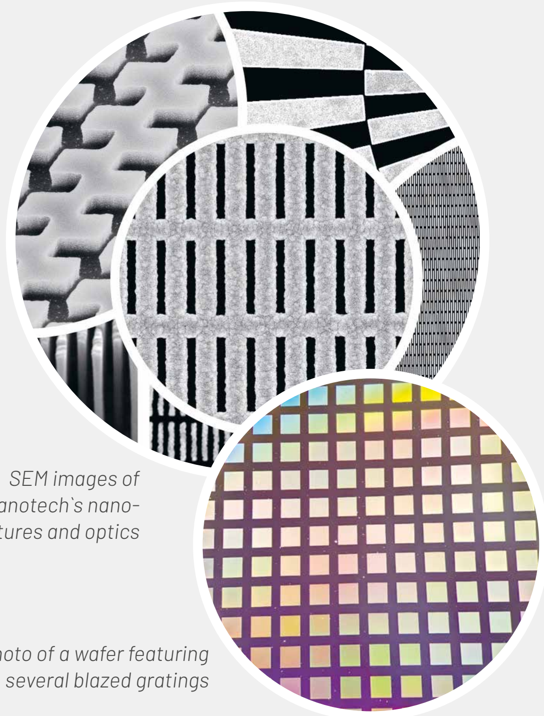
We want to be part of your success,
contact us at:

info@femtoprint.ch
femtoprint.ch
+41 91 960 10 70
Switzerland

FEMTOPRINT®

SWITZERLAND INNOVATION
PARK INNOVAARE

# INNOVATIVE DIFFRACTIVE OPTICS PUSH THE BOUNDARIES OF HIGH-TECH X-RAY APPLICATIONS



*SEM images of XRnanotech's nano-structures and optics*

*Photo of a wafer featuring several blazed gratings*

Diffractive optics are key to a wide range of high-tech applications in the scientific, industrial, and biomedical sector. XRnanotech, a spin-off from the Paul Scherrer Institut, is working with innovative fabrication methods to expand on what is currently possible in these segments. The start-up located at the Park Innovaare manufactures highest-quality nanostructures and optics (figure 1).

One example are high aspect ratio Fresnel zone plates produced by using a special line-doubling technique. This method allows achieving sub-10 nm resolution for X-ray microscopy. The process comprises coating a sparse template with atomic layers of Iridium before stripping the base structure off through reactive ion etching.

Another innovation is made for optimizing the photon efficiency. Here, a process for manufacturing multi-step blazed gratings (figure 2) was implemented, increasing the theoretical photon efficiency limit from 40% as seen with traditional binary gratings to 80%. This is enabled by using electron beam lithography allowing for this special multi-step design. Under real world conditions, a photon efficiency of more than 50% was achieved with diffractive zone plates, whereas the industry standard is 10-20%. This way, the throughput of high-tech instruments and scientific experiments at large X-ray sources can be doubled, enabling more progress in shorter time while saving costs.

To go even beyond solely diffractive optics, the concept of achromatic lenses was realized for the use in X-ray microscopy. Therefore, a diffractive element made by nanolithography was combined with a refractive structure produced by 3D nanoprinting. This overcomes the limitation of monochromatic lenses allowing a greater part of the light being effectively used, which results in higher efficiencies and sharper images.

Overall, the implementation and combination of innovative fabrication methods on the nanoscale, not only enables the improvement of existing processes, but also allows for previously unthinkable applications in the X-ray sector and beyond.

*The positioner installed on the Apache Point Observatory (NM) for the SDSS-V astronomical survey (Courtesy of MPS Microsystems).*

# THE ESSENTIAL ROLE OF SWISS PHOTONICS EXPERTISE IN THE DISCOVERY OF THE UNIVERSE

In just a few years, as astronomy has sought to map the universe and measure the movement of the most distant galaxies and stars, Swiss expertise in microtechnology has become essential to any innovation that accelerates the collection of the light emitted by the luminous objects that form the universe. Indeed, thanks to the scientific knowledge of the EPFL's photonics and microtechnology institutes and the unique skills of the Swiss industry in the industrialization of microsystems, Switzerland is equipping one after the other the largest telescopes on earth such as the VLT (Very Large Telescope) in Chile or the Apache Point Observatory in New Mexico (USA).

Multi-Fiber Spectroscopy allows the simultaneous spectra measurement of several night sky objects with just one telescope. This is achieved by placing optical fibers in the focal plane of the telescope. In order to capture the light of the stars or galaxies, the fiber ends are precisely positioned, such that the fiber cores match their designated targets on the sky. Between observations, the optical fibers are repositioned in the XY plane to match the desired fiber pattern of the new objects. Repositioning the optical fibers and guaranteeing absolute positioning requirements of less than a few micrometers is one of the key challenges of such systems. If today telescopes are equipped with 1'000 to 5'000 fibers each, the current developments are focusing on a miniaturization of the positioning systems and thus on an increase in densification to 20'000 or even 25'000 fibers per telescope. EPFL and the Swiss industry are at the forefront of the research in this field. The new generation of ultra-miniature positioners coming from the Swiss scientific and industrial community are expected for the year 2025. They will allow to generate an innumerable quantity of information which, hopefully, will allow a decisive advance on the explanation of the inflation of the universe or of the dark matter or of any other parameter not yet elucidated.

# 3D VISION FOR INDUSTRIAL AND TRANSPORTATION SAFETY

In machine vision, 3D vision sensors have expanded from laser triangulation or line scanning to time-of-flight imaging (ToF). They are used by autonomous logistics vehicles, for safe robot guidance or people counting. Full-frame imaging increases field of view resolution. Autonomous vehicles triggered innovation in light detection and ranging (LiDAR). Volume deployment started with premium vehicles for long-range highway applications, mostly using scanning LiDARs. Research now focuses on near-range solutions (P 1,2) with low latency and robustness to avoid 250'000 collisions with pedestrians and cyclists yearly. Solid-state flash LiDARs emerge as a candidate of choice due to their price/performance ratio.

*(P 1) Near range – Autonomous Vehicles*

*(P 2) Near range – Cobotics*

**The Fastree3D Single photon detection on standard CMOS solution**

Single-photon avalanche diode (SPAD) arrays (P 3) deliver the highest time-resolved performance. Their implementation in CMOS semiconductors has progressed to on-chip, pixel-level, timestamping, and processing. 3D wafer bonding technologies push the limits of ToF imaging (longer ranges, sub-cm resolution, high angular resolution, fast capture, background immunity, eye safety, and multi-camera operation). Large SPAD imagers have been demonstrated (up to megapixels) with single or coincident photons detection. The generalization of SPAD sensors in mobile phones prepared the manufacturing of near-range digital 3D imagers at affordable prices for industrial and automotive applications.

*(P 3) SPAD Array*

*(P 4) HDK*

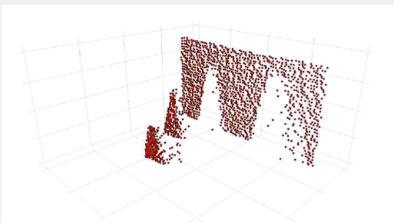
**Application development with software-defined detectors**

Developing a 3D direct ToF application is complex since the measurement depends on system configuration: timing, illumination, and optics. Arrays of vertical-cavity surface-emitting lasers (VCSELs) enable new eye-safe pulsed illumination (with sub-nanosecond pulses up to 100W peak in NIR wavelengths). Fastree3D has developed hardware kits (HDK) (P 4) to help optimize software-defined detectors for each use case. The HDK distributed by GMP captures 2K pixels (32x60) and generates a reliable 3D point cloud (1 cm resolution, 50ps) under adverse lighting or in multi-camera operations (P 5). The real-time quality control of every pixel reduces false positive or negative detections by adapting most parameters (P 6). An onboard Linux computing platform with firmware allows application trials.

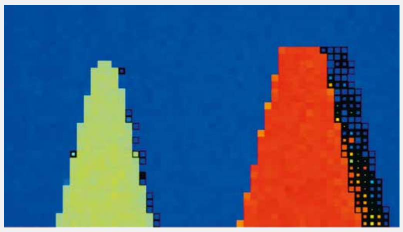
**Continuous performance improvement**

A circuit available in 2023 will detect 16K pixels (64x256x4SPADs), providing several outputs 2D (intensity imaging), 3D (point-cloud with 2cm resolution), quality (confidence level per pixel) at ranges of 50m (with 60° FoV dependent on optics, under 50klux sunlight). The global shutter can capture fast-moving targets (at 100fps) without motion distortion. On-chip algorithms can be executed at the frame rate and improve actionable information. This architecture leads to a compact form factor and affordable sensors.

*(P 5) Point Cloud*

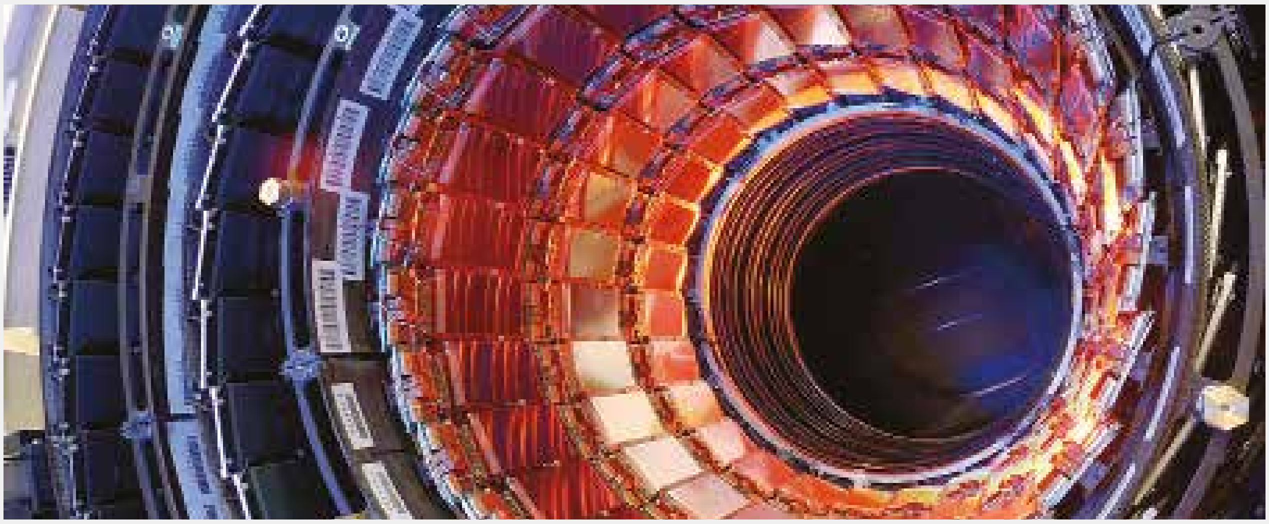


*(P 6) Pixel quality*



HAMAMATSU
PHOTON IS OUR BUSINESS

# PHOTONICS' MISSION TO ACCELERATE SCIENTIFIC DISCOVERY



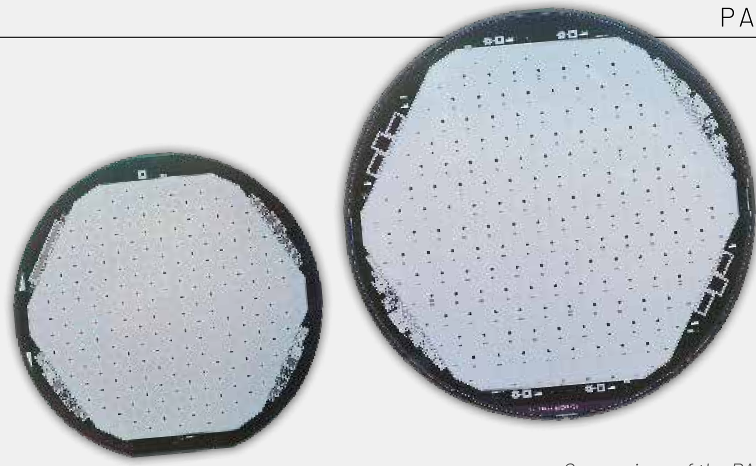
*Silicon strip detectors installed in CMS experimental apparatus (image courtesy of CERN)*

Switzerland fosters some of the most recognized international research institutes. They bring together nations from all over the world and unite like-minded scientists together with the goal of uncovering the mysteries of our universe. Hamamatsu Photonics, an established player in terms of photonics-lead innovation, has the pleasure to support some of these major institutes. One of these, CERN, has been working on the High Luminosity Large Hadron Collider (HL-LHC) project, which aims to amplify the performance of the LHC to increase the potential for discoveries after 2029.

Based on the existing LHC, the most powerful and largest particle accelerator in the world, the objective is to increase the integrated luminosity by a factor between 5 and 7 beyond the LHC's design value. Therefore, the particle and light sensors used in those experiments have to meet severe conditions, such as high Photon Detection Efficiency, strong radiation hardness, and low dark current among other conditions. Achieving this goal means pushing the development of these technologies to a new level.

Impacting both ATLAS and CMS, the upgrades specifically concern sub-detector systems including calorimeters, trackers, timing layers, and more. All require new sophisticated photon/particle sensors and front-end electronics, so they can deal with the higher luminosity and collision frequency of the HL-LHC. Newly designed large hexagonal multi-PAD sensors, now stretching to an 8-inch sized wafer, have been developed for the high granularity calorimeter (HGCAL), helping to improve the overall detection resolution of CMS.

Timing layers are now introduced in both ATLAS and CMS to tackle the higher collision rates. Typically, SiPMs (Silicon Photomultipliers) and LGADs (Low Gain Avalanche Detectors) will be selected since they can match the fast speed requirements of these timing layers. ATLAS and CMS trackers, based on pixel and strip sensor technology, will be replaced with improved sensor design features, flip chip bonding and assembly techniques, and improved ASIC features.



*Comparison of the PAD wafers sensors from 6-inch to 8-inch wafers*

In addition to the well known Si Strip and Si Pixel sensors, SiPMs, which are also now recognized as an essential sensor technology, have been custom-made and used in several of these experiments' sub-detectors. Finally, although Si sensors are the preferred choice in many sub-detectors, PMTs (Photomultiplier Tubes) are still present in the upcoming upgrades, as they offer unbeaten features of low dark current, high speed and high gain (e.g. in ATLAS TileCAL).

Each innovation brings about the possibility of a new application. By pushing the limits of technology for these major research institutes, through improved custom-made solutions, Hamamatsu was also able to support other sectors. In this case, thanks to the collaboration with CERN, it has been possible to transfer the improved sensor technology to PET instruments. This has allowed for more innovative, compact and low-cost instruments to support better patient care.

# BLACK MARKING FOR MEDICAL INDUSTRY WITH ULTRA-SHORT-PULSED LASERS

Using lasers for permanent markings is a well-known method and standard in many areas in industrial manufacturing. Various processes on all kinds of materials are used to achieve durable markings. Whereas laser marking processes are mostly easy to handle it becomes challenging if the markings need to fulfill the requirements of the medical industry.

The demand for markings in the medical industry is increasing because of changing regulations in this sector. The labelling of medical devices with a traceable Unique Device Identification (UDI) code will be mandatory. Laser marking of medical steel needs to fulfill certain criteria where corrosion resistance, a toxicologically uncritical surface and good contrast, are key factors. Standard laser marking systems are reaching their limits to fulfill these criteria.

The best choice to accomplish this challenge is the usage of ultrashort pulsed (USP) lasers. The process using USP lasers, fulfilling the criteria of medical industry, is often called "Black marking". Black marking is a procedure in laser processing which causes extremely dark, high-contrast markings on a surface, without material ablation. Extremely short laser pulses cause periodic structures on the surface at the nanometer level. The micro structured surface reflects light in a very scattered manner, as well as absorbing it.

Processing with a laser causes a noticeable color change on the metal – right through to a deep, dark-black color. Black marking also creates a strong contrast and a very matte appearance, without reflections.

*Figure 1: Viewing angle independent legibility*


*Figure 2: High contrast black marking*

When the laser pulses used for this marking are ultrashort, the color changes also remain corrosion-resistant within certain parameter ranges and remain legible even after numerous cleaning and passivation cycles.

The EU's Medical Device Directive and FDA regulations (Food and Drug Administration) in the USA require permanently legible labeling of medical devices with a traceable UDI code (Unique Device Identification). The properties of black marking using ultrashort pulses make it ideal in meeting all the requirements of UDI-compliant marking. The corrosion resistance, viewing angle consistency and deep black color of the UDI codes make them permanently legible even in the smallest dimensions.

To achieve these advantageous black markings there are several companies offering USP lasers and laser systems. Among them is TRUMPF Schweiz AG, which offers laser systems of the TruMicro Mark Series. The TruMicro Mark 2030 G2 S is especially suitable for performing black marking. This laser has the advantage of full flexibility of the important parameters, such as pulse energy, pulse frequency and pulse duration, to find the best parameter ranges for a certain material.

*Figure 3: UDI-compliant black marking*

LIGENTEC

# PHOTONIC INTEGRATED CIRCUITS AND THE ROLE OF SWISS COMPANIES

Photonic integration repeats success story of electronic integration

The optical equivalent of the well-established electronic integrated circuit (IC) is the photonic integrated circuit (PIC), which comprises a multitude of photonic components integrated into a single chip. While an electronic IC consists of transistors, resistors, and capacitors that work with electrons, PICs work with light and can embody modulators, lasers, detectors and more. Integrating various functionalities brings advantages such as extremely small footprints, high manufacturing scalability, low cost, high performance, power-efficiency, and low heat generation. Whereas PICs based on silicon waveguides have been around for more than 20 years, new material platforms were introduced in the past decade.

*Integration and testing of PICs.*

These new material platforms enable a new era of applications and markets and overcome the limitations of silicon in terms of propagation loss, modulation speed and wavelength coverage.

## APPLICATIONS FOR PICS

PICs will play a key role in tomorrow's infrastructure in communication, sensing and transportation. For the quickly growing areas neuromorphic computing, augmented reality, and quantum technologies PICs are a true enabling technology.

In communication for example, the need for more bandwidth and lower power consumptions in datacom and telecom brings the existing silicon photonics to its limits. Higher modulation speeds and low loss propagation and interconnects are needed. Channel spacing will need to change from widely spaced to narrow spaced with many laser lines next to each other. Additionally, coherent transceivers will become widely spread to meet the bandwith requirements. Companies in Switzerland are developing high-speed modulators that can be integrated into a low-loss PIC platform that also enables narrow linewidth lasers for coherent telecom.

A vast upcoming market for PICs is the automotive industry, especially LiDAR (Light Detection And Ranging). A LiDAR device emits light to the surrounding area and detects the reflections from objects. By measuring the time span between sending and receiving, the distance of an object can be determined. In addition to this Time of Flight LiDAR technique, Frequency Modulated Continuous Wave (FMCW) LiDAR also retrieves the speed of the object. Narrow linewidth tunable lasers together with high optical power propagation on chip and low loss for detection is needed. A PIC can integrate the individual components of traditional LiDARs such as the transmitter and even receiver, providing a one-chip solution.

*Figure 2: 200mm wafer with hundreds of silicon nitride PICs.*

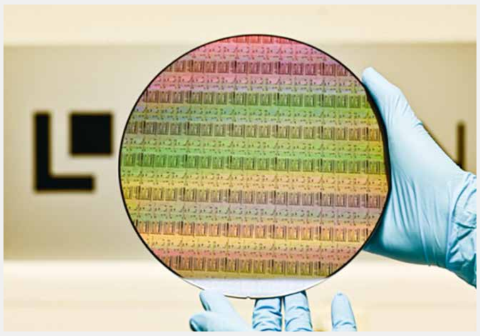


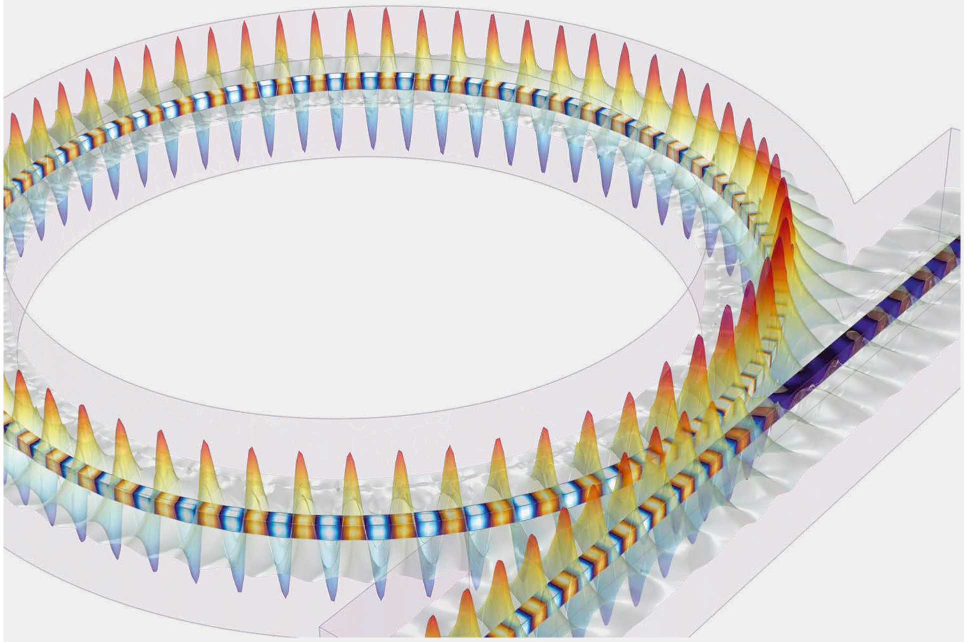
*Figure 3: Wafer level testing of a 200mm wafer with silicon nitride PICs.*

Another market where PICs are attracting a lot of attention, especially for the scaling potential, is quantum sensing, communication and computing. For quantum sensing a goal is to integrate field sensors and detectors on a PIC to optimize weight, size, and energy efficiency while increasing measurement sensitivity and precision by using quantum effects. On the other hand, different photonic quantum computer approaches need PICs as a photon source, the Qbit processing, and a detector. A PIC can simultaneously fulfill the quantum computing's need for small size, scaling to high volume and avoidance of movable parts for phase stability.

## SWISS PIC COMMUNITY

Switzerland's PIC ecosystem is ever growing. It hosts top-notch research groups at EPFL, ETHZ and PSI investigating chip-scale optical frequency combs, integrated electro-optic spectrometers based on metal-oxides, integrated quantum photonics for ion trapping, integrated plasmonics and microwave photonics. Private research at IBM Research Zurich is developing solutions for neuromorphic computing, including materials, photonic devices, and is investigating their interconnection and packaging possibilities. With LIGENTEC, Lumiphase, Polariton Technologies and Versics, there are multiple experts for design and manufacturing of PICs. Combined they offer silicon nitride (SiN), barium titanate (BaTiO3) on silicon photonics (SiPh), plasmonics on SiPh, and lithium niobate on insulator (LNOI) platforms. Deeplight, Enlightra, II-VI Laser Enterprise and Exalos provide laser modules and Vario-Optics is offering solutions for direct on-board coupling. Furthermore, CSEM is offering design, fabrication, test, and integration services, and the Swiss Photonics Integration Center, a newly established entity, is to provide precision assembly and packaging solutions for micro-optical systems and PICs.

# INNOVATING OPTICAL SYSTEMS MADE EASY – WITH MULTIPHYSICS SIMULATION



Optics and photonics are key enabling technologies of the 21st century, ensuring the speed of our communication and computing, the safety of our transport, improving our health, and making our energy landscape more sustainable. But what drives today's trailblazing inventions and innovations in optics and photonics?

The breathtaking progress of light-based technologies would be impossible without continuous improvement of experimental and manufacturing workflows and groundbreaking theoretical work. However, today's third pillar of innovation is optical modeling and simulation, empowering engineers and scientists to predict product behavior accurately and optimize designs before the first prototype is built. Testing and improving ideas virtually has fundamentally changed the way of engineering and dramatically reduced costs and time-to-market.

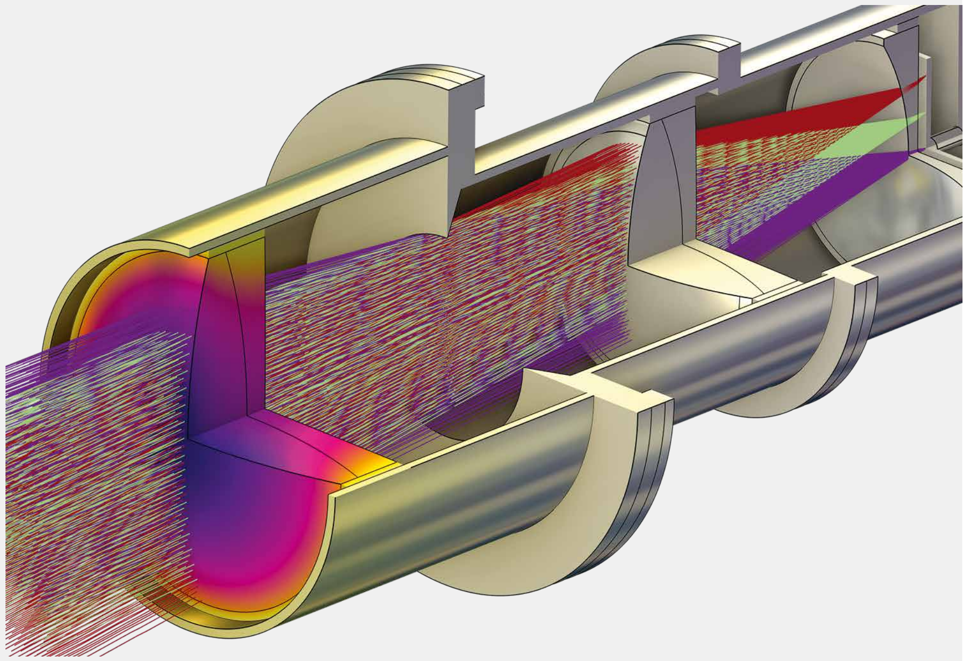
The integrated simulation platform COMSOL Multiphysics helps R&D engineers to design optical systems over a vast range of dimensions and power, ranging from single-photon technologies on the quantum scale to Megawatt concentrated solar power plants hundreds of meters in size.

Wave optics simulations ensure the reliable modulation of light in silicon photonics, faster transmission in optical fibers, and accurate sensor technologies based on plasmonic metamaterials.

Optical ray tracing is vital in designing lens systems in micro-cameras, LIDAR sensors, laser cavities, and spectrometers. Also, the interaction of high-power laser beams with materials for 3D printing, welding, or tumor ablation is optimized today with mathematical modeling.

The most exciting technologies today are based on the interaction of light with other physical fields. Emerging disciplines like optomechanics, electrooptics, photochemistry, optofluidics, optoacoustics, magnetooptics, photophoresis, quantum optics, and many more exploit coupled effects. On the other hand, there is a ubiquitous need to reduce unwanted couplings, for instance, distortions in optics caused by thermal or mechanical effects. Understanding, predicting, and optimizing couplings is key to success in creating increasingly complex optical systems in a fast-paced economy. Multiphysics simulation provides a powerful and efficient way to improve designs by coupling different physical field equations in one platform transparently in a user-friendly manner.

The three pillars of innovation would be impossible without human creativity. Therefore, we at COMSOL think of simulation from the perspective of collaborative work between simulation specialists, design engineers, lab technicians, and managers. Today, engineers can embed their mathematical models in dedicated GUIs and build simulation apps that can be operated by all stakeholders in the innovation process. Multiphysics simulation apps allow R&D teams to communicate technical information in a fundamentally new way and unleash synergies on all levels.



# THIN FILM LITHIUM NIOBATE ON INSULATOR PICS FOR LASERS: NEW HORIZONS

The combination of photonic integrated circuits (PIC) with dedicated lasers is providing powerful new options to generate, route and process light for applications in metrology, sensing, telecommunication or quantum computing. One of the most promising materials for integrated photonics is thin film lithium niobate on insulator (LNOI). It offers a variety of unique optical properties, including a high electro-optic (EO) coefficient, high intrinsic 2nd and 3rd order nonlinearities, and a large transparency window (350 to 5500 nm). For this reason, CSEM has been building expertise in design, simulation, fabrication and testing of PICs based on its in-house LNOI platform. Despite the proven advantages of the LNOI technology for many applications, as of today there is still no industrial foundry that can offer standardized production of LNOI PICs. CSEM is set to change that by establishing an open access PIC foundry for LNOI platform based on a well-tested process design kit (PDK) library. This endeavor has been strongly supported by several ongoing European and national projects to further develop both the wafer scale fabrication technology and the PDK. CSEM has been offering multi-project wafer (MPW) fabrication services to first selected external customers (Fig. 1).

At the same time, CSEM is well-known for its expertise in laser development, including ultra-stable CW lasers stabilized on optical reference cavities or atomic absorption lines, frequency comb solutions, high-power femtosecond lasers for industrial use, distance measurement, LiDAR and laser-based gas sensing. With respect to laser technology, LNOI PICs are game changers in femtosecond laser self-referencing (to obtain an optical frequency comb), because they can drastically reduce the laser pulse peak power (and hence average power) requirement, while, at the same time, requiring a much smaller volume than the traditional approach, based on nonlinear fibers and frequency doubling crystals. LNOI PICs will thus make optical frequency combs more affordable, compacter and less power hungry, which will significantly increase the range of potential commercial applications.

One example developed at CSEM is a carrier-envelope-offset frequency (fCEO) detection unit (Fig. 2) based on LNOI waveguide technology[ ]. A first prototype based on low-loss etching of a LNOI waveguide (<0.2 dB/cm),

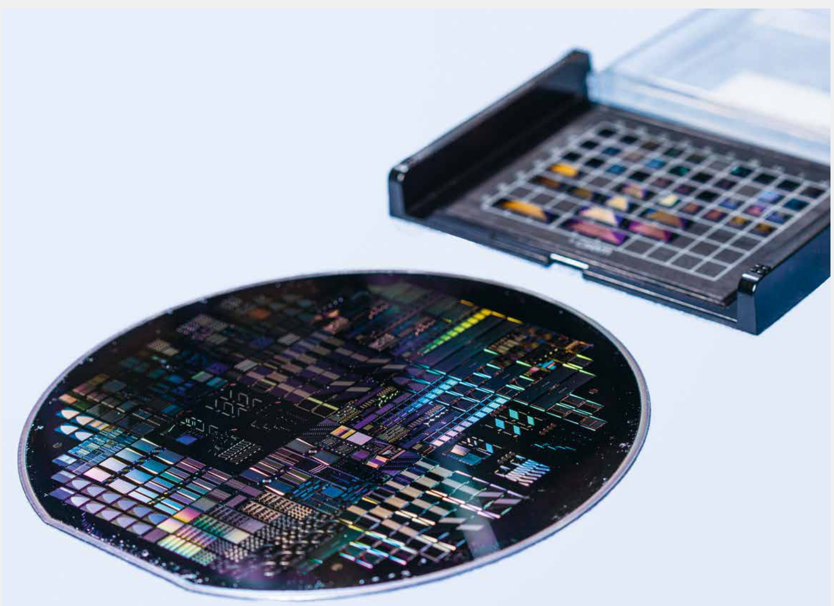


*Figure 1: Lithium Niobate on Insulator Multi-Project-Wafer (LNOI MPW) produced at CSEM*

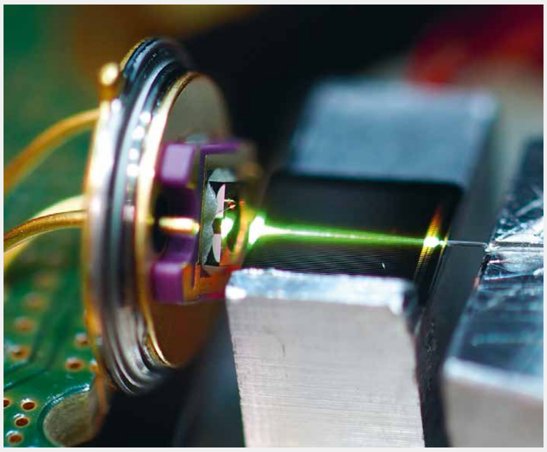


Figure 2: LNOI waveguide illuminated with 1.56um wavelength femtosecond pulses for fCEO detection

has proven high reliability under femtosecond pulse illumination[1] and efficient light coupling between the optical fiber and the LNOI waveguide (target of <1dB / facet with currently 4dB / facet). The 2nd and 3rd order nonlinearities of lithium niobate together with the small mode area in the waveguide lead to very efficient nonlinear interactions with the prospect to achieve fCEO detection with as low as 100 pJ pulse energy.

These promising results confirm that the rapidly maturing LNOI PIC technology, with its unique capabilities, offers a tremendous potential to impact many fields of application in the coming years.

*[1] Ewelina Obrzud et al.,"Stable and compact RF-to-optical link using lithium niobate on insulator waveguides", APL Photonics 6, 121303 (2021)*

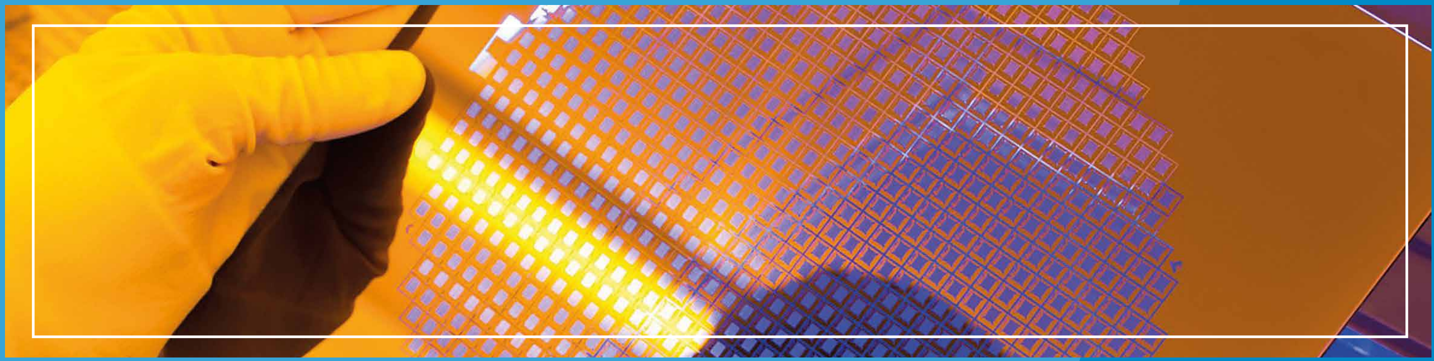
IMT

# FOUNDRY FOR MICROSTRUCTURES ON GLASS AND OPTICAL COATINGS

IMT is set up as a foundry for glass components for photonics and life sciences. At IMT the processes used for the manufacture of customized micro- and nanopatterned components and consumables employ equipment that are equally at home in the semiconductor industry. This in turn means that many of the manufacturing aspects so critical to the semiconductor industry; cleanliness, high volume and high yield in combination with cost-effective manufacture, singulation capability et cetera – are also key factors in ensuring the competitive advantage.

The unique skill-set comprises metallic and di-electric coatings, etching of metallic layers and coatings, glass etching, hole generation and glass bonding on the wafer level.

The customized components are used for a multitude of photonic applications, such as scanning and projection, reticles, light valves, beam splitters, micro-apertures, masks, encoder discs and scales, wave-guides with gratings, calibration plates, targets and mirrors. The same skill-set is used for flow cells for life sciences and genome sequencing.



# QUANTUM PHOTONICS IN SWITZERLAND

Switzerland's economy mainly relies on small and medium enterprises (SMEs) that often exploit niche markets with high-technology and quality products. Among the different quantum technology fields, such markets seem especially well adapted to Quantum Sensing and Metrology (QSM), a field in which small to medium production volumes are typical. In fact, QSM is already exploited in Switzerland since decades with atomic clocks. In addition, Quantum Communication (QC) experienced a similar trajectory while more recent.

QSM and QC are based on exploiting quantum properties of nature, quantum phenomena or quantum states towards exquisitely sensitive measurements. In this context, laser and detection technologies as well as photonic technologies in general are key to make these instruments and systems a reality. Such products have already reached the market, like atomic clocks, magnetometers, quantum gravimeters, nanometre scale resolution magnetometers or secure communication.

An amazing Swiss success story of QSM is the atomic clock. In full adequation with Swiss ADN for precision, it goes back to the 1960s in Neuchâtel. Nowadays, the world leading atomic clock companies are still located in the Neuchâtel area, with Orolia Switzerland, Oscilloquartz, and T4Science. These companies, supported by dedicated R&D at the University and by CSEM, provide clocks and timing solutions for the European Galileo global navigation satellite system (GNSS) and other GNSSs, as well as for telecommunication, defence, and science.

More recently, the continued and sustained Swiss programs in world-class basic quantum research has led to successful and promising start-up companies, some of which already have or are on a good track to become world leading in their domain. The Geneva-based company ID Quantique has been pioneering the commercialisation of QC and it has become a world-leading supplier of quantum key distribution (QKD) systems, Quantum Random Number Generators (QRNGs), and single-photon detection solutions. More recently, entrepreneurs created companies like Qnami, Q-Zabre, LiGenTec, Menhir Photonics,

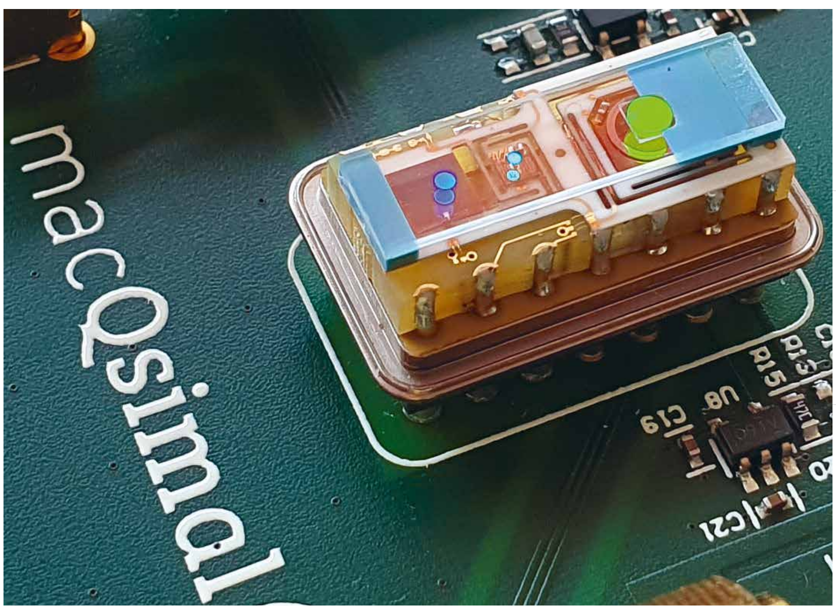



*Figure 1: CSEM patented physics package for a commercial miniature atomic clock.*

IRSweep, Enlightra, and Miraex all photonics related companies that are active in QSM, QC and key enabling technologies. Along the same lines, electronics companies like Zurich Instruments (recently acquired by Rohde & Schwarz) and Basel Precision Instruments are also part of this vivid ecosystem.

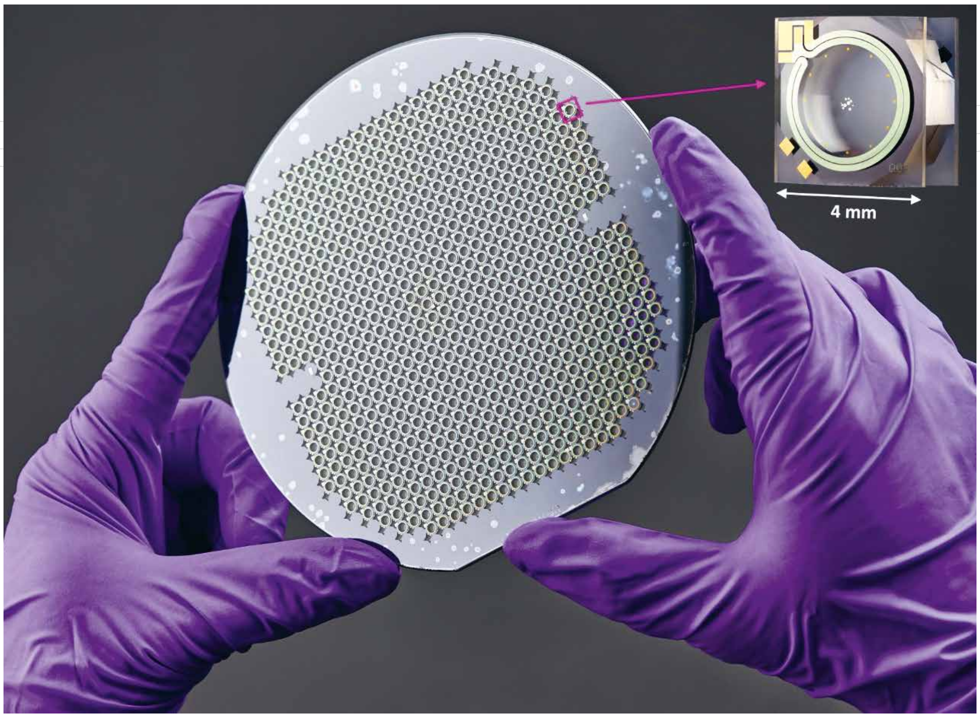



*Figure 2: Wafer-level fabrication of MEMS atomic vapor cell for commercial miniature atomic clocks.*

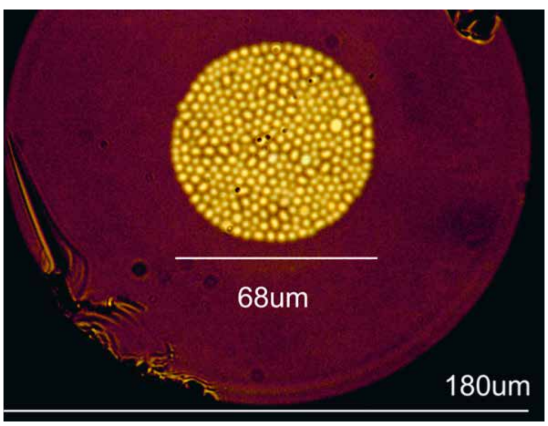
The Swiss quantum community is well distributed among research, development, innovation and industrialisation. The number of SMEs and start-ups is consequent for a small country like Switzerland and it is continuously increasing. Of course, upstream is also a world-wide recognized Swiss research ecosystem exploring numerous fields like for instance quantum computing with strong involvement of ETH, PSI, and IBM and excellent industrially driven initiatives such as Uptown Basel ('Quantum Basel' with the University of Basel, FHNW and IBM), as well as Quantum sensors and atomic clocks at CSEM.

# NEW OPTICAL FIBER DRAWING TOWER IN SWITZERLAND

Formerly hosted for 20 years in the „underground" of the Building of Exact Sciences of the University of Bern the optical fiber drawing tower has found its new location inside the SIPBB, in proximity of the railway station Biel/Bienne. It is jointly operated in a „shared cost - shared benefit" model by the University of Bern, the Switzerland Innovation Park Biel/Bienne SIPBB, the Institute for Applied Laser, Photonics and Surface Technologies ALPS of the Bern University of Applied Sciences BFH.

Additionally to being relocated, the drawing tower has been upgraded and expanded. A state of the art automation allows now to draw silica based optical fibers with higher reliability and precision than was possible before.

The drawing tower is equipped with a high temperature furnace that can be operated at temperatures well above 2000°C and is suited to draw straightforward silica fibers as well as fibers with transparent ceramic cores, such as high alumina aluminosilicate fibers for extreme temperature applications via the molten core technique.




*Fiber with 358 single mode cores of 2µm diameter each for high power top hat laser beam shaping. In medical applications this allows for laser treatment with small heat affected zone (under development).*

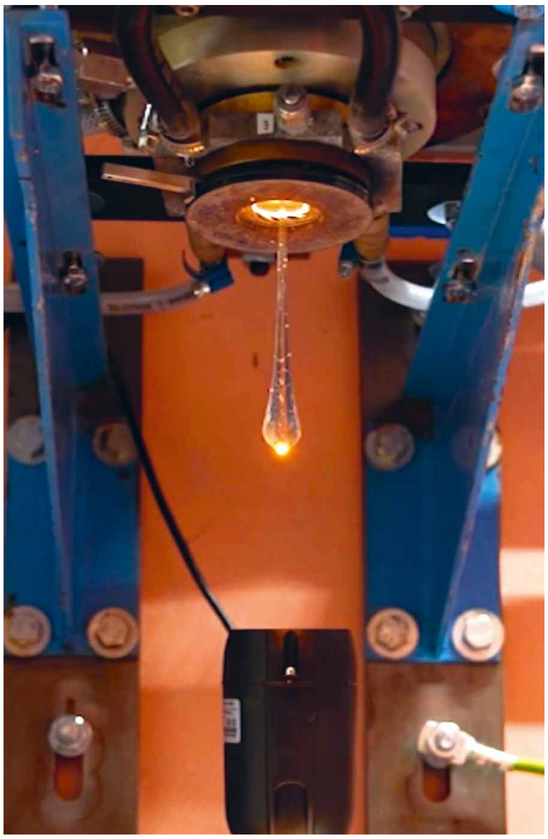
The techniques for preform production developped by BFH and IAP are well suited for the production of all sort of specialty fibers such as highly rare earth doped fibers as well as multiple rare earth doped fibers for fiber sensors or fiber amplifiers.

At present the drawing tower is being added features for precise pressure control in order to be able to draw hollow core fibers, e.g. for the delivery of ultrashort laser pulses and for diagnostics.

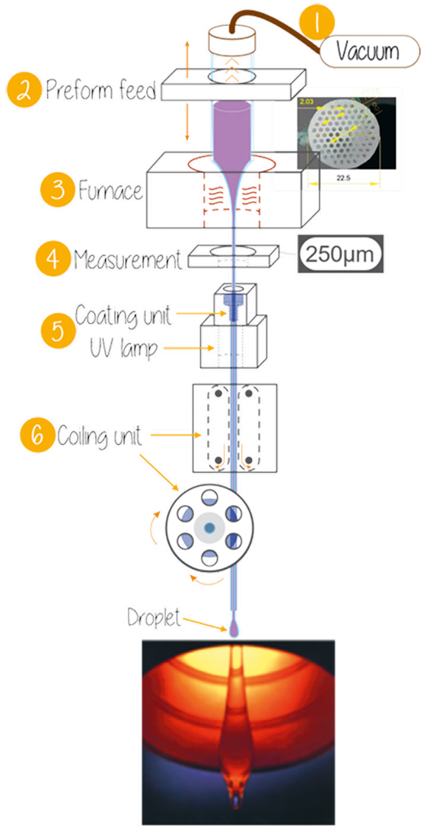
For the Swiss photonics community such a drawing tower offers unique possibilities: in the frame of collaborative research projects or product developments in their precompetitive stage it is possible to ideate and test fiber based photonics devices. With their in-house preform production techniques the three partners can offer a rapid preform and fiber prototyping technique that allows to obtain fibers with specific functionality in days rather than in months.

A significant part of the activities in the new drawing tower are devoted to student education at university level. Various research projects are already being executed that allow students to participate in real worls research at master as well as doctoral level.

The BFH-IAP-SIPBB drawing tower is part of the Swissphotonics National Fiber Laboratory cluster ( https://www.swissphotonics.net/clusters/guide ). Its activities are supported by Swissphotonics as well as by the NTN Innovation Booster Photonics.



Optical fiber droplet as it comes out of the furnace at 2000°C.




Optical fiber drawing tower: schematic representation.

https://youtu.be/ihRaqI0N3uw
For more information contact Prof. Dr. Valerio Romano
valerio.romano@bfh.ch or Dr. soenke.pilz@bfh.ch

SWITZERLAND INNOVATION PARK INNOVAARE

# THE SWISS PHOTONICS INTEGRATION CENTER

With the ever-increasing demand of photonic systems in existing and future markets including optical communications, sensing, quantum computing, autonomous driving, AI, AR/VR, medical, and many others, the complexity of photonic packaging is also increasing. Common challenges for Swiss industry, especially start-ups and SMEs include assembly & packaging, testing and qualification and therefore support in these areas is crucial.

The newly established Swiss Photonics Integration Center (Swiss PIC) addresses these needs by providing precision assembly and packaging solutions for photonics systems. The complete packaging offering - including optical, electrical, thermal and mechanical technology - ensures a controlled interfacing of photonic systems with the environment. Building up on a long history of precision engineering in Switzerland, the photonics packaging center offers highest standards in terms of quality and precision. It provides customers with packaging services covering prototyping as well as series production. The center will invest in qualified industrialized processes, high-tech machinery, and operate a qualified piloting and production line over time in Park Innovare.

The Swiss Photonics Integration Center strives for world-wide excellence to address the needs of the Swiss photonics industry and providing external packaging support by (Fig.1)

- Bringing together the required expertise will improve competitiveness of Swiss industry, especially the many device start-ups and SMEs whose market access can be multiplied with devices packaged for ease of use.
- Developing new packaging expertise to penetrate emerging areas, such as cryogenic packaging technology for quantum and space applications.
- Offering high manufacturing readiness levels and supporting technology transfer to industry.

The centers mission is to be the go-to partner for photonics packaging associated services in Switzerland and beyond:

- feasibility studies
- package design support (thermal, RF, etc.)
- environmental testing and qualification
- development and testing of new packaging technologies
- rapid prototyping to small-volume manufacturing
- transfer to in-house or contract manufacturers.

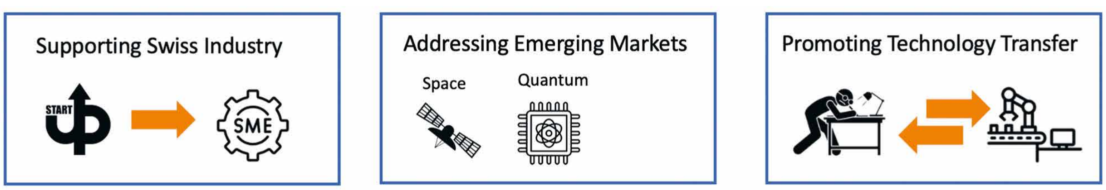



*Fig.1: Approach of the Swiss Photonics Integration Center (Swiss PIC)*

The Swiss Photonics Integration Center focuses on technology transfer, process industrialization and services for precision assembly (Fig.2) and encapsulation solutions for photonics systems (Fig.3). This ensures a controlled interfacing of photonic systems with the environment. Initially, the center focuses on the following photonic systems:

- Photonics Integrated Circuits
- Quantum Photonics Packaging
- Micro-Optical Hybrid Photonic Systems

Packages are offered as hermetic, semi-hermetic or self-hermetic solutions. As a logic extension of its services, the center will grow its offering depending on the market needs and aims for reliability assessment (Fig.4) and failure analysis services. In particular it will provide fiber-based solutions to the quantum-hub, which relies on optical readout for its quantum computers.

The center encourages partnerships within Switzerland, Europe and beyond.

*The Swiss Photonics Integration Center (Swiss PIC) is a member of the Advanced Manufacturing Technology Transfer Centers (AM-TTC) Alliance and a research institution of national importance. The center is funded by the ETH Board as well as by federal funds according to Art. 15 FIFG.*

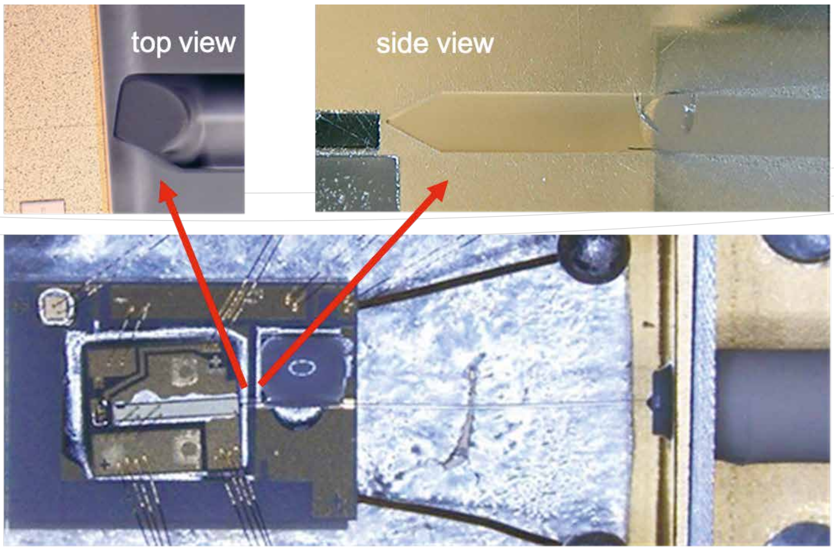



*Fig.2 State-of-the-art laser diode fiber pig tailing using adhesive bonding*

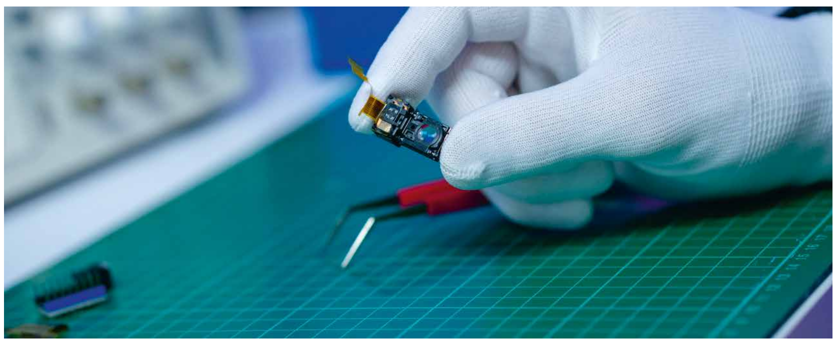


*Fig 3 The miniaturized imaging sensor assembly combines photonics and electronics in very tiny and lightweight configuration*

*Fig.4 Electrical and optical PIC testing to prepare packaging*

# WE SAY THANK YOU

We would like to thank all our partners who have made this brochure possible. We value your trust, support and engagement for the Swiss Photonics community.

enlightra

EXALOS
The bright light source company

FEMTOPRINT

GMP

LIGENTEC

lentiltec gmbh

Menhir Photonics

mesomatic fiberoptics

PROSPECTIVE

SÜSS MicroOptics

TRUMPF

## WHERE WE ARE

**SWISSPHOTONICS**

Sihleggstrasse 23
CH-8832 Wollerau
info@swissphotonics.net

WWW.SWISSPHOTONICS.NET

SWISS PHOTONICS