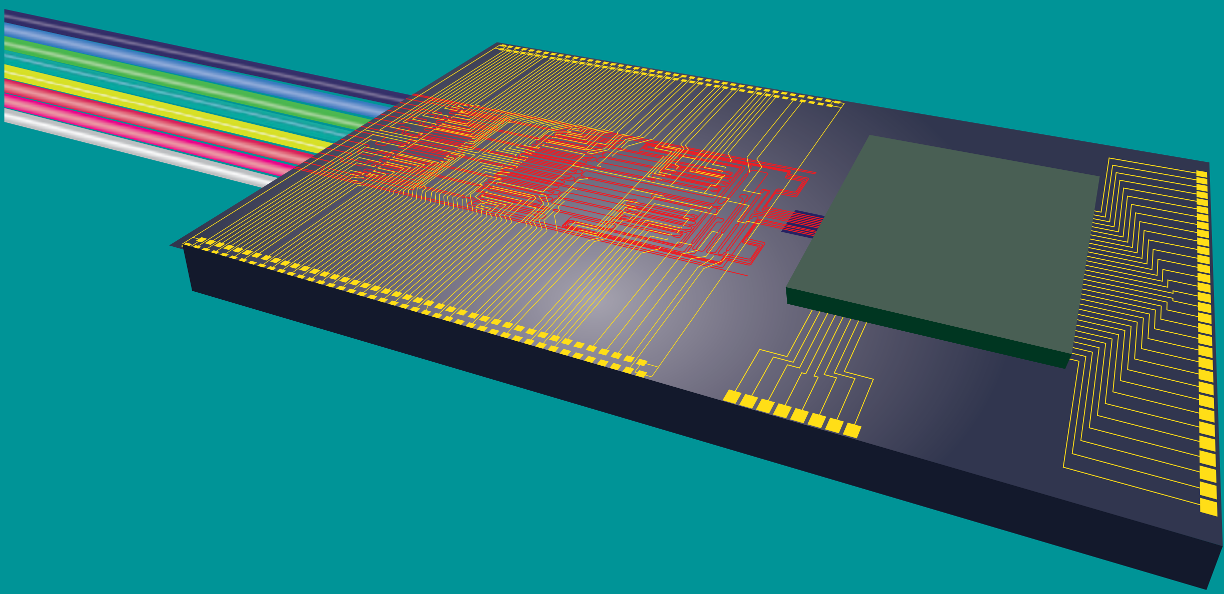
# FLEXIT

## The high-volume production line for Integrated Photonics



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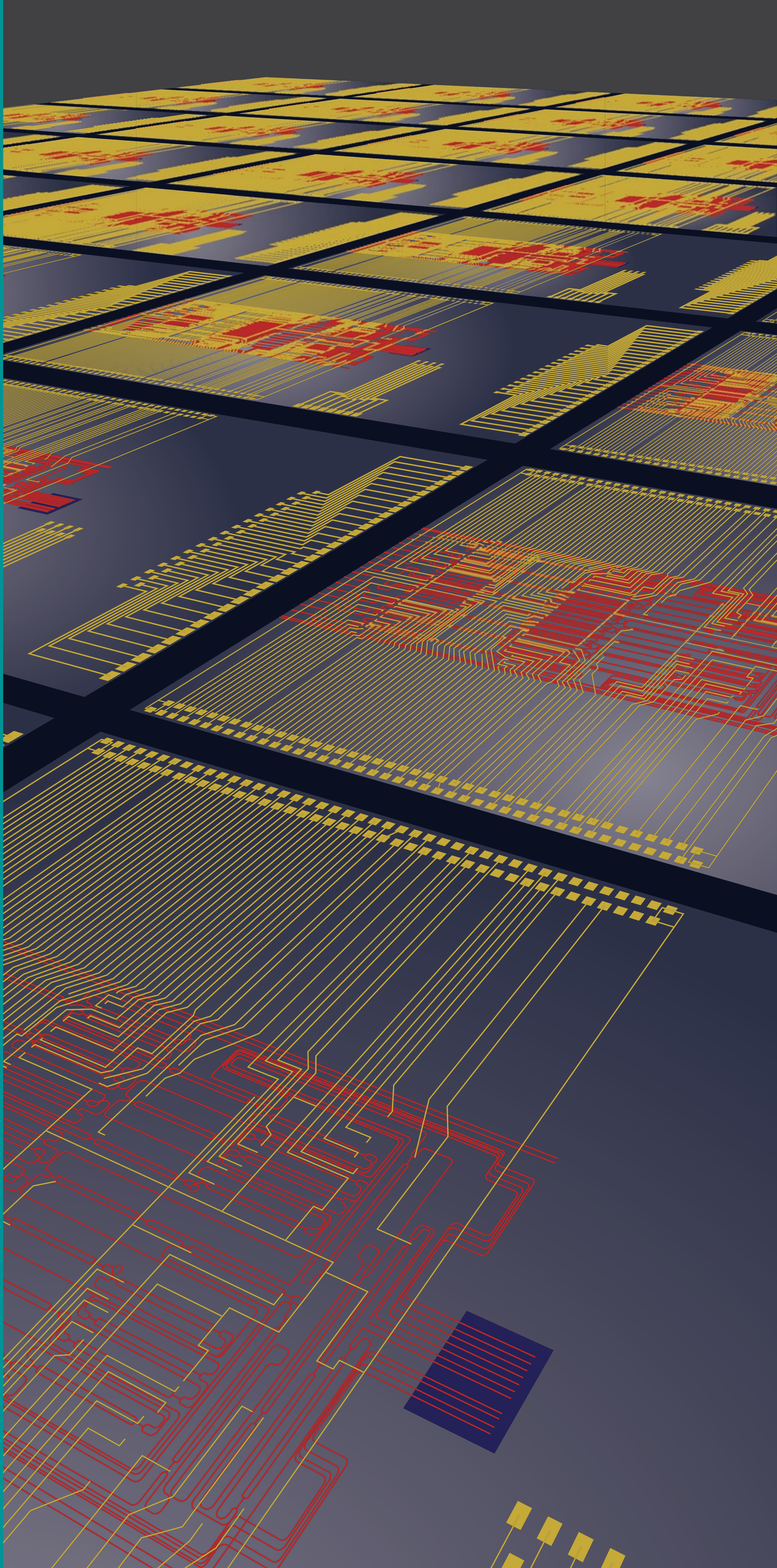


# The FLEXIT project: uniting the Netherlands' key photonics players

**Photonic integrated circuits (PICs) play an essential role in finding and developing solutions to many of the world's critical problems, such as reducing energy consumption, improving healthcare, fighting food waste and meeting our continuous hunger for information. However, a generic solution for the assembly and packaging of photonic chips does not currently exist. The FLEXIT project, which runs from January 2022 to December 2023, therefore sees an opportunity to unite high-tech companies in the Netherlands and push forward this highly promising domain.**

## A long history in semiconductors

Photonics concerns the generation, transport and detection of light waves and light particles; integrated photonics therefore refers to the miniaturisation and integration of photonics into chips. Photonic solutions address the growing need for fast, reliable communication, sensing and the digitisation of industry, but their success is contingent on the availability of efficient, advanced and flexible means of manufacturing. The Netherlands, with its long history in semiconductors, can provide this by bringing together key players within the FLEXIT project.

## The high-volume production line for integrated photonics

FLEXIT will enable this efficiency and flexibility through the further development of the FLEXIT method to process photonic chips at an industrial level. The project will also optimise all production processes in the supply chain using a design tool for product development and mapping of the full digital chain. Ultimately, two demo products will be selected to test the supply chain according to a new FLEXIT product standard for mass production, which will increase manufacturing yield, cut costs and ensure delivery reliability for the foreseeable future.

## An unmined market for the Netherlands and beyond

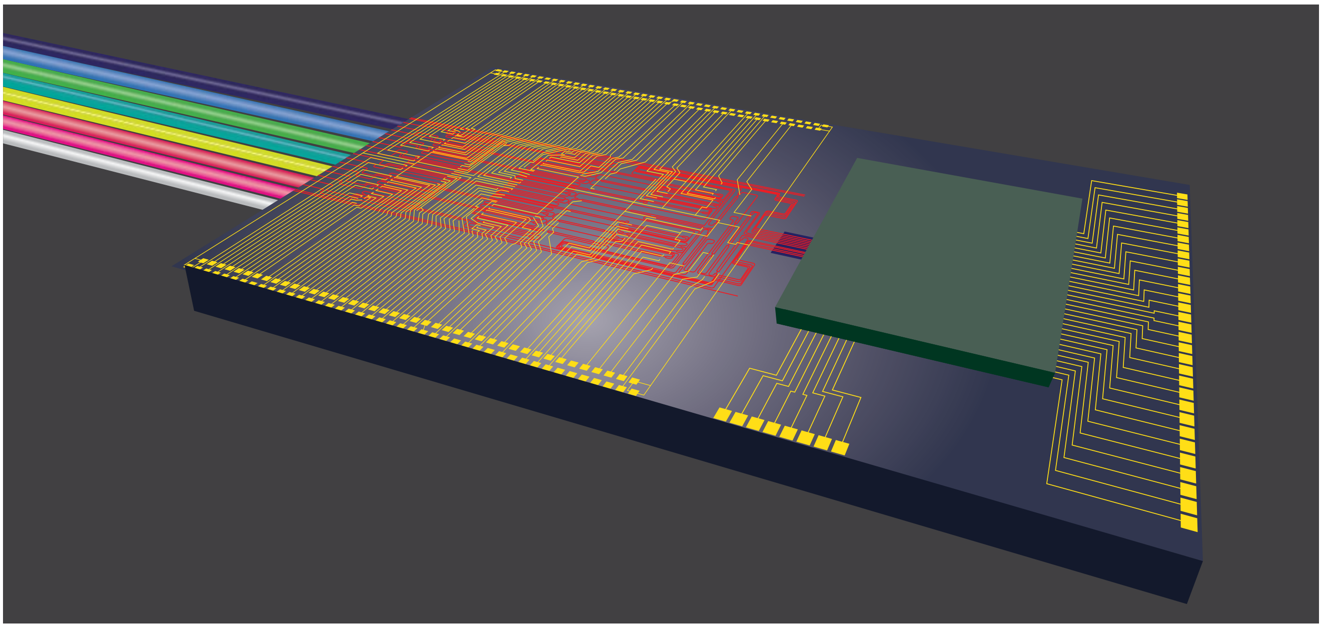
FLEXIT'S technology has never been realised elsewhere and the consortium considers this the missing link in the cost-effective integration and packaging of microelectronic photonic modules. Reducing the costs of assembly with the use of a combined flexible assembly technique and product self-alignment will considerably reduce the end-product cost price, resulting in faster adoption by the market. The possible benefits for society are considerable: Photonics21 estimates that over 11% of the European Union's target on $CO_2$ reduction can be achieved through photonics.

As FLEXIT's partners know one another well and cover the entire value chain of PIC production – from knowledge and ideas to photonic applications – the project processes have been seamlessly connected to create a full supply chain for the mass production of photonic components. The project scope also makes it possible for these developments to find their way to Dutch SMEs. By offering Dutch high-tech companies the possibility to claim this new, unmined market, FLEXIT can thus enable the Netherlands to become the international production centre for high-volume photonic manufacturing equipment and fulfil an enormous global demand.

The FLEXIT project is made possible with support from the European Regional Development Fund, funded as part of the Union's response to the COVID-19 pandemic.

## Why photonics?

Photonics provides the solution to societal challenges in climate, energy, health, safety, communication and mobility. Photons possess a high degree of effectiveness and precision and are the driving force behind many physical processes. In healthcare, for example, sensors in minimally invasive instruments and higher-quality video imaging in robot-assisted surgeries can ensure safer, more effective and more precise operations. In agriculture, work is underway on analytical equipment that uses spectrometry to ensure food safety and increase crop yields. And in the mobility sector, photonic sensors enable communication, monitoring, alerting and visibility in self-driving cars. The FLEXIT ecosystem is contributing to the integration of photonic applications in order to elevate them to the higher TRL levels needed to realise a direct impact on these domains and more.



## Several sorts of sustainability

In a project like FLEXIT, it is also essential to consider sustainability throughout the entire chain of production – and this is about more than just waste. Collaboration between different parties in the consortium has resulted in knowledge exchanges on how to use alternative raw materials for circular production and on how to reshape processes to become carbon neutral. In addition to the environmental benefits, this has allowed the partners to become more efficient in terms of time and finances.

## The technological benefits

From a technological perspective, FLEXIT focuses on an assembly process to interconnect indium phosphide (InP) PICs using a novel self-aligning concept. Optical self-alignment is achieved through an ingenious mechanical self-aligning attachment that uses flexible fingers made from silicon nitride (SiN) TriPleX® waveguide technology and matching facets in the opposing InP PIC. These InP PICs include functionalities for laser generation, amplification, control and detection, making them well-suited to communication and sensing applications. FLEXIT's technology is particularly revolutionary when applications require multiple optical connections. The following benefits have been observed when implementing it:

1. Robust passive alignment with +/- 2 um placement tolerant replaces time consuming submicron active alignment.
2. Relatively easy scalability regarding the number of optical inputs/outputs from chip to chip and from chip to optical fibres, including ample process-related margins.
3. Industrial-scale processing on the wafer level through precisely adjusted flip-chip technology.
4. Optimal photonic system designs through the selection of the InP/SiN platform for each component.
5. Integration into the building block philosophy and implementation in process and application design kits.

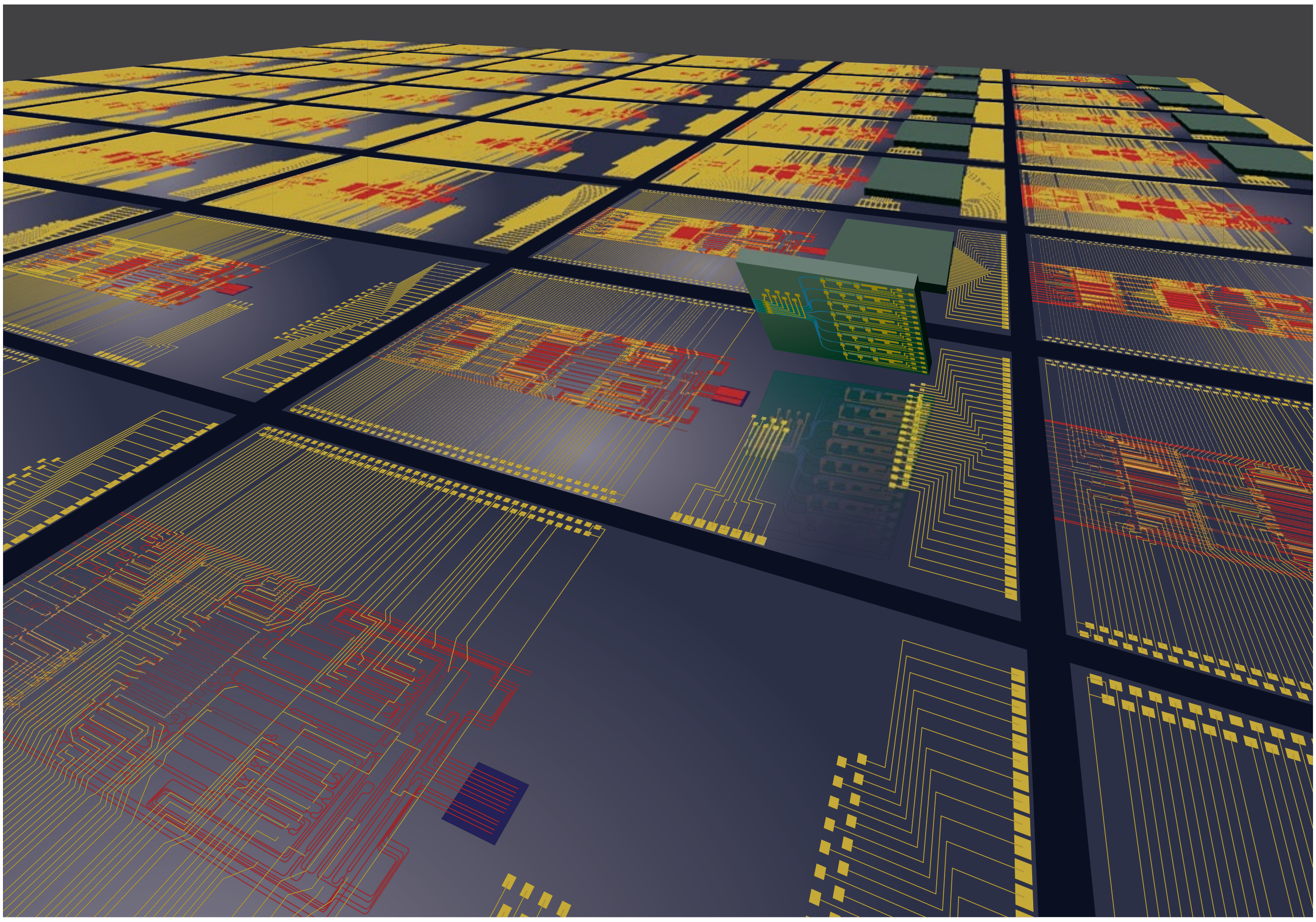
6. Connection with pre-aligned fibre arrays by leveraging the excellent properties of TriPleX® for spot size converter integration, which is essential for low-loss coupling with optical fibres.
7. The possibility to further integrate PICs and ICs into a single electro-photonic module.

By incorporating this into existing technologies for a straightforward connection of fibreoptic arrays to TriPleX® chips, FLEXIT provides a seamless link between cost-effective PIC-based system integration and packaging.

## A resilient economy

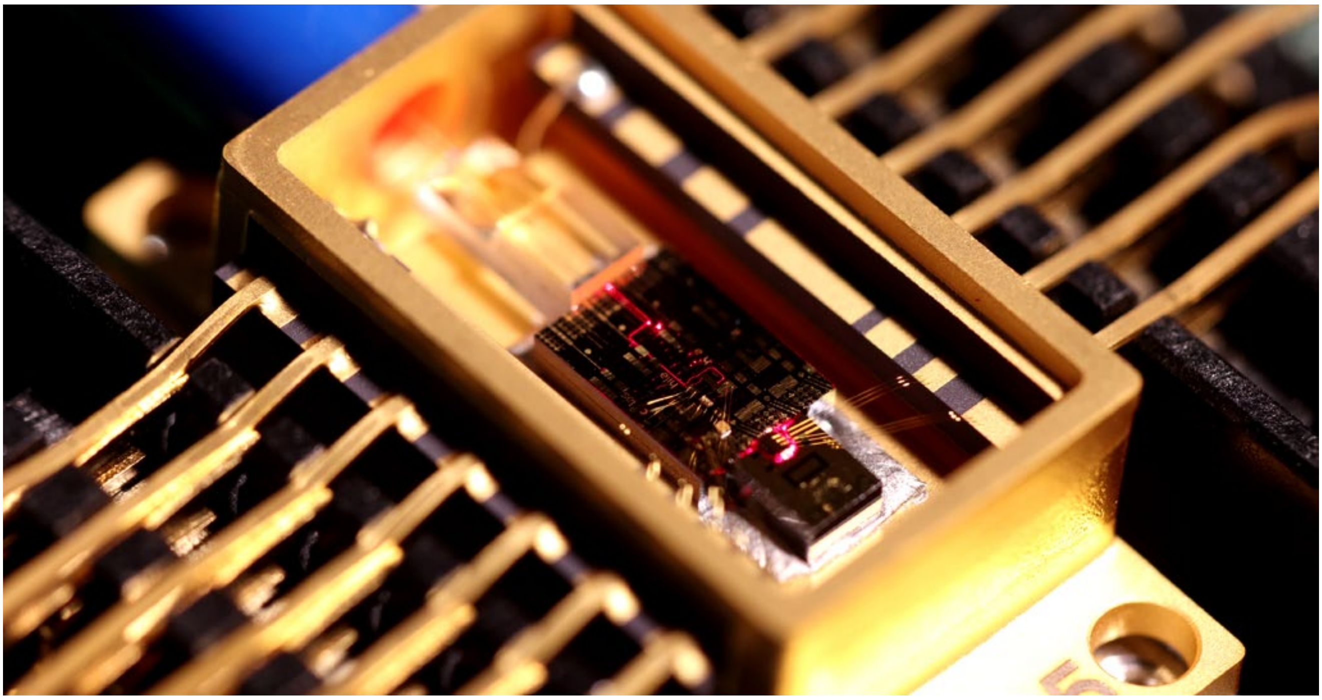
This technology is part of the smart industry domain. The resulting tools, like FLEXIT DesignTool and FLEXIT FactoryTool, allow data to be generated and analysed in order to enrich the entire supply chain with more digital technologies. For parties that take up these tools, this offers not just a strong productivity boost but also far greater flexibility – the 'flex' in FLEXIT. To enhance this even further, the project is creating interfaces to automatically share this data throughout the entire production network.

In the past, the semiconductor market experienced substantial growth following a period of collaboration to build up its potential. If a similar start is made in integrated photonics, we can expect the technology to become a driving force behind economic growth, including the creation of new markets, the enhancement of numerous existing products and the generation of high-quality jobs in everything from healthcare to telecommunications. This includes roles for those with medium to lower levels of education, particularly in production. Examples could include manufacturing, assembling and packaging PICs into complete systems, designing PICs for new applications or (re)designing processes in sectors that utilise PICs. A diverse range of employees with different levels of expertise will be required to develop and manufacture the products and services and build and operate the equipment that integrated photonics will enable. In this way, FLEXIT aims to make a long-term contribution to a resilient economy in the Netherlands.



# Chilas: a laser-focused role for hybrid photonic devices in the FLEXIT project

**The Chilas laser is one of the simplest hybrid photonic devices around, consisting of only two photonic integrated chips (PICs). Together, these offer unique characteristics: a wavelength agility with ultra-narrow linewidths of below 1 kHz, providing a very pure colour for a wide range of high-tech applications. Within the FLEXIT project, Chilas aims to adapt these two chips for compatibility with flip-chip assembly methods that rely on passive placing accuracies of ~1 μm for the scalable production of hybrid photonic devices.**



## Towards the future

On a technical level, Chilas develops and supplies high-end semiconductor external cavity tunable lasers with ultra-narrow linewidths, which can be tuned over the C-band to cover a wavelength range larger than 100 nm with a linewidth of less than 1 kHz, as well as high output power and low noise. This laser is temperature-stabilised and comes in a 14-pin butterfly package. The external cavity laser (ECL) is constructed via hybrid integration of both an indium phosphide (InP) gain section and a silicon nitride ($Si_3N_4$) wavelength selective feedback PIC. The InP gain section provides the high-power output (>30 mW with 100 mW under development) over a wide wavelength range, whereas the $Si_3N_4$ PIC provides the low loss configurable feedback to the gain section.

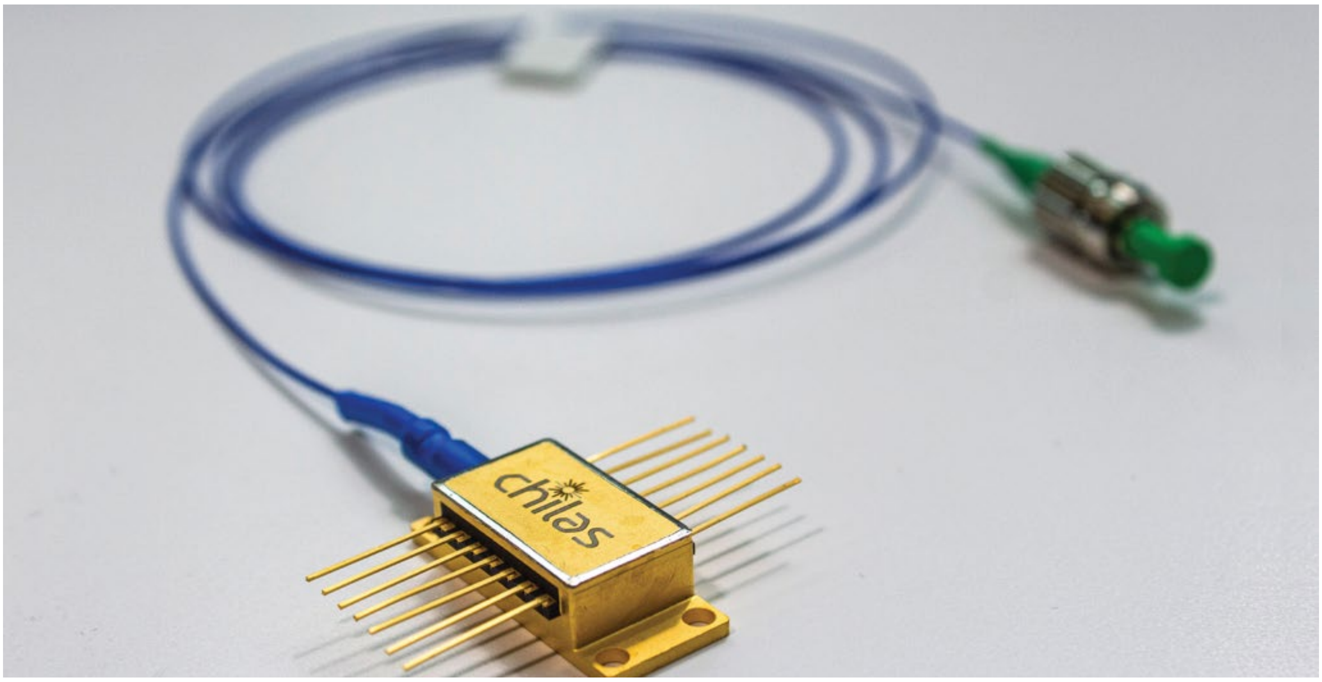
By harvesting the best of the InP and $Si_3N_4$, worlds, Chilas' technology serves as the workhorse for a large variety of applications. In Optical Coherence Tomography (OCT), for instance, resolutions can be boosted to microscopic levels via the 100-nm bandwidth, while the ultra-narrow linewidth is essential to applications like quantum computing, quantum sensing and quantum key distribution. The compact, robust character of the laser also allows the sensitivity of metrology applications to be increased in harsh environments.

Finally, the ultra-narrow linewidth (over 1 kHz), low relative intensity noise (greater than -155 dB/Hz) and low phase noise meet novel standards for small channel spacing and enable advanced modulation methods like PAM, PSK and QAM – the future of transceivers.

## Fruitful collaboration

For Chilas, the current state-of-the-art assembly method involves chip-to-chip interfacing via end-face coupling. In this process, the two chips are diced, polished and glued together using active alignment, providing the required sub-100 nm placing accuracy. This assembly method enables mid-sized volume production to the tune of 1000 PICs per year. In FLEXIT, flip-chip processing should allow for an expansion of the functionality of the hybrid photonic devices. Through the placement of gain sections, modulators and detectors, the project will pave the way for the development of devices with high optical power, fast modulation and on-chip detection.

Within the project, Chilas fulfils the role of end-user and, as a small team, most of its members are involved: Fathema Farjana, Wilson Tsong, Ian van den Vlekkert, Sami Musa and Dimitri Geskus are all enjoying fruitful collaboration with the other ten partners. In this ecosystem, which brings together key players from across the Netherlands, PHIX Photonic Assembly has created a solid marriage between SMART Photonics' semiconductor InP PICs and LioniX International's $Si_3N_4$ PICs.

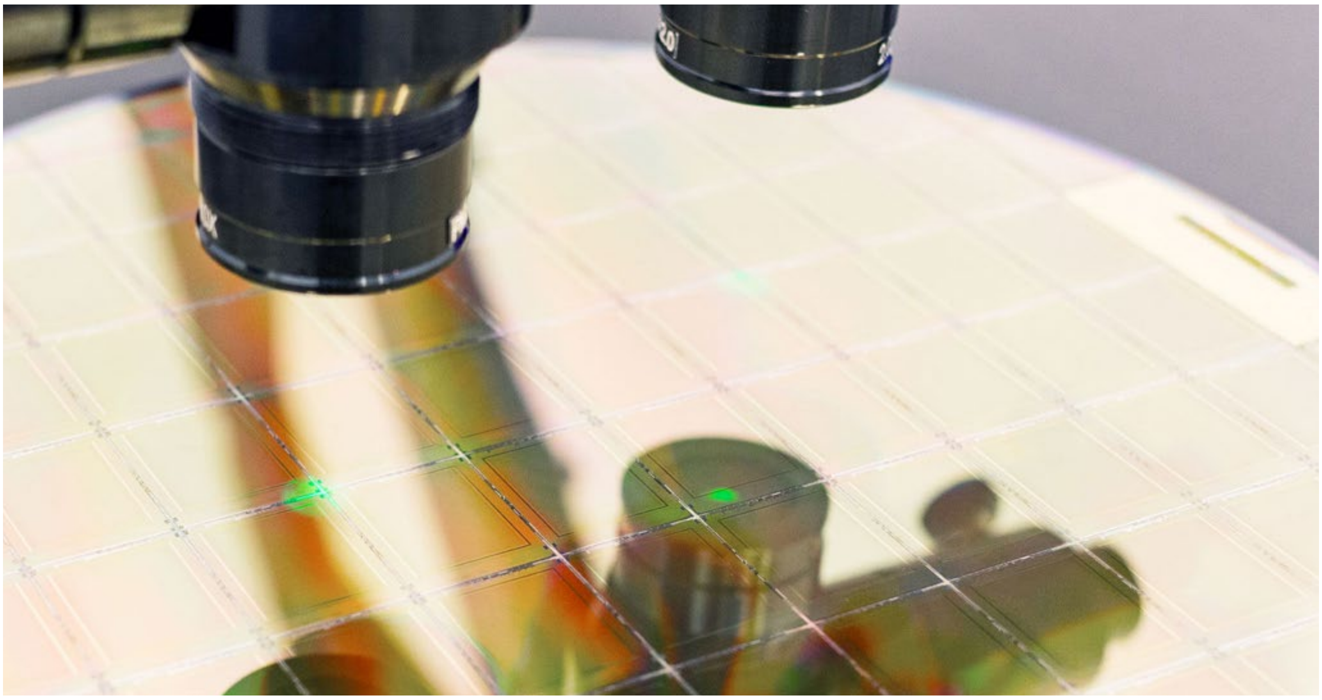



## A strong Dutch stake

Already, a new generation of chips have been designed and are being produced, while wafer-scale probing is under development and device performance traceability is being implemented. In the short term, the aim is for the first demo devices to give light. In the longer term, the goal is to develop volume-ready processes for the production of photonic devices. This includes wafer-scale characterisation tools developed by Salland Engineering and the tracing of characterisation data from the component level up to the product level, which is being developed by WorkFloor. Such results and aspirations perfectly illustrate how all partners – Chilas included – are driving FLEXIT's efforts to establish a strong Dutch stake in the new and as-of-yet unmined market in assembly and integration machinery for volume production of photonic systems.

# IMS delivers critical equipment in the FLEXIT supply chain

**Over the past decades, Integrated Mechanization Solutions, better known as IMS, has become an expert in handling production systems and processing delicate components with high accuracy. This expertise and experience have brought them to a leading role in the development of new photonics metrology equipment that is much needed in this industry – as well as in the FLEXIT project.**



## Cross-project connections

Production systems for precision optics and photonics rely on advanced metrology solutions to secure consistent performance at high accuracy and provide essential production data for quality control and continuous improvement to its users. No high-accuracy product is achieved without proper quality assurance and control; IMS' metrology equipment is therefore a must to guarantee that FLEXIT's technology is produced properly at a wafer level and is ready for implementation in back-end assembly and packaging.

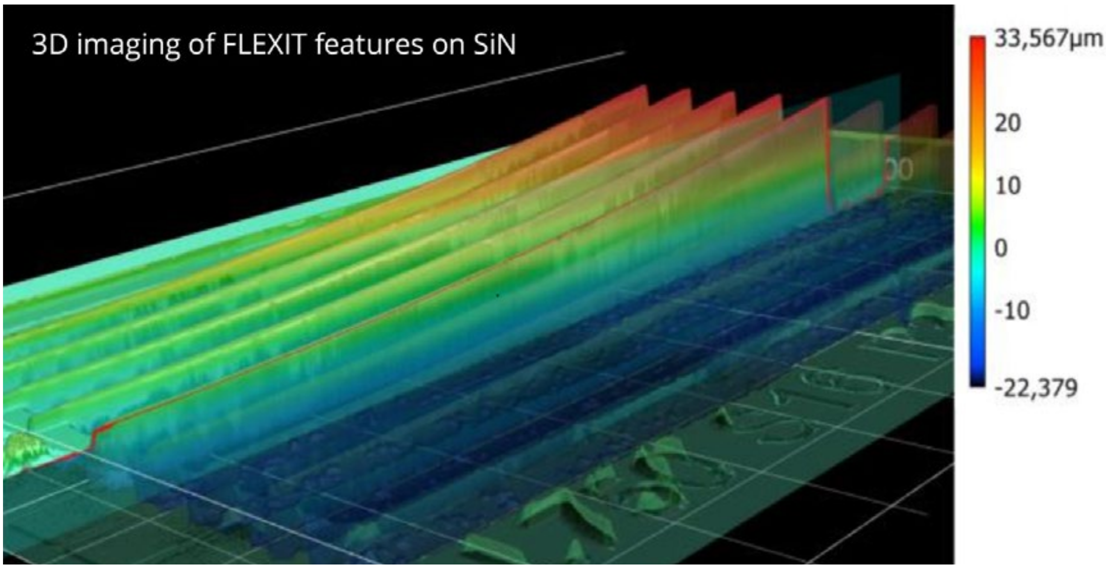
IMS is also contributing extensive experience in the field of high-volume production and test processes: the scaling up of (photonics) production requires not only a thorough understanding of the combination of fast and accurate part handling in specific environmental conditions but also sound, reproducible metrology procedures, a lot of data processing and excellent user interfacing for operators controlling the equipment.

Alongside FLEXIT, IMS is leading a consortium developing photonic wafer visual inspection equipment and photonic wafer level functional probing systems in the MEKOPP project (the Dutch abbreviation for 'Metrology Equipment for Critical Upscaling of PIC Production'). In 2023, the first launches of this metrology equipment will be announced. As part of this launch, the photonics wafer visual inspection system Helios will be tailored to the FLEXIT project as this presents a new application area. With the Helios system, the FLEXIT features on silicon nitride (SiN) created by LioniX International and on indium phosphide (InP) created by SMART Photonics can be inspected. This is a necessary and critical step to ensure proper front-end photonic integrated circuit (PIC) production, as well as the correct starting point for back-end integration of the components.

## Downstream and upstream

FLEXIT offers IMS several new dimensions for its photonics visual inspection systems. Firstly, this project is an excellent setting in which a complete supply chain/production chain demonstrates that close cooperation between partners involved in PIC production and integration will bring about more than just the sum of the individual companies. Every step in the process has consequences both downstream and upstream, which makes it necessary for each partner to understand how its contribution affects that of the other partners. The IMS team therefore includes hardware and software system architects, optics/photonics specialists and a variety of engineers and technicians to design, build and test the system, as well as a project manager to coordinate IMS' overall part of the project.

Secondly, the FLEXIT project is a new and specific application of the IMS photonics visual inspection system Helios. Exchanges of product and process information between the 11 partners in FLEXIT are necessary to make optimal use of Helios. The design of the first version of this system is now ready and IMS will build the system in the third quarter of 2023. Photonic wafers are being produced by LioniX and SMART Photonics with dies that are provided using FLEXIT technology and, in the final quarter of 2024, the Helios system will be put into action to inspect the FLEXIT features.




## A global ambition

Both within FLEXIT and outside of it, IMS develops its metrology equipment to meet the specific needs of the photonics industry. With an installed base of over 750 high-precision production systems worldwide, the company truly understands the intricacies involved in scaling up from low to high volume production and testing. The vast majority of these systems include optical and other types of metrology modules that are able to assess production process quality in an in-line and/or end-of-line manner.

IMS has a proven track record in designing, supplying and supporting robust and reliable equipment architectures with high value-added subsystems or modules, providing its customers with an excellent competitive advantage. These are the skills that IMS is bringing to FLEXIT and further developing within the project, feeding its ambition to become a leading provider of photonics production and test equipment.

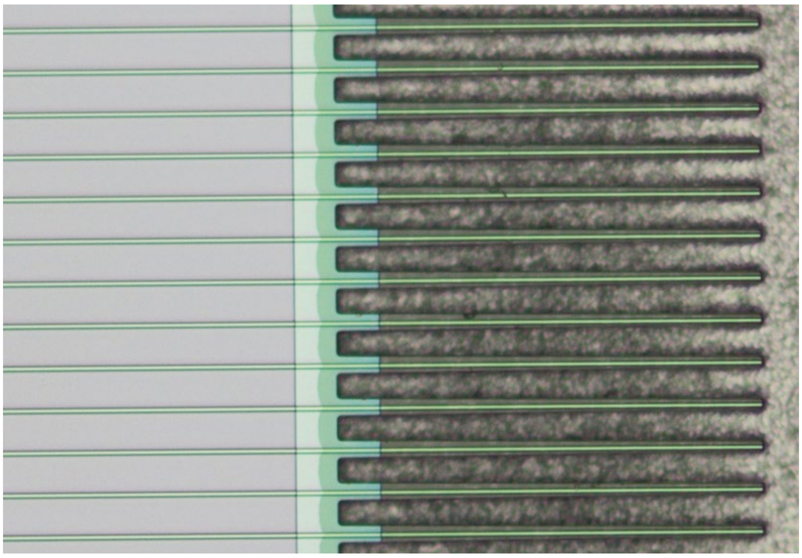
# LioniX International contributes decades of PIC/MEMS experience to FLEXIT

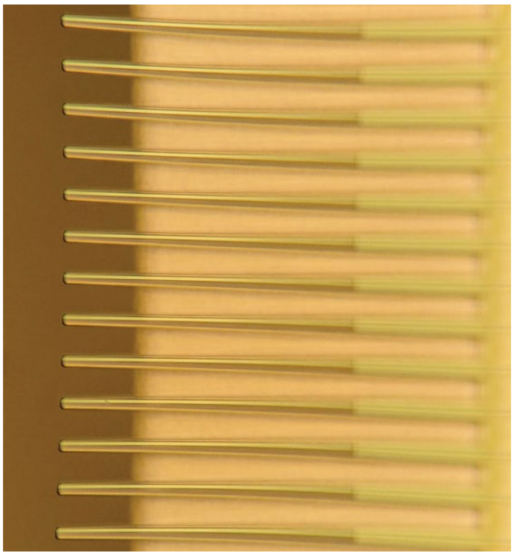
**Since 2001, LioniX International has been driving technological and commercial developments in their specialist fields of photonic integrated circuits (PICs) and micro-electromechanical systems (MEMS), ultimately becoming a leading provider of customised microsystem solutions globally. As a vertically integrated company, they work across all stages of the production process, from design to the delivery of a finished module. Their world-class fabrication facilities also allow them to scale production volumes as customer requirements grow. These are just some of the skills and assets that they are now applying to the FLEXIT project.**

## Communicative, cross-discipline collaboration

Besides the high-quality services that they provide, the strength of LioniX International lies in the creativity of their problem solving. By building multidisciplinary project teams together with customers and by asking the right questions at the right time, they deliver solutions that not only answer problems but also boost their customers' business. This makes them an ideal partner for FLEXIT, which brings together 11 organisations that span the entire ecosystem of Dutch integrated photonics and requires a communicative, cross-discipline approach to collaboration.

Within this, LioniX International is providing $Si_3N_4$-based chips using their proprietary and patented TriPleX® platform in two use-cases: hybrid tunable lasers and 100 Gb/s transceivers. LioniX International has developed a robust method to fabricate flexible TriPleX® fingers in which the amount of out-of-plane bending can be accurately engineered by choosing the right finger length, stress pad geometry and shape. These flexible fingers are currently under fabrication in two runs in which they are being incorporated in tunable laser cavity designs in the C-band and transceivers in the O-band on behalf of project partners Chilas and VTEC respectively.

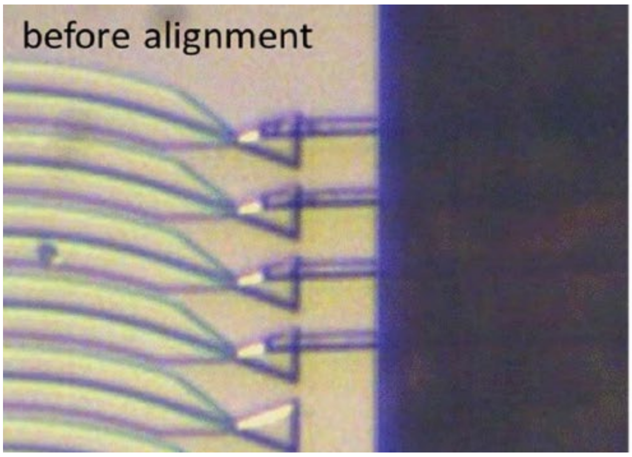


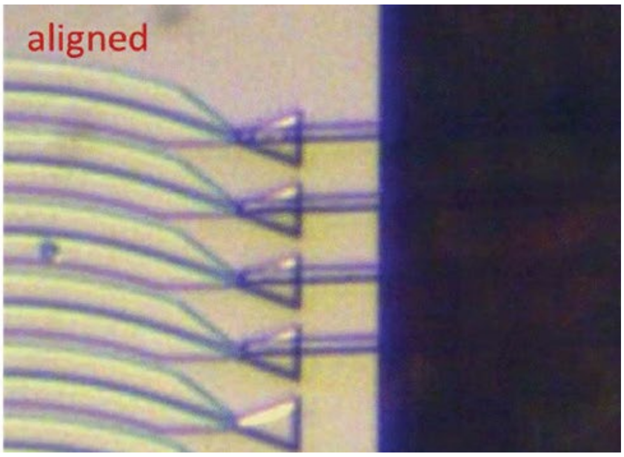


## Beyond the standard

In the FLEXIT project, facet structures are being provided by Smart Photonics as part of their indium phosphide (InP) integrated chips. These facets are special structures on the chip, comparable to a lock, that allow for direct on-wafer coupling to the light in the photonic chips and their output. Standard chips do not have a facet and access to the light and output is only possible after the complete fabrication of the wafer and upon the finalisation of the individual dies. To make the next step in low-cost wafer level testing and hybrid assembly, LioniX International has therefore developed a special etching procedure to generate flexible waveguide structures – 'waveguide fingers' comparable to a door key – that enable passive alignment to other technology platforms.

The focus of FLEXIT is on interfacing the TriPleX® waveguides to the active InP platform of Smart Photonics. LioniX International and Smart Photonics are therefore working in close collaboration to make sure that the flexible waveguides fit exactly into the etched 'locks' in the InP chips. This has proven the case thanks to FLEXIT's self-aligned assembly process, which has led to passive alignment.



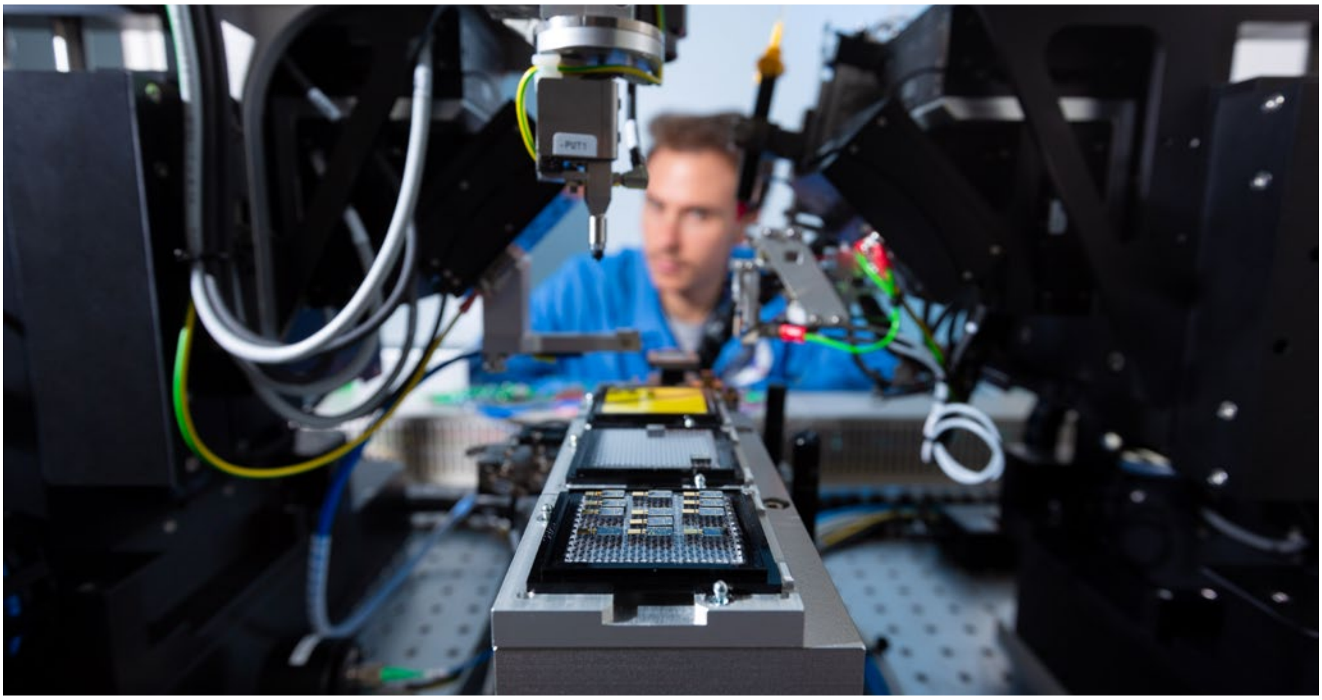

## The future of scalability

This improved assembly strategy, based on TriPleX® flexible fingers and InP pockets, is the primary advantage of the FLEXIT project as it strongly reduces time-consuming hybrid PIC assembly. Instead, fully automatic assembly is now possible using industrial pick and place equipment which is already available. And, with the process developments and wafer-level optical probing functionalities found within FLEXIT, LioniX International is able to increase assembly yield and lower their total assembly costs. This will further enhance the company's vertically integrated mindset and pave the way to the scalable hybrid integration of complementary PIC platforms.

To continue generating innovations in the future, LioniX International draws on its past: a proven track record in the field of integrated optics and MEMS processing going back more than 20 years. Having served hundreds of customers worldwide, LioniX International has experience in an endless list of applications and therefore understands what is needed for the near future when it comes to scalability. Aspects such as testing and assembly are vitally important to the entire supply chain and LioniX International provides a unique approach to each thanks to its vertical integration approach, playing a key role in securing the goals of the FLEXIT project.

# PHIX: expanding the boundaries of knowledge within the FLEXIT project

**Within FLEXIT's Dutch ecosystem for integrated photonics, PHIX leads the hybrid integration and assembly of PICs, providing scalable packaging solutions for a suite of applications to address various societal and technological challenges. Leveraging years of experience in product design, assembly development and equipment management in different industries, PHIX is contributing to FLEXIT by developing industrial processes for the high-speed, automated, robust and reliable assembly of modules based on InP and TriPleX PICs and their seamless integration with electronic ICs in scalable volumes. This will reduce production costs and accelerate the adoption of this new technology.**



## A long and complex process

Integrated photonics has emerged as the technology of the future. At the moment, there is no single material platform that can efficiently generate, guide, manipulate and detect light at a low cost while also being compatible with standard processes used in the semiconductor industry. Hybrid photonic packaging and the integration of photonic and electronic ICs is therefore necessary to satiate consumer demand. This activity is challenging for various reasons and can take up to 80% of a product's costs. For example, different material platforms have different optical, electrical, thermal and mechanical properties. Once they are assembled on the common substrate, each of these hybrid chip materials will react differently to moisture, mechanical and temperature stresses, particularly at the interface region between two chips, causing potential delamination. Meanwhile, the lack of standardisation makes it difficult for different modules and systems to be efficiently assembled to communicate together seamlessly in a package.

The commercial introduction of emerging technologies requires long and complex multi-layer product development, industrialisation and qualification cycles at all levels of the value chain, from initial product design, material sourcing, component-system-module manufacturing and testing to the marketing and delivery of new products to the market. Fortunately for FLEXIT, PHIX brings the wealth of experience in different industries needed to develop new assembly processes that will enable the complex hybrid integration of TriPleX® and

InP photonic integrated modules with electronic ICs in the same package. Their added value is anchored in packaging expertise and the development of automated, accurate and reliable assembly processes, including for the placement and fixation of modules, the implementation of a cooling system if necessary and the bridging of the gap between photonics and electronics ICs by making them compatible with the current manufacturing processes at PHIX.

## Promising performance

PHIX's photonics packaging solutions range from single manufacturing steps to complete joint development and manufacturing scale-up. They also possess state-of-the-art facilities, machines and assembly processes for pick-and-place complex hybrid integration of PIC-based modules, which are essential to the delivery of hybrid photonic modules within FLEXIT. Specialisation in optical coupling to fibre arrays and interfacing of direct current (DC) and radio frequency (RF) electrical signals also grants them a unique position within the photonics ecosystem, allowing them to seamlessly integrate photonic integrated modules and interface them with control electronics. This enables FLEXIT to cover the entire value chain of product manufacturing. PHIX's in-depth knowledge of photonics, front-end manufacturing processes, back-end manufacturing processes and chip-to-chip and fibre-to-chip coupling, as well as their ability to further contribute to the development of various applications beyond this project, represents a one-stop-shop for photonic assembly within FLEXIT – from design to volume manufacturing, perfectly tailored to customer needs.

Within the project, a selection of suitable demo products, system specification definitions and use cases have so far been created, including the product and chip design and interfacing electronics. Alternative design configurations have also been proposed as a back-up solution for the chip interface technology in order to minimise risks. PHIX is working closely with 11 members of the FLEXIT consortia – including VTEC, SMART Photonics, Workfloor, Chillas and LioniX – to provide packaging design guidelines and integration process flow that will be used in the FLEXIT manufacturing value chain. At the moment, PHIX is working on process development for the unique coupling technology developed in the FLEXIT project. Preliminary results have been obtained, revealing promising performance.

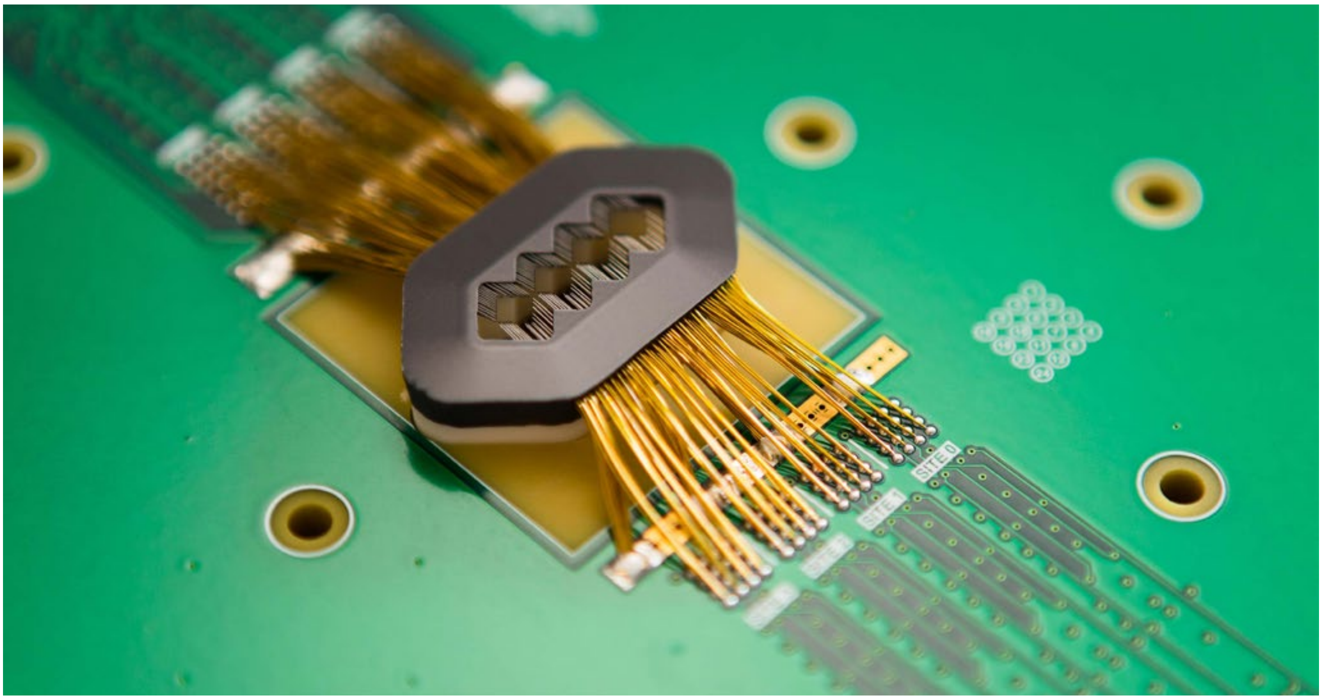
## The global forefront

Together with their partners, PHIX is expanding the boundaries of knowledge to improve the world. However, this would not be possible without an excellent team and a company culture that promotes knowledge sharing, equality, diversity and inclusion. The project is headed by Joost van Kerkhof (PHIX COO) and Milan Milosevic (PHIX R&I Manager) and is being executed by PHIX's engineering team with the help of the operations team. Marketing and communication specialist Gijs van Ouwerkerk is responsible for showcasing the success stories and disseminating the results from PHIX's side.

PHIX's ambition is to be a world-leading foundry for the assembly and packaging of advanced PICs with medium and high production volumes. Thanks to its unique position within FLEXIT, PHIX is strengthening its own position in the integrated photonics ecosystem, covering different application areas and emerging markets for photonics assembly. Through the results of this project, they expect to expand their product and service portfolio with the unique coupling technology which is being developed and industrialised. Furthermore, by combining the strengths of the partners within FLEXIT, PHIX is accelerating innovation and reducing time to market and production costs, thereby placing them, their partners and the Netherlands at the global forefront of photonics high-volume manufacturing in response to global challenges and the complex geo-political situation.

# Salland Engineering's test equipment development adds value to FLEXIT

**As a partner in the FLEXIT project, Salland Engineering contributes 30 years of experience in test solutions for the semiconductor industry, including test applications, instruments to fill the gaps in test needs (such as radio frequency, digital cards, analogue instruments and power supplies) and, more recently, software tooling focused on test data analysis, test execution and configuration management. Their work is made for engineers by engineers, with a strong focus on decreasing test and processing times to enable volume testing and reduce the costs of testing.**



## The test technology ecosystem

The organisation of a project like FLEXIT requires a great deal of coordination both externally and internally. Within Salland Engineering, participation is taking place from the Instrument and Software Tool Development group, headed by Erik Kloekke. Project leader Armando Bonilla Fernandez is coordinating the instrument and test setup development, which is being carried out by hardware, software and firmware engineers, while Johannes van Putten is leading the development of the software tools that are being created within FLEXIT.

As for wider collaboration with the other ten partners, the company can draw on prior experience working with research institutes, technical clusters and manufacturing and technology partners worldwide. Salland has a complete understanding of the test technology ecosystem that complements close cooperation with multiple stakeholders in this industry. This gives them the capability to offer functional solutions to test problems, focusing on engineering challenges similar to those confronted in FLEXIT. Salland engineers are fully able to read between the lines to fulfil expectations on increasing test capabilities with high parallel testing and quick and easy data analysis by adapting or designing software or instruments to match the needs of their customers and partners.

## Participation across the project

In concrete terms, FLEXIT sees Salland Engineering working with Chilas and VTEC to create an effective solution to validate their photonic parts. The first step is to focus on the test strategy and design of the testing on the demo devices, then to attempt to develop a test solution for diced chips, bars or wafers and evaluate them before assembly. Their participation also extends to:

- the selection and configuration of optical instruments to be part of the test rack for checking the demo products, which will be used within Salland Engineering's test runner (test sequencer).
- the development of electrical instruments that fill the gap for photonic integrated circuit (PIC) tests and are flexible enough to evaluate all other demo devices within the project.
- the creation of test plans and programmes for demo devices and software to administer them in the test runner.

As part of FLEXIT, Salland Engineering is also implementing DPlus, their in-house development data analysis tool that includes additional functionalities for data analysis and report creation and that can be stored in a manufacturing execution system (MES) like the FLEXIT-Factory tool by WorkFloor. This can be used to produce meaningful data representation for designers and the fabrication process. Version 1.3 of DPlus has now been released, allowing users to utilise comma-separated values (CSV) data files. This is more interactive and can create (semi-)automatic reports with charts and export statistical tables.

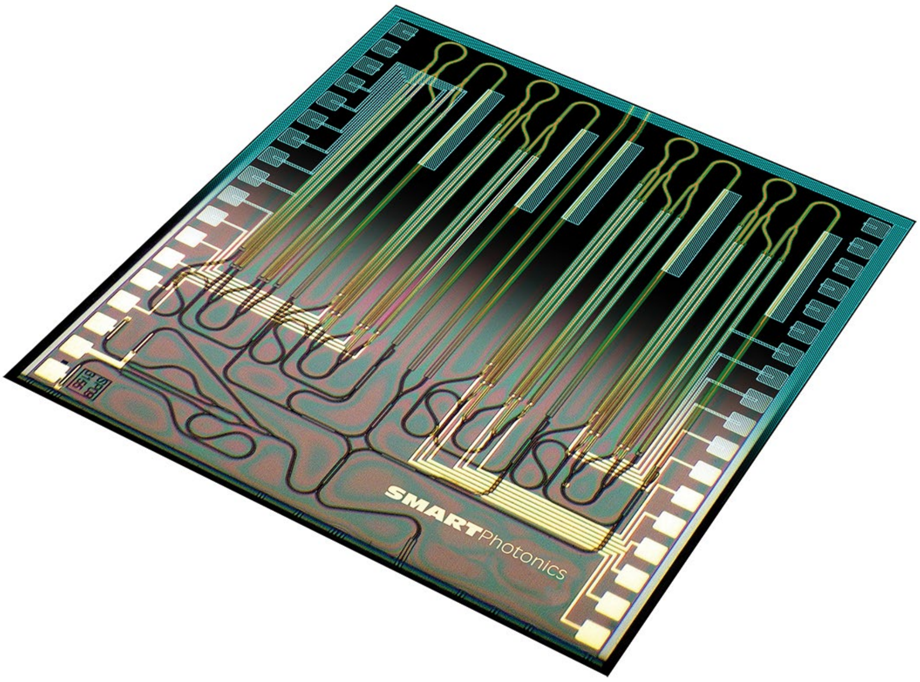
## The long-term value

Off the back of such efforts, several goals have already been achieved: optical instrumentation has been selected and is being configured to be used in the test programmes of the test runner, while a 16-channel PCI eXtension for Instrumentation Device Power Supply (PXI-DPS) is being developed. Based on the requirements of the project partners and a market analysis, this will evaluate the demo devices and future designs. Draft test plans have also been created and Salland Engineering is working with LioniX International on wafer-level measurements for electrical structures, such as lead zirconate titanate (PZT) actuators, to generate and analyse data before the evaluation of the end products.

As FLEXIT progresses, Salland Engineering is keen to further explore the principle of self-aligned fingers and facets alongside LioniX International and SMART Photonics, using this in an opto-electrical wafer prober concept to simplify wafer level testing for PICs. Alongside this, the company expects to build up knowledge on PICs measurement setups to offer Testing-as-a-Service (combining optical and electrical work) for photonic devices in the short term. Test solutions will be developed to evaluate the full speeds of devices that work at >100 Gbps per channel in opto-electrical configurations and DPlus will be used to process the test raw data generated. This will provide a better understanding of FLEXIT's coupling performance and help bring the added value of automated test equipment development to the other partners and to the project as a whole.

# SMART Photonics pushes forward PICs in the FLEXIT project

**As one of 11 partners in FLEXIT, SMART Photonics is an independent pure-play foundry which focuses on high-end PICs and offers solutions for data, telecommunication, sensing (such as Lidar) and medical applications. Involvement in the project is being carried out within the R&D team, headed by Ruud Vullers, while project leader Netsanet Tessema is coordinating her technical and administrative input together with her R&D colleagues. As the leading foundry for indium phosphide (InP) PICs, SMART Photonics offers FLEXIT many years of experience in producing active and passive building blocks within the same integration platform, thereby providing unique capabilities unparalleled by other InP foundries.**



## A unique device

Active elements generate, amplify or absorb light in response to an externally applied electric field. Typical active elements include amplifiers, detectors, lasers and modulators (like the recently developed high-speed modulators that allow transmission of multi-Gbps data rates for telecom and data centre applications). Passive elements – such as optical waveguides, multimode interference (MMI couplers) and (de)multiplexers – are used to transport the optical signal(s) in the PIC and to interconnect active elements. These components are integrated and fabricated onto a single substrate to create a uniquely compact and robust photonic device, significantly reducing space requirements and assembly costs.

In addition, SMART Photonics is always striving to achieve improved quality and higher yield in the PIC manufacturing process via the development of new, innovative ideas. This is in line with FLEXIT's vision on the development of assembly processes for mass production.

## Lock and key

To make this vision a reality, SMART Photonics' unique capabilities will be used to produce InP integrated chips equipped with facet structures: special structures on the chip that allow for direct on-wafer coupling of light into and out of the photonic chips. Standard chips do not have these facet structures; it is therefore possible to connect light into and out of a PIC only after the complete fabrication of the wafer and upon the singulation of the individual dies. Instead, the use of facets will enable easier connection of the InP PIC to an external optical element and allow the PICs to be tested while they are still an integral part of the wafer, translating into significant reductions to testing time and costs.

Optical contacts to the facets are obtained through the use of 'finger structures' defined on silicon nitride (SiN) optical chips. Thanks to the special design of the facets and the fingers, a simple alignment procedure enables physical contact between the two PICs, allowing the optical beam to travel from the InP to the SiN or vice versa. FLEXIT's self-aligned assembly process enables $Si_3N_4$ fingers (analogous to a door key) to fit into position inside of InP facets (analogous to a lock). This leads to a low coupling loss of <0.5 dB/facet. This key-lock structure has two further advantages:

- The assembly between the InP and SiN can be performed with larger tolerances (± 2 um) than what is typically required (< ± 0.5 um).
- The fingers can serve as an optical probe for wafer-level testing, enabling the identification of functional dies very early in the process.

So far, SMART Photonics has developed a new process flow for the production of quality facets with high surface smoothness. The smooth surface of the facet provides a flat landing area to the flexible fingers, which is important to maintaining low optical coupling loss. In 2023, SMART Photonics will focus on the development of the overall assembly through work on two different applications: an initial production run which will host C-band lasers (1550 nm) and a second production run which will host O-band modulators (1310 nm). Within these, the facet structures will allow for hybrid integration with $Si_3N_4$ chips produced by LioniX International, enabling the coupling of light between two integration platforms.

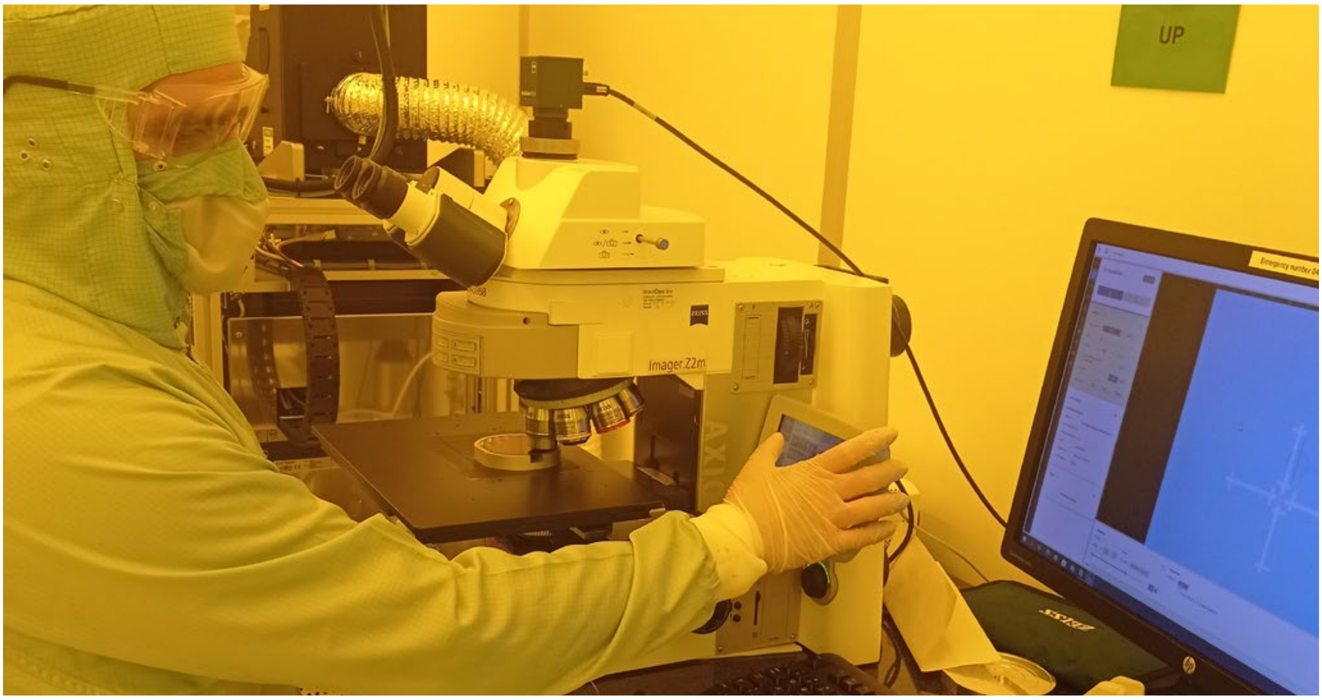
## Securing the future

As the assembly process for photonic chips is currently four times as expensive as the cost of the chip itself, market penetration has been significantly limited. The main value within the FLEXIT project will thus be the improved assembly technique based on InP facets and $Si_3N_4$ flexible fingers, through which the expensive, time-consuming alignment technique will no longer be needed. At the same time, the project will demonstrate the feasibility of an innovative on-wafer optical testing method, enabling the easier selection of known, good-quality dies in the future. The $Si_3N_4$ optical probes will be used to couple light into and out of InP wafers. This selection process avoids the expensive die-level testing that typically happens during the post-production of wafers.

In the near future, SMART Photonics would like to see successful prototypes that prove the feasibility of the new assembly process, enabling optical contact between InP facets and $Si_3N_4$ fingers. Following the demonstration of FLEXIT prototypes, new market possibilities are expected to arise for both SMART Photonics and the entire Dutch supply chain for the mass production of photonic components. In time, this will allow the Netherlands to become the international production centre for high-volume photonic manufacturing equipment in the face of enormous global demand.

# Innovation, optimisation and cost-efficiency: VTEC in the FLEXIT project

**To the FLEXIT project, VTEC Lasers & Sensors is bringing its expertise in the design, creation and testing of photonic applications and its deep knowledge of indium phosphide for the production of InP chips. Thanks to its experience developing the building blocks for multi-project wafers in the datacom and sensing domains, VTEC also has a strong awareness of how to get the best out of collaboration with diverse partners, making it a perfect addition to the FLEXIT ecosystem.**




## Technological opportunities

The goal in the FLEXIT project is the mass production of a compact, co-packaged transmitter for the O-band with a very high speed and low power consumption, as this market shows a lot of untapped potential. VTEC is at the processing stage, working on the fabrication of a Mach-Zehnder Modulator (MZM) with over 80 GHz of bandwidth and a half-wave voltage (VPI) of 2 V. This will enable 112 Gb/s non-return-to-zero (NRZ) transmission for data centres without any high-level modulation schemes. VTEC will also deliver a 60 GHz silicon-germanium (SiGe) MZM driver and a receiver with a demultiplexer.

In doing so, VTEC has the opportunity to develop a demo product that will challenge the planned assembly methods in the FLEXIT project: a 100 Gb/s NRZ MZM and a SiGe driver to build an optical engine that matches the requirements for co-packaged optics devices for data centres. The VTEC design of the MZM will enable much lower power consumption than silicon photonics-based devices.

## A combination of skills

FLEXIT isn't VTEC's first rodeo: they were among the earliest of 66 members to join PhotonDelta, which serves as a European hub for the integrated photonics industry from design and fabrication to packaging and testing. The experience gained here and elsewhere has helped them build up a varied portfolio of qualities and skills, including:

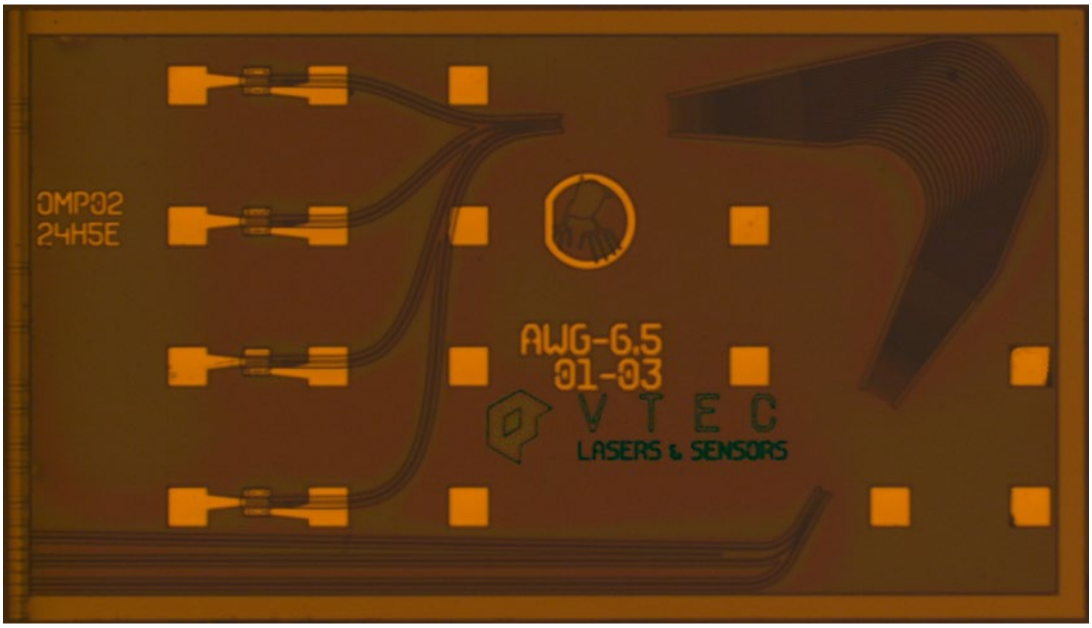
- **Innovativeness**. VTEC delivers the highest speed (112 GB/s) with thermal and mechanical stability (a position change of <5 micron). They also boast more than a decade of experience in leveraging indium phosphide for the design of photonic components.

- **Cost-efficiency**. VTEC has all of the required capabilities in-house, enabling short communication lines.
- **Optimisation**. VTEC is in control of the design and processing of all building blocks of their devices, enabling optimised solutions at the product level.
- **Vertical integration**. This unique vertically integrated capability allows VTEC to bring all of the aforementioned benefits together in the design and production of high-quality devices.

None of this would be possible without a strong team. VTEC's involvement in FLEXIT has therefore been entrusted in the skilled hands of Ankit Soni (Photonics Design and Test Engineer), Alexander Iatropoulos (Photonics Design and Process Engineer), Selma Henader (Photonics Design and Process Engineer) and Arun Ramachandran (Project Manager), as well as a number of supporting team members.

## Proof positive

As for the work in FLEXIT so far, the challenges for the assembly methods lie in fibre coupling using flexible fingers, radio frequency (RF) connections and flip-chip mounting of the MZM and the SiGe high-speed driver. Going forward, project partner PHIX will co-package the modulator and driver on silicon (SI) substrate using flexible fingers, creating a complete and compact product. The reliability of this product and its packaging will be tested at VTEC and will offer the possibility of an efficient, high-speed transceiver and an active optical cable when packaged with a high-speed avalanche photodiode that will be custom-designed by VTEC.




Ultimately, VTEC expects to get a design and chips for both the MZM and the driver. These chips will serve as the basis for a unique product – one which has been proven possible to assemble all thanks to FLEXIT's innovative equipment and processes.

# Managing the complete FLEXIT production line with Workfloor

**With a unique combination of extensive photonic integrated chip (PIC) knowledge and many years of experience in managing manufacturing automation, Workfloor provides the digital connection to FLEXIT and takes care of the flow of information for the complete production line. This enables strong collaboration across an ecosystem of Dutch photonics players via a platform for quick data analysis and product improvements.**

## The FLEXIT FactoryTool

This platform is Workfloor's FLEXIT FactoryTool, used to collect, manage and analyse data along the production chain. As a cloud-based manufacturing execution system (MES), it enables the various partners to upload and access data from the start to the end of their processes. Chilas, for example, serves as one of the demonstrators within the project; their laser design consists of a bill of materials and the process flows needed to create this laser. With the FLEXIT FactoryTool and its built-in, configurable approval flows, any changes to the laser design can be managed so that all revisions of the product are controlled.


The actual execution of these process flows happens at different locations, resulting in many kinds of data that are usually hard to correlate. The Chilas laser has two PICs that are connected using special flexible fingers, providing a simple way to connect these chips while maintaining optimal coupling efficiency. The gain block is an indium phosphide (InP) PIC provided by SMART Photonics while FLEXIT's silicon nitride (SiN) wafers are processed at LioniX International – but, with the FLEXIT FactoryTool, the complete process flow of these PICs can be managed across company borders.

An important part of the PIC production process is specialised equipment for PIC inspection and PIC testing, for which ten partners of the EFRO project MEKOPP (abbreviation for 'Metrology Equipment for Critical Upscaling of PIC Production') have been developing a Photonic Visual Inspection Tool and a Photonic Test Prober. Workfloor provides SECS/GEM-compatible interfaces that allow these to communicate directly with the FLEXIT FactoryTool, which manages the recipes needed to run these machines. The tool can therefore provide a real-time overview of the state of the different machines on the production floor.

## Configurable and traceable

For the FLEXIT FactoryTool, EZ-Connectors are also being developed through which specific folders on the equipment can be monitored for new test results. Once summary test files are written to these folders, the content is analysed and stored on that specific test step of the process flow. These different datapoints are used to perform statistical process control (SPC) checks and the SPC graphs are shown on a real-time, web-based dashboard. In this way, the FLEXIT FactoryTool provides a powerful way to analyse and improve any of the processes.

Based on this summary test data, web interfaces can easily be configured for operations later in the production flow. For instance, operators that need to pick the wafers for further processing can now select them with the best test parameters for specific devices. After dicing the collected wafer maps, the Photonic Test Prober can be used to skip any dies that fail the test. These wafer maps, based on semiconductor standards, can be displayed in the FLEXIT FactoryTool. Once the best PICs are identified for further processing, these dies are placed in gel packs. To maintain full traceability, the tool uses E142 transfer maps for tracking which PICs of which wafer are in which location in the gel pack.

## The digital glue

At PHIX, the FLEXIT FactoryTool's inventory receive process maintains an up-to-date overview of the PICs received from LioniX International and SMART Photonics. PHIX's assembly machines are connected to the tool with EZ-Connectors that collect different process parameters. Examples of the data collected include the alignment tolerances of the various steps and the coupling losses between the fibre arrays that are connected to the LioniX PIC. This coupling loss is measured before and after curing the glue, providing valuable insights by analysing the correlation and performance as a function of other process parameters.

Once PHIX completes the assembly, the lasers are sent to Chilas, where incoming inspection measurements are performed. The summary data of these measurements are uploaded to the FLEXIT FactoryTool, providing Chilas' engineers with a treasure trove of data to improve the design of the next version of the product. Extensive access management keeps this data secure: by defining user groups and assigning individual users to these groups, access to pieces of information can be managed at many different levels, from product designs to steps in different process flows.

This protection of intellectual property makes it the ideal tool for in-depth collaboration such as FLEXIT. For example, the project has connected Workfloor with leading suppliers of PIC design software, like Synopsys and their process design kits (PDK) for LioniX International and SMART Photonics' PICs. As a platform to make the measurement data available to Synopys engineers, the FLEXIT FactoryTool provides direct feedback for the improvement of these PDKs. The improved PDK building blocks can then be managed in the FLEXIT FactoryTool's revision-controlled design of the Chilas laser, creating a virtuous cycle. All in all, Workfloor's digital connections serve as the glue that holds FLEXIT together, allowing the partners to achieve better defined inputs that are available in a centralised system for quick and easy control, traceability and analysis.

# Elevating impact: the FLEXIT support network

## Synopsys

Synopsys supports the FLEXIT project with design software and tools for the development of PICs. Since 1986, Synopsys has been at the heart of accelerating electronics innovation, with engineers around the world having used Synopsys technology to successfully design and create billions of chips and systems that are found in the electronics that people rely on every day. Synopsys is at the forefront of Smart Everything with the world's most advanced technologies for silicon chip design, verification, IP integration and application security testing.

## Berenschot

Berenschot is a consultancy company that helps the project consortium in formulating the project plan and securing the funding. During the project's lifetime, Berenschot fulfills a role in supporting High Tech NL in the project management and is responsible for the financial and technical reporting.

Berenschot has a widespread reputation in multiple sectors in the Netherlands. Alongside knowhow on subsidy and funding opportunities for companies and institutions, they have the technological knowledge needed to manage a project in which a lot of complicated technological challenges are at stake. They are very familiar in the (Dutch) photonics ecosystem and know the possibilities for arranging funding of new innovative projects. On top of this, they are experienced in the formation and improvement of innovation ecosystems.

## High Tech NL

High Tech NL is the central partner responsible for project management, communication, knowledge dissemination and networking activities for the FLEXIT project. Together with Berenschot, High Tech NL keeps track of the project's progress, making adjustments when necessary. Moreover, Berenschot and High Tech NL are both involved in the promotion and dissemination of the knowledge developed in the project, making the FLEXIT technology known as a possible method to scale up the production of photonic chips in the Netherlands.

High Tech NL is the national trade association for the Dutch high-tech industry that drives innovation by connecting companies and knowledge institutes. High Tech NL Semiconductors is the contact point for the Dutch chip industry. As a member of the Silicon Europe Alliance, High Tech NL drives international collaboration and continuously develops the semiconductor ecosystem. They encourage interactions between companies, knowledge institutions and public authorities and have connections with innovation attachés, embassies and development agencies. Through its network, High Tech NL contributes to the application of key technologies such as integrated photonics and quantum computing.

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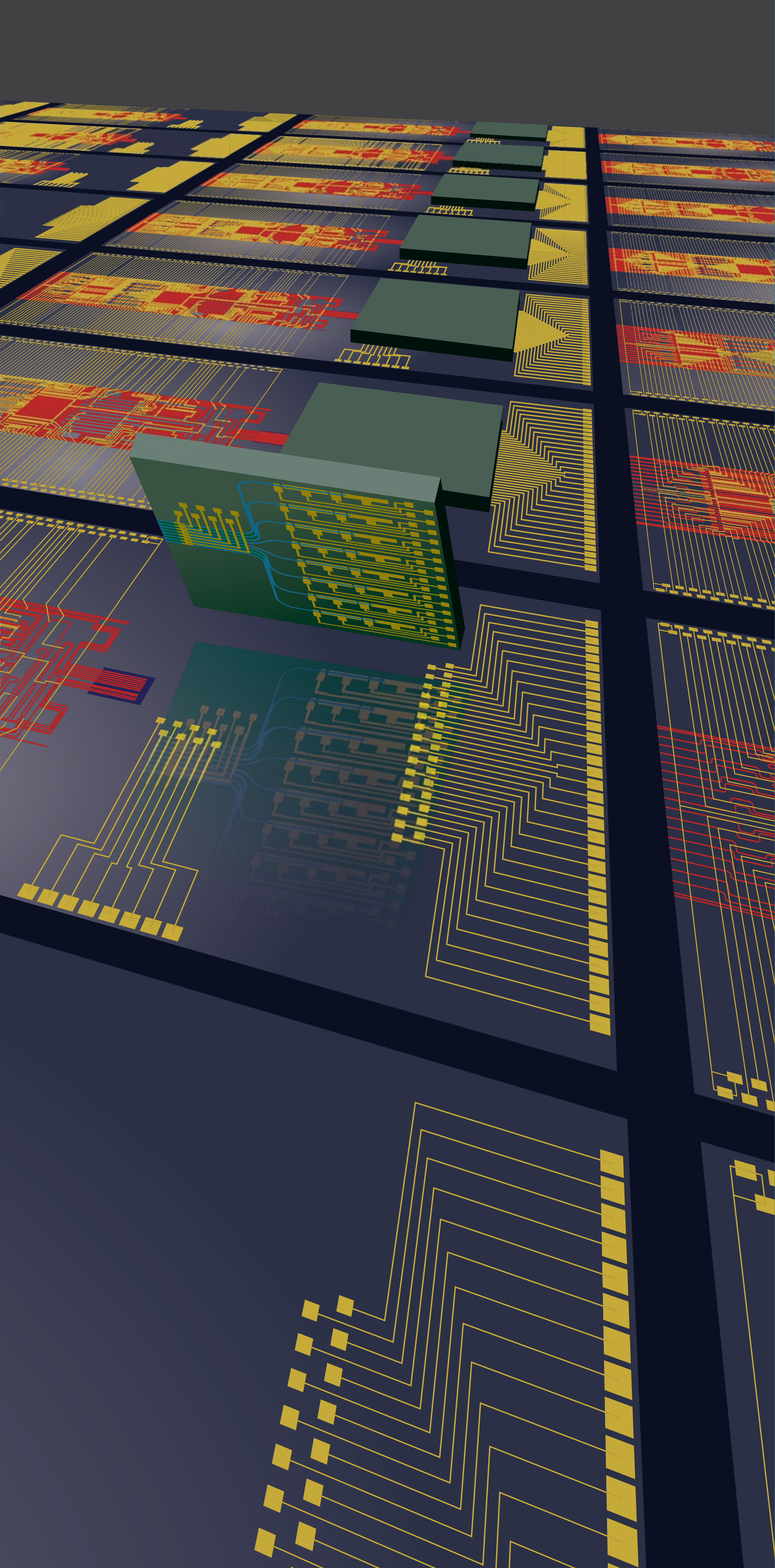

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