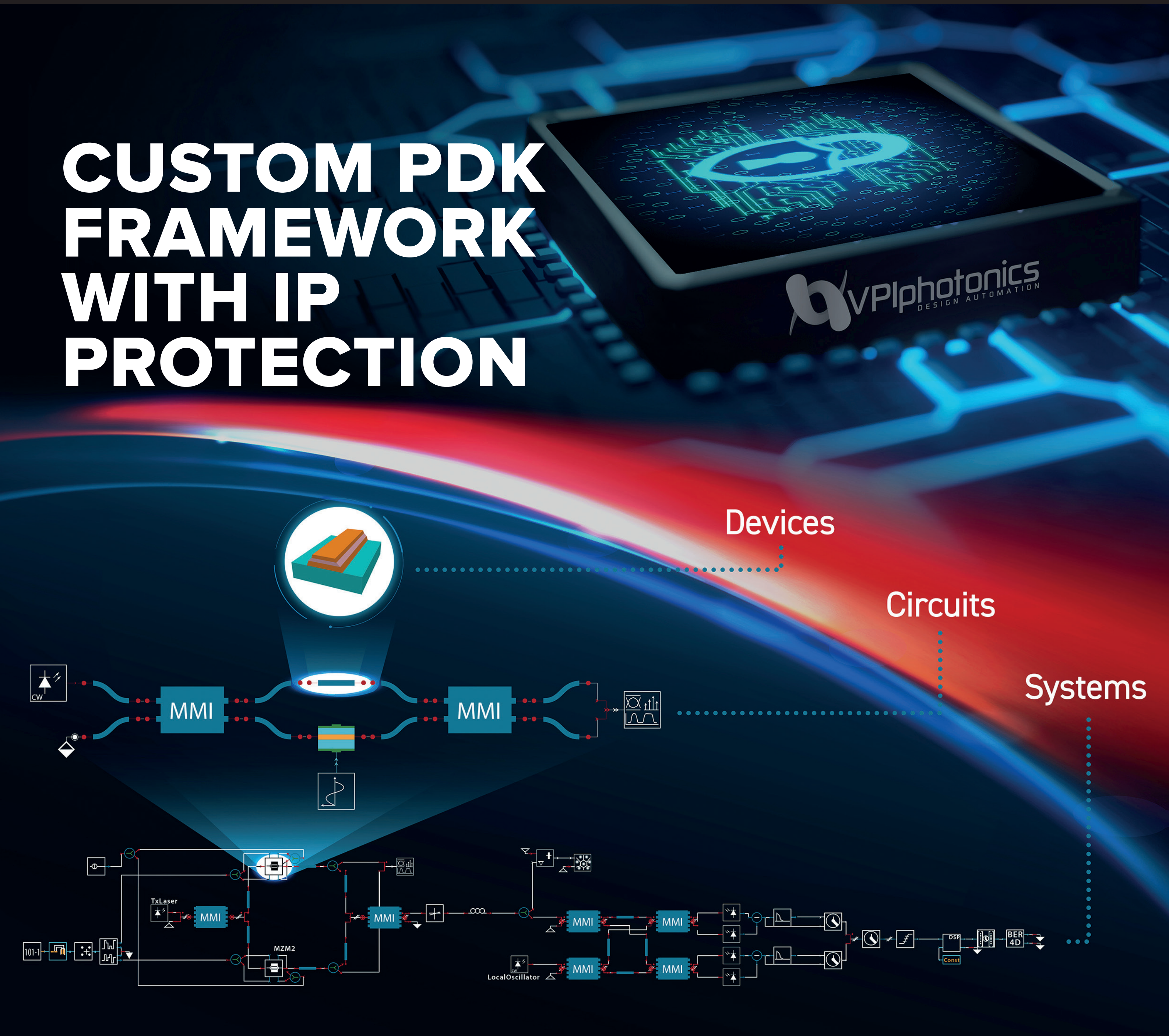
PIC
PHOTONIC INTEGRATED CIRCUITS
CONNECTING THE PHOTONIC INTEGRATED CIRCUITS COMMUNITY

CUSTOM PDK FRAMEWORK WITH IP PROTECTION



ISSUE I 2024
AN ANGEL BUSINESS COMMUNICATIONS PUBLICATION
PICMAGAZINE.NET

INSIDE

News Review, Features
News Analysis, Profiles
Research Review
and much more...

SUPPORTING AI WITH OPTICAL MODULATORS

To cope with surging internet traffic, datacentres can be upgraded with electro-optic polymer modulators

HIGH-POWER TRANSMITTERS FOR NETWORKS

Combine a laser, a modulator and an amplifier in a single device are laying the foundations for high capacity access networks

POLARISATION-INDEPENDENT MONOLITHIC PICS

As datacentre infrastructure races towards 200G per lane, delays remain significant hurdles in high-speed optical receivers


EVG®
invent
innovate
implement
www.EVGroup.com
INDUSTRY LEADING WAFER PROCESSING EQUIPMENT FOR PHOTONIC INTEGRATED CIRCUITS
Optical and Nanoimprint Lithography
Temporary and Permanent Wafer Bonding
NILPhotonics® Competence Center
EVG®7300
Multifunctional UV Nanoimprint Lithography System
GET IN TOUCH to discuss your process development and manufacturing needs
www.EVGroup.com

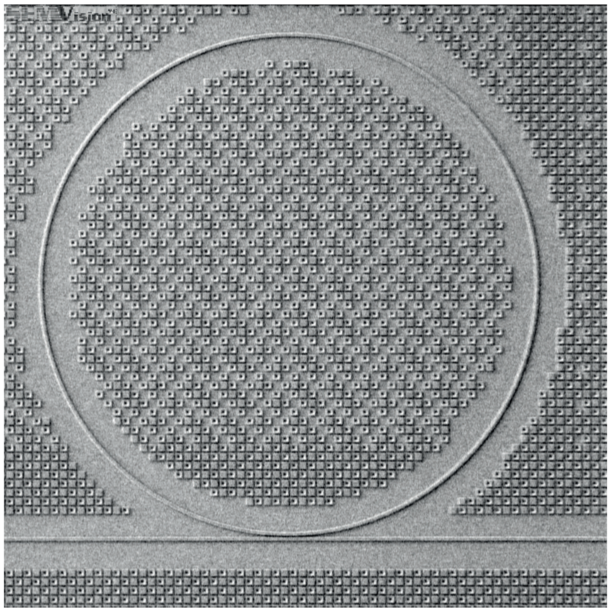
VIEWPOINT

By Laura Hiscott, Editor

The forces driving innovation

IT IS OFTEN SAID that "necessity is the mother of invention," and it is not difficult to find examples of this in any environment, least of all the technology industry. We are now more than a year on from reports of ChatGPT reaching one hundred million subscribers in two months – exceeding the growth rate of any consumer application before it – and it looks like AI's data demands may be the necessity that drives not only the invention of new photonic technologies, but also a major scale-up in the use of existing ones.

Photonics as the key to achieving higher data rates is a recurring theme in this issue. POET Technologies, for instance, distinguishes three ways in which the field is "positioned to be the catalyst for large-scale growth in hardware applications for AI," while Michael Lebby, CEO of Lightwave Logic, describes how electro-optic polymers could serve as faster optical modulators in transmitter PICs, helping datacentres to handle surging internet traffic.

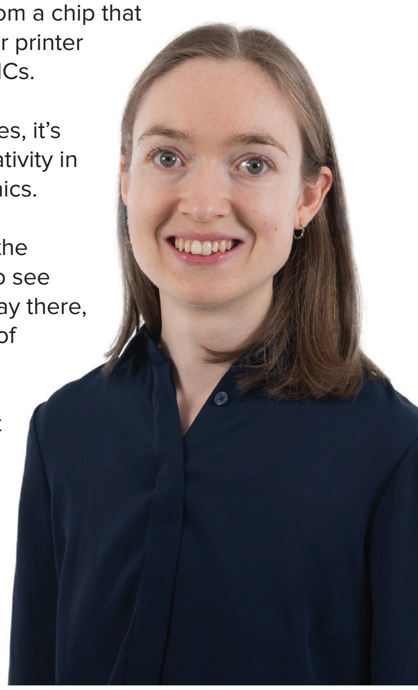


Meanwhile, GlobalFoundries reports progress in tackling polarisation-dependent loss – an important challenge for the industry to overcome on its way to achieving higher bandwidths – and Almae explains how a device that combines a laser, modulator, and amplifier can pave the way for higher-capacity access networks.

And it is not only the technological solutions themselves that are spurred by the need for them; there are ripple effects throughout the whole surrounding ecosystem.

On page 34, for example, EXFO describes how increasingly intricate PICs are pushing the boundaries of high-precision measurement techniques – something they are striving to address with their testing platforms.

Of course, external requirements are not the only motivation for technological progress. After all, conventional wisdom also advises us to "build it and they will come." Indeed, much of the technology that's poised to solve current problems would not be ready waiting if it were not for exploratory research. As the news pages show, exciting developments are being made in the lab all the time, from a chip that does maths with light to a laser printer that can fabricate rewritable PICs.

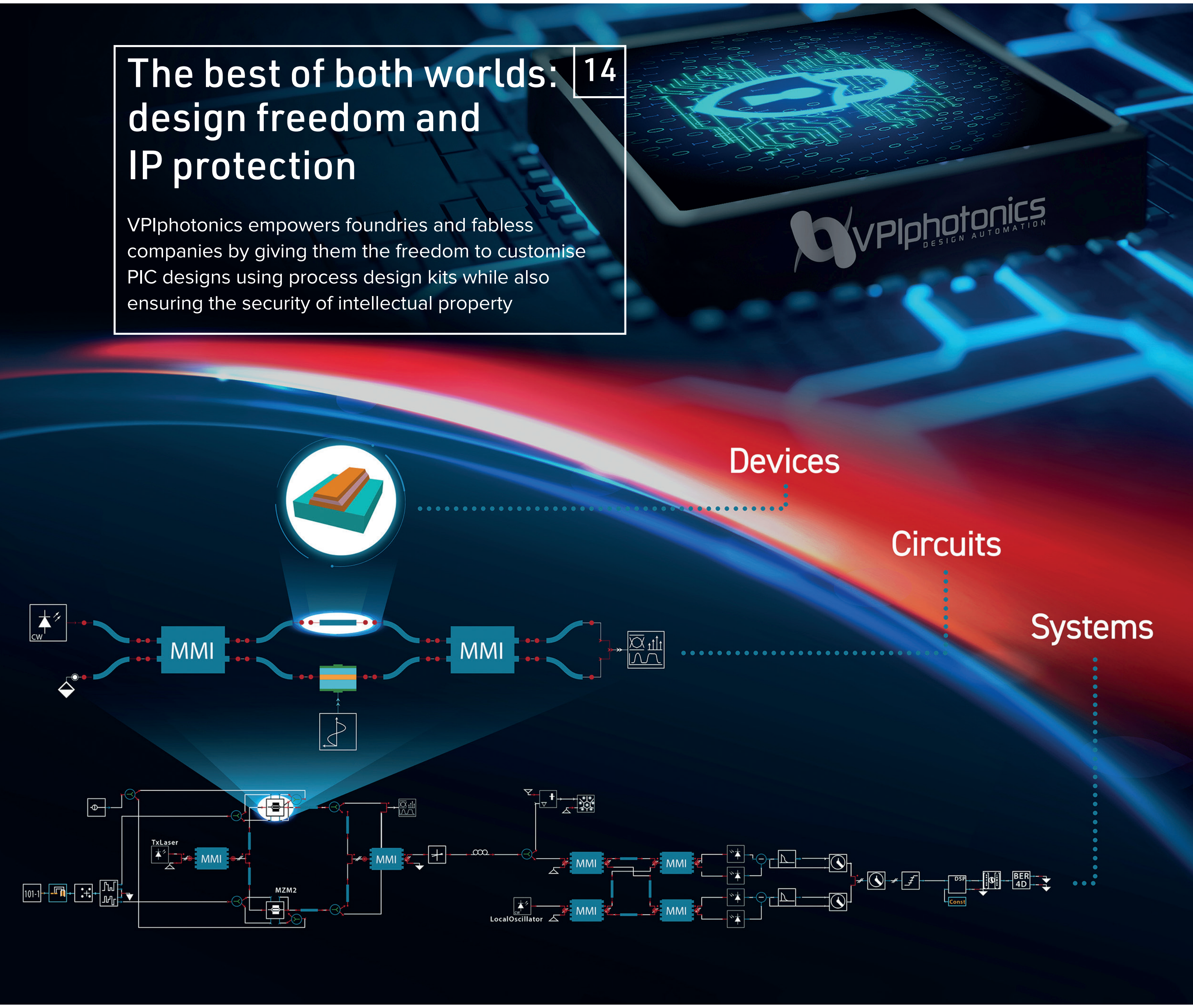


Amid these push and pull forces, it's certainly a time of intense creativity in the world of integrated photonics.

And with PIC International on the horizon, it will be fascinating to see the latest innovations on display there, whether they are the product of targeted, application-focused work or curiosity-led research. I look forward to seeing you at the event in April.

CONTENTS

PHOTONIC INTEGRATED CIRCUITS



30

NEWS

11

PHOTONIC INTEGRATED CIRCUITS

Editor
Laura Hiscott laura.hiscott@angelbc.com

Contributing Technical Editor
Richard Stevenson richard.stevenson@angelbc.com +44 (0)1923 690215

Sales & Marketing Manager
Shehzad Munshi shehzad.munshi@angelbc.com +44 (0)1923 690215

Design & Production Manager
Mitch Gaynor mitch.gaynor@angelbc.com +44 (0)1923 690214

Publisher
Jackie Cannon jackie.cannon@angelbc.com +44 (0)1923 690205

CEO Sukhi Bhadal sukhi.bhadal@angelbc.com +44 (0)2476 718970
CTO Scott Adams scott.adams@angelbc.com +44 (0)2476 718970

Published by
Angel Business Communications Ltd
6 Bow Court, Fletchworth Gate,
Burnsall Road, Coventry CV5 6SP, UK.
T: +44 (0)2476 718 970
E: info@angelbc.com

Angel BUSINESS COMMUNICATIONS

DustPhotonics raises $24 million in follow-on funding round

The company says the investment will boost production of its current products for 400G and 800G applications, as well as accelerate development of new products for 1.6T applications

DUSTPHOTONICS, a developer of silicon photonics technology for datacentre and AI applications, has announced that it has raised an additional $24 million in its Series B follow-on funding round. The company says it will use this new investment to scale production of its Carmel-4 and Carmel-8 products, used for 400G and 800G applications, and to accelerate development of its next-generation products, which aim to enable 1.6T applications.

DustPhotonics says this latest funding round was oversubscribed, and was funded by a combination of new and existing investors, such as Sienna Venture Capital, Greenfield Partners, Atreides Management, and Exor Ventures.

"We looked at innovative technologies supporting the fast-growing AI compute market, and DustPhotonics stood out as a leader in this market due to their technology and customer traction," said Isabelle Amiel-Azoulai, founding partner at Sienna Venture Capital. "We are excited by the customer agreements and backlog that the DustPhotonics team has generated with its Carmel-4 and Carmel-8 products, and look forward to working with the DustPhotonics team to help the company in this next growth phase."

"Greenfield Partners is excited to continue to support DustPhotonics in this upcoming phase of growth, on the back of strong execution by the DustPhotonics team across both product innovation and commercial wins," said Yuda Doron, managing partner at Greenfield Partners. "We continue to be firm believers in the prospect of silicon photonics becoming a key enabler for datacentres to meet the increasingly demanding requirements brought upon by AI, as demonstrated by the company's recent momentum." Ronnen Lovinger, CEO of DustPhotonics, commented: "We are seeing a lot of design-win momentum with our products, and are excited by the new opportunities ahead in both AI and cloud service datacentres. We are grateful to have a strong group of investors who have been supporting us from the early days, and are delighted to have new partners join our journey ahead."

Coherent CEO to step down

COHERENT has announced that the current CEO, Vincent ("Chuck") Mattera, has informed the board of directors that he intends to retire as CEO once a successor has been employed. The company emphasised that this decision was not due to a dispute or disagreement.

The board of directors has retained an executive search firm, which will immediately commence a comprehensive search process, evaluating both internal and external candidates, to identify a new CEO. A subcommittee of the board has been formed to oversee this process. Mattera, 68, joined Coherent 20 years ago, and has served as CEO for the last eight. He is the company's third CEO since its founding in 1971 as II-VI Incorporated, and he has also served as chair of its board of directors since November 2021. During his tenure, Mattera led the transformation of II-VI into Coherent. "Leading this 53-year-old company through its multi-decade growth transformation has been an incredible privilege," said Mattera. "I want to acknowledge and deeply thank our employees, investors, customers, partners, and especially our leadership team, as well as my fellow board members, for our shared accomplishments and for helping make my years at Coherent so rewarding and impactful.

"Since the strategic combination of II-VI and Coherent two years ago, I am most proud of the tremendous progress we have made to integrate our two organisations, optimise synergies, and place the company in an advantaged position for accelerated growth. With Coherent on a clear path to improved margins and continued profitable growth, its track record of product leadership, customer intimacy, operational excellence, and the unstoppable imagination of our world-class people, I believe that now is the right time to look toward the next chapter of the company's transformation."

Synopsys to acquire Ansys

The move combines the companies' expertise in electronic design automation, simulation and analysis

SYNOPSYS and Ansys have entered into an agreement under which Synopsys will acquire Ansys. The companies say that this step brings together Synopsys' pioneering semiconductor electronic design automation (EDA) with Ansys' broad simulation and analysis portfolio, creating a leader in silicon to systems design solutions.

"The megatrends of AI, silicon proliferation and software-defined systems are requiring more compute performance and efficiency in the face of growing, systemic complexity," said Sassine Ghazi, president and CEO of Synopsys. "Bringing together Synopsys' industry-leading EDA solutions with Ansys' world-class simulation and analysis capabilities will enable us to deliver a holistic, powerful and seamlessly integrated silicon to systems approach to innovation to help maximise the capabilities of technology R&D teams across a broad range of industries. This is the logical next step for our successful, seven-year partnership with Ansys and I look forward to working closely with Ajei and the talented Ansys team to realise the benefits of this combination for our customers, shareholders and employees."

Aart de Geus, executive chair and founder of Synopsys, commented: "Since inception 37 years ago, Synopsys has been an innovation pioneer, central to world-changing semiconductor advances in computation, networking, and mobility, and now enabling the new era of 'pervasive intelligence'. Joining forces with Ansys, a company we know well from our long-standing partnership, is the latest example of how Synopsys remains at the forefront.

"Our board and management team carefully evaluated our top strategic options to lead and win in this fast-growing new wave of electronics and system design. The technology-broadening team-up with Ansys is an ideal, value-enhancing step for our company, our shareholders, and the innovative customers we serve."

Ajei Gopal, president and CEO of Ansys, said: "For more than 50 years, Ansys has enabled customers to design, develop and deliver cutting-edge products that are limited only by imagination. By joining forces with Synopsys, we will amplify our joint efforts to drive new levels of customer innovation. This transformative combination brings together each company's highly complementary capabilities to meet the evolving needs of today's engineers and give them unprecedented insight into the performance of their products."

Chip uses light to perform calculations needed for AI

ENGINEERS at the University of Pennsylvania have developed a new chip that uses light waves, rather than electricity, to perform the complex mathematics essential to training AI. The researchers say that this development, reported in a paper in Nature Photonics, could radically accelerate the processing speed of computers while also reducing their energy consumption.

The silicon photonic chip applies the work of Nader Engheta, who is H. Nedwill Ramsey Professor in the School of Engineering, whose expertise includes manipulating materials at the nanoscale to perform mathematical computations using light. In particular, the chip's design is the first to combine Engheta's research with the silicon photonic platform, which uses silicon, the cheap, abundant element used to mass-produce computer chips.

The interaction of light waves with matter represents one possible avenue for developing computers that supersede the limitations of today's chips, which are essentially based on the same principles as chips from the earliest days of the computing revolution in the 1960s.

In their new paper, Engheta's group, together with that of Firooz Aflatouni, associate professor in electrical and systems engineering, describe the development of the new chip. "We decided to join forces," says Engheta, leveraging Aflatouni's group's research on nanoscale silicon devices.

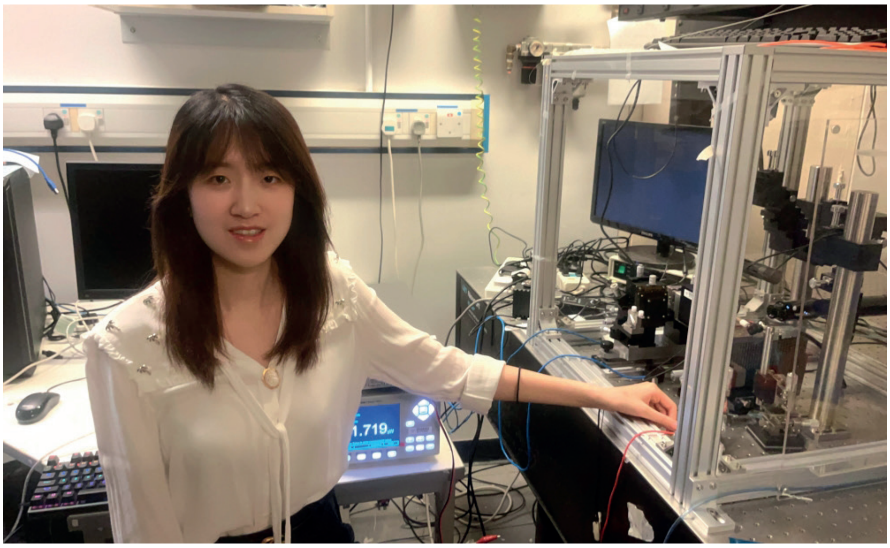
Their goal was to develop a platform for performing what is known as vector-matrix multiplication, a core mathematical operation in the development and function of neural networks, the computer architecture that powers today's AI tools. Instead of using a silicon wafer of uniform height, explains Engheta, "you make the silicon thinner, say 150 nm," but only in specific regions. Those variations in height — without the addition of any other materials — provide a means of controlling the propagation of light through the chip, since the variations in height can be distributed to cause light to scatter in specific patterns, allowing the chip to perform mathematical calculations at the speed of light.

Due to the constraints imposed by the commercial foundry that produced the chips, Aflatouni says, this design is already ready for commercial applications, and could potentially be adapted for use in graphics processing units (GPUs), the demand for which has skyrocketed with the widespread interest in developing new AI systems. "They can adopt the silicon photonics platform as an add-on," says Aflatouni, "and then you could speed up training and classification."

New technique enables efficient integration of III-V with silicon

The method involves selectively growing III-V materials on silicon-on-insulator laterally, without thick buffers

RESEARCHERS at the Hong Kong University of Science and Technology (HKUST) have developed a new integration technique for efficient integration of III-V compound semiconductor devices and silicon. The scientists say this method paves the way for photonic integration at low cost, large volume, and high speed and throughput, potentially revolutionising data communications. The findings are reported in the journal *Laser & Photonics Reviews*.



Unlike conventional integrated circuits, or microchips, that use electrons, photonic integrated circuits use photons, or particles of light. Photonic integration combines light and electronics to speed up data transfer. Silicon photonics, in particular, is at the forefront of this revolution as it enables the creation of high-speed, low-cost connections that can handle massive amounts of data at once.

While silicon can handle passive optical functions, it struggles with active tasks, such as generating light (lasers) or detecting it (photodetectors) – both key components for data generation and readout. This necessitates the integration of III-V semiconductor materials (which use elements from groups III and V of the periodic table) onto a silicon substrate for complete functionality and enhanced efficiency. However, while III-V semiconductors do the active tasks well, they do not naturally work well with silicon. The team, led by Xue Ying, research assistant professor, and Lau Kei-May, research professor from the Division of Emerging Interdisciplinary Areas (EMIA), tackled this challenge by finding a way to make III-V devices work efficiently with silicon.

They developed a technique called lateral aspect ratio trapping (LART) – a novel selective direct epitaxy method that can selectively grow III-V materials on silicon-on-insulator (SOI) in a lateral direction without the need for thick buffers.

While no integration methods reported in the previous literature could solve the challenge with high coupling efficiency and high production volume, their method achieved an in-plane III-V laser, so that the III-V laser can couple with silicon in the same plane, making it efficient.

“Our approach addressed the mismatch of III-V devices and silicon,” said Xue. “It achieved excellent performance of III-V devices and made it easy and efficient to couple III-V with silicon.”

In the past decades, data traffic has grown exponentially, driven by emerging technologies such as big data, cloud applications, and sensors. The field of integrated circuits, also known as microelectronics, has enabled that growth by making electronic devices smaller and faster thanks to Moore’s Law, an observation that the number of transistors on a microchip doubles about every two years. But the continued explosion of data traffic has pushed traditional electronic devices to their limits. The start of the Zettabyte Era in 2016 ushered in soaring growth in data generation, processing, transmission, storage, and readout. This surge poses critical challenges of speed, bandwidth, cost, and power consumption. This is where photonic integration, in particular silicon photonics, comes in.

In the next steps, the team plans to show that III-V lasers integrated with silicon waveguides can perform well, with a low threshold, high output power, long lifetime, and the ability to operate at high temperatures.

Xue added that there are key scientific challenges to address before the new technique can be used in everyday technologies. However, the scientists say it will enable new-generation communications and various emerging applications and research areas, including supercomputers, artificial intelligence (AI), biomedicine, automotive applications, and neural and quantum networks.

Creating photonic chips with a laser printer

Researchers have developed a new technique for fabricating rewritable PICs using phase-change materials

AS PICs find applications across a broad spectrum of near-future technologies, from LiDAR and biomedical sensors to 6G and quantum computing, access to fabrication equipment for them is becoming increasingly important.

However, today's nanofabrication facilities cost millions of dollars to construct and are well beyond the reach of many colleges, universities, and research labs. Those who can access a nanofabrication facility must reserve at least a day for the time-consuming lithographic process. Furthermore, if there is a design error, or if the chip doesn't work properly, it must be discarded, the design adjusted, and a new chip fabricated. This often results in days or even weeks spent in the cleanroom.

But now, as described in a new paper in *Science Advances,* a research team led by the University of Washington Department of Electrical and Computer Engineering (UW ECE) has devised a way to bypass expensive nanofabrication facilities and produce PICs almost anywhere. The team has developed an innovative method with which these circuits can be written, erased, and modified by a laser writer into a thin film of phase-change material similar to what is used for recordable CDs and DVDs. With this new process, PICs can be constructed and reconfigured in a fraction of the time it would take at a nanofabrication lab.

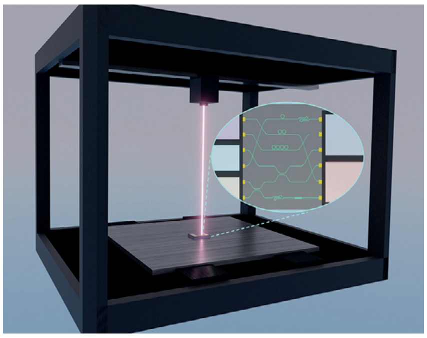
The multi-university team was led by Mo Li, a professor of physics and associate chair for research at UW ECE. "Photonics technology is on the horizon; therefore, we need to train or educate our students in this field," says Li. "But for students to study and have hands-on experience with photonic circuits, currently, they need access to a multimillion-dollar facility. This new technology addresses that problem. Using our method, photonic circuits that previously had to be fabricated in expensive and hard-to-access facilities now can be printed and reconfigured in labs, classrooms, and even garage workshops, by a speedy, low-cost device about the size of a conventional desktop laser printer."

Researchers can also benefit from this advance, which will enable a much quicker turnaround time for prototyping and testing out a new idea before booking valuable time in a nanofabrication facility. And for industrial applications, a big advantage of this method is reconfigurability.

For example, companies could possibly use this technology to create reconfigurable optical connections in datacentres, especially in systems that support artificial intelligence and machine learning, which would reduce costs and boost efficiencies.

Li's research team included UW ECE graduate student Changming Wu, who is lead author of the paper, and, along with Li, came up with the idea for this novel technique. UW ECE graduate student Haoqin Deng also contributed to the effort. Their work is the latest result of a six-year line of research that includes advances in optical computing. It is also a continuation of a productive collaboration with professors Ichiro Takeuchi and Carlos Ríos Ocampo and their students at the University of Maryland. The work was funded by the Office of Naval Research and the National Science Foundation.

"Being able to write a whole photonic circuit using only one single step, without a complicated fabrication process, is really exciting," says Wu. "And the fact that we can make any modification to any part of the circuit in our own lab and rewrite and redo it is amazing. It's a matter of minutes versus a full, day-long process. It's a huge relief to be able to finish the whole fabrication



process within a few minutes instead of what often is several days or even a week."

The method the team developed has been proven to work, but it is still an early-stage concept. However, Li has filed a provisional patent application, and he is planning to build a desktop laser writer for PICs. The team's vision is of a laser printer that uses a staging system to move the substrate in a much more precise manner than in a traditional desktop printer, and which can be sold at an affordable price and distributed widely to research labs and educational institutions around the world. The researchers are also looking at reducing optical loss in the phase-change material, to enable the printing of even more detailed and sophisticated circuits.

Li is already engaging with industry leaders to promote possible applications of this new technology in programmable PICs and reconfigurable optical networks. "This technology can create the photonic circuitry you want, but it also can be added onto already-existing electronic circuitry," he explains. "And because it is reconfigurable and reusable, it just opens many possibilities for students, researchers, and industry. What's most exciting to me is that we'll potentially have a huge impact on the field of photonics in disseminating this new tool and technology to the broader research community."

Amazec Photonics awarded €1.5 million for PIC-based medical tech

The seed funding will be used to develop accurate and minimally invasive devices for cardiovascular monitoring and diagnosis, with clinical trials beginning this year

AMAZEC PHOTONICS, a company focused on using integrated photonics to advance medical technology, has secured a €1.5 million seed round to develop its diagnosis devices.

The round was led by PhotonDelta – an accelerator and ecosystem of photonic chip technology organisations – with several private investors also contributing. The funding will be used to develop devices for clinical trials.

Cardiovascular diseases are the world's leading cause of death, accounting for 19 million deaths per year. This is in part due to the difficulty in diagnosing conditions, leading to delays in treatment. Amazec says its solution – an easy-to-use cardiovascular monitoring tool – is a huge step forward, enabling much earlier and much more accurate diagnosis for minimal costs and complexity.

Existing solutions are complex, invasive, and often inaccurate. The most common technique to measure cardiac output is called thermodilution, which involves injecting a known volume of liquid upstream of the heart and then measuring temperature changes downstream through specialised catheters inserted into the patient.

This has several drawbacks, including an inability to be used reliably during routine examination, large variation between measurements, a lack of sensitivity, and high costs. Consequently, it often leads to late or misdiagnosis, severely impacting the outlook for patients.

According to Amazec, its new solution uses photonics-based technology to measure temperature changes to an unprecedented precision of 0.0001 degrees Celsius, compared to current accuracy of 0.01 degrees Celsius.

The monitoring device is external, meaning there is no need to insert catheters. The company also says that measurements can be made in real time, improving reliability compared with current methods, which use a single measurement.

Pim Kat, CEO of Amazec Photonics, said: "The number of people suffering from cardiovascular diseases has risen by 93 percent over the past 25 years and now impacts an estimated 550 million patients worldwide. Many of these people will die or suffer poor health outcomes because the tools we have to diagnose them simply aren't good enough.

"Our solution can make a real difference because, not only does it vastly improve the accuracy of testing for cardiovascular disease, it is also much less invasive and simpler to use. This will substantially reduce costs and open the door to many more people being tested much more regularly. With this funding round we will be able to build ten prototypes and undertake extensive clinical trials with the intention of producing and selling devices across the EU by 2028."

Laurens Weers, CFO of PhotonDelta, said: "Amazec has leveraged the power of photonics to create a device that can make a profound impact on the world. Cardiovascular disease is one of the biggest health challenges we face and better diagnosis can be the key to saving millions of lives. We're very proud to be a part of Amazec's journey - we believe it has the capacity to become one of Europe's most important medtechs and a standard bearer for a new generation of photonics-based technology."

PhotonDelta's investment in Amazec Photonics is the latest step in the organisation's goal to create a world-leading photonics industry in the Netherlands. PhotonDelta aims to help build 200 startups, create new applications for photonic chips and develop infrastructure and talent.

Amazec will begin clinical trials of its device at Catharina Hospital in Eindhoven this year, with an expansion to three other hospitals planned in 2025.

"The number of people suffering from cardiovascular diseases has risen by 93 percent over the past 25 years and now impacts an estimated 550 million patients worldwide. Many of these people will die or suffer poor health outcomes because the tools we have to diagnose them simply aren't good enough"

Cisco and Microsoft deliver 800G on Amitié Transatlantic Cable

The companies say that the trial, which was powered in part by silicon photonics, outperformed any other industry trial to date with DWDM 800G in a 150 GHz channel spacing

CISCO has announced that it has successfully transmitted 800G on the Amitié transatlantic communications cable, which runs 6,234 km from Boston, Massachusetts to Bordeaux, France. The trial was performed with the Cisco NCS 1014 platform enabled by Acacia's Coherent Interconnect Module 8 (CIM 8), which is powered by its Jannu digital signal processor and advanced silicon photonics.

The continued growth of cloud and explosion of AI services is driving the need for greater subsea network capacity, which requires advanced coherent transmission systems that support higher performance. This trial was conducted to target improvements in subsea transmission to provide increased performance and capacity.

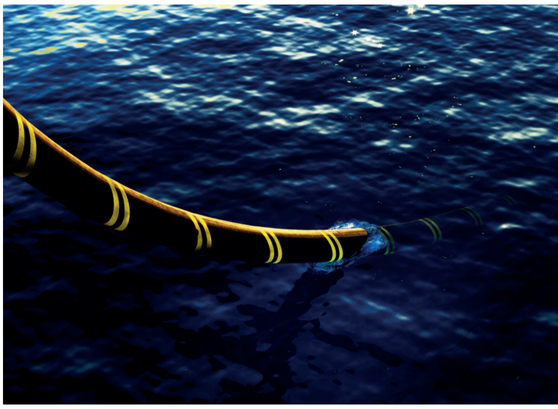
The Amitié submarine cable features Space Division Multiplexing (SDM) technology with 16 fibre pairs, more than traditional subsea cables, with repeater power shared across the fibre pairs to deliver the highest cable capacity.

According to Cisco, this real-time field trial exceeded any industry trial performance to date with Dense Wavelength Division Multiplexing (DWDM) 800G in a 150 GHz channel spacing, equivalent to a spectrum efficiency of 5.33 bit/s/Hz and a maximum spectral efficiency of 5.6 bit/s/Hz. In addition, 600G was transmitted over 12,469 km for a trans-atlantic loopback configuration.

The company says this is the first time a 140 Gbaud single carrier signal was demonstrated live, and is the longest distance ever reported at single carrier 600G DWDM transmission on an SDM cable.

The Amitié cable, a transatlantic submarine cable connecting the US, UK, and France, is now part of Microsoft's global network supporting all Microsoft services.

"In the era of AI, reliable and fast network connections are more important than ever," said Bill Gartner, senior vice president of optical systems and optics at Cisco. "Working with Microsoft on the Amitié cable to demonstrate the potential for improved overall network capacity with 800G at these distances is a significant



milestone for an SDM cable, and we're proud to drive the innovations that pave the way for ever-increasing network capacity needs."

Jamie Gaudette, general manager of cloud network engineering at Microsoft, added: "The transmission of 800G over 6,234 km is a milestone that demonstrates SDM cables can deliver increased capacity over traditional subsea cables. This field trial demonstrates what is now a commercial technology for subsea routes, and we can improve the network capacity to help drive digital transformation for people, organisations, and industries around the world."

The best of both worlds:
Design freedom and IP protection

VPIphotonics empowers foundries and fabless companies by giving them the freedom to customise PIC designs using process design kits while also ensuring the security of intellectual property

BY ANDRZEJ POLATYNSKI, STANISLAU SAVITSKI, CHRIS MALONEY, AND ANDRÉ RICHTER FROM VPIPHOTONICS

IN RECENT YEARS, rapid advancement in the PIC industry has led to the emergence of many advanced technological platforms for photonic chips. Those platforms are commercially available to enterprises and scientific institutions, often after passing long development cycles. Modern photonic design automation (PDA) tools provide access to these technologies via professional software environments, which support the design of application-specific photonic circuits and systems with foundry-dedicated building block libraries, better known as process design kits (PDKs). For instance, this industry ecosystem allows end users to create PICs whose spectral range of operation extends beyond the C-band, enhancing their use in telecommunications and data transmission networks, sensor systems, and biomedical devices.

However, since there is a need to balance customisability with intellectual property (IP) security, end users rarely have complete freedom in how they use PDKs. Photonic foundries that open their technology to third-party users specify stringent constraints describing their fabrication processes and design rules. Typically, only limited building block geometry and performance data is shared, as these details represent critical IP belonging to a foundry, collected after many years of development. Foundries limit the information accessible to end users to safeguard their proprietary knowledge, meaning that end users can often use only a basic subset of the platform's capabilities. They are usually also restricted to utilising predefined and optimised building blocks, providing only a few parametrised attributes to design their PIC.

To enable the broadest range of applications, and fulfil the PIC industry's needs, PIC designers will need access to more flexible PDKs, but there are two main challenges to overcome. First, there needs to be a way to customise existing building blocks without breaching the foundry's IP. Second, end users need to be able to create new custom building blocks, either based on device-level simulations or experimental data. Solving these issues would allow the designer to supplement existing PDK libraries with new building blocks, opening a wide range of new applications.

This is where VPIphotonics comes in. The company's solution is to provide a framework for generating custom PDKs, allowing designers to enrich existing commercial PDKs and to create new PDKs for other PIC platforms. This framework offers its users complete freedom to customise an existing PDK, allowing them to add complementary building blocks and enabling fabless companies to develop their own internal PDKs while protecting their IP.

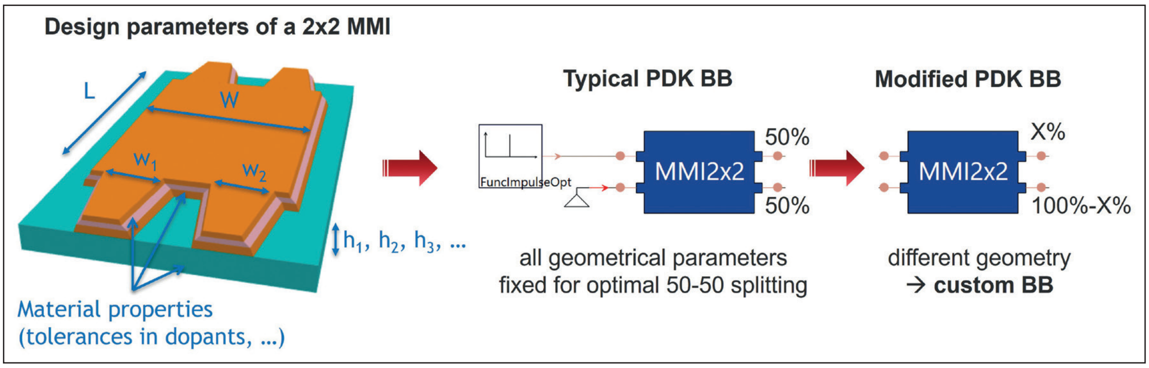


Figure 1. Customisation of the PDK building blocks (BBs) based on the example of an imbalanced 2x2 multi-mode interferometer (MMI).

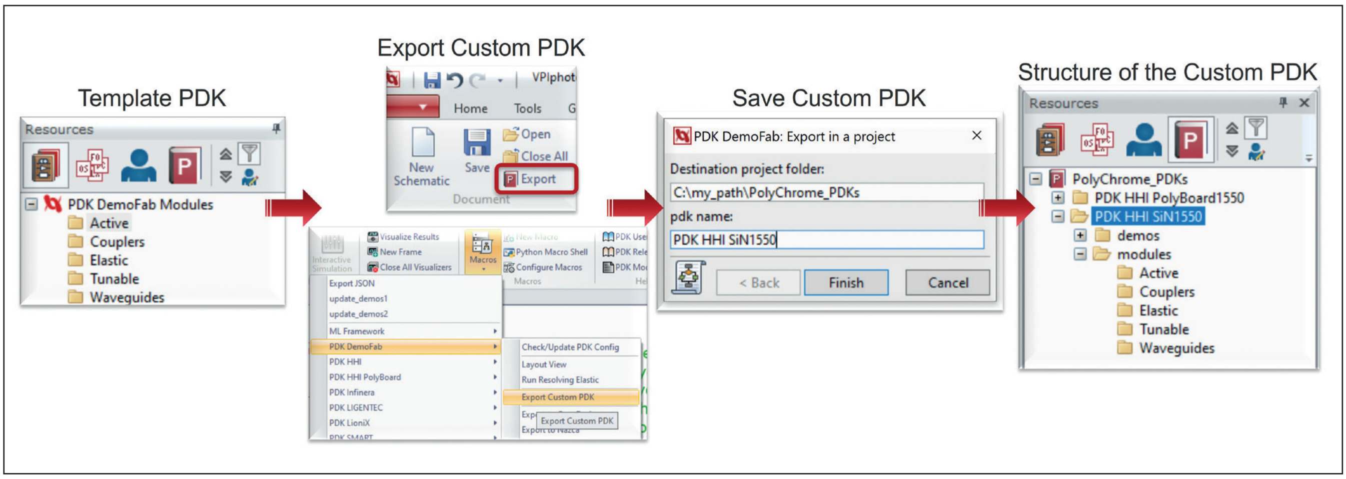


Figure 2. Generation of a custom PDK in VPIcomponent Maker Photonic Circuits.

Custom PDK generation

The process of generating a custom PDK is depicted in Figure 2, where the starting point is a demonstration library, here called PDK DemoFab. The user can specify a custom PDK name to create a new library, which includes all the necessary features of a standard PDK, including design automation macros, custom user interface toolbars, building block templates, and their links to layout descriptions. This process can be further customised to adapt the template models to the designer's unique requirements.

Moreover, users can add modules from commercially available PDKs. All added foundry components are directly encrypted to protect the foundry IP, and the user can automatically encrypt their custom building blocks to protect their own IP when shared as part of a custom PDK. Usage of the foundry components typically requires a confidentiality agreement with the fab and the allocation of a software license dedicated to the foundry PDK. Customised building blocks are licensed under the custom PDK framework and can be encrypted directly by the user. Thus, sharing those components does not require additional licenses and can be done directly by the user who developed the custom PDK.

An essential feature of professional circuit design tools is the capability of simulating fabrication tolerances. Therefore, just as with standard foundry PDKs, tolerances can be included in custom PDK libraries by adding the performance distribution directly to the description of a building block. The design process and challenges are identical in custom and commercial foundry PDKs and are described in detail in previous literature [1].

Design workflow, implementation, and interfaces

The workflow for using a custom PDK is equivalent to that of a standard PDK, utilising a layout-aware schematic-driven design methodology, as shown in Figure 3. The designer can use custom building blocks and standard PDK components to create a circuit design that can be simulated and further optimised. The user can also perform a tolerance analysis of their design. Thanks to the layout-aware simulation approach, the layout of the designed chip can be directly verified and visualised from the schematic perspective at any time. Moreover, the designer can utilise "elastic" components [2], ensuring that the waveguides used to connect building blocks will be automatically routed to fulfil the design requirements.

A typical simulation PDK must include building blocks verified by the foundry with proper interfacing between the simulation model and the device layout. The requirements are the same for a custom PDK, but now the PDK designer is responsible for the functional building block instead of the foundry. To ensure that the custom module performs correctly, designers must rely on their knowledge from previous foundry runs or device-level simulations. Characteristics from these sources can be included in the PDK library, allowing for circuit and system-level designs. The interface between the layout and simulation tool means that, with the press of a single button, the layout can be automatically exported from the simulation schematic. The designer can define a custom layout description compatible with a foundry's layer definition. Within the custom PDK framework available in VPIcomponentMaker Photonic Circuits, the interface includes templates for PDK module generation with example layout descriptions in several layout tools, as shown in

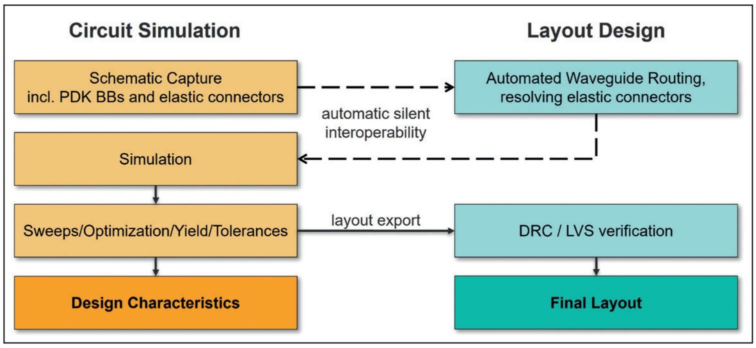
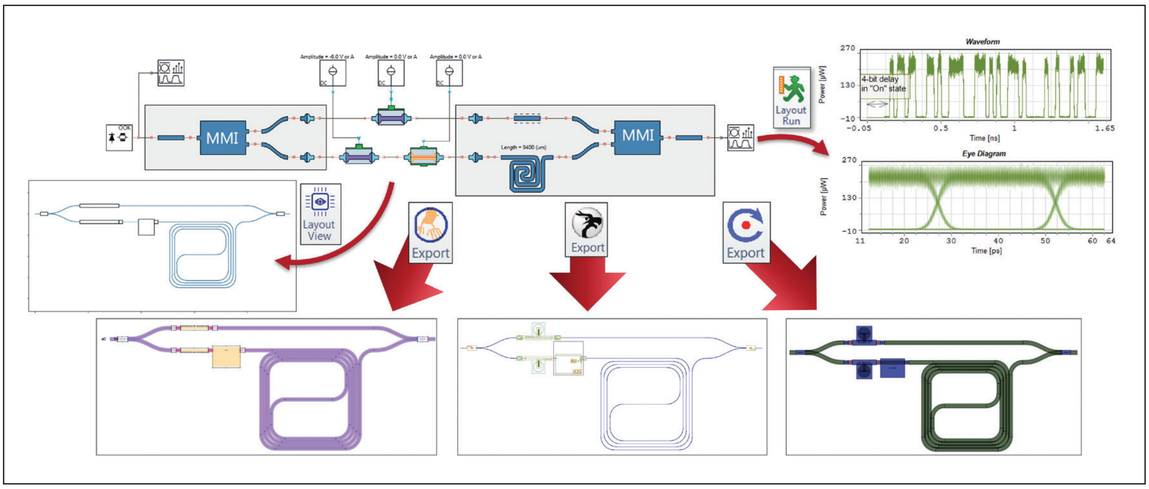


Figure 3. Block description of the layout-aware schematic-driven design methodology and its implementation with VPIcomponentMaker Photonic Circuits [2].



➤ Figure 4. Demonstration of the automated export from the simulation schematic to various layout tools.

Figure 4. Furthermore, dedicated macros can help the designer build custom PDK building blocks automatically by loading data files in a standardised format or via the interface with a device-level simulation solution called VPIdeviceDesigner.

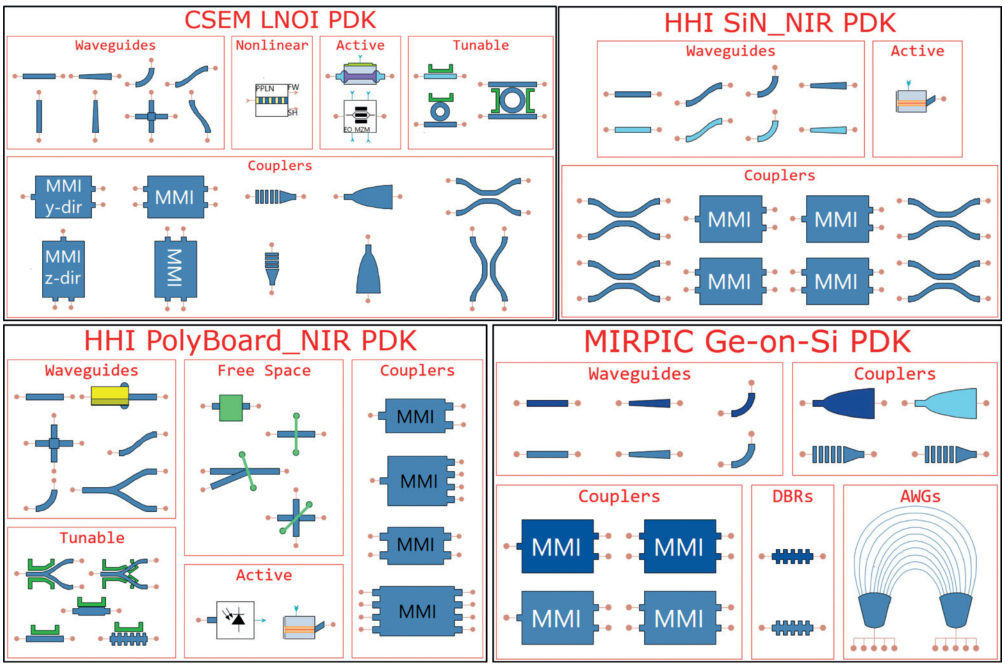
Many platforms, one solution

Another advantage of the custom PDK is that it is inherently platform agnostic; users can easily adapt it to any material, operational wavelength, and manufacturing process. Within the current state of the art, custom PDKs have been demonstrated for various platforms, including indium phosphide, lithium niobate, polymer, silicon, silicon nitride, and germanium on silicon. Several examples are shown in Figure 5. Achieving both flexibility for PIC designers and IP security presents an inherent challenge for the end users of PDKs, but VPIphotonics' custom PDK framework provides a flexible solution for foundries and fabless companies alike. Enabling the customisation of foundry building blocks and the development of customised PDK libraries, this solution offers all the features of a typical foundry PDK, including IP protection, while being easy to share and giving designers the freedom to add and adapt building blocks to their specific needs.

FURTHER READING / REFERENCE

➤ [1] André Richter, et al., "Schematic-driven PIC design process considering manufacturing tolerances," Proc. SPIE 11690, Smart Photonic and Optoelectronic Integrated Circuits XXIII, 1169004 (5 March 2021); https://doi.org/10.1117/12.2577209

➤ [2] S. Mingaleev, et al., "Rapid virtual prototyping of complex photonic integrated circuits using layout-aware schematic-driven design methodology," Proc. SPIE 10107, Smart Photonic and Optoelectronic Integrated Circuits XIX, 1010708 (20 February 2017); https://doi.org/10.1117/12.2252001



➤ Figure 5. Demonstration of custom PDKs dedicated to various platforms developed under European and regional R&D projects, including polymer, silicon nitride (PolyChrome project, polychrome-berlin.de), lithium niobate (ELENA project, www.project-elena.eu), and germanium on silicon (MIRPIC project, www.mirpic.eu). Various waveguide colours determine different modules' cross-sections.

Supporting AI with new optical modulators

To cope with surging internet traffic, datacentres can be upgraded with electro-optic polymer modulators. This technology requires no changes to the rest of the infrastructure and has performance headroom to support continual upgrades for decades.

BY MICHAEL LEBBY, CHIEF EXECUTIVE OFFICER, LIGHTWAVE LOGIC

THERE HAS long been talk of AI's transformative potential, and the last year has made it clearer than ever that the AI revolution has begun. The technology is already reshaping many aspects of our daily lives as end users. But behind the scenes, AI is also impacting the industries and infrastructure that play a role in providing access to it. And photonics is no exception.

To understand how this trend might affect photonic integrated circuits (PICs), we must first consider how AI relates to the internet and optical networks. Although we would all like to see optical computing, and optical computational processing, this holy grail has yet to become widely commercialised like semiconductor microprocessing units (MPUs) or graphical processing units (GPUs).

For this reason, the industry currently uses photonics to send the information from MPUs and GPUs from source to destination, with fibre optic cables that form the architecture of the internet and optical network.

At the highest level, electronics does the computational processing, and is expected to continue doing so in the near future, while photonics helps convey huge amounts of generated information optically.

The photonic components that make up the communication are laser diodes, modulators, and photodetectors. These components are now becoming integrated into PICs, typically with one PIC transmitting data, and another receiving it. PICs are found in transceiver modules, which, in turn, are found in the switches and router equipment that make up a datacentre.

As surging AI usage demands higher data rates, PICs are therefore one piece of the puzzle in upgrading datacentres to meet that demand. As well as looking at the challenges posed by AI, this article describes how electro-optic polymers are driving new hybrid technologies for increased PIC performance.

Skyrocketing data rates

It is widely expected that AI will substantially increase the bandwidth required to operate the internet at the speed users have come to expect. This is because AI users are increasingly experimenting with innovative ways to drive new applications which require large amounts data to be synchronously exchanged between switches and users.

In the 1980s, it would typically take tens of minutes to download a 10 Mb file, but this can be done today in less than a second. Videos were virtually impossible to download and send around back then, but today we share short video clips, even movies, with friends and family regularly. Thanks to these advances, images and videos have become the largest generators of internet traffic. But it now seems likely that AI will surpass them. Whereas it took Netflix 3.5 years to get to one million subscribers, it took ChatGPT just five days to reach the same milestone.

Additionally, over the past 60 years, computing power in high computational processing systems has skyrocketed. Its growth initially doubled every 3-5 years [1], and, since about 2020, it has increased by over an order of magnitude, to a doubling of computational power every 3-4 months in terms of petaflops [2]. Naturally, this puts strain on the infrastructure supporting it.

All parts of the network need to cope with increased quantities of information, from the fibres that optical signals travel down to the places performing optical routing and switching – which typically happens in datacentres. The financial cost for internet and optical network operators will be substantial. Further, it is not only the increased performance of sending information through the optical network that needs attention, but also ensuring power consumption is kept at reasonable levels, as data rates increase.

Datacentres and the internet

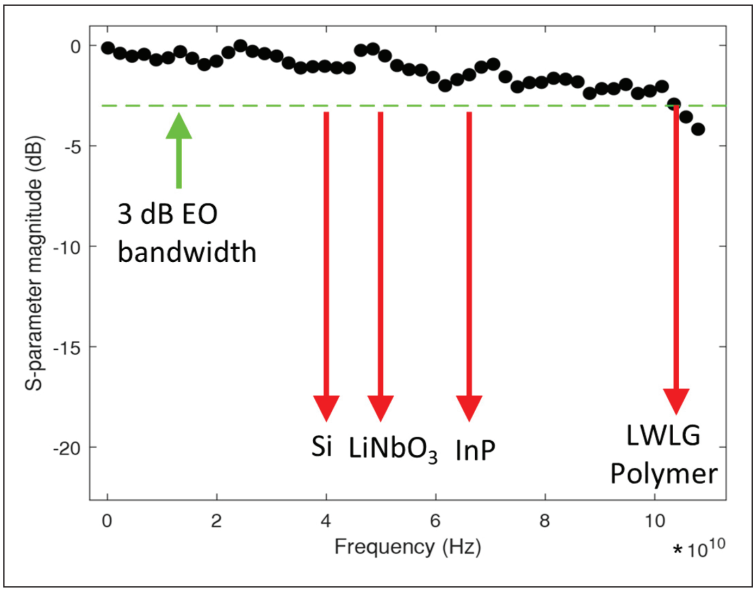
As AI becomes increasingly integrated within our daily activities, we are already seeing datacentres being upgraded today in a fashion that the industry has not seen before. This feels reminiscent of the internet bubble of 2000.

As we are in a growth stage, we don't yet know if the trend is bubble-like. However, it is worth noting that the markets for the internet bubble collapsed largely due to poor growth and business. What is different today is that we are seeing datacentre companies already investing to update their equipment with solid, committed capital expenditure. This effect looks to be stronger than in 2000 and could drive robust growth for electronic computational processing chips and photonic chips over the next decade.

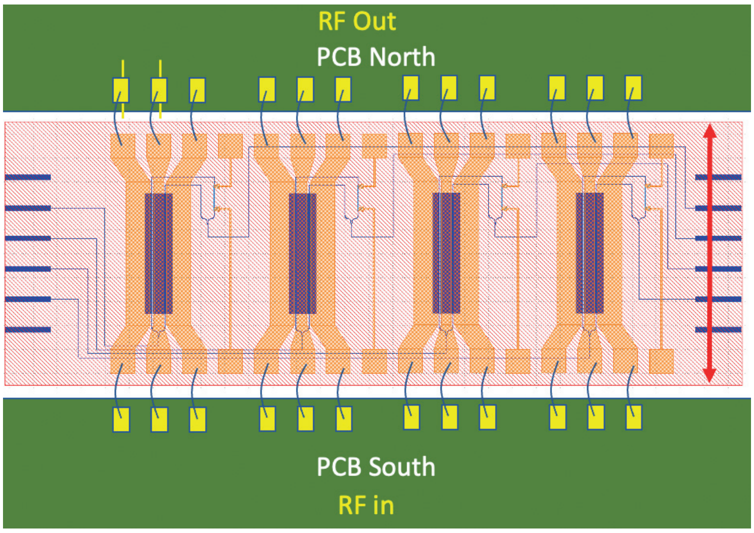
What is interesting from a photonics standpoint is that datacentre operators have pretty much ignored the photonics node of 400G and are focusing on 800G and 1.6T (or 1600G). Just two years ago, every market analyst covering datacentres, and more specifically optical transceivers, was forecasting huge growth in 400G with optical transceivers as the main vehicle. Datacentres were looking at 4-channel 100G and 8-channel 50G as key solutions for aggregation into 400G. Today, this has all changed; forecasts for 400G are flat if not declining, and the focus is on 800G.

Unfortunately, the industry is not ready for 4 lanes at 200G, so initial prototypes demonstrated at major industry trade shows in 2023 are implementing 800G as best they can: using 8 channels with 100G lanes. However, the move towards 200G lanes is accelerating, pulled along by the excitement around AI, and by datacentre operators' motivation to upgrade equipment as quickly as possible. Simply creating a 4-channel 200G-lane optical transceiver is not easy. Many in the industry are now realising

➤ Datacentres need to upgrade to meet the unabating demand for higher data rates.



➤ High EO S21 RF bandwidth measurement of an electro-optic polymer modulator with approximate comparisons of other materials.



4-channel 200G PAM4 1310 nm PIC design using electro-optic polymers.

that the photonics need to upgrade also, and 20-30 GHz optical 3 dB bandwidth modulators for the transmitter PIC are too slow.

In general, optical modulators are components that switch and modulate light, and there are millions of them embedded in the internet. However, the higher data rates necessitated by increasing AI usage are pushing incumbent semiconductor solutions to their limits. This has led the industry to look for faster optical modulators that have 3 dB optical bandwidths double or triple the bandwidths of today's solutions (silicon, indium phosphide, lithium niobate).

Further, optical transceivers need to rein in their power consumption. While the majority of power is consumed by the electronics, there are still significant savings to be made through more efficient use of PICs. Lastly, another major factor for optical transceivers is size or footprint; as transceiver sizes are shrinking, smaller-footprint photonics is key.

These requirements of higher speed, lower power, and smaller size create big challenges for both the electronics and photonics industries. The electronics industry is addressing this via linear pluggable optics (LPO) to reduce power consumption. Meanwhile, the photonics industry is turning to innovative optical modulator technology for PICs.
One promising solution is electro-optic polymers, which offer a hybrid solution, as the material is organic and can be spun or dropped onto an existing PIC platform made of silicon or another material. The polymers are physically positioned in front of lasers that are also part of the PIC. Excitingly, electro-optic polymers significantly outperform semiconductor technologies being used in the internet today. With optical 3 dB bandwidths exceeding 100 GHz, and that have been measured to over 250 GHz, electro-optic polymers are well positioned to enable 800G, 1.6T, 3.2T and even higher speeds over the next decade.

Additionally, with drive voltages in the sub 2 V that range down to the 0.5 V level, this technology minimises power consumption effectively. And finally, with electro-optic modulator device structures such as the slot, footprint sizes are extremely tiny, and can therefore work with many different form factors for optical transceivers, within both pluggable design as well as co-packaged, on-board optics design.

Lightwave Logic's electro-optic polymers

Lightwave Logic [3] has been pursuing this potential of electro-optic polymers to replace existing modulators, using its patented Perkinamine molecular compounds – state-of-the-art organic materials that can be used to create the polymers. The company starts with its proprietary organic chromophores, which are a key ingredient of polymers, and deposits them onto a silicon chip to add an optical modulator function.

During fabrication, the polymers are aligned through brief application of a high voltage, enabling ultra-fast modulation at ultra-low power. Both the polymer materials and the silicon PICs they are incorporated into perform stably and reliably, meaning they are well positioned to displace current semiconductor technologies.

The silicon-based chips used are about a few millimetres on each side, and they act as the engine of a fibre optic transceiver, which is a core component of switches and routers in datacentres. One of the advantages of using polymer modulators can be understood through the analogy of automotive vehicles; using these modulators is akin to upgrading a car simply by replacing its engine with a better one, while keeping the rest of the structure the same. Similarly, polymer modulators can improve the fibre optic modules, while leaving other parts of the datacentre infrastructure as they are.

Thanks to velocity-phase matching of the electrical signal and the optical beam, electro-optic polymers

During fabrication, the polymers are aligned through brief application of a high voltage, enabling ultra-fast modulation at ultra-low power. Both the polymer materials and the silicon PICs they are incorporated into perform stably and reliably, meaning they are well positioned to displace current semiconductor technologies

have inherently high performance, and, crucially, the potential for this to increase even further in later-generation products. Technology with this performance headroom is essential to support the continual upgrading that the internet and optical networks need. Conversely, competing technologies – both those that are incumbent and those competing for new business – may not work well beyond the maturation of the current generation of technology.

One way to visualise this performance potential is to consider the same baseline of 3 dB optical bandwidth in each modulator. Over the past 10 years, semiconductor modulators have generally been achieving around 20-30 GHz, but recent enhancements to both silicon and indium phosphide designs have raised their performance to 40-50 GHz, occasionally approaching 60 GHz. In general, to achieve 100G (or 100 Gbaud NRZ) and 200G (or 100 Gbaud PAM4) encoding, a 70 GHz 3 dB optical bandwidth is required.

Today, many datacentre operators are seeking technologies that can achieve 200G per lane. Since polymer modulators can reach 70 GHz, and even 150 GHz – about double current lane rates – they could pave the way for 1.6T with 4 lanes at 400G. Moreover, when enhanced with plasmonic designs, modulator devices using Lightwave Logic's electro-optic polymer material have exhibited 3 dB bandwidths exceeding 250 GHz.

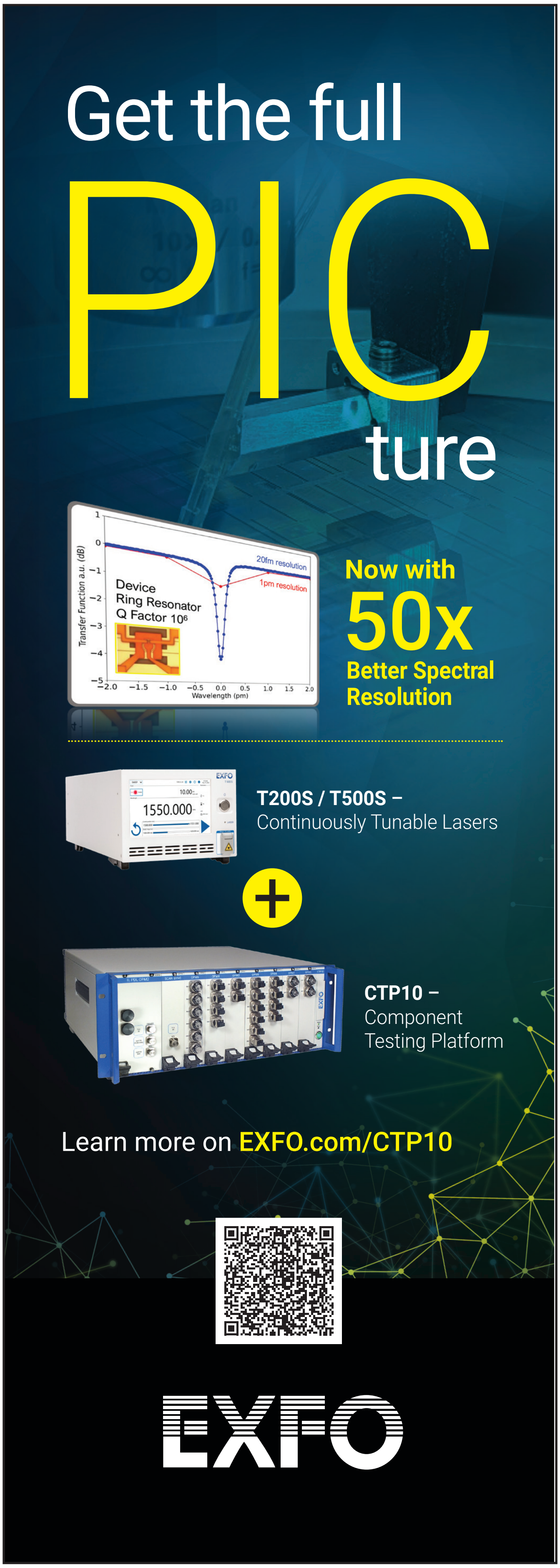
Polymer modulators for AI

It is the potential performance of new technologies in photonics that will enable datacentre operators to navigate the demands of AI. Further, a new technology platform that can turbo-boost existing transceivers without changing the network architecture and infrastructure is a low-cost approach to speed up the internet, keep power consumption at bay, and keep the footprint and size the same.

The potential for Lightwave Logic's polymer technology to make datacentre operators more competitive with their equipment upgrades has never been higher. As AI changes our lives, we face grand challenges ahead, but we have the motivation to utilise our toolkits to meet those challenges. I'm sure this will involve developing numerous new technologies, but electro-optic polymers are certainly an excellent candidate to move the needle forward for all of us.

FURTHER READING / REFERENCE

- [1] OpenAI, The Economist, Data Center World, "Computing power used in training AI systems"
- [2] https://datacenters.lbl.gov/sites/default/files/Masanet_et_al_Science_2020.full_.pdf
- [3] https://www.lightwavelogic.com



Caswell Science and Technology Park was originally built in the countryside to avoid aerial bombing during WWII. However, today, this location means there is plenty of space for it to grow.

Lumentum expands Caswell fab, reflecting company-wide plans for growth

Lumentum is due to complete a 25 percent expansion of its wafer fab at Caswell Science and Technology Park in April this year. Editor, **Laura Hiscott** visited the facility to learn how these activities fit into the company's wider strategy for growth.

IIN THE HEART of the UK countryside, surrounded by fields and more than half an hour's drive from the nearest train station, is a large campus where around 400 people gather to work each day. Caswell Science and Technology Park certainly seems far from the hustle and bustle of a city, but its remote location belies the integral role it plays in the modern world.

The site is a 3-inch indium phosphide fab belonging to the global photonics company Lumentum, and it manufactures photonic chips for data transmission over optical fibres – essential components underpinning the internet and our digital lives.

Caswell's rural setting is a historical legacy – it was originally developed during the Second World War, when its founder was encouraged to build it far away from London and the risk of air raids. Today, however, being surrounded by empty fields offers an entirely different advantage: there is plenty of space to grow. And Lumentum is taking full advantage of that potential.

After gaining Caswell as part of its acquisition of optical manufacturing company Oclaro in 2018, Lumentum initially leased the land it was situated on. But in September 2023, the company bought the land, and is now investing in significant upgrades. Chief among these is a major expansion of the cleanroom, which is due to be completed this spring, increasing its size and production capacity by 25 percent.

These actions affirm the facility's value to Lumentum, and its key role in the company's plans moving forward. "Lumentum's investment in equipment, infrastructure, and people at Caswell will be key to the company's continued success," says Sal Pavone, vice president of operations. "We are committed to make this the centre of excellence for the manufacture of photonic products.

Many of our key products are manufactured at Caswell and are dependent on the leading-edge technology that is developed here on site." Indeed, Lumentum's 800G ZR+ and 400G ZR+ 0 dBm transceivers, and 130+ GBaud components and Smart TROSAs, which were on display at ECOC 2023 in Glasgow last year, all contain chips from Caswell. They include, for example, InP modulator chips that incorporate multiple Mach-Zehnder modulators and on-board optical amplifiers, as well as on-chip photodetectors for monitoring and control functions.

Paul Johnson, senior director of product line management for cloud and networking, points out that these chips offer several key advantages of InP over other PIC platforms, enabling differentiated performance for cloud and networking. "They have very high-speed capability beyond 100 GHz electro-optic bandwidth, optical light generation and amplification, and ease of integration of these capabilities," he says. "We can combine the best of laser and modulator or receiver performance without compromise, enabling optical fibre data transmission at 800G per fibre or higher, a 1,000 times greater capacity than the typical fibre-to-the-home connection."

Global network

Caswell is one of eight manufacturing facilities that Lumentum operates across three continents, with many more non-fab sites around the world. This global presence means that the company can be close to all its various customers. While different locations may have a different focus, they all perform several functions, and employees at different sites work together towards the company's overall goals.

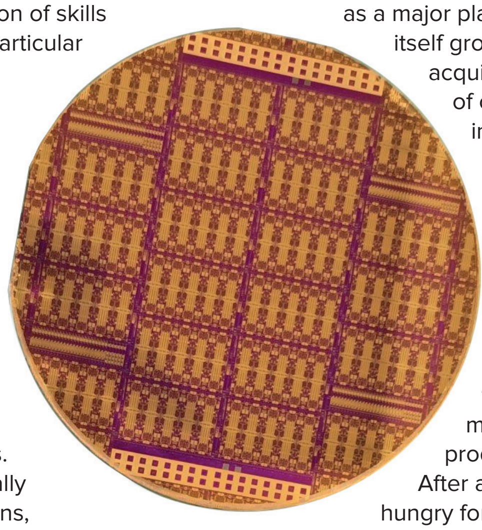
An important advantage of having the same products manufactured at multiple sites is the redundancy and the associated supply chain security that this distributed structure offers. Additionally, forming teams of people across the different locations, rather than limiting them to employees at the same site, widens the possibilities for finding the optimal combination of skills and perspectives needed for a particular project.

The chips made at Caswell are generally transferred to Lumentum's other facilities for packaging into final products. However, in addition to producing photonic chips, the site also plays an active role in developing the company's future-generation products. For this reason, it has a smaller-scale assembly line to enable rapid development of prototypes. There are R&D teams based locally working on improving chip designs, process integration and optical sub-assemblies (OSA). Caswell also has R&D teams researching the integration of chips into larger components and developing the test infrastructure. "The need for innovation to move to higher baud rates doesn't stop," comments Lloyd Langley, vice president of R&D. "I remember introducing products with lasers operating at 10G many years ago. Now we have products operating at 130 Gbaud, and advanced technology work aimed at 260 Gbaud for 1.6T per laser applications. These higher rates are operating with RF signals exceeding 100 GHz. In addition, other aspects such as minimising power consumption are an important consideration."

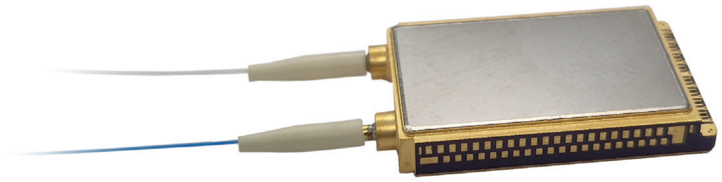
➤ Caswell manufactures indium phosphide optical modulator chips, which can be found in many of Lumentum's products.

Company-wide growth

Besides affirming Lumentum's investment in the region, the expansions underway at Caswell also reflect wider growth across the company. Last year, for example, it announced that it had increased manufacturing operations and R&D capabilities at its site in Slovenia, which focuses on custom optical fibres found in many Lumentum products. Furthermore, the company has made multiple acquisitions in recent years, cementing its position as a major player in the industry, which is itself growing. Among its most notable acquisitions are two manufacturers of optical modules for datacentre interconnects: NeoPhotonics in 2022, and Cloud Light in October last year.



As Lumentum continues to grow, in terms of both its manufacturing and research capacities, it has every reason to believe that there will be demand for as much volume and as many product updates as it can deliver. After all, our modern lifestyles are hungry for higher data rates; streaming



➤ At ECOC 2023 in October last year, Lumentum introduced a 130+ GBaud Smart TROSA, which incorporates components manufactured at Caswell.

services and the rise of cloud computing were already fuelling an unwavering rise in internet traffic, even before the explosion of widely available AI and machine learning applications in the past few years. As computational workload increases continue to outstrip Moore's Law, network bandwidth will need to expand by as much as an order of magnitude to handle all that information, and using optics can help to achieve that.

"AI is driving a need for scalable interconnect solutions within datacentres. Intra-datacentre transceivers, operating at 400G to 1.6T, will grow to be a $10 billion market by 2028," explains Johnson. "The addition of Cloud Light to Lumentum helps us address that demand. As a combined company, we believe we can bring advantages such as first-to-market high-speed transceivers customised for the hyperscale market, utilising in-house manufacturing for lowest cost at scale, with the security of supply that the market requires."

As the industry sets its sights on securing bandwidths of 800G, and moving towards 1.6T, Caswell and Lumentum are striving to stay ahead of the game in providing the supporting infrastructure. "Our process and design teams work at the cutting edge of compound semiconductor wafer manufacture and performance of PICs," says Langley. "We have design experts in semiconductor materials, optical waveguides, very high frequency electromagnetics, test, and reliability."

Yet, as the company and its technologies evolve, one thing looks set to remain the same. As Pavone puts it: "Caswell has been producing leading edge technology in the UK and will continue to do for years to come."

ESG Commitments

AS WELL as developing its facilities and technology, Lumentum is evolving several other aspects of its operations too. In a time of greater emphasis on corporations' environmental and social responsibilities, the company has been redoubling its commitments to sustainability and to its employees.

Caswell is one of several Lumentum sites running on 100 percent renewable electricity, with the latest three locations to make this transition being Navanakorn, Thailand, and two sites in the US: San Jose, California and Dallas, Texas. Overall, 61 percent of electricity used by the company's operations for last year was from renewable sources.

"Lumentum remains a leader in reducing its carbon footprint and continues to invest in green programmes and equipment as part of our corporate responsibility agenda," says Pavone.

Going beyond the initial impact of devices during the manufacturing stage, Lumentum has also begun to conduct energy life cycle assessments of its products, accounting for aspects including, manufacturing, transport, and usage. The assessments carried out so far have highlighted that the largest proportion of emissions associated with a product occurs in the use phase, motivating Lumentum to continue improving the energy efficiency of the products themselves, as well as the facilities that manufacture them.

And finally, the company is also helping its employees to reduce their individual carbon footprints by facilitating more environmentally friendly choices. Several EV chargers have been installed at Caswell, for instance, and staff in the UK can also lease an EV and participate in a car-pooling programme. As for the social aspect of "ESG," Lumentum has been taking steps to invest in its people as much as its facilities. The company has an active Diversity, Inclusion & Belonging (DIB) Council with a presence at sites across the world. Nadege Rebuffie, OSA design manager, is a member of this council, and says that its initiatives are strongly driven and supported by the leadership team, including CEO and president, Alan Lowe, who joined the coalition CEO Action for Diversity and Inclusion in 2022.

"As a global company, Lumentum values creating an inclusive environment for all employees. Each employee's unique experiences enhance our competitive edge," says Rebuffie. "Our DIB programme aims to enhance diversity across our workforce, with progress regularly reviewed."

To this end, one of the main activities of the DIB Council is establishing and supporting Employee Resource Groups (ERGs), which create spaces for staff facing specific challenges to come together and be heard and supported. For example, one ERG with a presence at Caswell is a group called Women@Lumentum, which was established to promote professional development and career advancement for women.

Two other ERGs that are active at Caswell are Working Parents and Caregivers@Lumentum, which supports staff juggling caregiving responsibilities with their work, and Next-Gen Luminaries@Lumentum, which helps early-career employees settle in through regular social activities, tutorials on soft skills, and access to a "Survival Guide" for their first days at the company.

Three ways photonics can catalyse hardware evolution for datacoms

As the computing industry faces ever-growing demands for higher speeds, photonic technologies can facilitate the necessary hardware evolution, through hybrid integration, chip disaggregation, and enabling 200G per lane.

BY SURESH VENKATESAN, CHIEF EXECUTIVE OFFICER, POET TECHNOLOGIES

OF THE MANY THINGS artificial intelligence has upended, the microchips industry may be the sector that has seen the most disruption. AI applications are gluttonous for speed and power, and, as the computing industry has raced to meet the demand, it has become apparent that existing solutions will not suffice. There is a growing sense of urgency across the industry as it becomes increasingly clear that optical interconnects enable large-scale AI compute and other data-intensive workloads to operate at bandwidths, energy efficiencies, and latencies that are unachievable through today's electrical-based interconnect technology.

Sixty-plus years after engineers commercialised the first monolithic integrated circuit chip, the explosion of AI and the insatiable demand of hyperscale datacentres for more bandwidth have offered a remarkable opportunity for chipmakers to move beyond traditional solutions in a dramatic way. While materials such as indium phosphide and gallium arsenide have been used in commercial applications for decades, the growth of material-agnostic optical platforms has presented the chance to transition from "silicon-only" to "silicon-plus" designs. Whereas the absolute need for silicon will never wane, the slowing of Moore's law has opened the door to "augmented silicon" technologies.

These approaches aim to enhance silicon's innate capabilities and advantages through the incorporation of new materials (germanium, indium phosphide), new architectures (chiplet and hybrid system partitioning), and 3D packaging and assembly. That's the reality many manufacturers and industry observers have recognised so far this decade.

One of the ascendent technologies is photonics, with many companies currently in the midst of identifying optical computing solutions that will drive the next generation of device manufacturing. The following are three key areas where photonics — which was once a boutique niche — is positioned to be the catalyst for large-scale growth in hardware applications for AI and hyperscale datacentres.

Hybrid Integration

With a hybrid-integration approach to wafer-scale chip design, developers can assure those manufacturers who have built their entire operations around silicon that the coming wave of product design will have several familiar pieces. In this way, hybrid integration allows for a seamless transition to future paradigms.

At POET Technologies, our "semiconductorisation of photonics" approach is a form of hybrid integration. That term is meant to underscore the intention behind our designs: to make it as straightforward as possible for the semiconductor industry to move to photonics-first solutions that are material agnostic. Our elegant design eliminates dozens of parts because we rely on passively attached optical components to move data, leveraging the broad semiconductor industry's investments in advanced packaging technology.

Based on a "silicon for photonics" interposer platform, POET's products offer manufacturers a critical piece of the puzzle of achieving high integration, especially for 1.6T, 3.2T, and beyond. With its "silicon for photonics" hybrid integration approach, POET is focused on addressing the shortcomings of more conventional silicon photonics solutions. To this end, POET's technology includes features like passive alignments, low-loss multi-layer waveguides, and integrated optical passives like multiplexers and de-multiplexers that have the flexibility and fungibility to address a broad range of market requirements.

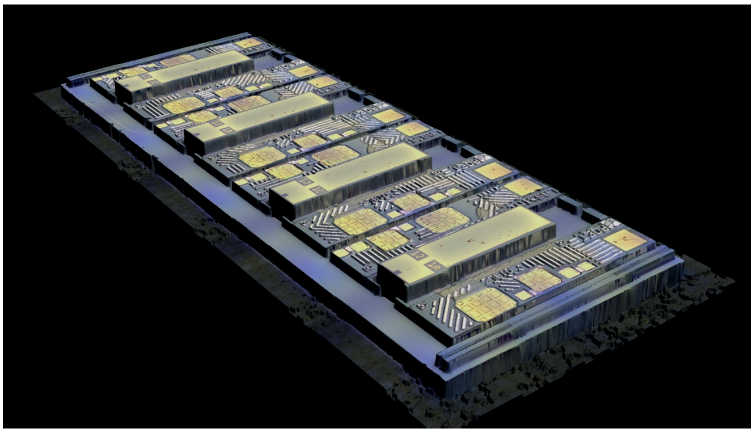
Such flexibility and integration are crucial, because serial data communication channels have not been able to keep pace with growing bandwidth. The number of communications lanes increases as data rates increase. Those manufacturers who rely on conventional discrete assembly are challenged to economically deploy products that perform consistently within eight-channel architecture – which is needed for 800G speeds – and are incapable of accommodating 16-channel lanes – which is necessary for 1.6T and 3.2T, the speeds of the future.

POET achieves 16-lane capability by using 3D assembly techniques and stacked non-interacting waveguides. It's a simplified process that drives data communications at unprecedented speeds.

200G per lane

Moving data simultaneously through more lanes is one way that photonics brings superior capability to the market. Another is its ability to increase the speed that can go through each of those lanes. Conventional speeds are currently 100G per lane but photonics can operate at 200G per lane, busting the bottlenecks that cause latency and high power consumption. At 200G per lane, AI and hyperscale datacentres and cloud networks can surge towards new capacity limits.

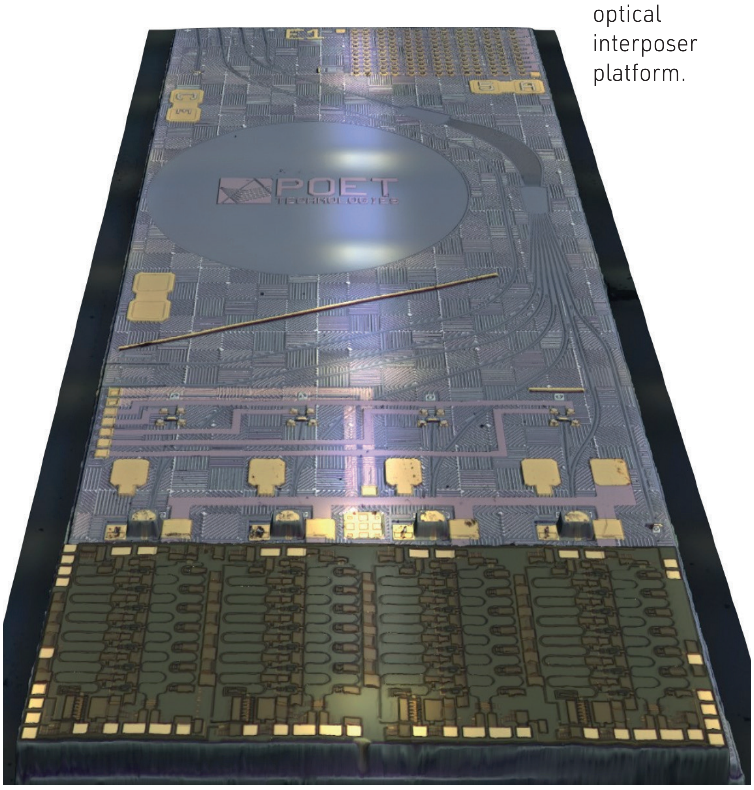
Among the giants touting the merits of 200G per lane solutions is Broadcom, which demonstrated



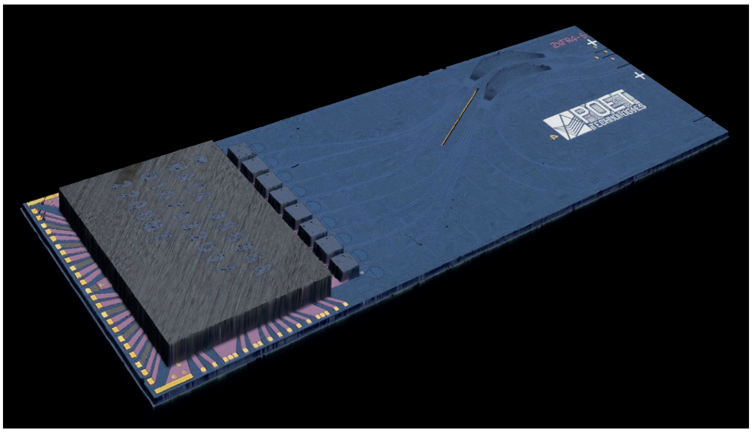
➤ The POET Technologies O-Band LightBar, shown with lasers assembled, is developed to help AI manufacturers bring next-generation products to the market.

an optical transmission link using that configuration at OFC 2023. "The demo not only validated the feasibility of 200G per lane optical links for datacentre networking, but also reassured the ecosystem that 1.6T optical modules can cost-effectively be deployed to address the growing bandwidth demands in datacentres supporting AI applications and workloads," wrote the company's master engineer Khanh Lam.

A key component needed to achieve 200G per lane is an externally modulated laser (EML). Already, more than 90% of 800G modules in production today use EMLs, which present the primary path to 200G per lane solutions. The performance of EMLs and the industry trust they have attained are reasons why POET has retooled its optical



➤ The POET Technologies 400G Infinity Transmit Chiplet demonstrates the flexibility of the company's optical interposer platform.



The POET Technologies 800G solution includes 2xFR4 receive optical engines with a trans-impedance amplifier and photodiodes.

interposer platform to include both EML and DML (directly modulated laser) solutions.

Disaggregation

"Chip disaggregation, or chiplets, offers an alternative to the traditional monolithic SoC scaling approach. Aggregating multiple chiplets to perform the function of a single monolithic IC de-risks the overall system by reducing complexity and increasing yields," writes chip producer Rambus. With the conventional processor-centric computing architecture and copper interconnects, the chips based on 3 nm technology that have dominated semiconductor design for decades are approaching their physical limitations. The necessity for faster data transmission has gone beyond what these chips can capably deliver. As a result, disaggregation is going to push the need for photonic connectivity. It's already happening at Google, whose AI servers are exploiting disaggregation to connect to networks with 800G transceivers — making the search-engine leader the first company to commit to using that speed for its datacentres.

Products such as the POET Infinity chiplet, and the family of engines built from them, provide an answer for pluggable transceiver and module designs. The Infinity, a 400G transmitter chiplet, can be configured in a daisy-chain architecture to reach speeds of 800G (2x400G chiplets), 1.6T (4x400G), and beyond. As with all products built from the POET Optical Interposer, the Infinity chiplet includes a monolithically integrated multiplexer, and eliminates wire bonds and active alignments of components.

Photonics-first innovations such as those being introduced to the market by POET and other companies promise to pave a new path forward in the AI era. The industry is in the middle of an important stage as it develops new processes to power computing performance. The platforms and products that are adopted now are likely to be the de facto choices for chipmakers for decades to come.

Extremely high-power transmitters for access networks

Sources that combine a laser, a modulator and an amplifier in a single device are laying the foundations for high capacity access networks

BY HÉLÈNE DEBRÉGEAS FROM ALMAE TECHNOLOGIES

DUE TO THE PHENOMENAL rise of YouTube and TikTok, many are watching more content on-line. To accommodate this trend, there's been a tremendous rise in internet traffic, with this growth showing no sign of abating. Consequently, capacity has to increase throughout the fibre-optic network, from the long-haul links that span many thousand kilometres to the shorter connections, such as the optical access networks providing the 'last mile' between internet service providers and their customers.

Given this state of affairs, it's not surprising that optical access networks are continuing to be rolled out at great pace. And as well as this additional deployment, throughput is on the up – initially, transmission speeds were 2.5 G, recently they climbed to 10 G, and sometimes data rates are now as high as 25 G and even 50 G.

Unfortunately, increasing the capacity of optical access networks is more complex than it appears at first glance. While sources with higher optical modulation rates are essential, they are not the only factor that matters.

In addition, there's a need for a high optical power, because access networks – also known as passive optical networks (PONs) – have no optical amplification, setting them apart from other long-distance networks. This lack of amplification means that the losses resulting from propagation in the fibre and splitting among multiple end users ultimately limit both the network's geographical coverage and the number of its end users.

To optimise the capacity of PON networks, they must include highly sensitive photodiodes that detect the low optical power they receive, and transmitters delivering the highest possible output power. For current applications, such as 10G-PON, 25G-PON and 50G-PON, the modulated power in the fibre needs to be around 4 mW. However, to increase capacity, new access networks are demanding a modulated power of up to 10 mW in the fibre, with even higher values sure to follow.

For upstream transmissions – that is, transmissions from the end user to the network – O-band wavelengths are used. This spectral domain, which is around 1.3 µm, benefits from an absence of chromatic dispersion in the fibre. A lack of distortion of the optical signal results, enabling implementation of powerful yet low-cost transmitters on the user's premises. In this case, the most suitable source is the directly modulated laser: by simply modulating the electric current injected into the laser, modulation of the emitted power follows.

It's a very different story for downstream transmission, which involves the transfer of data from the network to the end users. Wavelengths used for this task vary, ranging from 1342 nm for 50G-PON to 1577 nm for 10G-PON. However, in all cases, there is significant chromatic dispersion in the fibre.

One troublesome consequence of this dispersion is that the quality of the signal that's emitted by directly modulated lasers is insufficient for transmission with an acceptable degree of errors. Due to this, externally modulated lasers (EMLs) are deployed for downstream transmission in access networks. This class of laser comprises two sections: a laser, powered by an electrical current, that emits a constant optical signal; and an electro-absorption modulator section, which is transparent at zero voltage, but absorbs light under a negative voltage. Through application of a modulated voltage, typically between 0 V and -2 V to the modulator section, successions of bits 0 and 1 can be transmitted at high data rates.

The downside of the EML is that it is more expensive to manufacture than the directly modulated laser. However, the additional cost is acceptable, because the component is only deployed in core network terminals and not on the user's premises. The EML has a high reputation, thanks to its capability to transmit a much higher quality signal: there is a strong power contrast between the 0s and 1s; and there is high spectral purity, ensuring the source is resistant to chromatic dispersion. Following continuous improvements to EMLs for access networks, the modulated power in the fibre now reaches the order of 4 mW, meeting today's needs.

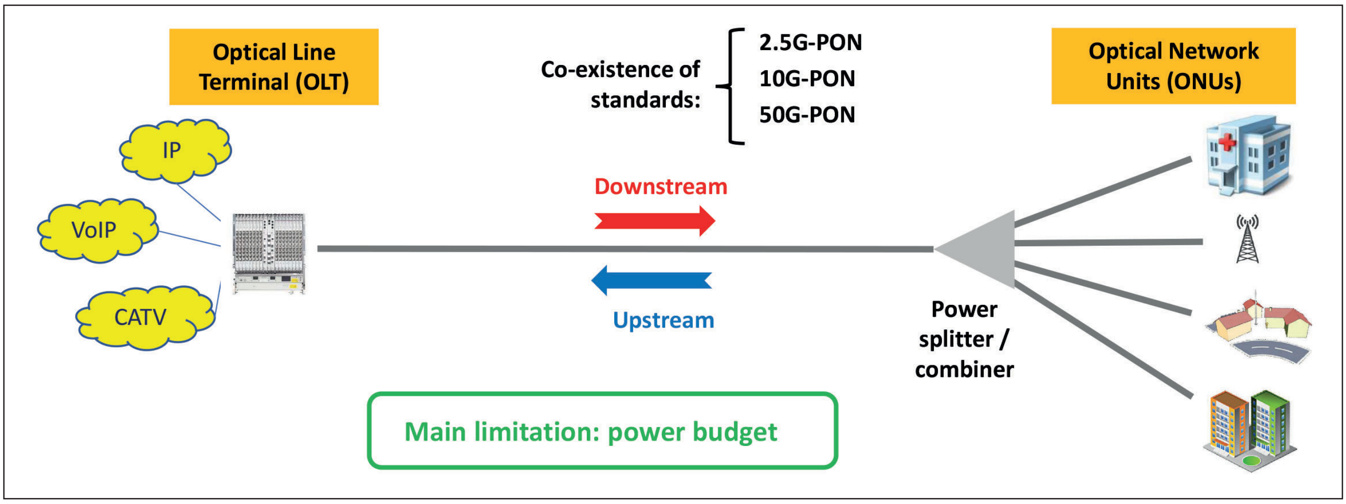
However, while the power provided by the EML is adequate for access network coverage, it is still a limiting factor. What's more, this weakness is only going to become more of an issue, as a further power increase is a key differentiator in next-generation high-capacity access networks.

A radical approach is needed to address this concern, because EMLs are getting close to the glass ceiling for their output power. Even if the power of the laser section is increased, it's not possible to maintain the performance of the modulator. That's because there is an intrinsic issue, associated with absorption of photons that create electrical carriers in the modulator. As the injected power increases to a very high value, carrier evacuation cannot keep up, so the carriers accumulate and screen the voltage that's applied to the modulator. Making matters worse, the photogenerated electric current creates an opposing electric voltage in the modulator supply circuit. Both these effects contribute to a distortion of the signal emitted by the EML, and impose modulation voltages that are too high for implementation in the system.

Amplifying concerns

Offering a way forward that allows the realisation of modulated powers of 10 mW or so is the addition of a third section to the EML: a semiconductor optical amplifier (SOA). With this refinement, injection of an electric current into the SOA ensures optical gain in this section through a multiplication of the photons that are passing through it. In theory, the SOA simply boosts the power emitted by the EML.

There are several advantages that come from this approach. First, the EML no longer needs to emit as much power, since there is now optical gain from



➤ Figure 1. An illustration of a Passive Optical access Network (PON).

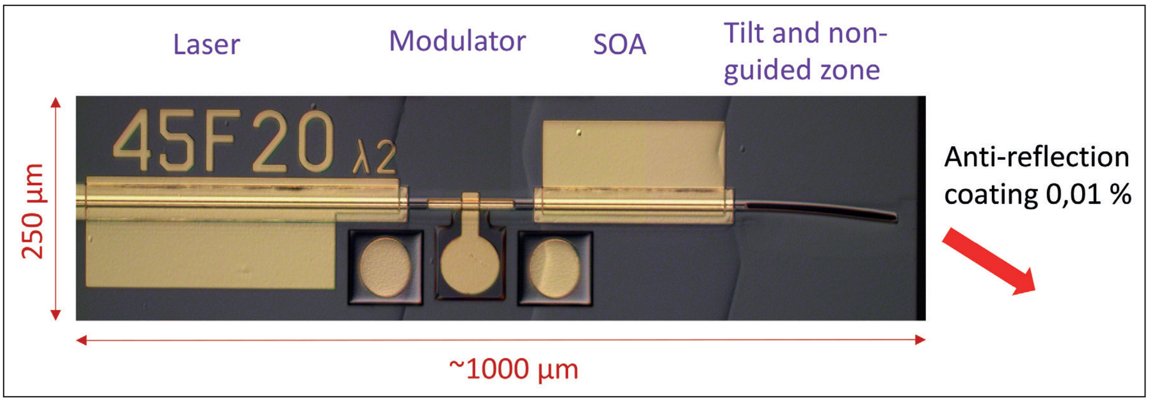


Figure 2. Top view image of a high-power transmitter (EML-SOA), including laser – modulator – amplifier – output passive tilted waveguides.

the SOA that is located after the modulator section. Thanks to this refinement, the problems associated with modulator saturation and the loss of modulation efficiency are eliminated. What's more, as the SOA section is very similar to the laser section, it can be manufactured using the same processing steps. The only noteworthy change is that the surface area of the chip increases. Finally, the SOA section improves the quality of the optical signal through the addition of so-called negative chirp, increasing the capability to combat chromatic dispersion in the fibre.

However, it is far from simple to enjoy all these benefits. That's why the EML-SOA is only starting to be offered as a practical option for the transmitter. Note that great care is needed when taking this approach, because there is the threat that the SOA can severely degrade the performance of the EML.

One of the causes of this is that the SOA suffers from saturation. When too much optical power is injected, the density of photons propagating and multiplying reaches a value that leads to the consumption of all injected electrical carriers. At this point, the SOA fails to provide amplification, a condition described as gain saturation. This is highly problematic, as when the modulated optical signal injected into the SOA goes from a bit 0 to a bit 1, the injected power suddenly increases and the gain saturates in a few hundred nanoseconds. Due to this, the power of bit 1 gradually decreases, resulting in very high noise levels for bit 1s, an issue that prevents data transmission.

A second concern is that the EML is very sensitive to optical feedback at the output facet. While most modulated light leaves the chip, a small portion is reflected by the facet and excites the laser section, which begins oscillating at a resonance frequency of a few gigahertz. This oscillation totally disrupts the emitted signal, preventing the correct transmission of the information bits. To limit this effect on an EML, an anti-reflection coating of around 0.01 percent is applied to the output facet.

However, with the EML-SOA, optical feedback is amplified by around a factor of ten as light traverses back and forth along the SOA. Due to this, there's the need for a 0.001 percent facet anti-reflection coating, which is not industrially feasible.

Finally, the SOA section requires an additional electrical current. However, this is restricted, because there's a need to limit the power consumption of the transmission modules. It can be assumed that the total for the laser and the SOA should be in the same range as the current for just an EML laser.

Addressing the challenges

At Almae Technologies of Marcoussis, France, we have tackled all these concerns while developing an EML-SOA for emerging high capacity access networks. Our device, suitable for 10G-PON and 50G-PON, targets a very high modulated power in the fibre of around 10 mW. To realise this level of performance we have adapted the design, so it is

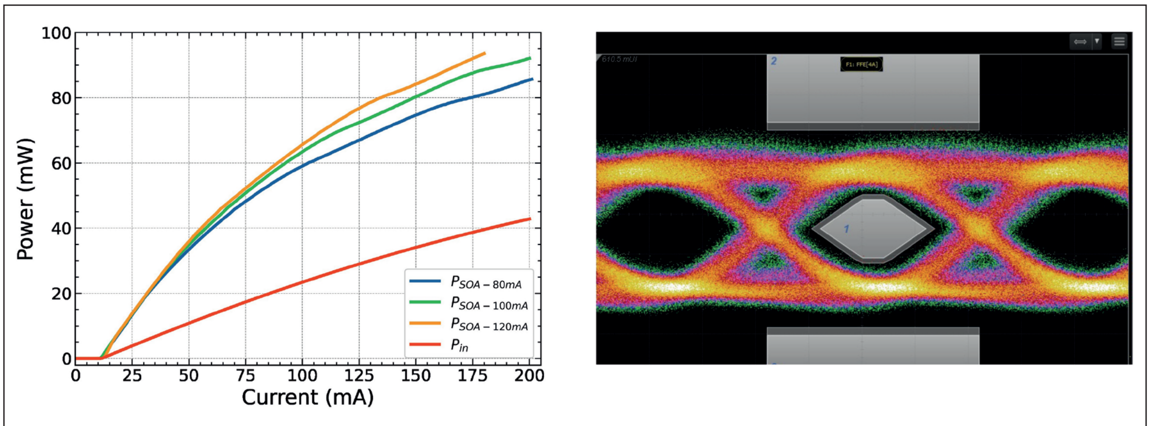


Figure 3. (Left) Output power produced by the semiconductor optical amplifier as a function of input power. (Right) 25 G eye diagram with mask margin.

capable of a high-quality modulated signal and a low power consumption.

Our design excels by incorporating a fourth optical waveguiding output section, comprising a bend leading to a 7° output tilt, and a section without a waveguide where light diffracts. Thanks to this architecture, the optical mode is very wide and at an angle of 7° when it encounters the 0.01 percent anti-reflection coated output facet. This ensures that the small portion of reflected light is strongly spread out spatially, forming an angle of 14° with the optical guide. It is a configuration that ensures 99 percent of the reflected light is radiated, while just 1 percent is recoupled into the optical waveguide, where it could possibly disturb the laser section. The combination of the tilt and the unguided zone ensures that despite the SOA section, the device remains compatible with a standard 0.01 percent facet anti-reflection coating, while avoiding laser oscillation.

When designing our EML-SOA, we did not focus on optimising the laser section by placing our emphasis on a high power and low threshold current, but directed our attention to the SOA section. For this part of our device, we placed a premium on realising the highest possible SOA saturation output power. To achieve this, we selected a stack of semiconductor layers that reduced propagation losses, and ensured a less-confined optical mode to avoid too high a photon density. These choices enabled us to more than double the saturation output power of the SOA.

With these optimisations, our EML-SOA operates at record output powers, without any degradation in the quality of the modulated signal. For deployment in 50G-PON networks, our device provides 4 mW modulated in the fibre, for an EML with a laser current of 110 mA; and 10 mW modulated in the fibre, from an EML-SOA with only 135 mA of total laser and SOA current. And for the 10G-PON, we go from 3.5 mW modulated in the fibre with an EML having a laser current of 110 mA to 7 mW modulated in the fibre with an EML-SOA having a total laser and SOA current of just 150 mA. If it seems that there are too many numbers to digest, just note that we have more than doubled the modulated output power for an increase of only 20-30 percent power consumption.

Our EML-SOA results are extremely important for next-generation access networks because in addition to increasing the modulation rate, they open the door to very large capacities, in terms of both geographical coverage and the number of users. Our devices are currently in pre-production phase, with market launch slated for later this year.

It is possible that our technology may also have a role to play in other networks. It is unlikely to be deployed in long-haul networks, as in this case transmission is in the C-band, centred around 1.55 μm, where signals can be amplified by erbium-doped fibre amplifiers. But our EML-SOAs might serve in networks involving O-band transmissions around 1.3 μm, as today they do not have any form of in-line optical amplification. The O-band is used for interconnections between datacentres (400 G Ethernet and beyond), with data transmission supported by several very high-speed 100 G EMLs. Here the transmission distance is limited by the optical power budget to around 40 km, and the introduction of our high-power EML-SOAs could increase that distance by several tens of kilometres. So it’s clear that our device has plenty of promise.

Almae Technologies: A French integrated device manufacturer of InP photonic devices

FOUNDED IN 2016, Almae Technologies is a spin-off from III-V Lab, which is a joint research laboratory between Nokia Bell Labs, Thales R&D, and CEA-Leti. The aim of Almae is to build an industrial supply chain for producing and marketing InP components coming from advanced research and development.

Today, Almae has 40 employees, all experts in the field. The company – a well-known Integrated Device Manufacturer (IDM) for advanced InP based photonic chips in Europe – is located south of Paris. From this location, equipped with a 1,700 m^2 clean room, the company undertakes the design, development, and end-to-end manufacturing of InP wafers, including the epitaxial growth of materials, testing and prototyping.

Almae’s debut component is a 10 Externally Modulated Laser (EML) for transmission up to 80 km that covers Dense Wavelength Division Multiplexing (DWDM) channels within the C-band, which spans 1530 nm to 1565 nm. This laser, now produced in volume on an in-house production line, is qualified by external customers for field applications.

The team at Almae engages in a great deal of innovation, enabling development of many new products for emerging markets. All these new components, which are based on optimised and specific designs, use exactly the same technology as the 10 G EML. This means that these novel components can take advantage of the maturity and efficiency of the production line for design-focused development, to ensure rapid qualification and time-to-market.

New products in Almae’s market launch phase include 100 G EMLs for datacentre interconnection, 1577 nm EMLs for 10G-PON, and high-power O-band or C-band lasers as sources for silicon photonics modulators, lidar and sensing. EML-SOAs for very high power 10G-PON and 50G-PON (10 mW modulated in the fibre) are in the pre-production phase, with a market launch scheduled for 2024. Another part of Almae’s technology involves the integration of laser components or gain sections into silicon platforms using low-cost passive alignment processes.

Getting the full PICture:

Testing microring resonators with sub-picometre spectral resolution

Microring resonators are key components in many PIC technologies, but, as their performance continues to improve, they require increasingly precise test and measurement solutions. EXFO's testing platforms can help to address this need.

BY SOPHIE LANGE, BUSINESS DEVELOPMENT ENGINEER AT EXFO

AS THE FIELD of integrated photonics continues to advance, microring resonators have become a key enabler of this technology. The interferometric devices create very sharp spectral features, and can be used as ultra-sensitive detectors or as wavelength filtering devices in PIC-based low-linewidth tuneable lasers. They could also be used as compact and ultra-low voltage optical modulators, potentially proving to be a game-changer in the increasingly energy-hungry telecom and datacom industry.

As the name implies, a microring resonator consists of a ring-shaped waveguide placed close enough to a linear waveguide (or multiple linear waveguides) for some light to couple between them, creating a highly efficient optical resonator. The quality factor, or Q-factor, is a figure of merit of a device's interferometric efficiency (the higher the Q-factor, the more efficient the device) and is directly linked to its spectral performance. With the development of low-loss structures and materials, interferometers based on integrated photonic ring resonators can achieve Q-factors of several million.

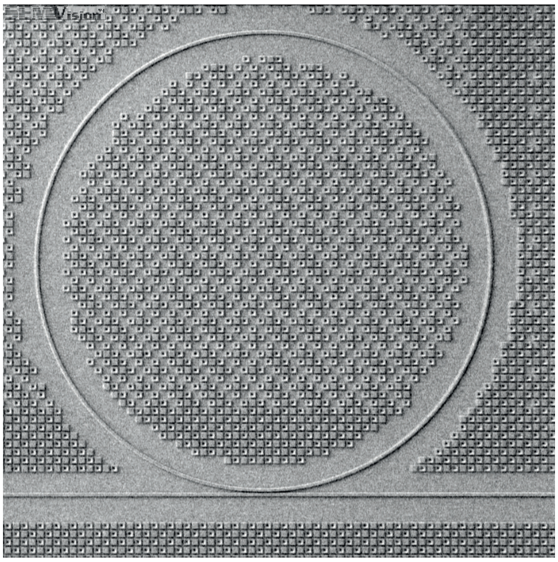


Figure 1. A ring resonator consists of a ring-shaped waveguide close to a linear waveguide. Picture courtesy of CEA-Leti.

However, characterising devices like this is becoming more and more challenging. The spectral measurement of the Q-factor, among other performance parameters, needs to be tested with high accuracy and precision, but also within a short timespan, since a single integrated photonics wafer can count several thousands of these components.

This article details the key challenges associated with measuring these ring resonator structures and provides insights into how to achieve fast, accurate, and highly resolved spectral characterisation of optical microring resonators. A measurement of a high Q-factor resonator, provided courtesy of CEA-Leti, demonstrates a path to efficient characterisation of these key components of PICs.

Spectral characteristics of microring resonators

The base pattern of a ring resonator's transmission spectrum consists of a Lorentzian-shaped trough corresponding to a resonance of the ring cavity. This pattern is then repeated at an interval that corresponds to the free spectral range of the resonator. These high-contrast features depend strongly on the ring's physical and optical properties and on effective interaction with the nearby linear waveguide(s).

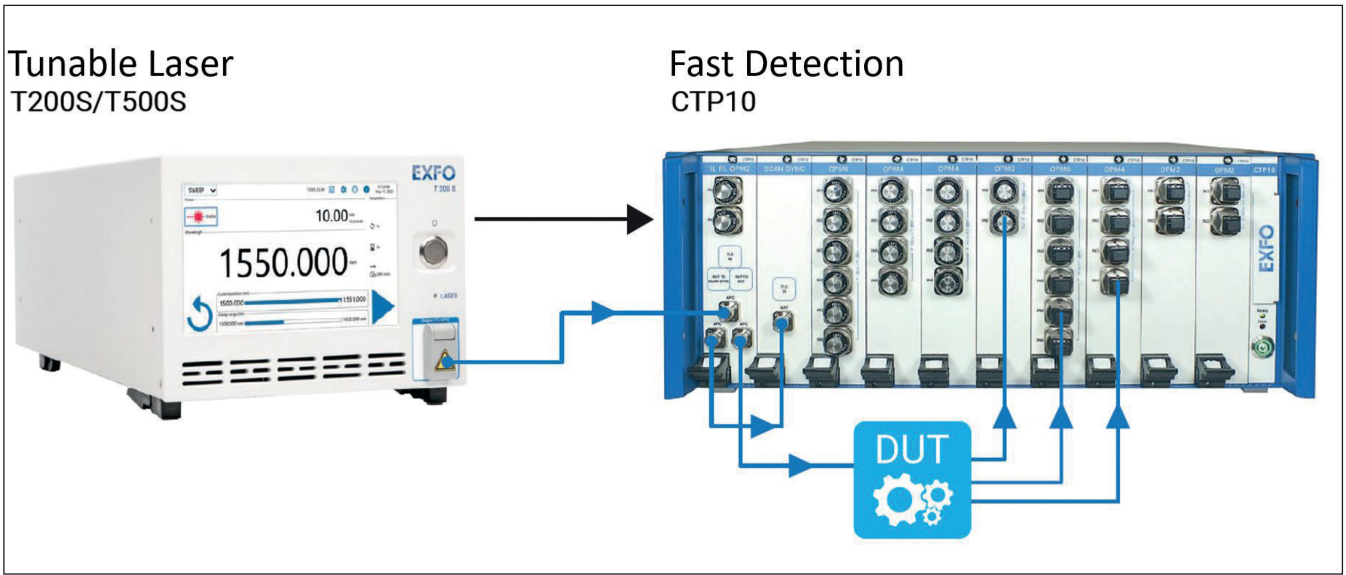


Figure 2. Example of spectral characterisation instruments for the swept laser method, consisting of the tuneable laser (T200S/T500S from EXFO) and a bank of power meters integrated into a component testing platform (CTP10 from EXFO). (DUT represents the device under test.)

In recent years, ring resonators with a Q-factor of several million have been demonstrated and readily used as modulators, filters, or sensors. Such Q-factor values roughly translate into a spectral resonance bandwidth of less than 1 picometre with optical peak depths of several decibels. When characterising such devices, the spectral position of the peak, spacing between peaks, and their height and width provide critical parametric information that can determine whether the cavity can be used for the intended application.

This, however, poses a difficult challenge when it comes to acquiring such a spectrum. Reliable readings of both wavelength and optical power information are needed while passing through these extremely high-contrast features. As a result, the test instrument requires femtometre-scale spectral resolution and needs to deal with power fluctuation of 10 dB per picometre.

The best technique to perform a fast, reliable, and high-resolution spectral measurement of ring resonators is to use a continuously tuneable laser together with one or more fast detectors. The laser needs to cover the relevant operating wavelength range while offering low linewidth and good spectral quality to avoid measurement artefacts. The detection part of the test system needs to have excellent linearity and enough dynamic range so that the full spectral contrast of the device can be captured in a single measurement without any distortion or discontinuity.

Additionally, the overall system needs excellent wavelength accuracy and repeatability as well as high spectral resolution to collect all the data points at the correct wavelength with femtometre-scale precision within seconds. Finally, polarisation control is often required to ensure coupling of the signal into the correct transmission mode.

Efficient and fast spectral testing with femtometre resolution

Figure 2 shows a spectral characterisation solution where the component testing platform takes control of the laser and monitors the wavelength, power in, and power out of the device under test synchronously. Such systems have been demonstrated to also capture return loss and polarisation-dependent loss measurements and to provide high-quality spectral performance required for ring resonator testing.

Figure 3 shows a measurement performed on a ring resonator device with a Q-factor of 6 million, provided by CEA-Leti. The graph demonstrates the accuracy level achieved with the high-resolution mode of the test solution used in this case. Thanks to an “on-the-fly” optical wavelength detection, the laser wavelength is precisely determined at each tuning step, avoiding any measurement

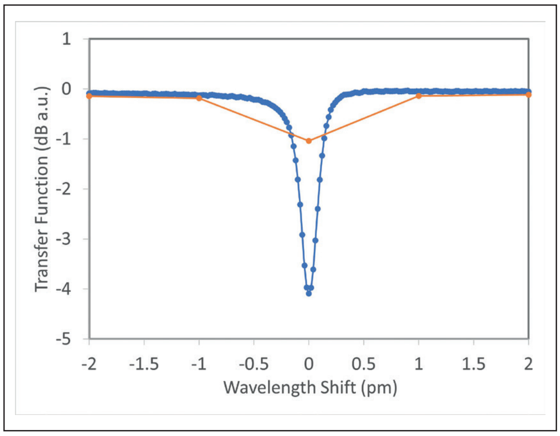


Figure 3. Spectral response of a high Q-factor ring resonator using resolutions of 1 picometre (red) and 20 femtometres (blue) measured with the CTP10 component testing platform. Device courtesy of CEA-Leti.

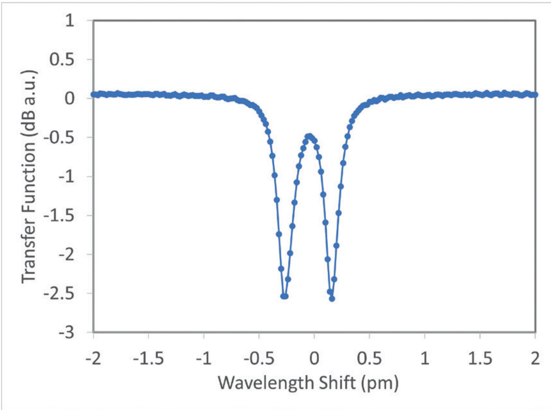


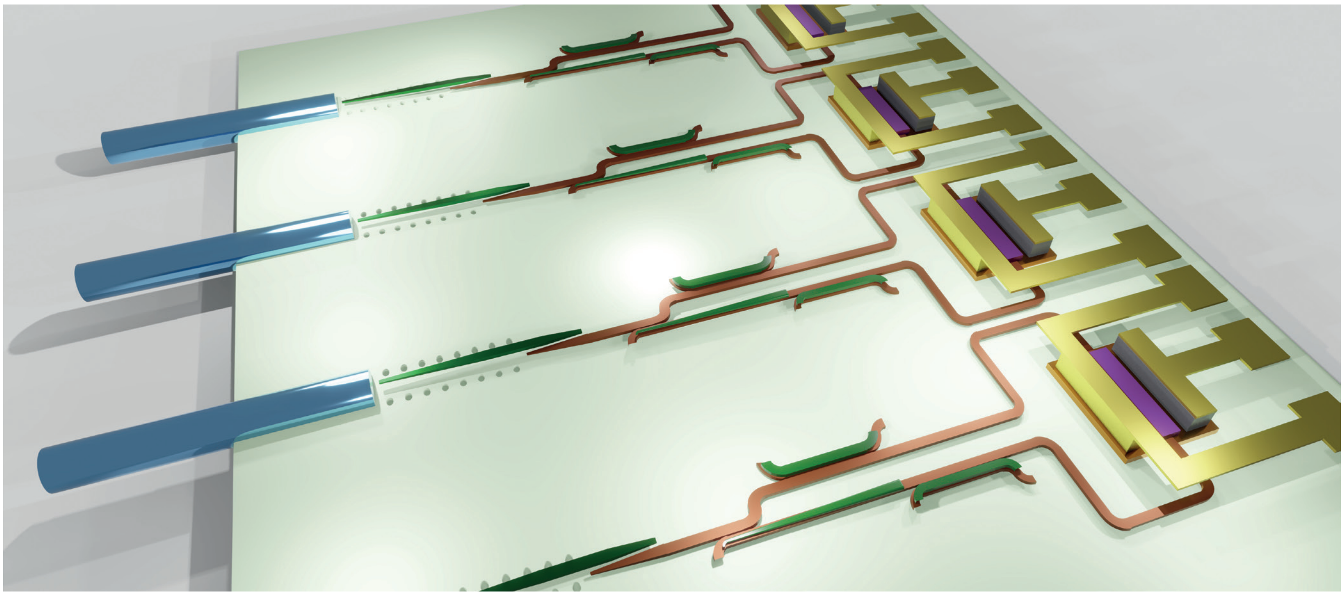
Figure 4. Example of a mode splitting spectral event (on the same ring resonator as in Figure 3) at a spectral resolution of 20 femtometres measured with the CTP10 component testing platform. Device courtesy of CEA-Leti.

Ring resonators and integrated photonics as a whole are pushing the boundaries of spectral testing, as well as photonics measurement techniques more generally.

inaccuracies due to factors such as laser speed variation. Together with the fast, high-dynamic-range photodetectors, the Lorentzian shape of the resonance is spectrally resolved without any distortions or artefacts.

A system like this also provides highly repeatable measurements, ideal for characterising the resonance position versus other ring resonator parameters such as the applied voltage for phase-shift or thermal control. As a matter of fact, the system's femtometre-scale acquisition allows the resolution of complex behaviour such as a mode splitting effect – a spectral event observed when defects in the ring create counter-propagating modes, resulting in two resonant peaks instead of one, as shown in Figure 4.

Ring resonators and integrated photonics as a whole are pushing the boundaries of spectral testing, as well as photonics measurement techniques more generally. Ever-increasing Q-factors require higher and higher spectral precision and resolution, and minimised testing time. This is a challenging but exciting time for test and measurement engineers and researchers alike.



Moving towards polarisation-independent monolithic PICs

As datacentres race towards 200G per lane, polarisation-dependent loss and differential group delay remain significant hurdles in high-speed optical receivers. GlobalFoundries researchers have made significant progress in addressing these challenges.

BY YUSHENG BIAN, MASSIMO SORBARA, WON SUK LEE, SUJITH CHANDRAN, TAKAKO HIROKAWA, ABDELSALAM ABOKETAF, KEVIN DEZFULIAN, RYAN SPORER, KEN GIEWONT AND TED LETAVIC, GLOBALFOUNDRIES

TO COPE with ever-growing bandwidth demands, datacentre communication applications are transitioning to 200G PAM-4 transmission per optical wavelength (200G per lane), doubling the symbol rate to 106.25 GBaud compared with 53.125 GBaud found in 100G-per-lane systems [1, 2]. However, in 200G-per-lane systems, managing the significant impact of polarisation-dependent loss (PDL) and differential group delay (DGD) on optical receivers is increasingly challenging, particularly in optical interconnection schemes deploying monolithic silicon photonic technology.

To facilitate seamless integration between photonic and CMOS components with an optimised process flow (Figure 1), the waveguide layers incorporated into the monolithic silicon photonic platform are typically thinner than those in standalone photonic

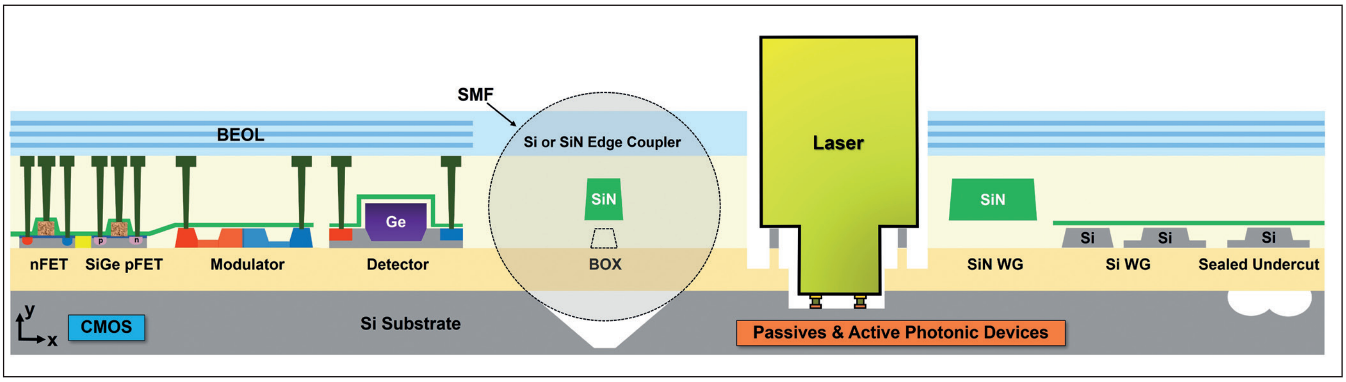


Figure 1. GlobalFoundries Fotonix™ platform monolithically integrates advanced photonic devices and CMOS components on the same SOI substrate [3].

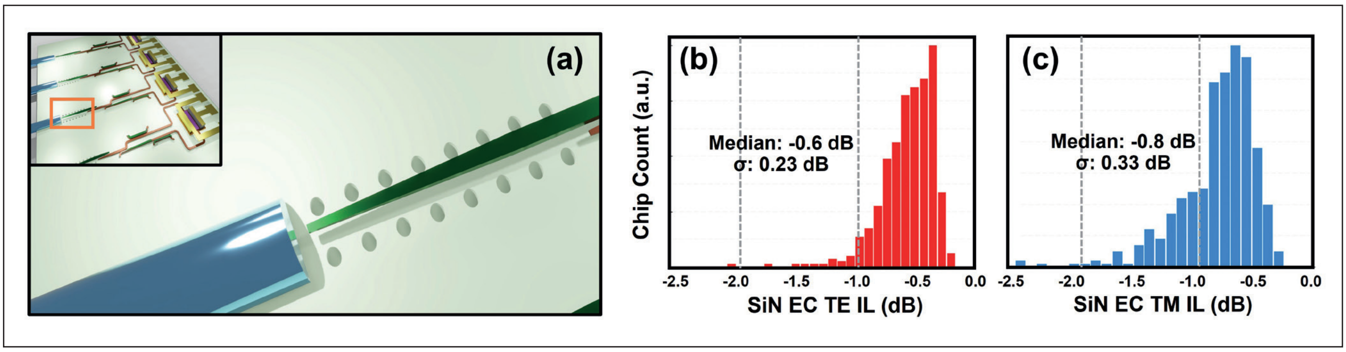


Figure 2. (a) Schematic illustration of silicon nitride edge coupler in a monolithic optical receiver. (b)-(c) Statistical yield distributions of the TE and TM ILs at 1310 nm.

technologies [3-10]. However, this thinning can result in non-negligible birefringence and PDL, affecting both waveguides and other functional devices. As most optical transmitters are optimised for transverse electric (TE) operation – as opposed to transverse magnetic (TM) operation – PDL becomes pronounced in optical receivers due to the rotating state-of-polarisation in the fibre optic cable. In high-speed data communication systems, it is critical to minimise the net optical path loss and PDL to optimise the system's overall signal-to-noise ratio (SNR) performance.

Alongside PDL, significant DGDs between TE and TM signals arise from birefringence and polarisation mode dispersion in waveguides and other building blocks within the monolithic optical receiver [11]. These DGDs typically surpass 50 percent of a symbol interval in 200G-per-lane transmission, resulting in self-induced inter-symbol interference (ISI) out of the photodetector (PD) output current.

This leads to further closure on the eye diagram and shifting of the optimal sampling of the received PAM-4 signal. This article presents recent advancements in enhancing the functionality of critical monolithic building blocks deployed in an optical receiver front-end, with a primary focus on reducing insertion losses (ILs), net PDL as well as DGD compensation. The performance enhancements are achieved by optimising both the design and processes to improve the balance between the TE and TM paths in a receiver. Combining all improvements, we effectively demonstrate a nearly polarisation-independent receiver circuit with a PDL of only 0.38 dB and negligible DGD, utilising monolithic silicon photonic components.

Reducing IL and PDL for monolithic silicon photonic components

To explore the optical performance of each component and associated IL reductions, we begin by focusing on the silicon nitride edge coupler (EC) using V-groove technology [12]. This component serves as the broadband high-power optical input/output (I/O) for transceivers and PICs leveraging edge coupling schemes (Figure 2a). Design and process optimisations, such as adjustments in the crystallographic etch module and the back-end-of-line cladding removal, ensure precise V-groove dimensions for optimal coupling with the single-mode fibre and protection of the silicon nitride spot-

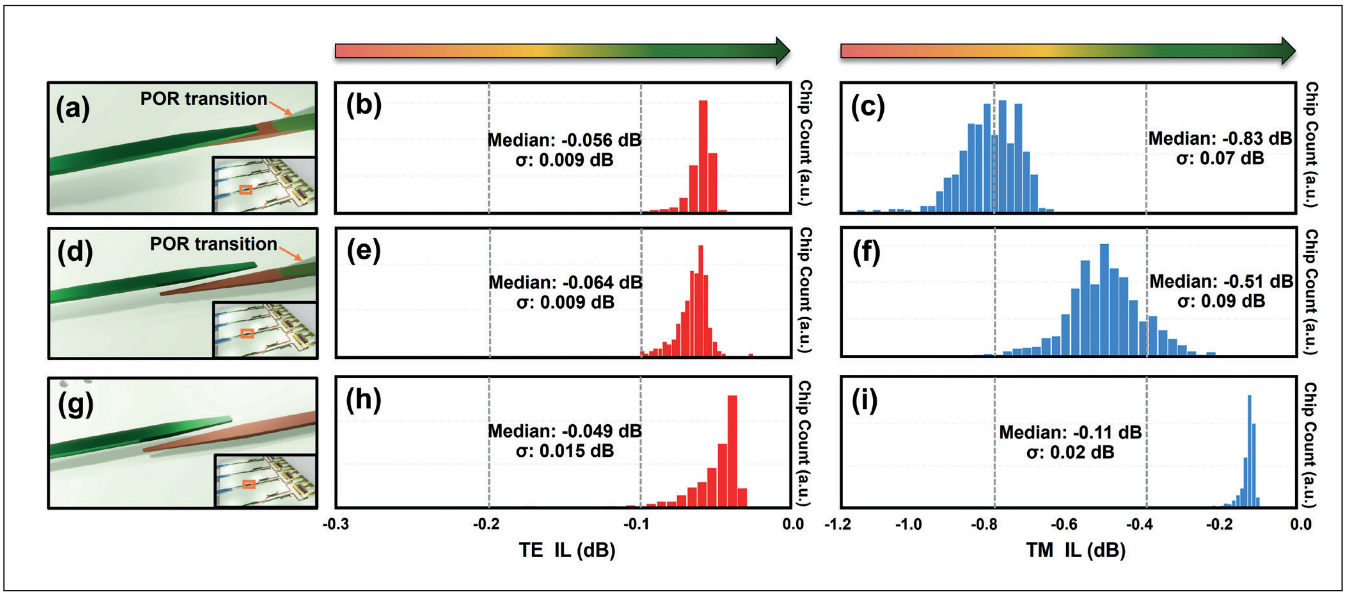


Figure 3. Evolution of IL and PDL reduction in silicon-silicon nitride coupler. (a), (b), (c) silicon-silicon nitride vertical coupler. (d), (e), (f) silicon-silicon nitride diagonal coupler. (g), (h), (i) silicon-silicon nitride diagonal coupler featuring an enhanced transition design for integration with standard silicon waveguide. All statistical measurement data was acquired at a wavelength of 1310 nm.

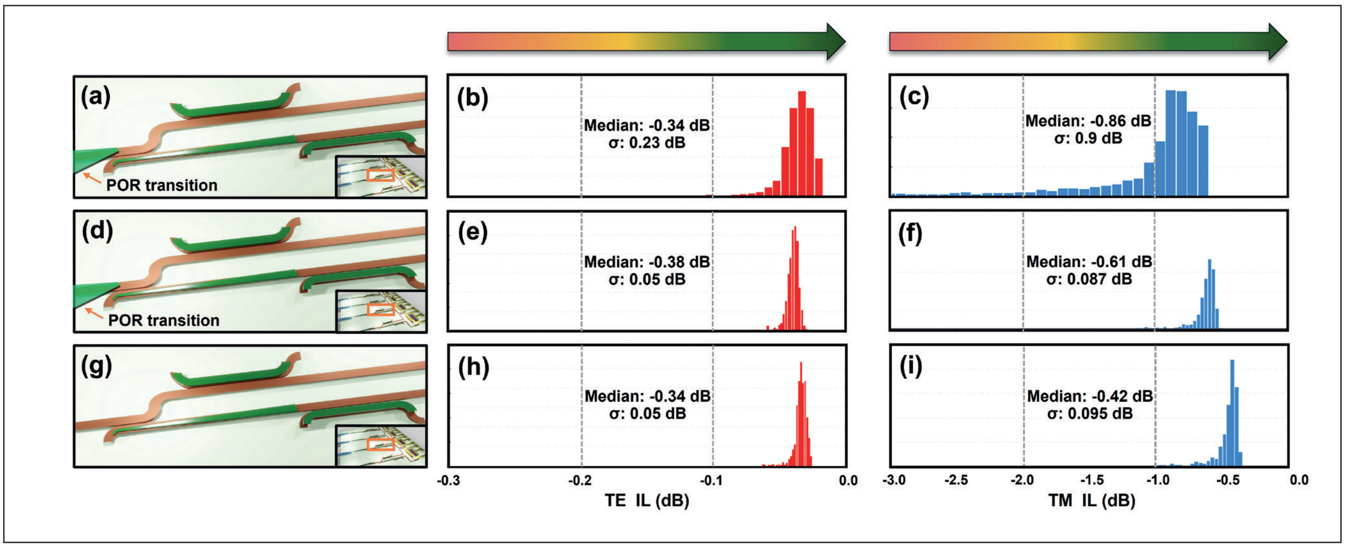


Figure 4. Progression of IL and PDL reduction in PSR. (a), (b), (c) PSR. (d), (e), (f) PSR with enhanced process implementation. (g), (h), (i) Enhanced PSR resulting from both process improvement and advanced transition design. All statistical measurement data was acquired at 1310 nm.

size-converter beneath the dielectric cladding for minimal mode conversion loss.

Our refined process flow yields low IL for both TE and TM modes (-0.6 dB and -0.8 dB) with minimal standard deviation of 0.23 dB and 0.33 dB respectively for the two corresponding polarisations (Figure 2b and 2c). This results in a minimal PDL of 0.2 dB at 1310 nm, representing approximately 0.3 dB improvement when compared to the initial PDL value prior to the process optimisation.

The next component to consider is the silicon-silicon nitride coupler. Since the monolithic silicon photonic platform integrates both silicon and silicon nitride waveguides [13-14], it requires a compact transition design for efficient, broadband and polarisation-independent light transfer between these layers. We have thoroughly explored design options within the platform to continually enhance the coupler performance.

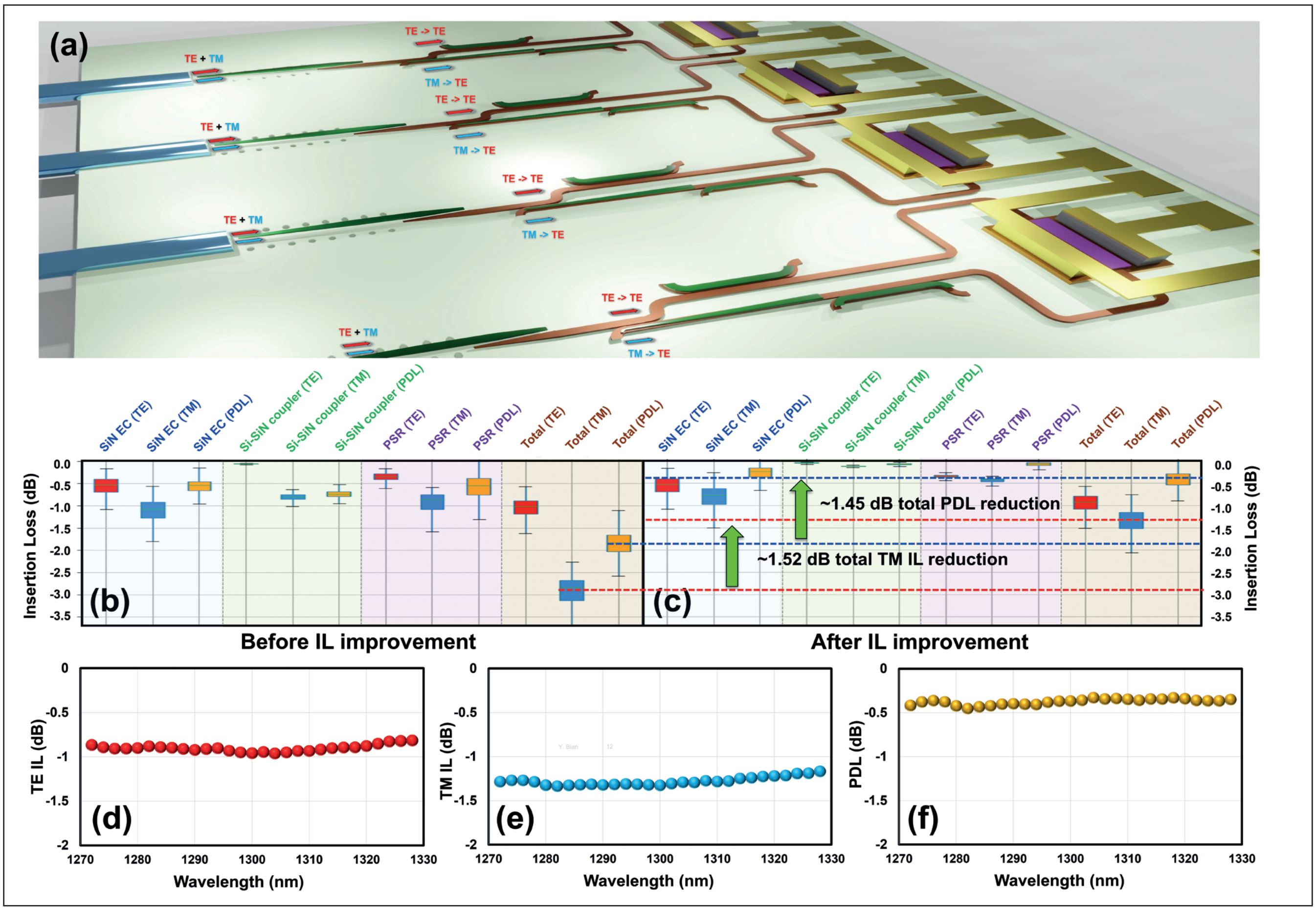
The evolution of the silicon-silicon nitride coupler, as illustrated in Figure 3, involves transitioning from a vertical coupler design (Figure 3a) to a diagonal coupling scheme (Figure 3d), accompanied by an improved transition design outside the coupler region (Figure 3g). The initial design (Figure 3a) features an ultra-compact footprint and low TE IL (Figure 3b) but significantly higher TM IL (Figure 3c), resulting in a pronounced PDL up to 0.77 dB. By introducing a lateral offset in the silicon nitride layer (Figure 3d), we can achieve a diagonally coupled silicon-silicon nitride transition, which significantly reduces TM IL by 0.32 dB, while maintaining low TE IL (Figure 3e and 3f). Advanced transition design within the non-tapered silicon region (Figure 3g) further reduces the TM IL to 0.11 dB, and the TE IL to 0.049 dB, as shown in Figure 3h and 3i, resulting in an impressively low PDL of 0.06 dB.

Finally, Figure 4 illustrates ongoing efforts to enhance the performance of the polarisation splitter rotator (PSR). This component employs an innovative adiabatic design concept to manipulate TE and TM polarisations, leveraging a hybrid silicon-silicon nitride structure coupled to a silicon waveguide to achieve polarisation splitting and rotation [15]. The initial device (Figure 4a) shows a notable loss imbalance between the two polarisations, with TM IL substantially higher than TE IL, resulting in > 0.5 dB PDL (Figure 4b and 4c).

Through continued process optimisations, we have succeeded in reducing the TM IL by 0.25 dB while maintaining low TE IL, as evident in Figure 4e and 4f, resulting in a PDL reduction of > 0.2 dB.

Component	TE IL (dB or dB/cm)	TM IL (dB or dB/cm)	PDL (dB or dB/cm)	DGD (ps or ps/mm)
SiN EC	0.6	0.8	0.2	0.05
Si-SiN coupler	0.049	0.11	0.061	0.37
PSR	0.34	0.42	0.08	5.2
Si WG	1.0	0.9	-0.1	5.3

Table 1. IL and DGDs for critical silicon photonic building blocks in a monolithic optical receiver.



➤ Figure 5. (a) Optical receiver circuits consisting of silicon nitride edge coupler, silicon-silicon nitride coupler, PSR and dual-input PD. (b)-(c) TE IL, TM IL, PDL of each component and the total net IL and PDL of the receiver circuit. The loss associated with waveguide routing is neglected in the calculation due to minimal PDL and short waveguide length. (d)-(f) Through-band performance from the silicon nitride edge coupler to the PSR.

Leveraging the advanced transition design originally developed for the silicon-silicon nitride coupler, we further reduce the PSR TM IL by an additional approximately 0.2 dB (Figure 4i). This achievement has yielded a record low PDL of < 0.1 dB at 1310 nm, surpassing previous PSR demonstration utilising a poly-silicon waveguide layer within the monolithic silicon photonic platform [16].

PDL reduction and DGD compensation for a monolithic optical receiver

The essential building blocks discussed, along with routing waveguides and photodetectors, form the core framework of a typical optical receiver. Utilising the representative receiver architecture shown in Figure 5a, we explore the cumulative improvement in IL and PDL. Figure 5b and 5c summarise the IL and PDL for each component before and after the enhancement. Remarkably, substantial reductions in TM ILs have been achieved in both the silicon-silicon nitride coupler and the PSR, without compromising the TE IL, consistent with the data presented in the histograms in Figure 3 and Figure 4.

This notable enhancement has led to a record-high 1.52 dB reduction in overall TM IL, resulting in a total PDL reduction exceeding 1.45 dB and a net PDL of 0.38 dB. Moreover, due to the broadband nature of the improved design, both the IL and PDL reductions apply across a wider wavelength range (Figure 5d and 5e). Importantly, these performance improvements are achieved through design and process optimisations without impacting the stack-up or integrity of the monolithic silicon photonic platform.

Turning to DGD compensation, Table 1 presents the nominal ILs and DGDs of critical passive components utilised in the monolithic receiver circuit. As passive components are connected in the receiver towards the photodetector, DGDs accumulate. If the net DGD at the photodetector occupies a significant portion of the PAM-4 symbol interval, it will introduce substantial ISI, necessitating compensation by the receiver's digital signal processor (DSP).

To demonstrate the impact of DGD on the receiver performance, Figure 6 illustrates the degradation of a PAM-4 eye diagram resulting from the DGD introduced at the photodetector output, represented as a fraction of the symbol interval (T).

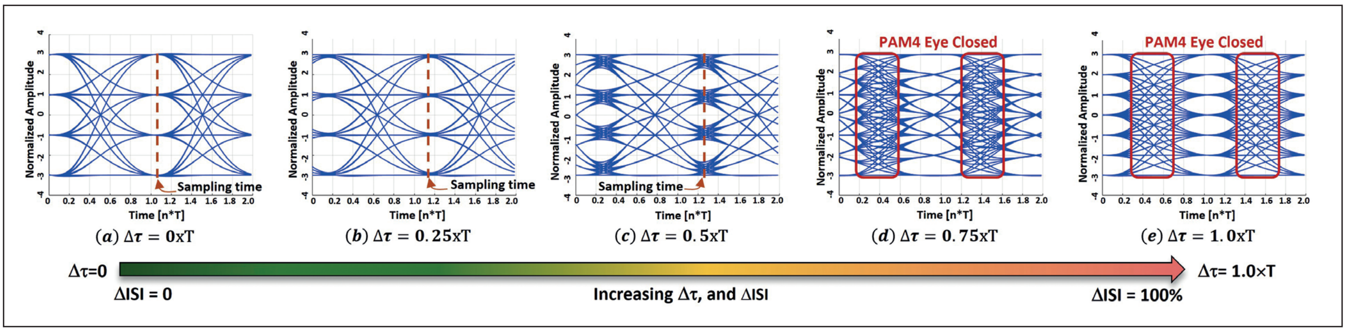


Figure 6. Impact of DGD and eye diagram at PD output as a fraction of symbol interval.

In this scenario, we assume equal amplitudes of the TE and TM components. The degradation in the received optical eye is observed as the DGD (Δτ) varies from 0xT to 1.0xT. When the added DGD exceeds half of the symbol interval, the received eye diagram becomes closed, which significantly complicates the equalisation and detection of the PAM-4 symbols in the receiver's DSP.

To mitigate cumulative DGD and further minimise the PDL, we propose employing a waveguide delay and variable optical attenuators (VOAs) on both outputs of the PSR before feeding signals into a dual-port photodetector, as illustrated in Figure 7. For 200G PAM-4, with a symbol period of T = 9.4 picoseconds, the accumulated DGD from the silicon nitride edge coupler to the PSR output, including the routing waveguide, is 8.96 picoseconds, occupying 95% of T. Therefore, introducing a waveguide length DL in the TM-to-TE path of the PSR provides adequate delay to compensate for the DGD.

With this additional delay, the net DGD added in the receiver at the photodetector is nearly zero. The VOAs can be incorporated to further minimise the PDL. By compensating for DGD and PDL optically, the received PAM-4 signal will have zero added ISI, and the eye diagram will be restored for 200G transmission. Any remaining differential delay at the PD (for example, less than 10 percent of the symbol interval) can be compensated for by the adaptive equaliser in the receiver.

Summary

In this article, we have highlighted our efforts in minimising losses in critical passive silicon photonic building blocks essential for optical receivers. Collective improvements in PDL, achieved through enhancements in edge couplers, silicon-silicon nitride couplers and PSRs, result in a substantial 1.45 dB reduction in system-level PDL. This translates to a mere 0.38 dB imbalance in TE-TM IL for a typical optical receiver circuit, with similar PDLs observed across a broader wavelength range in the O-band.

Furthermore, we have outlined strategies for mitigating DGD in the receiver, resulting in minimal ISI and restored eye diagrams for 200G applications. The approaches and techniques presented in this article pave the way for the development of polarisation-insensitive PICs for diverse applications beyond datacentres.

AKNOWLEDGEMENTS

The authors would like to thank: Thomas Houghton, Yarong Lin, Karen Nummy, Jae Kyu Cho, Arpan Dasgupta, Zahidur Chowdhury, Farid Barakat, Jason Kim, Michelle Zhang, Shenghua Song, Helen Wong, Chris Ritchie, Michal Rakowski, Hanyi Ding, Qidi Liu, Ming Gong, Francis Afzal, Salman Mosleh, Fahimeh Banihashemian, Norman Robson, Teck Jung Tang, Frederick G Anderson, Brian Popielarski, Petar Ivanov Todorov Mohamed Gheith, Ian Stobert, Mini Modh Ghosa, Apoorva Vakil, Kate McLean, Ryan Gallagher, Ranjani Sirdeshmukh, Yangyang Liu, Janet Tinkler, George Gifford, Vikas Gupta, Anthony Yu, Isabelle Ferain, Ed Kaste, Gregg Bartlett and the rest of the GlobalFoundries team for their development engineering support for Fotonix™ technologies.

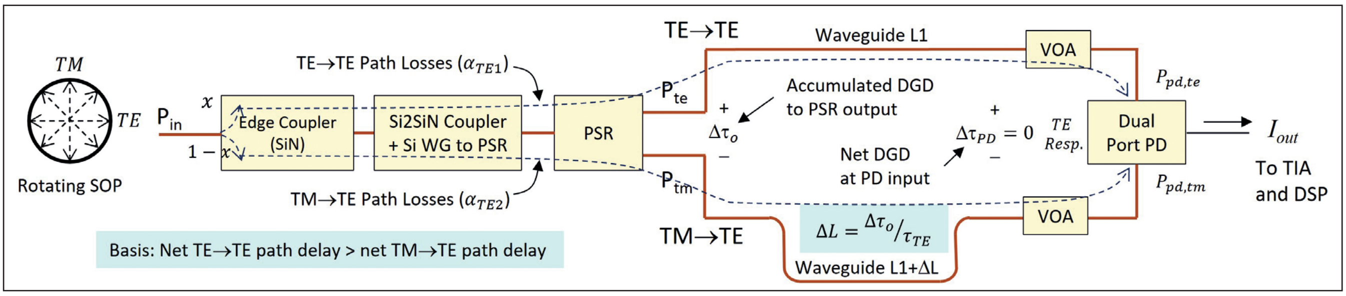
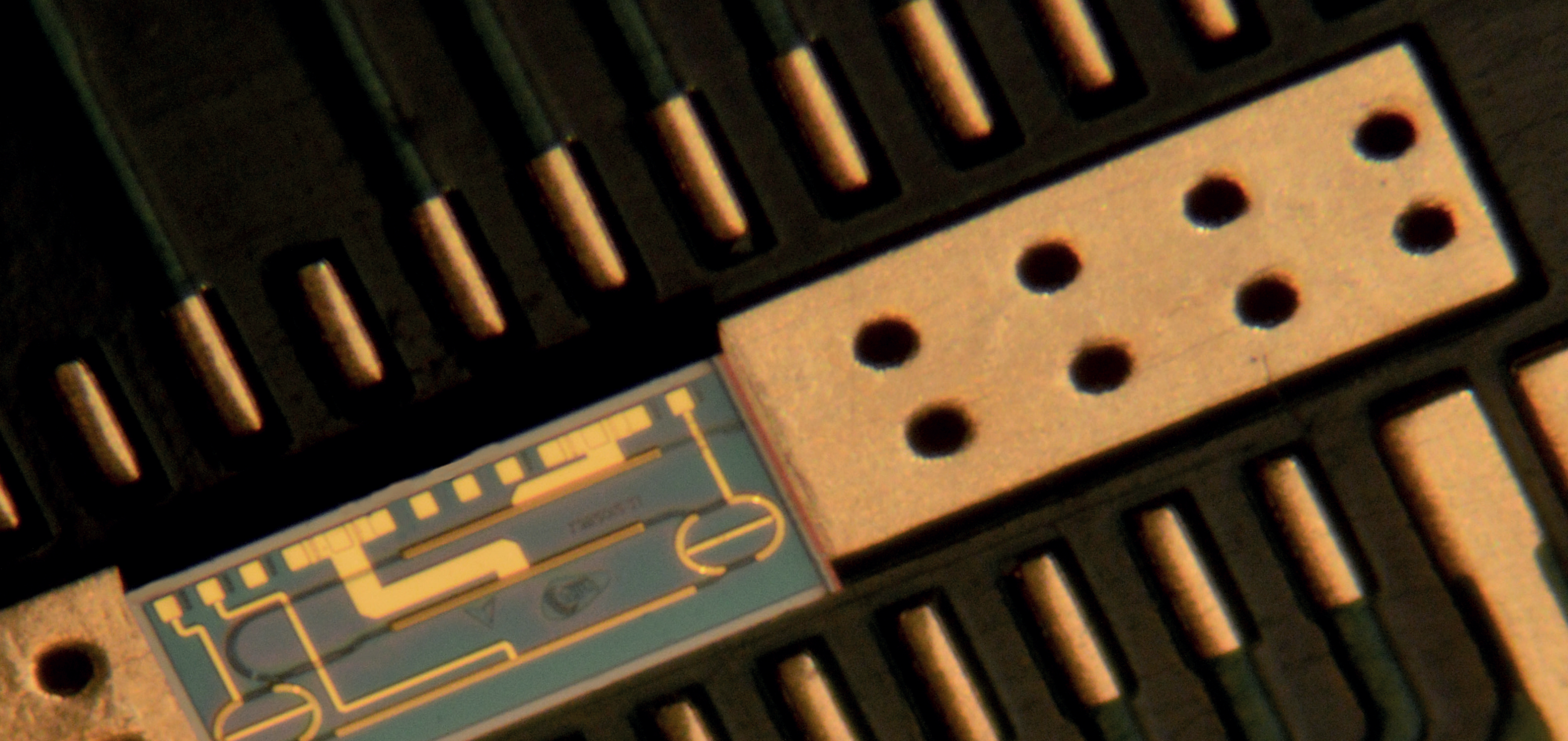


Figure 7. Monolithic optical receiver structure for DGD and PDL compensation.

FURTHER READING / REFERENCE

- [1] IEEE Standard for Ethernet - Amendment 11: Physical Layers and Management Parameters for 100 Gb/s and 400 Gb/s Operation over Single-Mode Fiber at 100 Gb/s per Wavelength, IEEE SA - IEEE 802.3cu-2021
- [2] IEEE 802.3dj, IEEE P802.3dj 200 Gb/s, 400 Gb/s, 800 Gb/s, and 1.6 Tb/s Ethernet Task Force (ieee802.org)
- [3] Y. Bian et al., “3D Integrated Laser Attach Technology on a 300-mm Monolithic CMOS Silicon Photonics Platform,” IEEE J. Sel. Topics Quantum Electron., Vol. 29, no. 3, pp. 8200519, 2023.
- [4] V. Stojanović et al., “Monolithic silicon-photonic platforms in state-of- the-art CMOS SOI processes,” Opt. Express, vol. 26, no. 10, pp. 13106–13121, 2018.
- [5] K. Giewont et al., “300-mm monolithic silicon photonics foundry technology,” IEEE J. Sel. Topics Quantum Electron., Vol. 25, no. 5, Sep. 2019, Art. no. 8200611.
- [6] M. Rakowski et al., “45 nm CMOS silicon photonics monolithic technology (45CLO) for next-generation, low power and high speed optical interconnects,” OFC, T3H.3, 2020.
- [7] Y. Bian et al., “Towards low-loss monolithic silicon and nitride photonic building blocks in state-of-the-art 300 mm CMOS foundry,” Frontiers in Optics, pp. paper FW5D. 2, 2020.
- [8] T. Letavic et. al., “Monolithic Silicon Photonics,” BCICTS, 2a.1, 2023.
- [9] T. Hirokawa, et al., “Latest Progress and Challenges in 300mm Monolithic Silicon Photonics Manufacturing,” OFC, Th3H.2, 2024.
- [10] Y. Bian et al., “300 mm monolithic CMOS silicon photonics foundry technology,” Conference on Lasers and Electro-Optics, ATu3H.1, 2024.
- [11] Y. Bian et al., “Polarization mode dispersion in CMOS-integrated monolithic SiPh components: simulations and experiments,” OFC, Th2A.24, 2023.
- [12] Y. Bian et al., “Monolithically integrated self-aligned SiN edge coupler with <0.6/0.8 dB TE/TM insertion loss, <-39 dB back reflection and >520 mW high-power handling capability,” OFC, M3C.3, 2023.
- [13] Y. Bian et al., “Monolithically integrated silicon nitride platform,” OFC, Th1A.46, 2021.
- [14] S. Chandran et al., “High Performance Silicon Nitride Passive Optical Components on Monolithic Silicon Photonics Platform,” OFC, Th3H.4, 2024.
- [15] W. Lee et al., “Low-loss and broadband adiabatic polarization splitter rotator on a CMOS-integrated silicon photonics platform,” OFC, M1J.5, 2024.
- [16] W. D. Sacher et al., “An O-band polarization splitter-rotator in a CMOS-integrated silicon photonics platform,” Frontiers in Optics, pp. paper FTu2D. 2, 2016.



A tuneable laser chip on a custom test PCB - the device has a footprint smaller than 1 mm by 2 mm.

Tuneable lasers:
The elusive trifecta

Integrated tuneable laser assemblies serving in the C- and O- bands excel on three fronts by offering the unique combination of wide tuning, fast-nanosecond switching and a narrow linewidth

BY CAOLÁN MURPHY, SHANE DUGGAN, GAURAV JAIN, CRISTIAN VARGAS, AND DESI GUTIERREZ FROM PILOT PHOTONICS

TUNEABLE LASERS are now established as a key enabling technology in a wide range of applications, spanning various fields from optical communications to sensing.

In telecommunication infrastructure, particularly in the long-haul and metro networks, widely tuneable lasers with a low linewidth are indispensable components. When incorporated in coherent transceivers, their low linewidth enables increased data rates by supporting advanced modulation formats within dense wavelength-division multiplexing systems. The wide wavelength tuneability is a valued asset, simplifying network design and management by enabling resources to be dynamically assigned and optimised while reducing inventory requirements.

Meanwhile, in optical fibre sensing applications, such as fibre Bragg grating sensing, fast-swept tuneable lasers are used to interrogate sensors with Bragg gratings inscribed into optical fibres. These gratings reflect specific wavelengths of light, based on the strain and the temperature applied to the fibre, to create a distinctive spectral signature. When lasers offer fast switching and are widely tuneable, this enables precise and fast wavelength sweeps across the fibre Bragg grating sensor's bandwidth to ensure real-time, accurate readings of strain or temperature.

Fast tuneable lasers have also played a key role in the development of many optical switching architectures, involving rapid adjustments to the laser wavelength to quickly switch or route optical traffic without having to convert signals to the electronic form.

There is no doubt that the versatility of the tuneable laser has enabled widespread applications. However, today's commercially available widely tuneable lasers still fall short in some areas. In particular, they struggle to serve in applications requiring phase-sensitivity and very fast-switching/sweeping.

For instance, for frequency-modulated continuous-wave lidar, a cutting-edge technology in autonomous vehicles and remote sensing, they are not adept at providing the low linewidth and ultra-fast sweeping capabilities needed to precisely measure distances and velocities. Additionally, in systems that employ coherent optical time-domain reflectometry and optical frequency-domain reflectometry, rapid, phase-sensitive tuning is critical for accurate detection of disturbances or variations along the optical fibre, or for other devices under test. If optical packet or optical burst systems are to re-emerge, they will have to align with the demands of today's high-speed data transmission, which requires not only very fast wavelength switching, but the ability to handle phase-sensitive modulation formats.

Unfortunately, today's widely tuneable semiconductor lasers are not great allrounders. Typically, they offer either a narrow linewidth or fast tuning – but not both. An example is the sampled-grating distributed Bragg reflector laser, which is capable of tuning across tens of nanometres using the Vernier tuning effect, thanks to a current-injection-based tuning mechanism that enables swift optical switching. However, this comes at the expense of increased phase noise and broader linewidths, rendering this design unsuitable for the aforementioned applications.

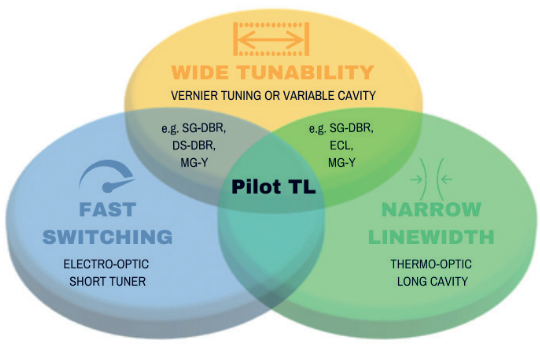
The alternative is to make use of an equivalent thermally tuned laser. This class of laser is capable of realising similar tuning ranges, while boasting low linewidths. However, fast electronic tuning is sacrificed. Similarly, SiN ring-resonator-based devices major in ultra-low linewidths via thermal tuning, but dramatically reduce switching speeds, also limiting usage in these applications.

The elusive combination of a broad tuning range, narrow linewidth and either rapid switching or sweeping, has been a long-standing industrial challenge. Breaking through this impasse to fulfil the elusive trifecta is our team at Pilot Photonics of Dublin, Ireland. Working with the InP foundry Smart Photonics, we are trailblazing lasers that blend all three desirable properties.

Figure 1. Tuneable laser form factor offerings: Photonic Integrated Circuit (PIC), the laser cavity consists of a gain section providing optical gain in either the C or O bands, two ring sections that act as tuneable mode selectors through the Vernier effect, and a common phase section to allow finer tuning of the laser cavity mode; 14-pin butterfly package; OEM benchtop unit; nano-integrated tuneable laser assembly package.

Available in both the C-band and O-band, our ground-breaking lasers unlock new possibilities across a spectrum of applications, from lidar to optical coherence tomography, dense wavelength division multiplexing, coherent optical communication, distributed fibre sensing, gas sensing, sensor interrogation, fibre optic testing, and optical switching. That's a vast and varied range of applications.

Currently available in a 14-pin butterfly package, or instrument formfactor, our nano-integrated tuneable laser assembly that's targeting high-volume communication applications will be released later this year (see Figure 1). Each package features an integrated feedback control, based on wavelength-meter and wavelength-locker systems. Incorporated in the wavelength meter are a linear filter and a photodetector, employed to estimate the current lasing wavelength, and a wavelength locker that consists of an etalon and photodetector – this allows the monitoring of the wavelength on a 50 GHz or 200 GHz grid. Combining the two feedback systems ensures closed-loop control of the device during operation.



The three desirable characteristics for tuneable lasers, as well as the typical design rules required to achieve them. Few designs are able to achieve the combination of wide tunability, fast switching and narrow linewidth.

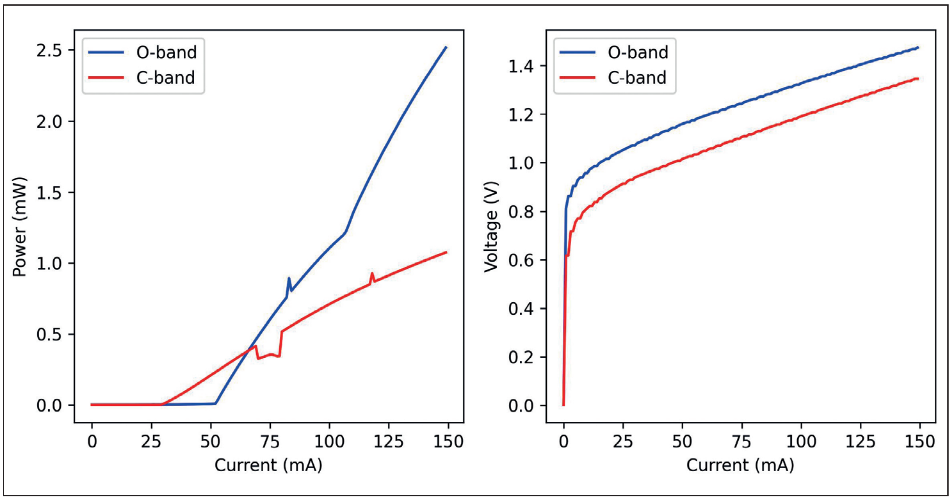


Figure 2. Example of Light-Current (L-I) and Current-Voltage (I-V) curves. The C-band device has a threshold current of 30 mA, while the O-band device has a higher threshold of 50 mA. However, a higher slope efficiency in the O-band device results in a higher optical power at a nominal current of 100 mA. The O-band device is expected to operate at a higher voltage due to the wider bandgap required to generate light in the O-band.

Monolithic dual ring architecture

Our lasers are fabricated on a monolithic InP chip utilising an active-passive integration scheme. The design employs a looped cavity with a gain section that provides optical gain, and two ring-resonators that act as transmission filters for wavelength selectivity through Vernier tuning (see Figure 1 for details). The ring-resonators, which are electro-optically tuned through reverse-bias voltage application, have remarkably low dark currents – they are in the low milliampere range. These low-power, low-current passive tuning sections are crucial to realising optimum device performance. Low dark currents minimise linewidth broadening and device power consumption, while low heat dissipation in the tuning sections eradicates troublesome slow thermal transients. Thanks to these strengths, we realise nanosecond-level switching speeds.

Wide-band tuning is achieved with the Vernier effect. The desired emission wavelength is selected through the overlap of the transmission filters of two ring resonators, each with a slightly different free spectral range. These filters produce a series of discrete lasing modes when one ring is tuned relative to the other. A long phase tuning section in the large outer loop provides fine tuning of the cavity mode within the ring filter envelope.

One of the benefits of the Vernier mechanism is that it opens up an avenue for 'step-and-sweep' style tuning, important for many frequency-modulated continuous-wave lidar systems. The idea behind step-and-sweep is as follows: tune the rings relative to each other to produce a series of discontinuous hops between ring modes (step), before ramping the phase section with a defined signal to produce a continuous change in frequency (sweep) within each of these modes.

To increase the output power, we integrate a semiconductor optical amplifier. This boosts the output to 30 mW (+14 dBm), with further increases

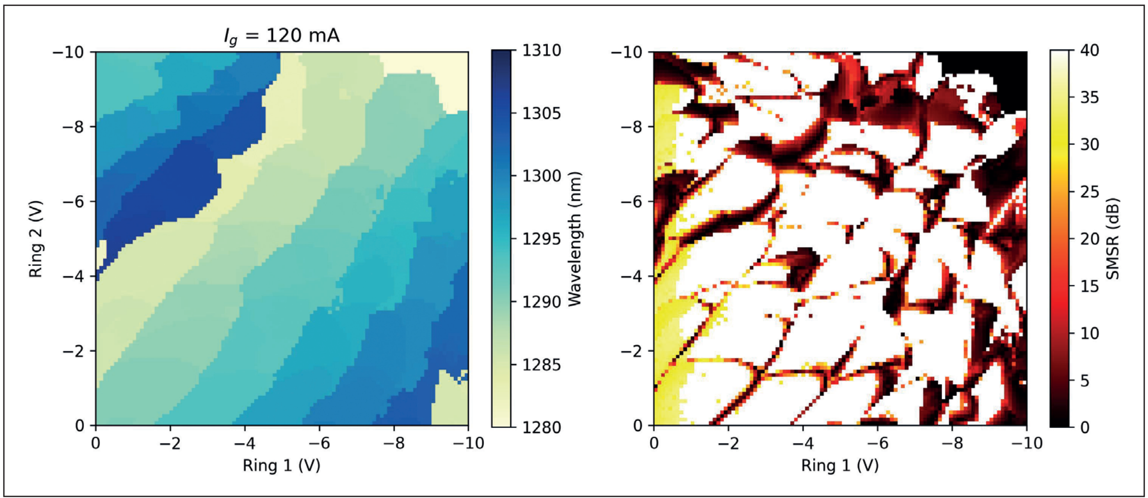


Figure 3. Mode maps generated by sweeping voltages to the two ring tuners (with current into the gain section and voltage to the phase section held fixed). The wavelength map on the left shows a series of discrete regions, in which wavelength is relatively fixed (the modes). A map of the side-mode suppression ratio (SMSR) on the right indicates regions where only a single lasing mode is dominating. Regions of low SMSR (<30 dB) indicate a transition between modes (mode hops).

expected. The addition of this amplifier also enables output power stabilisation, thanks to the possibility to readjust the output independently from the cavity.

We have recorded the characteristics of our original C-band designs and our more recent designs in the O-band. By plotting light-current-voltage curves, we have determined the likes of lasing threshold, slope efficiency and power consumption. Our C-band devices, which do not include a semiconductor optical amplifier, produce an optical output power of 0.5-1.0 mW. O-band variants have a higher lasing threshold but compensate with higher optical powers. Without the addition of the amplifier, the output power is 1.0-2.5 mW (see Figure 2). During normal operation, the devices typically consume 130 mW, excluding the power drawn by the thermo-electric cooler.

For the spectral characterisation of our devices, we use 'mode-maps'. These two-dimensional maps represent the tuning space of the laser – in other words, the lasing wavelengths produced by every combination of voltages supplied to the two rings on a two-dimensional grid (see Figure 3 for more details). These wavelength maps feature a series of discrete regions (modes), in which the wavelength varies continuously. Crossing a boundary between the modes results in a wavelength discontinuity, known as a mode-hop.

Another important quantity to record on these maps is the side-mode suppression ratio. The value for this ratio offers an insight into the competing modes in the optical spectrum – when this ratio is low, that's below 30 dB, a mode hop is about to occur.

These maps can also be used to determine suitable operating points for the laser under step-and-sweep operation, and to identify optical switching pairs.

By sweeping the phase section, the tuning space for these maps expands into the third dimension, providing a more comprehensive characterisation. However, such maps are much more difficult to visualise.

We have used mode maps to determine the tuning range for our lasers. It's nearly 30 nm in the O-band and over 35 nm in the C-band.

Once a suitable set of operating points are extracted from the mode maps, it is possible to measure the optical switching speed (see Figure 4). To validate the nano-second switching speeds expected from the device, we use a simple frequency discrimination technique. By supplying one or more tuners with a low-frequency square-wave signal, with a suitable amplitude to produce a hop between two modes, we produce a repetitive optical switching signal. Following photodetection, this produces an electrical signal of the same frequency as the input signal, with the rise/fall time being equal to the optical switching time.

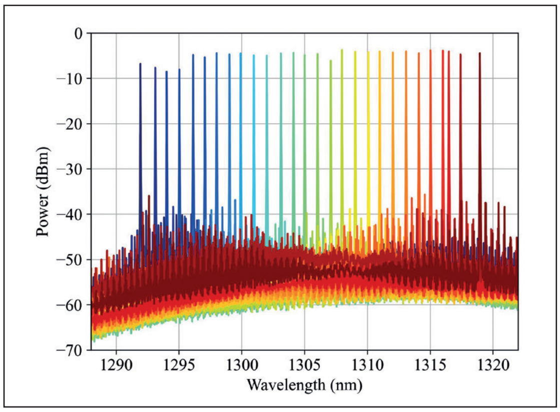


Figure 4. A set of individual spectra taken across the optical O-band. Each line represents a discrete tuning mode of the laser.

Using this method, we have recorded switching speeds consistently below 10 ns, and as short as 3.6 ns (see Figure 5 for more details). That's up to three orders of magnitude faster than typical lasers based on thermal tuning.

Having established that our laser is fast, the next crucial question is this: what is its noise characteristics, and in particular its linewidth? To answer this, we have used a delayed self-heterodyne technique to measure the linewidth, obtaining values from 400 kHz down to 100 kHz in both C- and O-band devices (see Figure 6). While this is still broader than most external-cavity-type

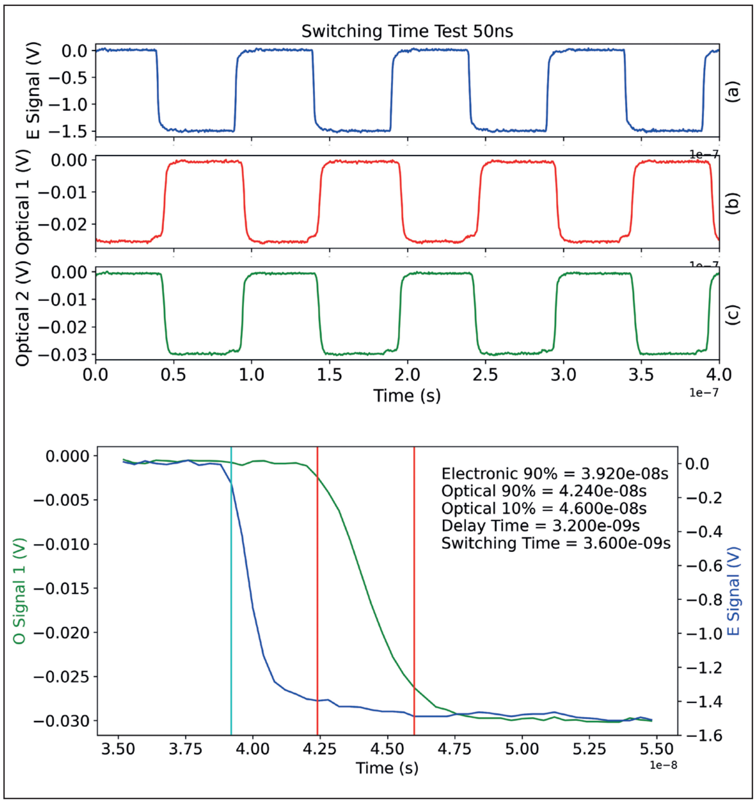


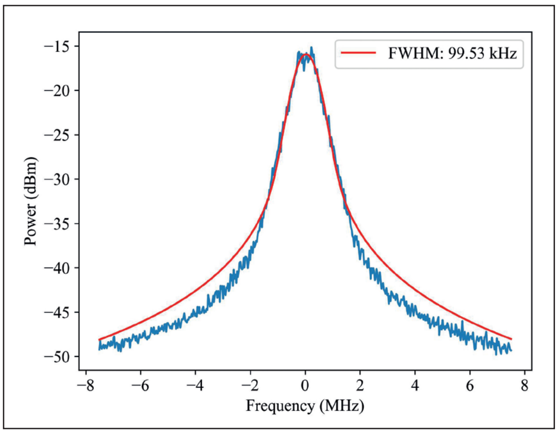
Figure 5. A switching speed measurement taken using a frequency discriminator. The square-wave voltage applied to one of the rings (a) produces two complimentary optical signals (b), (c) – one for when the optical filter is centred on each of the two switching modes. The switching time is equal to the fall time of the optical signal, measured to be 3.6 ns.

lasers, it is a significant improvement over fast-tuning sampled-grating distributed Bragg reflector lasers, which would be expected to have linewidths in the megahertz range. The level of noise indicates that our devices are suitable for coherent transmission applications. With our collaborators in Dublin City University, we have proven this, realising 480 Gbit/s 16-QAM transmission over 25 km of optical fibre. This result demonstrates the capability of our lasers for serving in optical access, metro, and data-centre networks.

Future impact

According to the *Tunable Laser Market Research Report*, published by Market Research Community, the tuneable laser market is projected to grow by 8.8 percent per year from now to 2030, by which time it will climb to $23.2 billion. Helping to fuel this growth will be improvements to the technology, such as those just described, that will enable new applications, enhance existing ones and have far-reaching impacts on healthcare, telecommunications, transportation and many other sectors.

There is no doubt that producing tuneable lasers that combine wide tunability with a low linewidth and either ultra-fast switching or sweeping is an important step forward. In the optical networking field, it enables new datacentre switching architectures that promise to trim power consumption by keeping as much traffic in the optical domain as possible, and only converting to the electronic domain the traffic that is necessary.



➤ Figure 6. Spectrum fitted to a Voigt profile. Lorentzian linewidths as low as 100 kHz have been recorded.

The evolution of telecom protocols like 5G and the anticipated 6G necessitate ever-faster laser switching speeds, wide tunability, and low latency – all are required to ensure the seamless communication that's essential for our connected future. Moreover, the impact of lasers that excel on all these three fronts extends to advancements in metrology techniques, benefiting applications such as lidar, healthcare diagnostics and industrial sensing, where phase sensitivity and speed are critical.

Key to the potential of this unique laser is its monolithic integration. Thanks to this, it can be manufactured at wafer scale using today's InP processing techniques, ensuring a cost profile that is compatible with the very high-volume applications envisaged today and into the future.

FURTHER READING / REFERENCE

➤ S. Andreou *et al.* "Electro-Optic Tuning of a Monolithically Integrated Widely Tuneable InP Laser with Free-Running and Stabilized Operation," J. Light. Technol. **38** 1887 (2020)

➤ G. Jain *et al.* "Widely tunable C-band laser and module with fast tuning and narrow linewidth," Proc. SPIE **12424** Integrated Optics: Devices, Materials, and Technologies XXVII, 124241M (2023)

➤ C. Murphy *et al.* "Widely Tunable O-band Laser with Narrow Linewidth, Fast Switching Speed and an Integrated SOA", ECOC 2023, Th.B.4.2.

➤ M. Troncoso-Costas *et al.* "Experimental demonstration of 480 Gbit/s coherent transmission using a nanosecond switching tuneable laser", Opt. Commun. **554** 130164 (2024)

semi

SMART MANUFACTURING

SMART MOBILITY

SMART MEDTECH

SMART DATA-AI

Connecting Semiconductors and Electronics

WORKFORCE DEVELOPMENT

Global ADVOCACY

Sustainability

MIT MARKET INTELLIGENCE TEAM

About SEMI:
SEMI connects more than 2,500 member companies and 1.3 million professionals worldwide to advance the technology and business of electronics design and manufacturing. The breadth and depth of our events, programs and services help members accelerate innovation and collaboration on the toughest challenges to growth.

1000+ STANDARDS

THOUGHT LEADERSHIP

SEMICON

TECH COMMUNITIES

SEMI UNIVERSITY

Cyber Security

ESDA Electronic System Design Alliance

FlexTech

FOA Fab Owners Alliance

MEMS & SENSORS INDUSTRY GROUP®

SOI Industry Consortium


VPIphotonics
DESIGN AUTOMATION
PROFESSIONAL SIMULATION TOOLS &
EXPERT DESIGN SERVICES
Integrated Devices, Waveguides & Fibers
VPIdeviceDesigner™
Photonic Integrated Circuits
VPIcomponentMaker™ Photonic Circuits
Fiber Amplifiers & Lasers
VPIcomponentMaker™ Fiber Optics
Transmission Systems
VPItransmissionMaker™ Optical Systems
Lab-proven DSP Algorithms
VPItoolkit™ DSP Library
Quantum Key Distribution
VPItoolkit™ QKD
We empower you to
define the cutting edge.
Request an evaluation
www.VPIphotonics.com