PIC MAGAZINE

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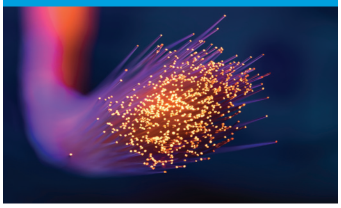
Market opportunity for Photonics



Self-calibrating optical beamformers

global internet system hybrid PICs

photonics built on a software foundation

Membranes underpin masterful modulation

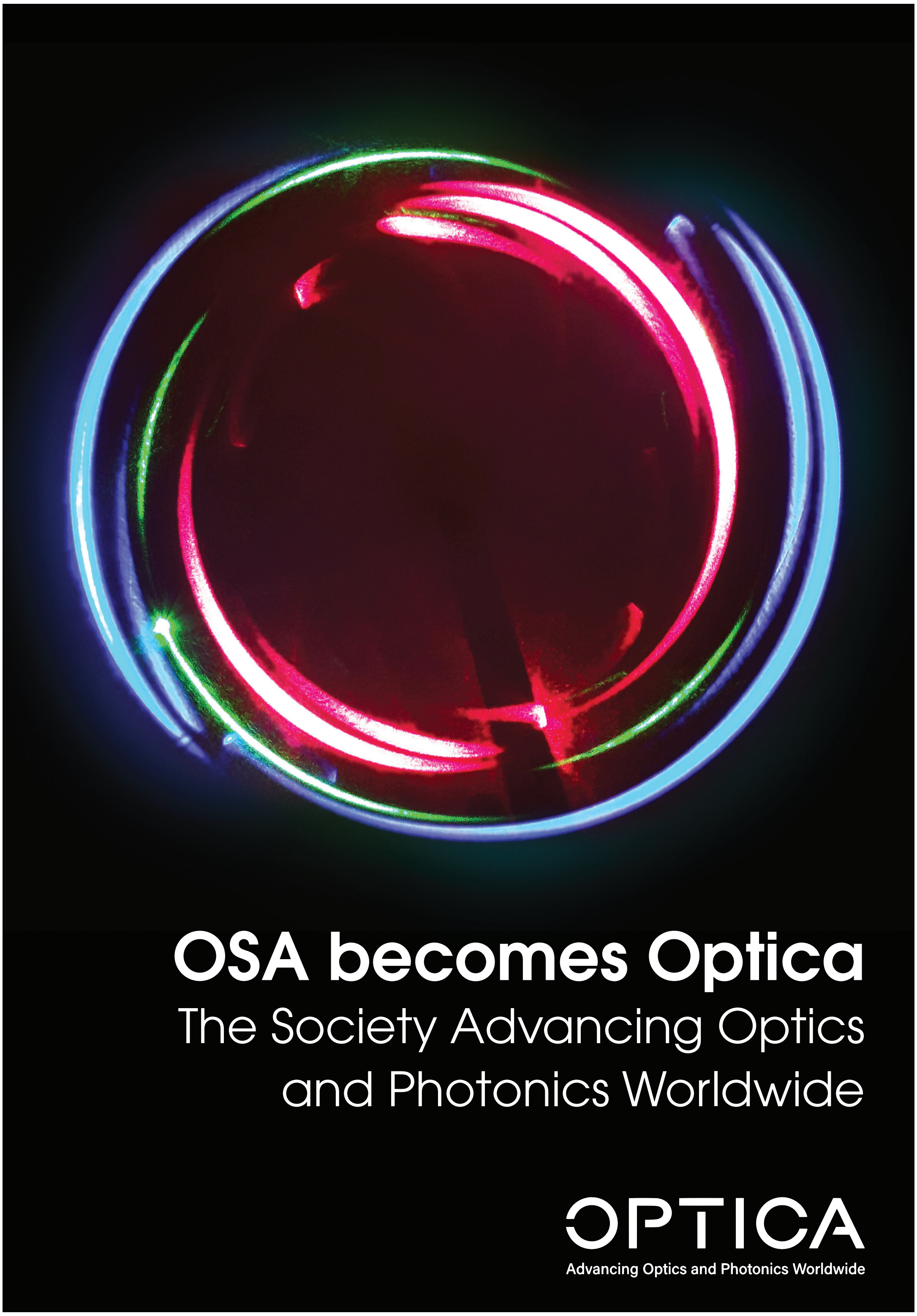


Image Credit: Albetro Tufaile, Soft Matter Lab, EACH-US

Viewpoint

By Mark Andrews, Technical Editor

Challenges are just opportunities in disguise

HOW DO YOU approach a challenge? Do you dig in and work solo, or do you seek collaboration? How we achieve our goals says a lot about character and how we view our post-pandemic world.

For some, we have more challenges than opportunities. Supply chain disruptions are top of mind, but so also are the myriad other issues that now seem commonplace. When some see challenges exceeding resolutions this evidences a need to embrace what industry's leading success makers already know: challenges are opportunities in disguise.

At the start of the pandemic, practically no one appreciated what this meant for them, their families or their work. Today, we have vaccination programmes spreading across the world and prospects for normalized business inching closer. Will the next 6-12 months be easy? Probably not. Will we succeed? Yes—because challenges are being transformed into opportunities.

The European Conference on Optical Communications (ECOC) was held in mid-September as an in-person event. Other conferences are transitioning back to in-person meetings while companies find workarounds for problems that once seemed unsolvable. AngelTech 2021, including the PIC International conference, is planning its return as an in-person event 9-10 November in Brussels.

In this PIC Magazine, a Strategy Analytics articles describes ways that opportunities continue to arise. Optical and photonic systems have great expectations due in part to the pandemic's reworking of how and where broadband access is most needed.

At ECOC, past PIC Award recipient Lightwave Logic announced its record-setting performance (higher speed / less power consumption) with partner company Polariton Technologies. As Lightwave's CEO Michael Lebby likes to say, his company transforms the impossible into reality. Put another way, they turn challenges into opportunities.

In this PIC Magazine we explore other ways that photonic integration is meeting ever increasing data demands. The T&M experts at EXFO look at what's ahead in 2022. Experts from EPIC and the Ethernet Alliance discuss how PICs are critical to next generation systems. We look at the move by the Optical Society of America (OSA) to rebrand itself as 'Optica' in light of growing international opportunities. We also explore new technologies from imec, CEA Leti and other industry leaders.

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NeoPhotonics Introduces higher output 400G module

NEOPHOTONICS, a developer of silicon photonics and hybrid PIC-based lasers, modules and subsystems, has announced a new, high output power version of its 400G Multi-Rate CFP2-DCO coherent pluggable transceiver with 0 dBm output power and designed to operate in metro, regional and long haul ROADM based optical networks.

This new power module is based on NeoPhotonics vertically integrated InP technology platform, including our ultra-pure Nano tunable laser and Class 40 Coherent Driver Modulator (CDM) and Coherent Receiver (ICR). The module operates at up to 67 Gbaud enabling longer distance transmission and exhibiting superior receiver Optical Signal to Noise Ratio (rOSNR) performance.

An important, differentiating feature is that the transmitter integrates an optical amplifier to achieve the 0 dBm output power, while simultaneously achieving what the Company believes is the best transmitter OSNR and out-of-band OSNR performance in the industry. Higher transmitter OSNR enables longer distance transmission or more ROADM stages, while higher out-of-band OSNR ensures less crosstalk for colorless ROADMs.

In addition to the high output power and superior OSNR performance, ROADM applications also depend on a CFP2-DCO's optical filtering tolerance when its signal passes through multiple ROADMs in a network. This is because each ROADM stage applies optical filtering and causes the signal to lose power at the spectral edges.

The CFP2-DCO module is well suited for metro ROADM applications to cover a network distribution of up to 16 ROADM spans, encompassing almost all network scenarios. In addition, this module runs at a high spectral efficiency with 75GHz DWDM channel spacing. The same 400G CFP2-DCO module has sufficient performance to cover long-haul applications at 400G and 200G.

"Our newest CFP2-DCO coherent pluggable module, with high output power, robust ROADM filtering tolerance and demonstrated transmission over 1500 km, allows customers to use one coherent pluggable solution to cover essentially all metro ROADM use cases, simplifying network design, enabling disaggregation, and lowering inventory costs." said Tim Jenks, chairman and CEO of NeoPhotonics. "The key to achieving line card equivalent performance in a pluggable module, but with significantly lower power than a line card, is the vertical integration of our optical solution and Nano tunable laser," concluded Jenks.

Vector Photonics receives £600k for TITAN project

VECTOR PHOTONICS has received £600k for the newly awarded TITAN project, developing PCSELs for low-power consumption, optical interconnections between servers in hyperscale data centres. Of the total project value, £300k has come from Innovate UK's Investor Partnership Programme. This has been match-funded by private investment from UKI2S, a specialist, deep-tech seed fund for UK-based, research spinouts; the Scottish Growth Scheme, managed through Foresight Group Equity Finance; and Equity Gap, an angel syndicate investing in emerging Scottish businesses.

Neil Martin, CEO of Vector Photonics, said: "The rising power usage of hyperscale data centres is being driven by escalating demand from network connected devices, such as smartphones, PCs and the IoT. Hyperscale data centres currently rely on high-performance lasers for the optical interconnects between servers. These lasers require so much electrical power to operate, that it is the heat they create, and the energy used by the systems which cool them, which has become the limiting factor to any increases in optical performance. "The TITAN project will fund the early-stage development of PCSELs, which aim to solve this major heat problem. PCSELs require only half the electrical power of the incumbent lasers, for the equivalent system performance. Less heat is produced and less energy is used for cooling. Since we anticipate the system optical performance requirements of next-generation, hyperscale data centres increasing in future, it is only low-power consumption systems using PCSELs that can realistically facilitate this increase."

Project TITANs full name is PhoTonIc CrysTal LAsers for EtherNet applications.

Yokogawa launches extreme precision optical spectrum analyzer

YOKOGAWA has launched a new optical spectrum analyzer (OSA) designed to offer the extreme high precision demanded by researchers developing the next generation of optical communication components.

With the exponential growth in the Internet of Things, as well as cloud computing services, video broadcasting and conferencing, and the rise in access to mobile broadband, demand for data capacity will expand hugely over the next few years. High capacity optical backhaul networks will be needed to serve this growing traffic density. Dense wavelength division multiplexing (DWDM) is an optical multiplexing technology used to increase bandwidth over the existing fiber network.

As data hungry applications push the performance requirements of DWDM systems, telecommunication channels become ever more closely spaced, making it more difficult to separate the individual channels in the wavelength division multiplexing (WDM) analysis on an OSA. The Yokogawa AQ6380 OSA offers unequaled optical performance to allow engineers and scientists to develop and improve the speed, bandwidth and quality of the next generation of communication networks, while its ease of use ensures it can be operated quickly and efficiently.

"The AQ6380 is demonstrably the world's best grating based OSA, outperforming its nearest competing solution on wavelength accuracy, resolution, dynamic range, and actual measurement speed," says Terry Marrinan, Yokogawa Test & Measurement's Vice President, Marketing.

"The new product also offers a highly capable alternative to other measurement technologies, comparing favorably on wavelength range and actual dynamic range, and offering superior measurement speed and application adaptability, as well as a highly competitive price."

The AQ6380 has excellent optical wavelength resolution down to 5 picometers (pm), allowing optical signals in close proximity to be clearly separated and accurately measured. With the AQ6380, waveforms that were previously not even visible in a typical OSA, such as modulation side peaks in the laser spectrum, can now be accurately visualized.

It also offers a wavelength range of 1200 to 1650 nm, allowing one unit to meet diverse wavelength measurement needs. With the ability to alter the wavelength resolution from 5 pm to 2 nm, a wide range of applications can be supported, from narrowband peak/notch measurements to wideband spectral measurements.

A major challenge for optical researchers has been maintaining the accuracy of their instruments, with ambient temperature change, vibrations, and shock all potentially affecting the measurement accuracy of optical spectrum analyzers. To maintain consistently high accuracy, the AQ6380 features on board calibration based on a built-in light source. Wavelength calibration is automatically performed at set intervals by switching the optical path with an internal optical switch.

Another important parameter in optical waveform analysis is close-in dynamic range, defined as the difference in power level measured from the peak of the signal to the noise at a specific distance from the peak wavelength. The AQ6380 features a newly designed monochromator with sharper spectral characteristics than previously available, achieving a close-in dynamic range of up to 65 dB. The result is that signals in close proximity can be clearly separated and accurately measured.

The new monochromator also offers very high stray light suppression, an important criterion in optical measurement. For example, in situations such as laser SMSR measurement, where several optical spectra with different levels are measured at the same time, the stray light may interfere with the measurement. The AQ6380 offers a best-in-class stray light suppression value of 80 dB.

Fast measurement speed is another major benefit, with the AQ6380 capturing data points in only 0.23 seconds compared to 5.4 seconds for the existing model (AQ6370D) in certain conditions. The new AQ6380 is also designed for ease and efficiency of use, ensuring the measurement scheme can be set up rapidly and data can be acquired easily. The high-resolution, responsive 10.4-inch touchscreen LCD makes the device as easy and intuitive to operate as a tablet. When it comes to analyzing results, the AQ6380 has built-in analysis functions to characterize optical spectrum from a variety of optical systems and devices, such as WDM system, DFB-LD, EDFA, and filters.

Analysis functions include: DFB-LD; FP-LD; LED; Spectral width (peak/notch); SMSR; Optical power; WDM (OSNR); EDFA (Gain and NF); Filter (peak/bottom) and WDM filter (peak/bottom).

The AQ6380 also features an application menu "APP mode", which makes measurement set-up much easier. Pushing the APP button brings up an overview of the pre-installed testing apps – WDM, DFB-LD, FP-LD and LED testing. A guide through wizard leads the user through an easy set up process for specific measurements and analysis. New or additional testing applications will be made available for download from the Yokogawa website and can be added to the AQ6380 by future firmware updates.

NeoPhotonics announces components for Coherent Lidar

NeoPhotonics, a developer of silicon photonics and advanced hybrid photonic integrated circuit-based lasers, modules and subsystems, has announced a new, tuneable high power FMCW (frequency-modulated continuous-wave) laser module and high power semiconductor optical amplifier (SOA) chips.

Both components are optimised to enable long range automotive lidar and high resolution industrial sensing applications. The FMCW Laser is C-band tunable and can be directly modulated to provide >21dBm (126mW) fiber coupled power and a narrow linewidth FMCW optical signal. The SOA chip is designed for integration with Photonic Integrated Circuit (PIC) lidar engines and provides >23dBm optical output power.

These new high output power SOAs and FMCW lasers are based on NeoPhotonics photonic integration platform and improve sensitivity and range, which enables automotive lidar systems to "see" considerably farther than 200 meters, allowing for enhanced safety. Both products operate in the 1550 nm band, which is believed to be more "eye safe", and are currently being sampled to key customers. In addition, tuneable FMCW laser sources enable lidars with configurable operating wavelength thus further enhancing the immunity of coherent lidars to external light interference.

Coherent lidar, also called FMCW lidar, uses coherent technology to greatly increase range and sensitivity by measuring the phase of the reflected light instead of relying only on intensity measurements. Coherent technology was pioneered by NeoPhotonics for communications applications and implemented in PICs using NeoPhotonics InP and Silicon Photonics integration platforms. Coherent lidar systems require similar chip-scale manufacturing to reduce costs and enable high volume. Coherent detection, whether for lidar or Communications applications, uses photonic integrated circuits (PICs) to extract phase and amplitude information from the optical signal. Narrow linewidth and low phase noise lasers are required for precise phase measurements and high optical power is required to compensate for optical loss in the Silicon Photonics optical chips and to provide a sufficient return signal from distant objects for efficient detection. NeoPhotonics narrow linewidth laser and SOA can be used together or separately to optimize the lidar module performance.

"We are excited to apply our high volume photonic integration coherent technology, which we have honed for over a decade, to the adjacent market of lidar and autonomous vehicles," said Tim Jenks, chairman and CEO of NeoPhotonics. "The benefits of coherent technology and the physics enabling it mean we can bring the same benefits to customers in these new markets that we have brought to communications customers for many years," concluded Jenks.

Vector Photonics characterises PCSEL performance

The optical performance of Vector Photonics' 1310nm PCSELs has been successfully characterised, demonstrating a 40dB SMSR, as the technology continues to be commercialised.

This demonstrates that these surface emitting lasers have achieved a key figure of merit for their performance, on a par with current, market-leading datacoms laser technology.

David Childs, director of product development at Vector Photonics, said: "A 40dB result matches incumbent laser technology performance and shows we are on track with the successful commercialisation of this revolutionary, new, semiconductor laser technology."

The Vector Photonics 1310nm PCSEL (Photonic Crystal Surface Emitting Laser) has been developed as part of the Innovate UK-funded, LOCAL project. The test results demonstrate that the laser should meet the industry specifications for the network processing architecture of next generation, hyperscale data centres – its target market.

LIGENTEC and X-FAB creates Europe's largest foundry for PICs

LIGENTEC, pioneer in high-performance, low-loss, silicon nitride photonic solutions, and specialty semiconductor producer X-FAB Silicon Foundries have announced a strategic partnership resulting in the large-scale supply of integrated photonic devices.
Photonic integrated circuits (PICs) are set to repeat the success story of electronic integrated circuits (ICs). Working with light instead of electrons, PICs will play a key role in tomorrow's infrastructure for communication, biosensing and transportation.

"Silicon nitride offers superior performance to manage the light in the chip circuitry, with unprecedented low propagation losses and high-power handling," states Michael Zervas, co-founder of LIGENTEC. "While there is growing worldwide demand for silicon nitride PICs, the missing piece is a commercial volume foundry that can keep pace with the expected uptake."

LIGENTEC has implemented its proprietary, patented, low-loss silicon nitride process technology within X-FAB's existing high-throughput foundry workflow. It means that LIGENTEC PICs are now commercially available in high volumes out of Europe, a key requisite enabling the secure and independent supply of the quantities foreseen in relation to sensors for self-driving cars, environment monitoring, quantum computers and an array of other applications.

"This partnership allows us to offer the benefits of our technology to high volume customers," says LIGENTEC's Director Thomas Hessler. "X-FAB's advanced equipment and superior process control will enable us to serve the mass market with elevated performance PICs. Its multiple sites and capacity to deal with 100,000 new 200 mm wafer starts per month gives exceptional supply assurance and almost limitless scope for scaling. The proven track record X-FAB has in the automotive and medical sectors will open up new opportunities for LIGENTEC."

"The integrated photonics market has huge potential. We have partnered with LIGENTEC because it has the highest performance and the most mature offering for passive PICs.
This is complemented by a great customer orientation and strong development pipeline, rooted in the company's long- term R&D relationship with EPFL in Lausanne. We are highly committed to exploring the future possibilities of PICs through our partnership with LIGENTEC, acting as a pillar of strong growth for X-FAB's specialty foundry business," adds Rudi De Winter, CEO of X-FAB.

Thanks to this strategic partnership with X-FAB, LIGENTEC now takes volume production requests for low-loss silicon nitride PICs, based on 200 mm wafers. For enquiries, please contact info@ligentec.com

iPRONICS appoints Dr Ana Gonzalez as Director of Strategic Partnerships

On September 10, 2021, Dr Ana Gonzalez joined iPRONICS Programmable Photonics as Director of Strategic Partnerships. In this role, she will be responsible for all sales and service activities building strong relationships with clients and strategic partners, closely working together to achieve long term goals and objectives.

Ana joins iPRONICS after more than 15 years of expertise in photonic integration, strategy, operations, and sales. She spent 5 years at the European Photonics Industry Consortium (EPIC) as R&D Manager identifying business opportunities among the European ecosystem and facilitating the exploitation of R&D results in the photonics community. Gonzalez graduated from the Autonomous University of Barcelona with a Bachelor of Chemistry. She also holds a PhD in diagnosis developing photonic devices for medical applications from the Catalan Institute of Nanoscience and Nanotechnology, Spain.

"Ana's knowledge of the photonics industry and technology is the perfect fit to realize our long-term vision for the company", says Prof. Jose Capmany, Chief Operations Officer at iPRONICS.

GÉANT delivers 800G with Infinera ICE6

INFINERA has announced that GÉANT, Europe's leading collaboration on network and related infrastructure and services for research and education, completed a live network trial of 800G transmission on its pan-European production network.

Powered by Infinera's ICE6 800G coherent technology on the GX Series Compact Modular Platform, this trial demonstrated the ability of GÉANT's network to massively increase capacity and scale significant amounts of bandwidth to meet the growing needs of the research community.

Scientists and researchers from areas such as bioinformatics, medicine, physics, astronomy, and climate change rely on the network provided by GÉANT and its NREN partners to share vast amounts of vital data; consequently, the network needs to stay well ahead of bandwidth requirements.

Traffic levels have grown by an average of 30 percent per year over the past five years, and the GÉANT network carries around 7 petabytes of data every day.

"Infinera's ICE6 800G coherent solution demonstrated superior performance in increasing optical reach and capacity, demonstrating its ability to help us accelerate service for the research and education community to meet their critical needs.

This trial clearly shows the value of Infinera's innovative technology, and we are pleased to trial this technology with a trusted partner," said Bram Peeters, chief network operations officer, GÉANT.

"GÉANT is a leader in developing collaboration services that facilitate important international cooperation between researchers and educators, and deploying the latest technology to stay at the forefront of this is critical to their organization," said Nick Walden, SVP, Worldwide Sales, Infinera.

"The demonstration with Infinera's ICE6 800G solution proves that the industry's latest technology can seamlessly power GÉANT's network with high-performance and high-capacity services, significantly enhancing their overall network."

Vector Photonics appoints business director for USA

ADAM CARTER has joined Vector Photonics as business development director for North America, based in Silicon Valley, his home for many years.

"Adam Carter is a semiconductor communications industry veteran, with an impressive, 25-year track record", said Neil Martin, CEO of Vector Photonics. "He has been instrumental in the growth of some of the world's leading manufacturers of integrated, optical components, modules and subsystems, including several, successful business exits, turnarounds and acquisitions. We are extremely pleased Adam has chosen to join Vector Photonics and he will be a great asset to the business."

Carter was most recently chief commercial officer at Foxcon Optical Interconnects. From July 2014 to December 2018, he was a key executive officer in the team which turned Oclaro from a loss-making manufacturer of optical products, to its sale to Lumentum Holdings for $1.85 billion.

From 2007 to 2014, Carter was a senior director and general manager of Cisco's Transceiver Module Group, where he led the acquisition of Lightwire, a Silicon Photonics start-up. Before that, Carter held strategic marketing and business development roles at Avago Technologies, Agilent Technologies and Hewlett Packard, having started his career as a process and device Engineer at BT & D.

Carter holds a BSc Honours in Applied Physics from Portsmouth University and received a PhD from the University of Wales, Cardiff, for his research on the plasma etching of III-V semiconductor materials.

OSA becomes OPTICA

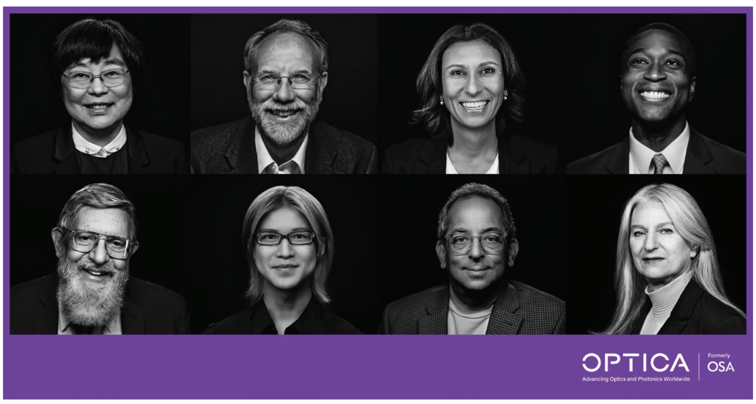
The society advancing optics and photonics worldwide

New brand honors the organization's legacy, reflects who it has become, and positions it for the future.

TODAY MARKS an historic day for OSA, as the organization changes its name to Optica, the Society advancing optics and photonics worldwide. Its new name reinforces the Society's position as the leading forum for advancing light science and technology. It also reflects its diverse, global community.

Optica was founded in 1916 to promote the generation, dissemination and application of knowledge in optics or light science. Since that time, both the discipline and the Society have grown. While the generation, detection, direction and modulation of light remains at the core of optics, the field has expanded to include light-enabled technologies ranging from modern communications, imaging, and sensing – or put another way, photonics. With its new name, the Society is well-positioned to further advance optics and photonics to solve some of the world's most challenging problems.

Started as a regional organization in the United States, Optica now encompasses a community that is 432,000+ large, representing 93% of the world's countries. Optica President, Connie Chang-Hasnain, said: "When the organization began more than 100 years ago, it was primarily focused on supporting a small group of members and companies in America who were working on technologies like lens design and photography. Today the optics and photonics industry has grown exponentially. The field has evolved and now includes metamaterials, ultrafast laser science, quantum technology, 5G networks, and many other technologies. As a champion of the field, our organization's name must reflect the work being undertaken and the people performing the work. Now is the time for our name to change to one that honors our legacy, is true to our present and embraces our future."



Elizabeth Rogan, Optica's CEO, said: "Our new name was developed in collaboration and consultation with our community. We knew it was critical to choose a name representing who we have become and possessing a strong strategic fit for our next chapter. Optica works on so many levels – it's already a well-known name due to our highly-regarded journal, it's geographically neutral, and it translates well in many languages."

Satoshi Kawata, Optica's 2022 President, agrees the new name is the right one: "Our new brand signals who we have become and propels us toward where we are going. It enables us to deliver on our goals including upholding excellence, empowering discovery and innovation, connecting our community and advocating for those in our field."

As the organization embraces its new brand, it will be introducing new programs and services. For example, starting in 2022, Optica members who reside in emerging market countries will be able to participate in the Society's in-person and virtual meetings for free. Offering waived registration removes significant financial barriers for these members and ensures learning, connecting and sharing is accessible to everyone.

In conjunction with the launch of Optica, a visual celebration of the extraordinary diversity of its global community was created. This collection, called Faces of Optica, includes close to seventy portraits of people from nine cities in Asia, Europe and the USA captured over the last three months by renowned portrait photographer Sam Barker. Visit optica.org/faces for more information and to view the full gallery of images.

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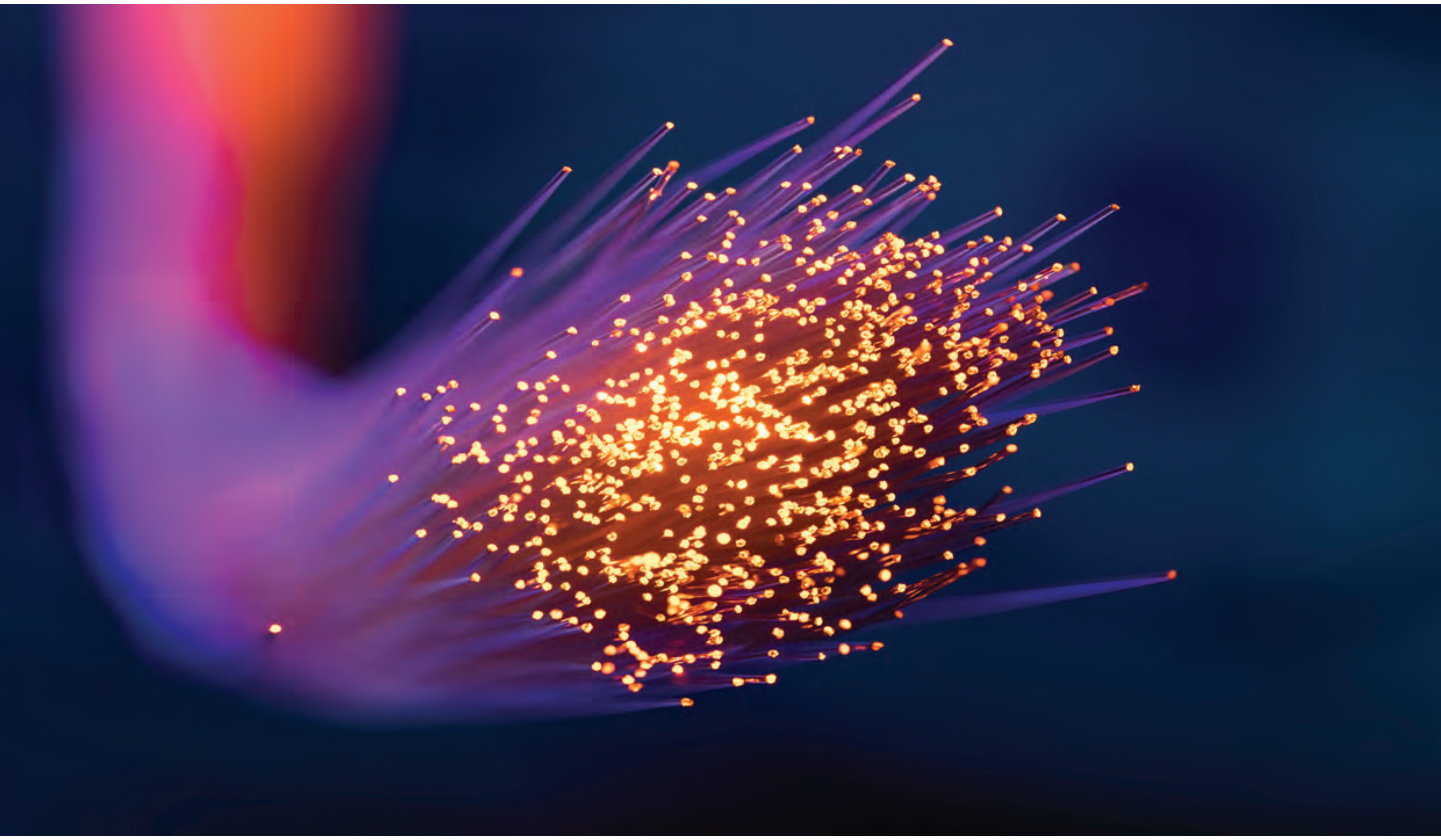


The market opportunity for photonics

The trends that will drive the evolution of markets revolve around higher data rates in optical transceivers, more semiconductor content, higher levels of photonic integration and increasing market share for silicon photonics.

BY ERIC HIGHAM, DIRECTOR ADVANCED SEMICONDUCTOR APPLICATIONS AND ADVANCED DEFENSE SYSTEMS STRATEGY ANALYTICS

AN EVER-EXPANDING WEB of connectivity enmeshes users. The promise and vision of emerging 5G wireless networks and devices intrigues us as we wonder how this wireless standard will enrich our lives. We embrace more and higher definition video capabilities and the world shrinks as social networks grow. These capabilities are not ubiquitous, but companies like Google, Facebook, Amazon and others are developing solutions to provide broadband connectivity to roughly half of the global population that is currently unserved.

The result of these developments is an explosive increase in data traffic. The solid line in Figure 1 shows the impressive growth of data since 2010, extrapolated to 2030. This is total data, so it has both a wireless and a wireline component. The message in this chart is that every bit of information, regardless of where or how it originates must travel on a network. The networks, access methods, physical transport media and the servers that make up “the cloud” define the trends for the optical market, but data traffic is the growth engine. Of course, no analysis is complete without a discussion of the effects of the COVID pandemic. A rough estimate of the increase in data traffic brought about by the shift to more home-centric activities is shown in the dashed line in Figure 1. The data traffic increase is obvious, but this COVID-induced traffic increase will cause operators to accelerate their network capacity plans by about 3 years.

The optical market has a long history and this segment was notable for its volatility. Traditionally, telecom companies and MSOs (Multiple Systems Operator) have managed the networks supporting the data traffic. This transport network consists primarily of fiber and much of that network is underground. Adding fiber is an expensive and disruptive process, as streets and yards must be excavated. Because of the cost and scope of this effort, the operators typically added excess fiber capacity and waited for that capacity to be absorbed before repeating that cycle.

The growing importance of data companies and data centers has broken this telco/MSO-driven boom or bust cycle for the optical industry. Exhibit 2 shows Cisco's 2018 estimate for data center traffic extrapolated to 2030, with the COVID increase shown in the dashed line. This traffic is about six times larger than the data traffic shown in Figure 1, with a similar anticipated growth rate. The details of this traffic lead to some very interesting optical opportunities. Not only is the data traffic larger than the transport network traffic, roughly 75% of that data remains within the data center. In addition, this estimate does not address "rack local" data that stays within the same server rack. This traffic is estimated to be up to twice as large as the data traffic within the data center, creating a very large opportunity for short-reach, high data rate connections and transmission.

Data center traffic has smoothed the growth trajectory of the optical market, removing much of the cyclical nature described earlier. The datacom companies (like Facebook, Amazon, Netflix and Google) do not worry about "monetizing the pipe". To these companies, the pipe is a conduit expanding and extending the reach of the services they offer. Their business model is getting internet access to more people to enable more clicks, video streams, searches and internet orders. This value has become apparent as we moved home during the pandemic and the home, rather than the office became the center of data traffic. Once a data center is built, additional capacity means buying and installing more servers, not digging up streets. This change in business model has created an inflection point for this market and has reduced the volatility and uncertainty substantially.

The Opportunities

The optical/photonic opportunity is very large. Figure 3 shows an average of recent industry forecasts for optical transceiver revenue. The consensus is for

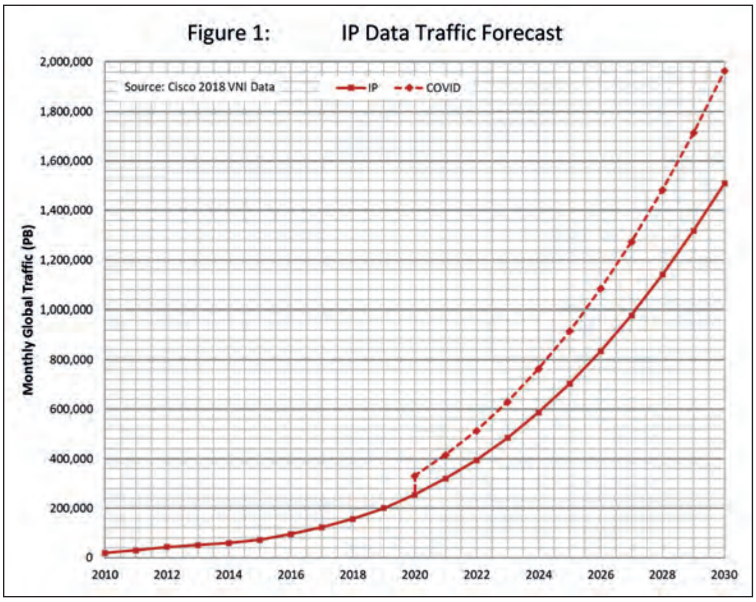


Figure 1: IP Data Traffic Forecast

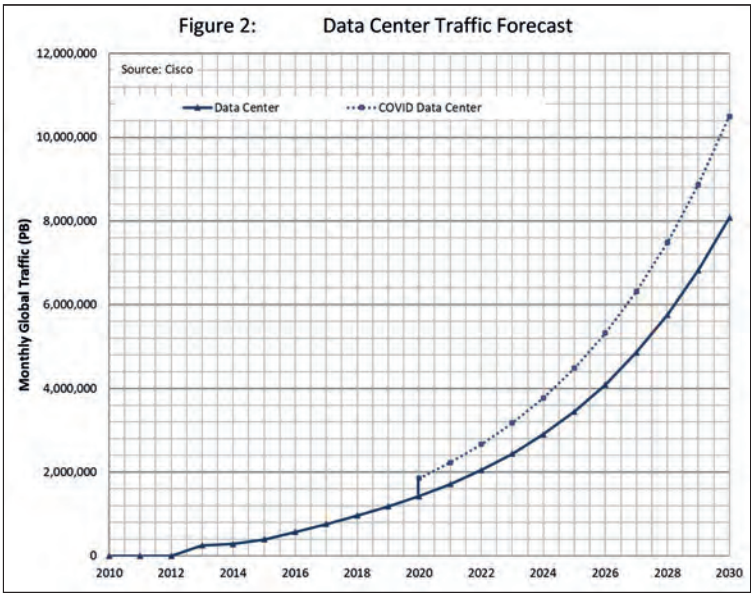


Figure 2: Data Center Traffic Forecast

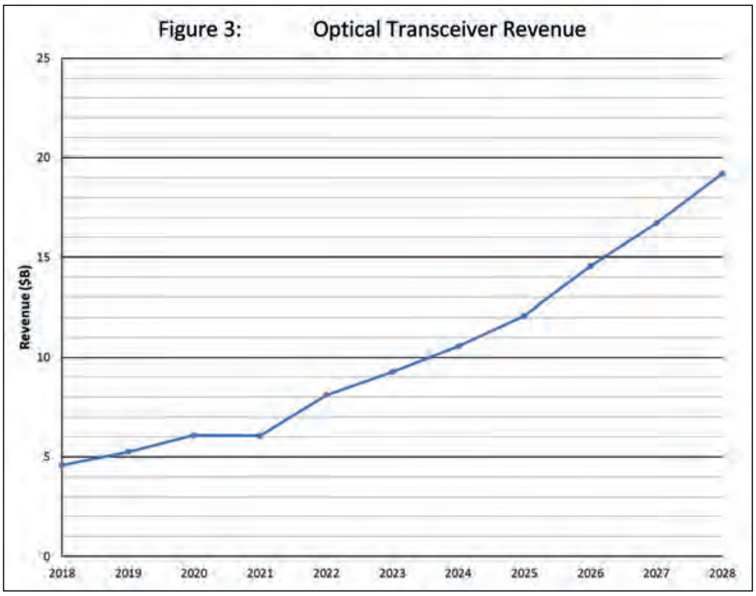


Figure 3: Optical Transceiver Revenue

flat revenue in 2021, as a result of the pandemic's influence on supply chains and the recent silicon chip shortage. Like most electronics markets, this one is heavily dependent on China and the final revenue trajectory will be influenced by factors like how quickly China's economy recovers from COVID and the timeline for 5G deployments.

Also of interest are the sources of the discontinuous traffic growth created by COVID. Figure 4 shows the enormous growth of non-traditional sources of data traffic, along with quantifying the shift to "at home" services resulting from the COVID-imposed lockdowns. The growth of these services, along with the expected increase in 5G deployments has operators thinking that the discontinuity caused by COVID will become the new future trajectory.

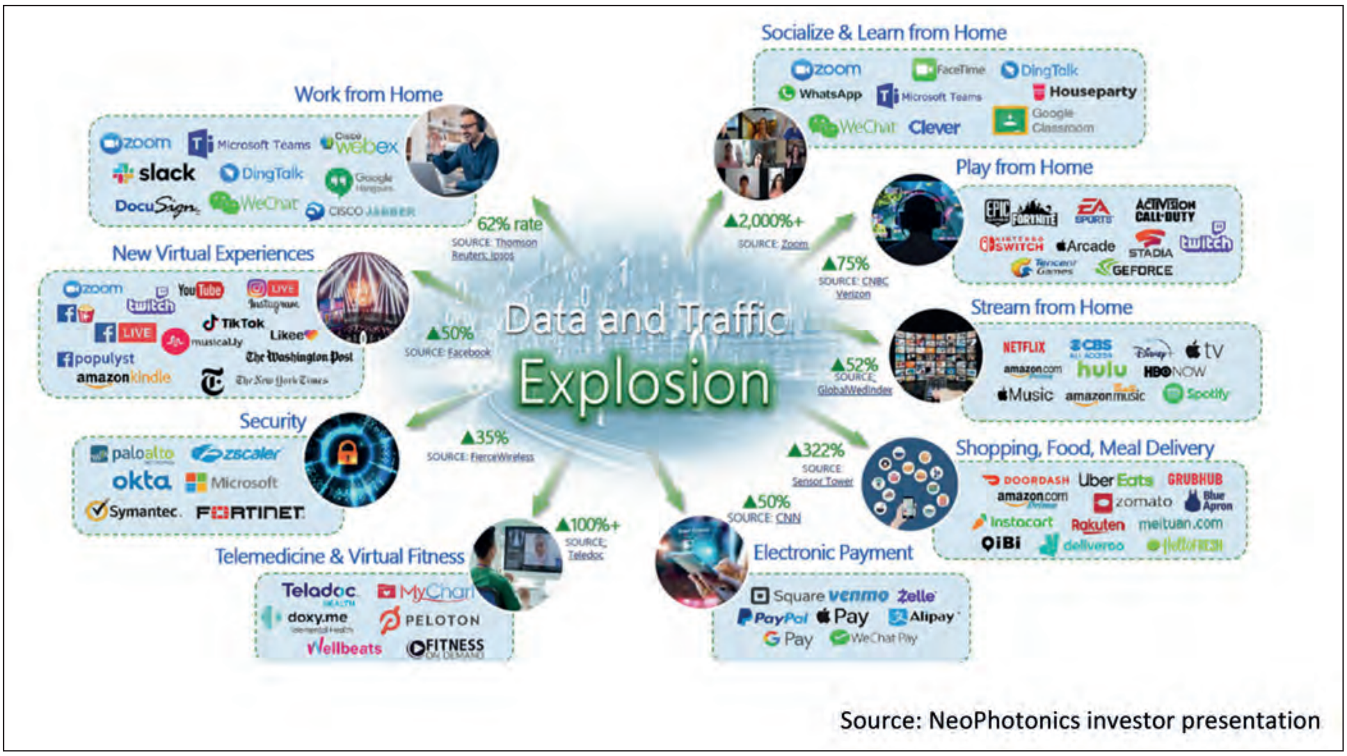
Monetizing the Network and Transport Opportunities

So, how does the supply chain capture and monetize these opportunities? As data traffic increases and consumers and businesses demand faster data rates and more capacity, devices, networks, transport and data centers must respond with higher performance. While fiber is an excellent transmission medium for light, it has loss and dispersion. At regular intervals and when signals are injected or removed, the signal is transformed from the optical domain to the electrical domain to be reconditioned before it is converted back to the optical domain for further transmission.

Figure 5 shows a simplified block diagram of a 400 Gbps optical module using a direct detection scheme. This module architecture illustrates a few notable features of the optical transport architecture. The input "line rate", in this case 400 Gbps, is demultiplexed into lower speed lanes. These lanes contain the reconditioning and silicon control functions for these demultiplexed signals. After conditioning, the lanes are multiplexed back to the higher line rate. The number of lanes multiplies the opportunity for silicon and compound semiconductor devices.

This architecture also illustrates one of the fundamental challenges. The rapid growth of data traffic demands higher line rates, but there is a cost and complexity trade off to consider. As the number of lanes in a direct detect receiver become prohibitive,

Figure 4: Why is Data Growing?



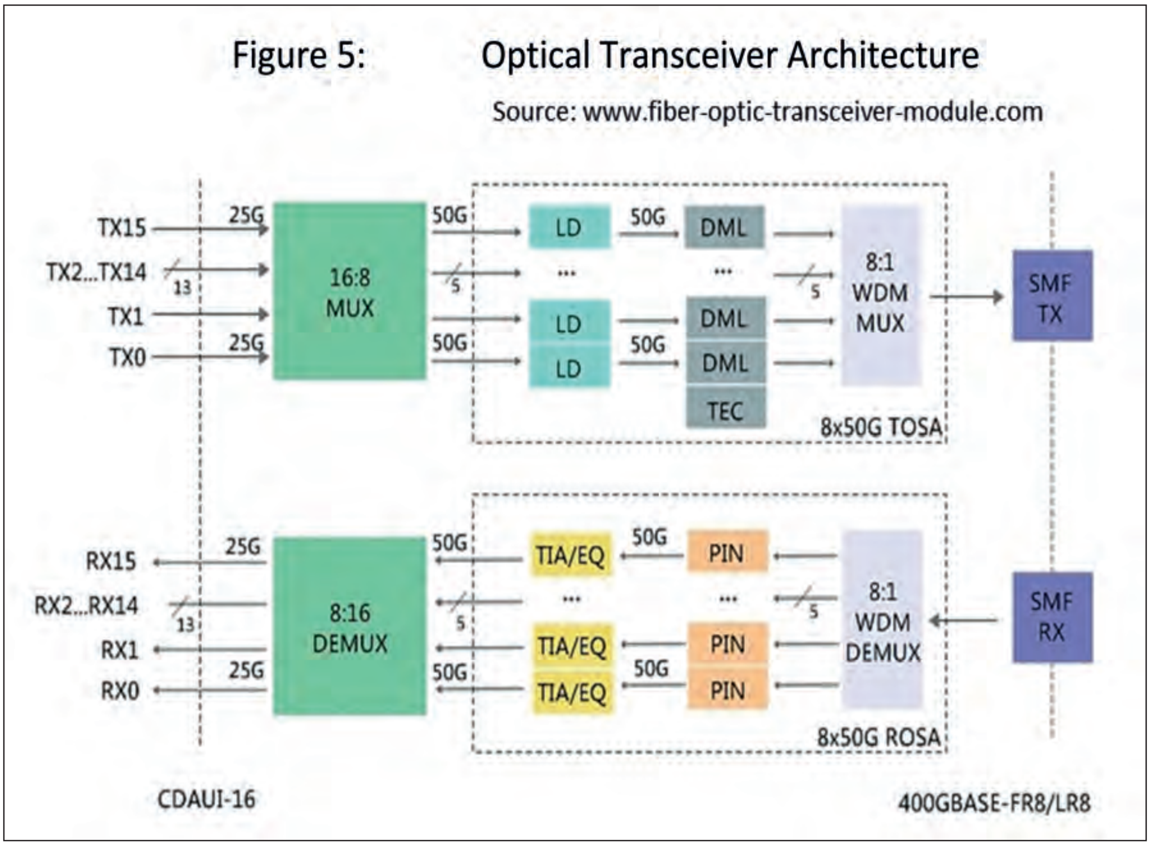


Figure 5: Optical Transceiver Architecture

module manufacturers are refining coherent detection techniques that achieve higher data rates per lane but depend much more heavily on DSPs and error correction techniques.

The chart in Figure 6 shows the expected speed evolution in optical modules. As line rates have increased, module speeds and lane rates have gone up in response. As the chart shows, 100 Gbps modules have become the workhorse of the industry, but we believe 200 Gbps and 400 Gbps modules are growing quickly. Figure 6 shows revenue, and the higher speed modules must improve the $/bit cost metric to see the widespread deployment that is being forecast.

Data Centers and Photonic integrated Circuits

In Figure 2, we saw that data center traffic is large and growing explosively. The data that stays within the data center and the server racks presents an enormous opportunity for short reach technologies that can offer advantages over the legacy copper and optical cable connections. This application looks poised to be a significant driver for photonic integrated circuits (PIC) and silicon photonics (SiPh).

Figure 7 shows a forecast for semiconductor revenue in optical transceiver applications. This market opportunity makes use of several different semiconductor technologies and this illustrates the PIC opportunity. The integration opportunity arises because GaAs, InP and silicon all have different advantages and different technology combinations meet different performance requirements. The result of these requirements is a large opportunity for InP-based integration and devices.

Silicon photonics will play an increasingly significant role by taking advantage of the manufacturing and

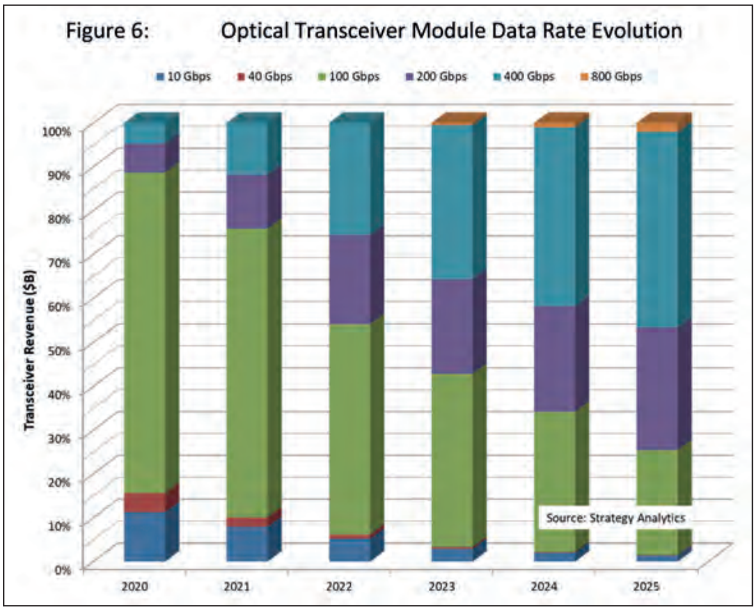


Figure 6: Optical Transceiver Module Data Rate Evolution

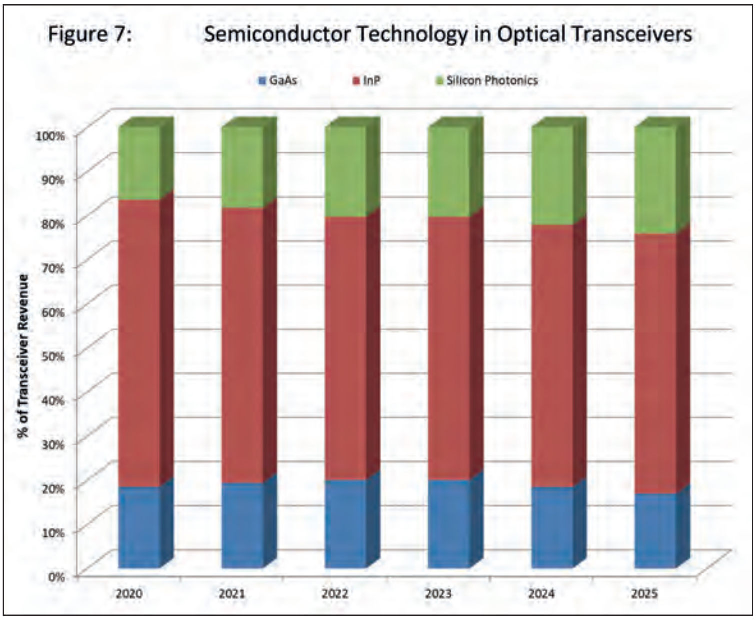


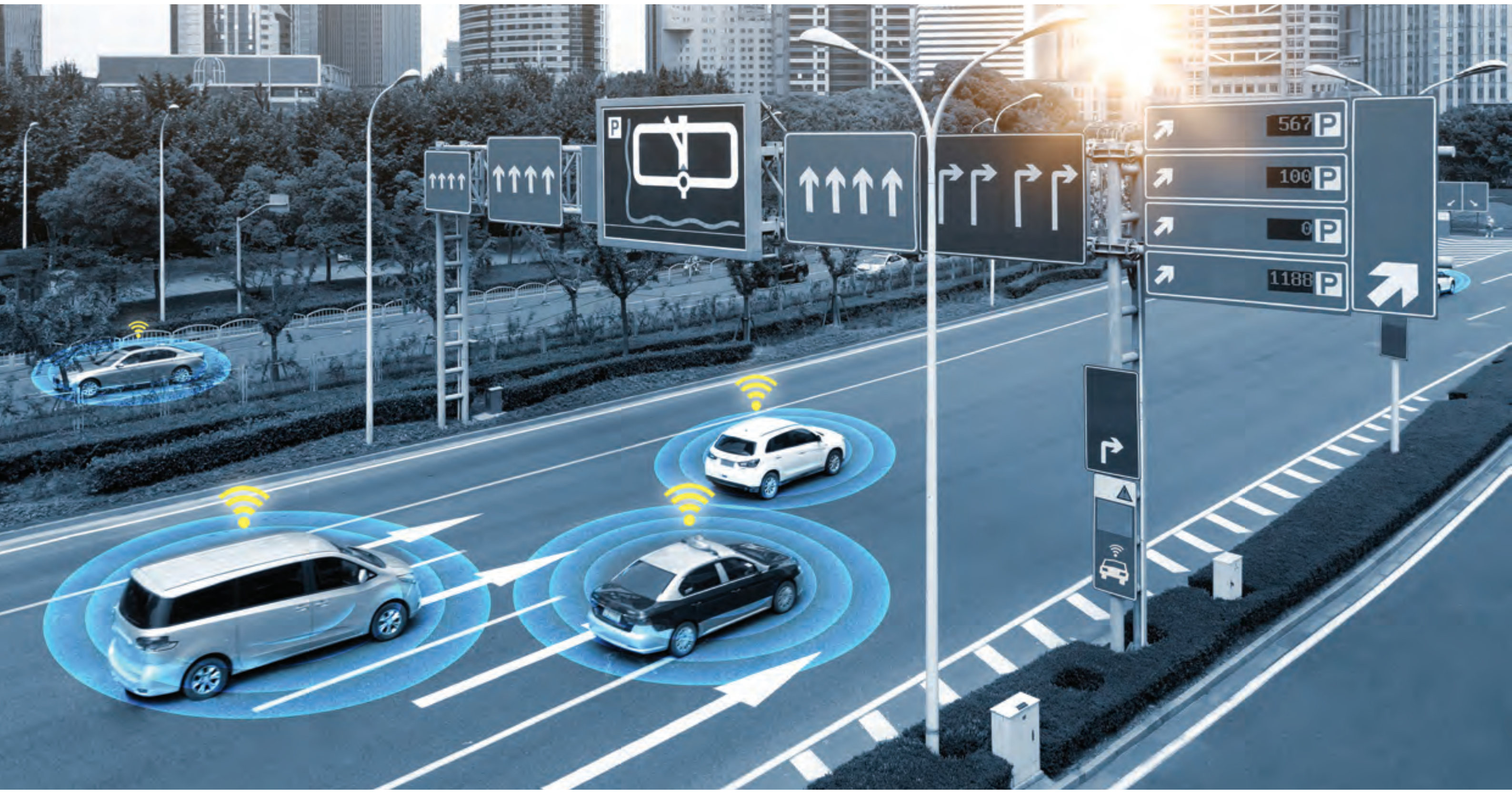
Figure 7: Semiconductor Technology in Optical Transceivers

cost advantages of silicon. There are significant product, process and packaging efforts underway to take advantage of the benefits of silicon for optical transceivers. Silicon is a very poor lasing device, so a silicon-based transceiver relies on another technology, increasingly InP, for the laser. We expect that the silicon photonics-based revenue will almost triple over the forecast.

Conclusions

Data traffic continues to explode as users demand increasingly sophisticated wireless and video applications, workers embrace "work from home" and more services go into the cloud. Data traffic will also increase as 5G network and device deployment expands. There will be growth opportunities for the networks that enable and transport the data and the data centers that represent the physical manifestation of "the cloud".

To support this data tsunami, the optical content in access and transport networks, along with data center interconnections is also increasing. The trends that will continue to drive the evolution of this market revolve around higher data rates in optical transceivers, more semiconductor content, higher levels of photonic integration and increasing market share for silicon photonics.



New imec research demonstrates fully digital, self-calibrating optical beamformers

Optical beamformers will play pivotal roles in emerging applications targeting assisted and autonomous driving, high resolution earth observation, crop monitoring and 5G communications. Imec's new on-chip solution is a self-calibrating optical beamformer with no mechanical moving parts, enabling higher resolution performance while being inherently more reliable.

MANY NEW APPLICATIONS (autonomous vehicles, virtual reality, medical imaging) rely on 3D sensors that use the steering, shaping, and focusing of light to visualize the environment. Most current beamforming solutions are expensive and bulky and need to be calibrated and operated by experts. They typically rely on mechanically moving parts to manipulate the sensing light beam, making them vulnerable to defects.

With integrated photonics, it becomes possible to do the beamforming process with a compact photonic integrated circuit. Researchers from the research & innovation hub imec recently published a unique concept for a fully digital, self-calibrating optical beamformer.

Imec's beamformer relies on a waveguide that passes through phase shifters to reach an array of on-chip

Figure 1: SEM image of SiN-on-Si optical phase array antenna

antennas (Figure 1). Through controlled phase modulation, these antennas can transmit signals in a controlled direction.

In imec's latest demonstrators, the beamformer can cover a 40-degree angle (FoV) with below 0.2-degree angular precision. These specifications are not limited by the enabling design (Figure 2) or technology (figure 1) in this demonstration. Actually, it shows that this OPA concept based on Si/SiN photonics is scalable and even tighter specifications could be achieved, based on the customer requirements.

A combination of silicon and silicon nitride
The main novelties of imec's solution are in the architecture and the choice of material platforms. Where typical solid-state lidar systems are built either in silicon or silicon nitride photonics, imec has made a smart combination of both. Building the waveguide and the antennas in SiN will enable low loss and high-power handling performance plus high process control. In this concept conventional Si photonics is used to build efficient phase shifters and on-chip compact photodetectors. Si-photonics-based phase shifters are the preferred option over the SiN platform to achieve low-power operation and still be low loss. Because the entire system is compatible with semiconductor manufacturing flows, it allows to drastically reduce the production cost at high volumes using standard CMOS foundry facilities.

On-chip interferometers for self calibration

On top of its performance and low-cost-manufacturability potential, the imec solution is self-calibrating via an on-chip solution. This is important, because no matter how precise your system is, when processing at the nanometer scale, there will always be slight process and material-related deviations. These result in no antenna or other on-chip building block being 100% identical to its neighbor and inevitably cause deviations in the phase modulation and behavior of the system. As a result, the calibration is required to compensate for these inherent aberrations.

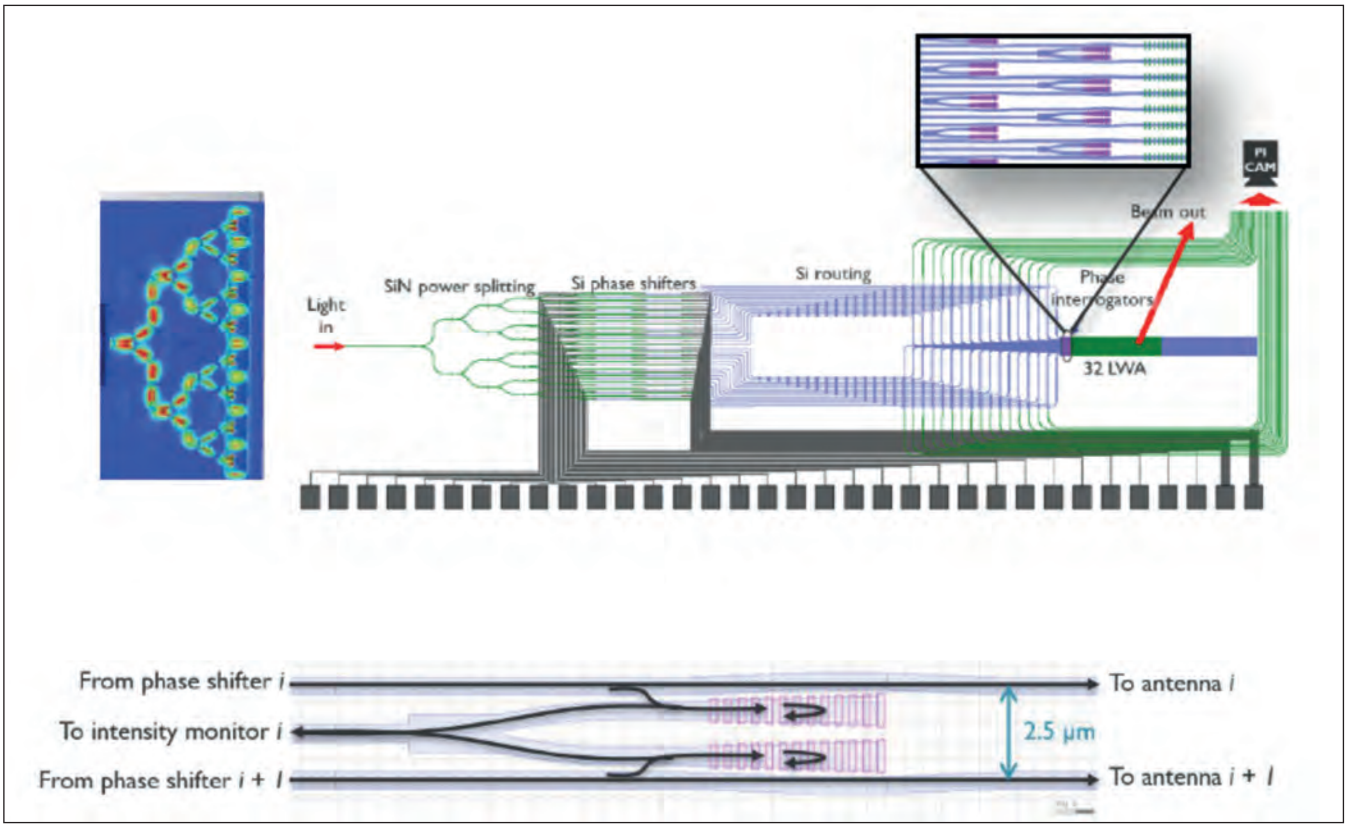


Figure 2: Design of the optical beamforming chip fabricated in the imec 200mm photonic pilot line, based on SiN on Si technology for LiDAR application. (From: Kjellman et al. (2020), Silicon photonic phase interrogators for on-chip calibration of optical phased arrays, SPIE conference paper, DOI: 10.1117/12.2546542)

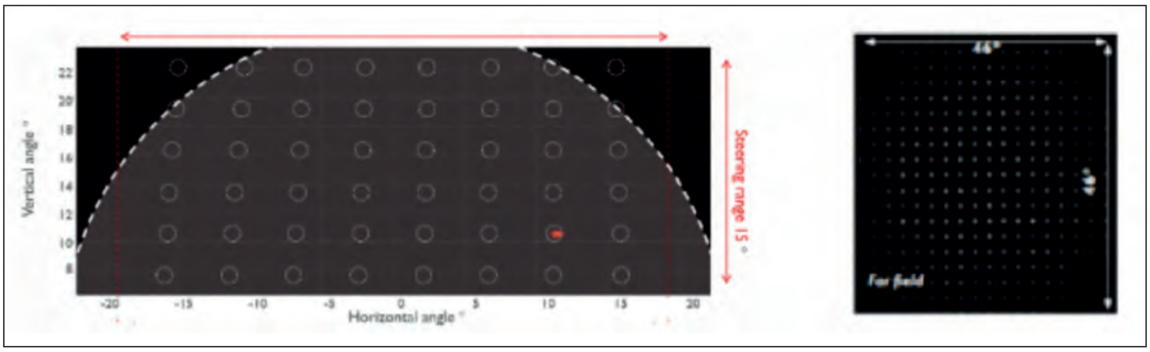


Figure 3: (left) 2D single-spot scanning-LiDAR demonstration; (right) 2D steerable structured light LiDAR demonstration.

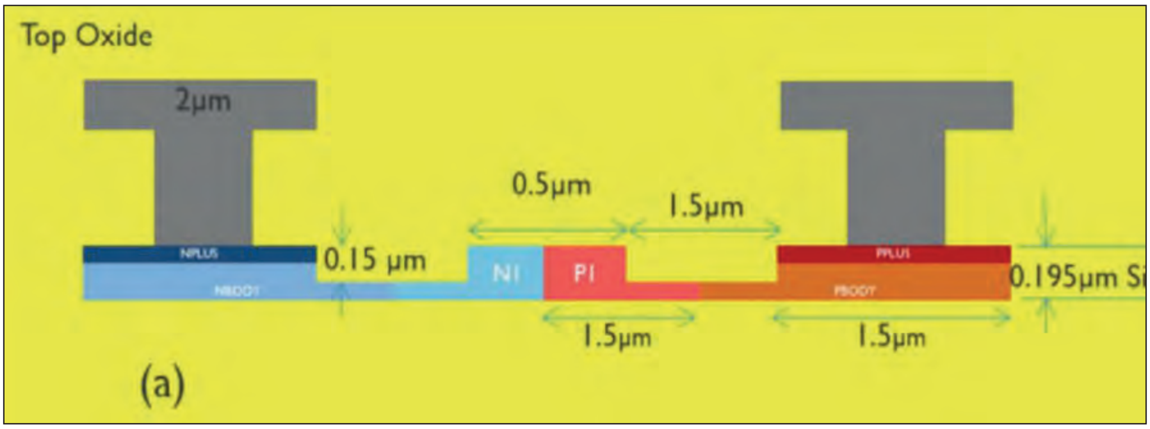


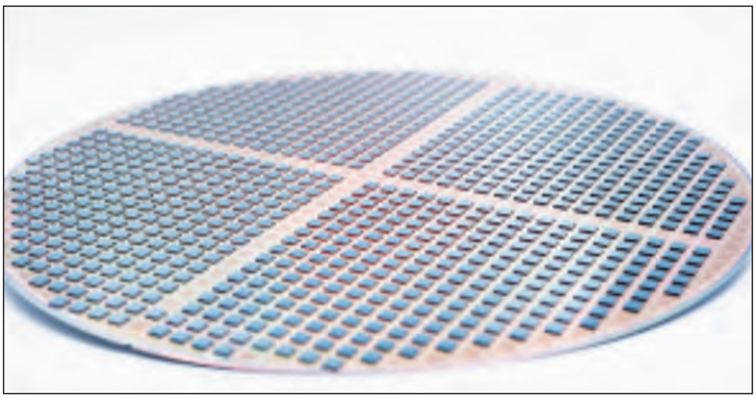
Figure 4: Cross-section of the silicon PN junction photodiode (From: Dwivedi et al. (2021), All-Silicon Photodetectors for Photonic Integrated Circuit Calibration, IEEE Photonics Technology Letters, vol. 33, no. 16, pp. 836-839, doi: 10.1109/LPT.2021.3065222)

Normally, such calibration is done in a controlled and complex optical setup designed to represent what happens if you would send and retrieve signals over distances of hundreds of meters and to correct for the observed deviations in the measured field. This setup is very unpractical in terms of throughput (when a large number of devices needs calibration) and for use cases where recurring calibration might be needed (e.g. automotive application).

As a solution to this problem, imec has embedded on-chip interferometers in between the phase shifters and very close to the antennas. These assess the actual phase difference between two adjacent antennas. Measured with integrated photodiodes (figure 3), this information provides an absolute indication of the far-field beam quality, (e.g. direction and size,) and allows compensation for non-idealities before the signal gets transmitted.

Recently, this technology was used to generate multi-spot sensing by exploiting imec's design expertise to steer structured-light with a 46-degree field of view in the vertical and horizontal directions (Figure 4).

Figure 5: Wafer-scale PIC manufacturing



Future work

Future work will focus on increasing the beamformer's accuracy and range. Next, R&D on adjacent components and building blocks that are specific to one or more application domains will be performed. For example, a high-speed linear optical modulator for over air laser communication and microwave 5G applications are part of the imec roadmap. The heart of the research is carried out to allow for device manufacturing in a 200 or 300mm CMOS line using wafer-scale processes (Figure 5) and including electro-optic materials (e.g. BTO) to ensure a lower cost of production. Also, imec will gradually tackle adjacent components such as the photodetectors for signal detection and the ranging engine that does the computation of incoming data.

More info: www.imec-int.com/en/beamforming and Amin.Abbasi@imec.be

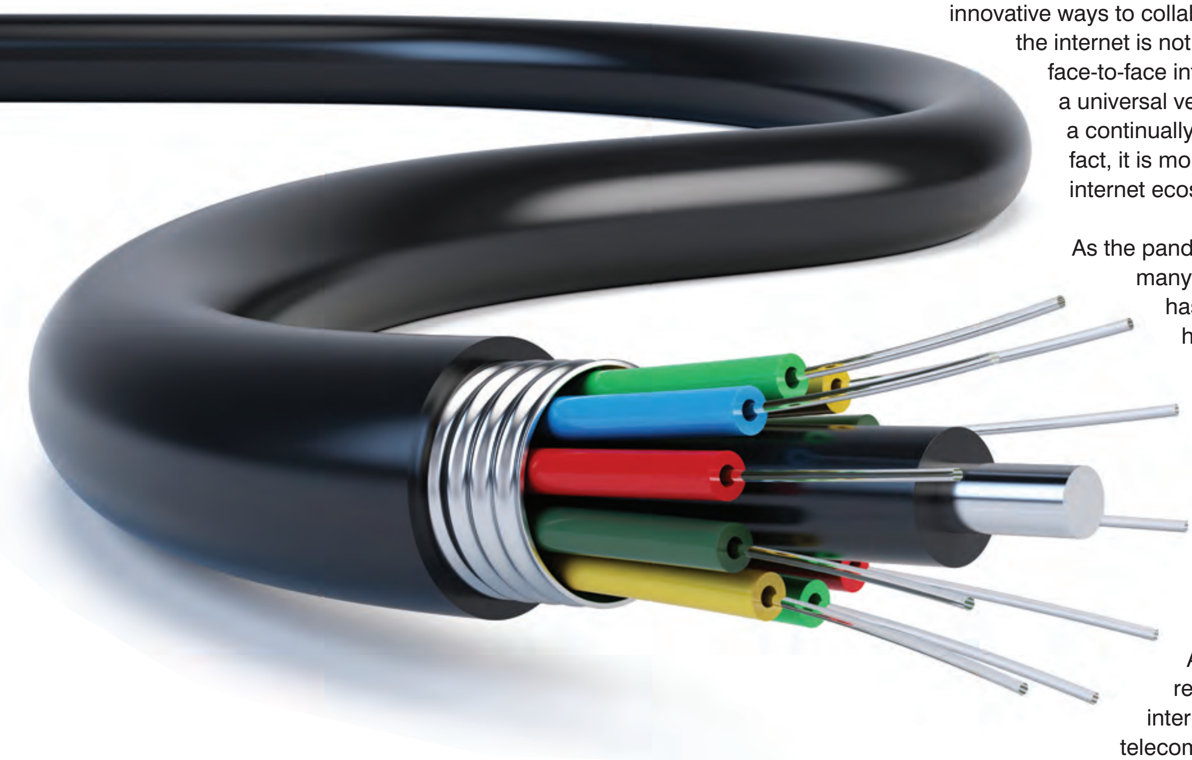
A global internet ecosystem:
powered by hybrid PICs…

The state of the fiber-optics telecommunications industry, datacenters, optical networks, and optical components such as lasers and modulators and more specifically PICs will carry us through the next few decades of photonics transformation and evolution of the internet at light speed powered by PICs

BY MICHAEL LEBBY, CEO OF LIGHTWAVE LOGIC

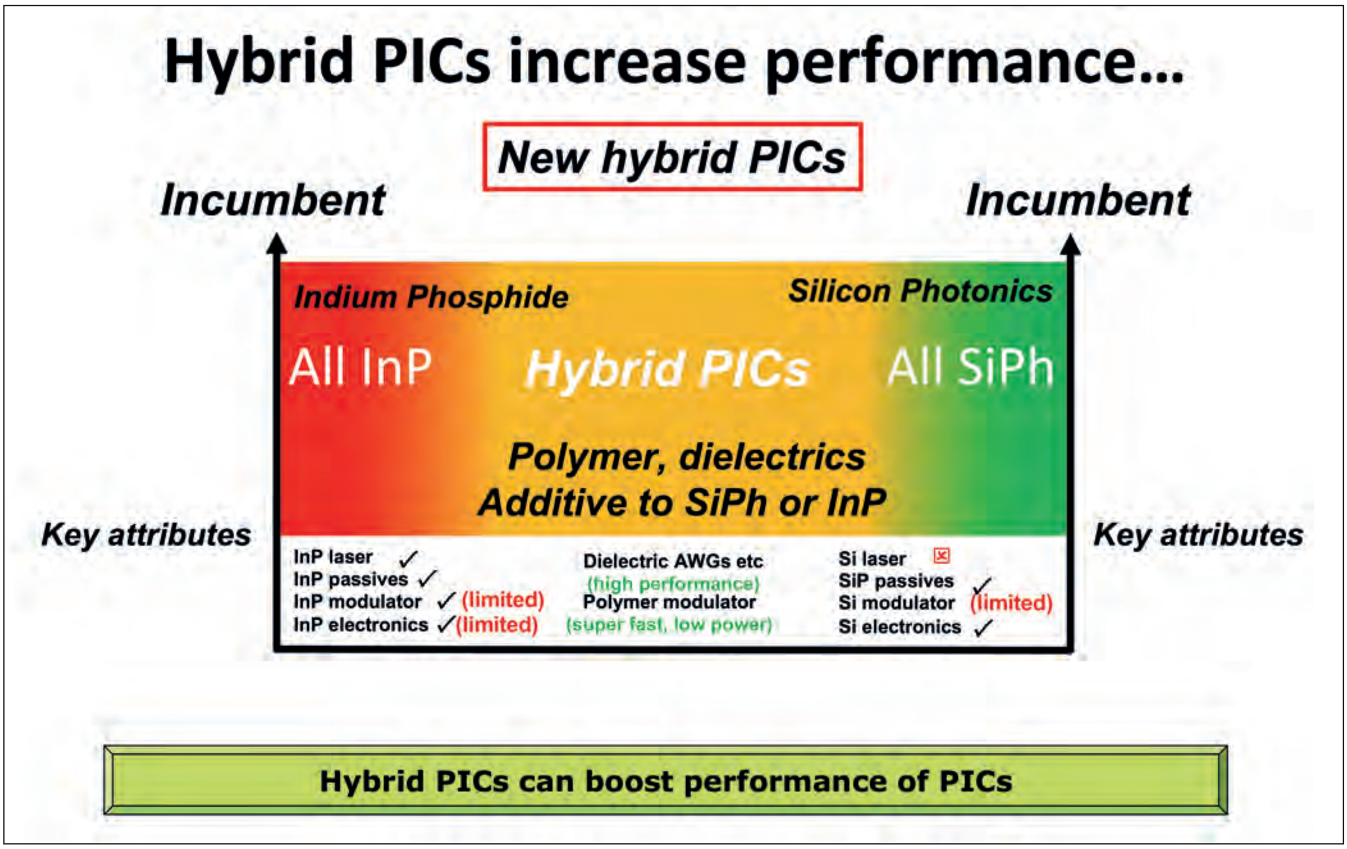
THE LAST TWO YEARS has been transformational for many of us: we've figured how to work at home, remotely, taught our children similarly, and some of us have even prevented our pets from photobombing our image on a video platform! We've learnt how to order food and household supplies from our computer, and we have connected with our families. There are many other things we have learnt, but for a second, just imagine if the internet was not available? Life and working remotely would be much more difficult.

The internet is now considered a utility that provides us with many things that make up a richness in our lives. The obvious things it provides is data that can bring email, video calling, shopping, and be able to pay bills. The less obvious things the internet can do includes things like health, education, and more innovative ways to collaborate and socialize. While the internet is not a perfect replacement for face-to-face interaction, it does provide a universal vehicle that is global and is a continually growing infrastructure. In fact, it is more than that: it's a global internet ecosystem.



As the pandemic has raged through many countries world-wide, it has been the internet that has delivered telemedicine, medical equipment, children's classes, business meetings, and Friday afternoon social drinking parties. We can see the important aspects of the internet, but what is it, and how does it work?

As the PIC Magazine reader well knows, the internet is based in fiber-optic telecommunications technology



where the infrastructure is globally interconnected using fiber-optic cables. These cables are made from glass, and the glass is so pure that lasers that generate light can send light hundreds of km across oceans and countries. Some of the communications are wireless in space, some use under-sea cables, and others use wireless with things like 5G for more local cellular environments.

The common denominator for the global internet ecosystem is being able to evolve our growing fiber-optic communications infrastructure to more advanced and seamless design. Remember the days when we had to use a modem dial up for the internet, or if we had a mobile cellphone in the 1990s all we could do is use audio or text using pagers. Today, we can access the internet from any number of consumer portable products, and be able to work, play, shop and pay bills from almost anywhere.

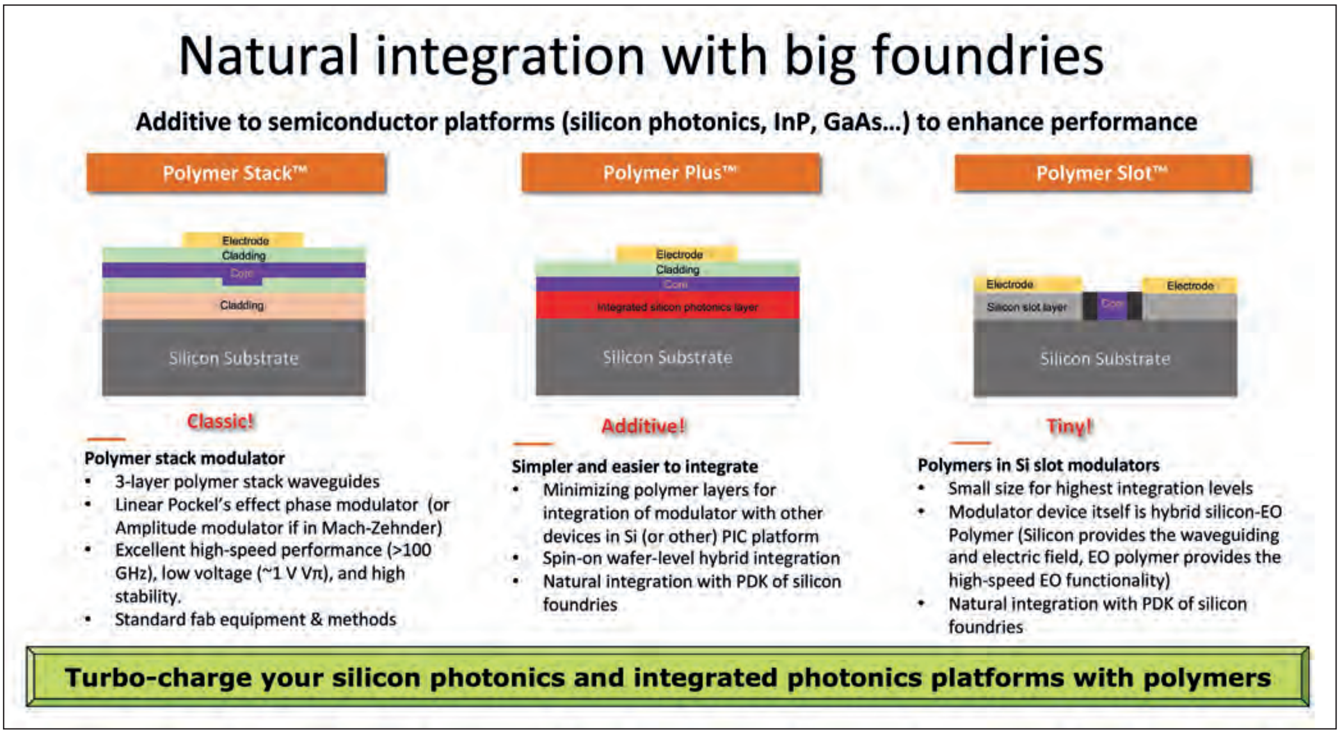
How does the internet ecosystem evolve? Simply put, more advanced technology solutions must be designed, implemented, and run. The domain for lasers sending light, and photodetectors receiving light is called, of course, photonics. As photonics technology advances, we can send the light faster, consumer less power, and communicate more efficiently.

We have seen over the past 4-5 decades that photonics in general has enabled many things and it has become part of our lifestyle. We've seen this with fiber-optics as it is one of several basic technologies that are the foundation of the internet (like plumbing and electricity in buildings).

Photonics in general has enabled a broad portfolio of things that improve our quality of life such as: displays, LED lighting, laser-based manufacturing, image sensors as cameras, solar cells, and with a little more brainstorming, the list continues extensively.

We also know that photonics will be integrated just like Integrated Circuits (IC) over 50 years ago. Integrated from an electronics IC standpoint is putting many transistors onto a semiconductor chip. Today, there are many billions of transistors in the advanced chips that are designed in silicon. In photonics, similar trends apply, although photonic devices are typically bigger than transistors, the expectation is that integrated photonics (typically referred to as Photonic Integrated Circuits – PICs) will become the engine for new designs that will positively impact our lifestyle.

As part of this lifestyle, PICs will enable new products, and those products will be over and above the current major incumbent business for PICs today – fiber optic communications for the internet. Future PICs will be key to quantum communications and quantum computing, and things that are becoming important in today's world: security and quantum cryptography. These PICs will contain many technologies so that



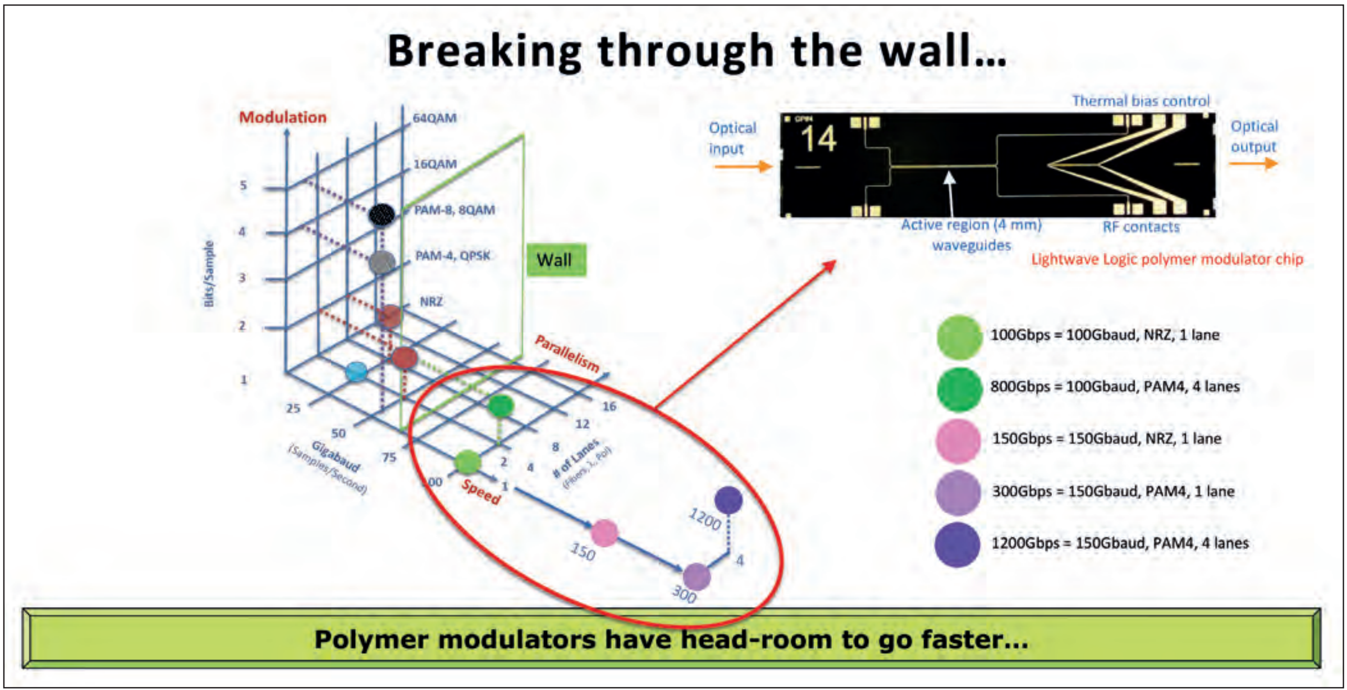
their performance will be enhanced. Folks in the industry term this 'hybrid PICs'. The figure above shows how different materials can be added to existing PIC platforms to increase performance and functionality. Today, we see InP lasers added to silicon photonics, and silicon electronics (DSP, ASIC ICs) added to InP PICs. The evolution of hybrid PICs means that new materials platforms such as polymers, dielectrics etc., will be added to PICs as the application space grows over and above fiber optic communications.

Fiber optic communications has been driven essentially through the delivery of high-speed data in fiber optic cables for the telecommunications, datacenter, data communications, and high-speed computing industries. As we use the internet more frequently, we have derived the term 'heavy data' where we utilize more and more data to communicate, especially in and around datacenters. These basic technologies have nurtured the optical networking platforms of social medial companies such as Google and Facebook. We have traveled a long way since the days of the early, even clunky internet browsers.

The markets for fiber optic communications that includes the sub-segments that deal with 'heavy data' over the next decade can be estimated to be over $500B1 growing toward $1T by the end of this decade. The major engine for products in these markets is the PIC engine that is a critical part of a transceiver – an optical device that sends and receives optical data quickly and efficiently and contains not only lasers to generate the light, but high-speed modulators to switch the light. If modulators can be designed to be faster, then the signals over the fiber-optic cables can be sent quicker, and this means we can send more data – thereby aligning with the term 'heavy data'.

Today, we see many of these optical components being semiconductor based with integrated photonics platforms such as silicon photonics, indium phosphide etc. A transformation is happening with advanced materials that will help save the semiconductors by boosting performance and lowering power consumption. This family of materials are polymers, in fact electro-optic polymers2 that in a modulator device structure naturally switch light very fast, and with very

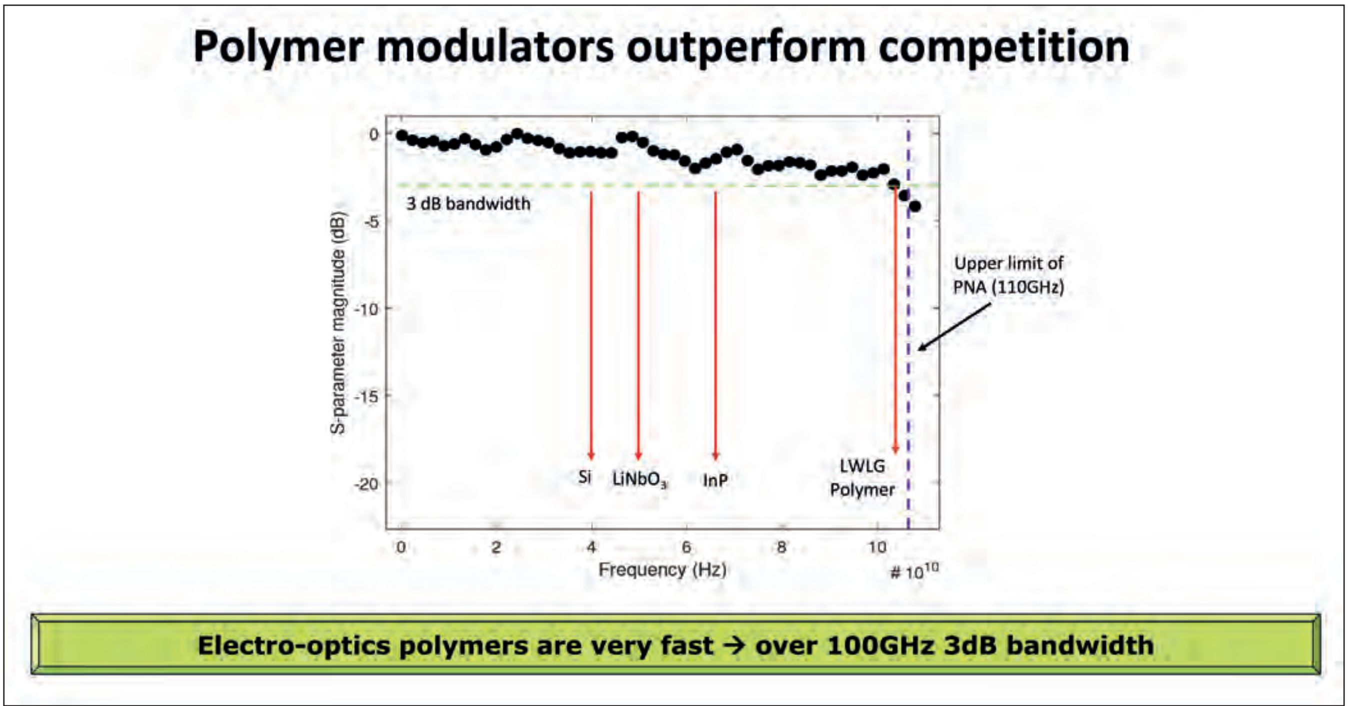
Today, we see InP lasers added to silicon photonics, and silicon electronics (DSP, ASIC ICs) added to InP PICs. The evolution of hybrid PICs means that new materials platforms such as polymers, dielectrics etc., will be added to PICs as the application space grows over and above fiber optic communications



low voltage, and this leads to low power consumption. This is an exciting transformation, and in part is like what polymers have done for TVs and display panels/monitors with organic light emitting diodes (or more popularly known as OLEDs3).

The figure above shows that with electro-optic polymers, there are a variety of modulator vehicles that can provide high performance speeds with very low power consumption. The Polymer Plus™ and the Polymer Slot™ modulators integrate seamlessly with integrated photonics platforms such as silicon photonics. Process integration with foundry PDKs (process design kits) will allow efficient scaling for mass commercialization.

The global internet ecosystem, while based on fiber-optic communication markets today, has allowed technologists to design optical components such as lasers, modulators, photodetectors to send and receive light efficiently. In fact, the global internet ecosystem will be powered by PICs, and more specifically, hybrid PICs. The figure above shows the potential for higher speeds and data rates using



single lane and quad lane protocols of NRZ and PAM4 that are common in the industry today. With optical modulator bandwidths that exceed 100GHz, then higher data rates that aggregate to over 1Tbps are possible without the need to add complexity to the modulation encoding techniques that are widely available today. Thus, faster optical modulators can literally break through the wall where typical device bandwidths are around 30-50GHz. Electro-optic polymer modulators open the door for higher data rates, and an actual polymer modulator chip with optical input, output, thermal bias and rf contacts is shown at the top of the figure.

The figure above shows the optical 3dB bandwidth of electro-optic polymer modulators verses the 3dB optical bandwidth of competing technologies. Polymers have the wonderful and natural advantage that their materials properties are velocity-phase matched, and this allows their natural performance to exceed semiconductor materials technologies. In the figure, the electro-optic polymers are closing in at the upper limit of the latest test equipment of 110GHz. While fiber communications are the incumbent markets today, the global internet ecosystem will expand to other related and consumer opportunities that will also need PIC based optical engines: Automotive LIDAR for self-driving vehicles, self-driving or flying drones, photonic sensing and recognition, displaying information, images through displays, lighting and illumination using LEDs, solar powered plants and electricity generation using solar cells, AI (artificial intelligence), gaming, crypto-currency generation, agriculture, and advanced computational machines – and the list continues depending on how far you brainstorm markets and applications that require the ability to not only communicate with other parts of the internet but utilize photonics to drive our lifestyle.

To keep the global internet ecosystem growing we need to commit to ways to make sure sustainability in all these markets and applications is achieved. We need to expand the diversity of people in the photonics community, we need to educate and train a workforce in the photonics field, we need to balance investment with policies to enable entrepreneurship, innovation, and we need to build in security, safety, and protection to ensure seamless infrastructure operation.

These are big tasks, and if we succeed in our investments to grow the growing global internet ecosystem, the rewards are great; they provide us with vehicles to enrich our lives and benefit a whole range of industries from examples of say, defense to medical to simply eating a more efficient vegetable that has been assisted using solid state lighting with LEDs. The dependence of people's lives based on the global internet ecosystem are huge – their way of life will be affected directly by fiber-optic communications. As we steadily move out of the COVID pandemic we will see our lives have been improved by the global internet ecosystem, and we will have an appetite for more. We will have a much clearer perspective of what it takes to protect and uplift ourselves and our communities. The state of the fiber-optics telecommunications industry, datacenters, optical networks, and optical components such as lasers and modulators and more specifically PICs will carry us through the next few decades of photonics transformation and evolution of the internet at light speed! Cheers to the global internet ecosystem that will be powered by PICs.

FURTHER READING

1. https://www.grandviewresearch.com/industry-analysis/broadband-services-market

2. Electro-optic polymers are materials that work like liquid crystals where a voltage can be applied to switch the light. Electro-optic polymers are significantly faster at switching light than liquid crystal materials.

3. OLED stands for organic light emitting diode, where the organic material is polymer based that is designed to emit light.

Michael Lebby
Michael Lebby, is CEO of Lightwave Logic Inc., (OTCQX: LWLG), a company based in Colorado, USA that is focused on developing advanced photonics technologies such as modulators to transform the performance of the internet.



Photonic challenges in the **next generation of Ethernet**

PIC Magazine invited the Ethernet Alliance and EPIC—The European Photonics Industry Consortium, to discuss ways that internet access, next-generation photonic integration and the pressures to provide ever-increasing levels of service at lower cost will shape the future of how we communicate, work, and even live. If the pandemic taught us anything of value from a business perspective, it is that we not only can but must be able to run a world remotely. And in a word, to do that we all need: bandwidth.

BY ANA GONZALEZ, & ANTONIO RASPA FROM EPIC AND JIM THEODORAS, HG GENUINE

ETHERNET continues its relentless march forward, past current 400 Gigabit Ethernet rates, toward the great beyond. As always, a minefield of challenges stands in the way of forward progress, and it will take the combined talents of a global network of technology companies to make it through. The Ethernet Alliance (EA) and the European Photonics Industry Consortium (EPIC) are teaming up to bring industry technology leaders together to make the next generation of Ethernet a reality.

With each new generation of Ethernet, there is more of everything, yet each generation comes with the expectation of lower costs (price, power, form factor or 'space') per bit. The conundrum is how to achieve lower costs with ever increasing complexity.

There is a hidden cost to complexity, and it is not a linear relationship. The move from one to four channels does not necessarily cost four times as much (4N), but rather can be as much as 4^2, or 16 times as much. So how to achieve the impossible?

Faster, Wider, Complex

To go faster in optical communications, you can directly go faster (higher bit rate), you can go wider (more lanes of information), or you can increase modulation complexity (increase baud rate). All 3 methods are often employed in unison. The upgrade from 100 to 400 Gigabit Ethernet was a 4X step. On the electrical side, it was accomplished by doubling the bus width from 4 to 8 lanes and doubling the effective bit rate with PAM4 modulation. On the optical side, it was enabled by a 2X step in bit rate and a 2X effective increase in bit rate by moving to PAM4 modulation. Moving beyond 400 Gigabit per second information rates will require at least another 2X step.

Going faster

One option is to simply double bit rates. Existing optical modulation technologies are running out of steam and struggle to meet the nyquist bandwidths that will be required beyond 50 Gbaud per single lane rates. Many EPIC member companies are leading the charge to increase modulator bandwidths involving the use of new materials that can satisfy the new requirements of the industry in the long term. An example is the use of electro-optic polymers to build high-speed modulators that Lightwave Logic develops.

"Electro-optic (EO) polymers can provide much higher speeds and lower power consumption than current semiconductor solutions enabling the very fast switching of light - analogous to what we see when we watch LCD based displays such as televisions, except much faster than the LCD." said Michael Lebby - CEO of Lightwave Logic Inc. "These polymer materials have been used to develop a Mach-Zehnder modulators that operate with low drive voltage levels, and speeds of over 100GHz, which represents a 2-3X increase in raw optical device performance over incumbent modulator technologies today. Polymers also have the advantage of being additive and compatible to integrated photonics materials such as silicon photonics and Indium Phosphide, which allows a boost in performance to those platforms."

On the other side, Polariton Technologies' electro-optic modulators rely on plasmonics to develop modulators that demonstrated to be more than 10-times faster than current photonic modulators (500 GHz world record in the lab).

"Polariton modulators are >100-times more compact, 10x faster and more energy-efficient than conventional photonic ones," said Claudia Hössbacher - co-founder and CEO of Polariton Technologies. "Key to our technology is the coupling of light with electrons at a metal surface (Surface Plasmon Polariton, or SPP). In our plasmonic modulators, these strongly confined SPPs interact with an electro-optic material.

The tight confinement enables dense integration with device sizes of a few 10s of microns. As devices are small, capacitances are small too, thus boosting the bandwidth. This way, we can keep modulation formats simple and minimize power-hungry DSP."

Figure 1: Fully integrated coherent PIC fabricate by EFFECT Photonics (courtesy of EFFECT Photonics)

Lumiphase enhances the industry-leading silicon photonics platform with Barium Titanate (BTO), a material that allows high speed modulators with >70 GHz, > 10 years life-time in operation and 10x lower optical loss. Transceiver chips based on Lumiphase's platform are very easy to scale to large volumes in a cost-efficient way.

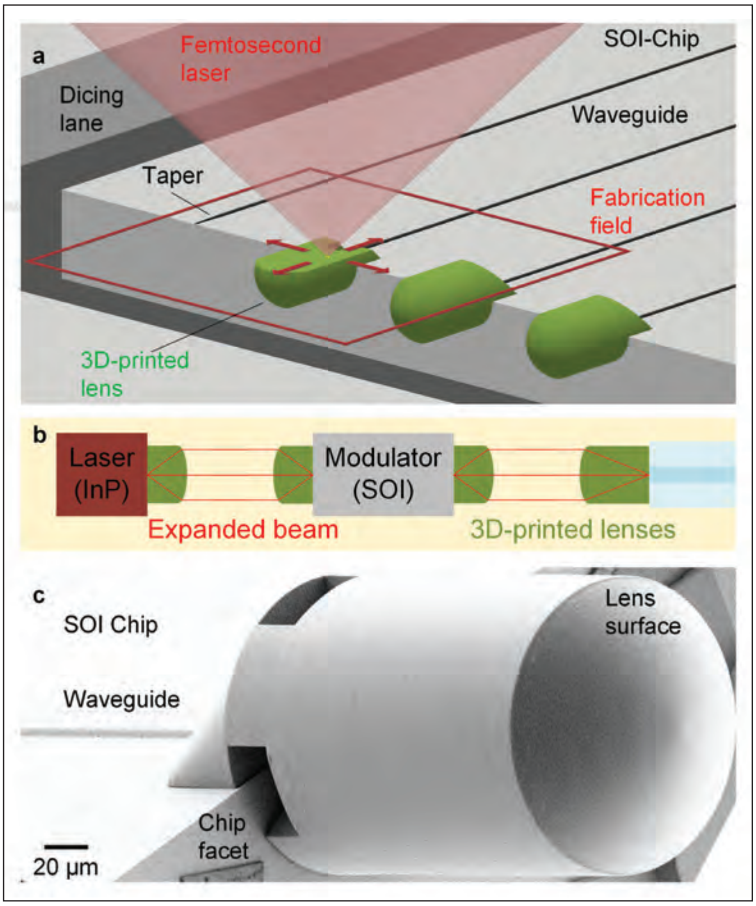
"Besides the obvious speed benefit, the use of BTO allows extreme low insertion losses which reduces the need for optical amplifiers or powerful lasers while ensuring robust reliability metrics," said Lukas Czornomaz, co-founder and Director at Lumiphase. "BTO allows us to address applications in the datacom, telecom, computing and sensing markets, in need of fast, ultra-compact, low-power and cost-efficient light control engines"

Going wider

Another option is to go wider. Just as the jump from 100 Gigabit Ethernet to 400 Gigabit Ethernet included (in one variation) a 2X increase from 4 to 8 electrical lanes, the same can be done on the optical side to quickly realize 800 Gigabit/s information rates. However, this is not without its challenges. Doubling the number of components in the optical system does not necessarily double the difficulty and expense, but rather both may increase exponentially. Current 400 Gigabit Ethernet optical front ends with 4 parallel color channels are at the limits of what can be manufactured using current techniques of combining discrete components on optical benches. Market pressures are driving costs per bit of optical information transmitted down, and anything beyond 400 Gigabit Ethernet will need to cost less per bit, not more.

Increasingly, the industry is realizing anything beyond 400 Gigabit Ethernet will require at least some level of wafer level integration of photonic elements – also sometimes referred to as Photonic Integrated Circuits (PICs). These can be as simple as 4 modulators on a common silicon bench or as complex as an entire coherent optical front end on an InP wafer.

An example of increasing capacity through PICs is The PASSION transmitter basic module that integrates 40 VCSELs and 100-GHz spacing multiplexers in a single Si photonic chip, using massive photonic integration to achieve up to 2 Tbit/s capacity per module. This module is the basis for developing an innovative sliceable bandwidth/bitrate variable transceiver (S-BVT) based on a modular approach to enable multi terabit transmission, providing an important reduction in terms of cost and power consumption. PASSION employs low-cost energy-efficient light sources — namely single-mode InP VCSELs from Germany-based VERTILAS — that operate in the C-band. These sources have a high



modulation bandwidth (around 20 GHz) and are directly modulated using PAM-4 or other multicarrier modulation formats, such as DMT, allowing at least 50 Gbit/s capacity per VCSEL. Four modules can be tuned by temperature, in a range from 0 to 75 GHz and interleaved with a spacing of 25 GHz, to obtain a 160-DWDM channel supermodule with a total capacity up to 8 Tbit/s.

In addition, by exploiting polarization division multiplexing (PDM) and combining two identical supermodules that are orthogonal in polarization, a capacity of 16 Tbit/s can be achieved. Furthermore, space division multiplexing using multicore fibers or bundles of fibers enables the achievement of more than 100 Tbit/s per link.

However, when talking about monolithic integration, InP technologies are set to drive a revolution in cost optimization for the next generation of coherent networks. An example of this technology is the Netherlands-based EFFECT Photonics which has developed the world's first fully integrated coherent PIC targeted at pluggable coherent transceivers for edge and metro/access networks which fits into the smallest modules (Fig. 1): QSFP28 and QSFP-DD. Main applications are multi-rate coherent 100-600G and low power short-range mode (10-200 km) and high OSNR (2000-8000) modes.

"Monolithic integration allows for the integration all functionalities such as lasers, modulators, detectors, splitters, and network filters, monolithically integrated in a single chip," said Tim Koene CTO at EFFECT Photonics. "This technology allows scaling volume production for applications such as metro-access and datacenter."

The challenge of PICs

While as scientists and engineers, we like to focus on the physics of how to create and integrate optical functions on semiconductor wafers of various types, the real-world challenge of PICs is how to test them. With discrete optical components, you can test laser power, back-reflection tolerance, color combiner/splitter passbands, modulator Vpi and bandwidth, photodiode responsivity, etc. by simply connecting a tester to each. However, once one or more of these functions is integrated onto a wafer, testing a parameter becomes much more difficult. And waiting until the PIC is integrated into a final product to perform functional validation is not economically viable. Poor performing optical elements need to be caught early in the production process, most often even before the whole wafer is cleaved into individual PICs.

Many EPIC member companies specialize in wafer-level testing of PICs. Wafer level testing is more than buying a unique test machine. Testing strategies must be chosen early in the PIC design process and test features incorporated. EPIC companies are trusted advisors that can work with you early in your PIC design to make sure you are ready for wafer-level test day one.

Companies developing high-precision automation tools such as Ficontec, Aifotec, Tegema and IMS-NL are working together with companies developing testing tools such as Roodmicrotec, EXFO and Quantify photonics, for developing wafer-level testing. Companies such as Photonics42 have developed custom-made and proprietary tool capabilities for wafer level testing: probe cards, instrumentation and measurement system design, modular and multi-channel probing, automation software.

Jenoptik's new UFO Probe™ technology targets the market for semiconductor equipment and processes for wafer-level testing in microelectronics. The technology is based on a concept for optical probing of photonic integrated circuits, which is insensitive to alignment tolerances in the wafer prober. As consequence, the opto-electronic probe card can be used with commercially available wafer probers and ensures an accordingly high throughput for testing photonic integrated circuits.

Automated manufacturing and alignment

With the increasing number of optical channels and the move to PICs comes an additional challenge – the time and cost of precise alignments, both electrical and optical. Most electrical circuitry is still kept off of PIC substrates. Instead, they are located along the edges or underneath the PIC. Both require very precise alignments, whether for bond wires or bump bonds.

Optical alignments are very challenging with PICs. A single optical alignment can quickly eat into cost, time, and power budgets as two elements have to be aligned within 6 degrees of freedom. With PICs, there can be dozens of alignments to be performed. PICs currently come in two main categories, those with integrated lasers and those with external lasers coupled into the wafer. Both eventually need to couple the output into parallel optical ribbon fiber.

Companies such as Ficontec and ASM AMICRA develop machines providing high-precision die bonder/flip chip bonder which supports ± 0.3μm @ 3s placement accuracy. A side effect of the increasing number of optical channels and alignments to perform is laser powers are increasing.

To compensate for the additional coupling and waveguide losses, PIC designers are simply increasing their source laser power. However, this is a self-defeating strategy as issues typically seen with lasers only increase the harder you drive them. And coupling losses can quickly outpace laser drive. The better solution is to simply tackle coupling losses directly.

With the increasing number of optical channels and the move to PICs comes an additional challenge – the time and cost of precise alignments, both electrical and optical. Most electrical circuitry is still kept off of PIC substrates. Instead, they are located along the edges or underneath the PIC. Both require very precise alignments, whether for bond wires or bump bonds

Several EPIC member companies have novel ways of improving the coupling of light on and off wafer and PIC structures such as Vanguard Automation, which offers machines and processes for automated multi-chip packaging based on 3D nano-print technology (Fig 2.), creating low-loss connections while lowering overall packaging cost.

a: Schematics of the concept: After drop-casting of liquid photoresist, a lithography tool localizes all components with sub-100-nm-precision on wafer level. The lithography tool solidifies resist by scanning within a pre-programmed lens shape. After lens fabrication, an automated processing tool develops the lens.
b: 3D-printed lenses allow relaxing alignment tolerances in a beam expansion approach and facilitate optical assembly.
c: Electron microscopy (SEM) image of a chip-facet-attached lens.

Multiphoton Optics offers 3D direct laser writing equipment that works using two-photon polymerization, a maskless direct laser writing technology. Nanoscribe also offers Two-Photon Grayscale Lithography system is designed for ultra-smooth micro optics with excellent shape accuracy in just one fabrication step and with enormous design freedom.

Guaranteeing reliability

The move beyond 400 Gigabit Ethernet to whatever is next comes with a substantial leap in complexity. Whether discrete or integrated, optical bench or PIC, silicon or InP, all potential solutions will be more complex than ever before. The only way to guarantee reliable operation of such complex optical systems is burn-in. And like performance testing, the earlier you burn-in a product in its manufacturing process, the better.

Integration techniques have the potential to make early burn-in of optical devices difficult if not impossible. Ideally, burn-in of anything with wafer level integration should occur at the wafer level. And like with performance testing, wafer level burn-in requires a strategy day one with supporting features included in the design. EPIC has several member companies with expertise in how to plan and execute wafer level burn-in of integrated optical devices and PICs such as Yelo and Aehr dedicated to developing test and measurement equipment.

Conclusion

Each new Ethernet speed step begins with exasperation, as veterans of the previous generation ponder how hard it was to reach the current level, their bag of tricks emptied by the effort. But as we as an industry embark on this latest endeavor, if we work together and bring all our technology to bare on the problem at hand, the next generation of Ethernet will become reality. The Ethernet Alliance and EPIC are proud to be a part of bringing together like-minded companies to work on the challenges ahead.

ABOUT THE AUTHORS

Dr. Ana González was the R&D Manager at EPIC (European Photonics Industry Consortium). Her role was to understand the technology developed by EPIC members and to identify potential collaboration between them. She also participated in different EC initiatives such the Pilot Lines in Photonics in which she was involved in business development and marketing strategy. Her expertise lies in the development of optical systems and the investigation of applications such as Sensing and Datacom. She received her bachelor's degree in Chemistry from the University Autonomous of Barcelona (UAB) and her PhD degree from the Catalan Institute of Nanoscience and Nanotechnology (ICN2). She is now currently working as the Director of Strategic Partnerships at iPRONICS. Her role is to investigate new applications and identify potential partners for the implementation of Field Programmable Photonic Gate Arrays (FPPGAs) including relationships with the supply chain and customer operations.

Jim Theodoras is currently VP of R&D at HG Genuine USA, where he oversees the design and manufacture of optical transceivers for data communication applications. He is an experienced optical communication professional with over 30 years of industry experience in electronics and optics, spanning a wide range of diverse topics. Jim is a past President of the Ethernet Alliance and past optical liaison editor for IEEE Communications Magazine. He holds 20 patents in the field of telecommunications, and is a frequent contributor to industry publications.

Antonio Raspa is currently the innovation manager of EPIC and has a back¬ground in electrical engineering with a specialization in quantum electronics. Before joining EPIC, he worked at Quanta System as R&D manager, developing solid-state laser sources and customized photonic systems for industrial and scientific applications. During this period, he was also in charge as lidar specialist of the Italian research program in Antarctica. Later he worked at Trumpf and Rofin-Sinar as an industrial laser products and processes specialist. In 2009 he again joined Quanta System, organizing and managing a brand-new structure to produce sterile optical fibers for surgery.

Acknowledgment:
PASSION is a research and innovation actions project funded by the EU's HORIZON 2020 and develops innovative photonic devices and an optical fibre network infrastructure for a sustainable metropolitan network in terms of huge capacity, low cost, reduced footprint, and low power consumption. PASSION technology exploits the capabilities of VCSELs by developing 25-GHz-spaced InP C-band WDM single-mode VCSELs directly modulated to achieve up to 50 Gb/s per SOP (state of polarization). Multiple single-mode VCSEL modules on silicon-on-insulator (SOI) chips adaptively load/manipulate the spectrum at the subwavelength level to generate flows aggregated to enable up to 16 Tb/s capacity per channel. This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 780326 and it is an initiative of the Photonics Public Private Partnership. This content reflects only the authors' view and the European Commission and Photonics 21 are not responsible for any use that may be made of the information it contains.

29 September 2021

LIVE BROADCAST

Integrated Photonics for Automotive

PhotonDelta Roadmap Launch

REGISTER NOW

The automotive industry is going through a rapid transformation, driven by electrification, autonomous vehicles, driver support systems, as well as changes in mobility patterns and city infrastructure. These trends significantly influence the design and capability of vehicles.

The increased need for sensors in vehicles, in electric/hybrid drivetrains and advanced driver-assistance systems (ADAS) up to autonomous driving systems, creates new significant opportunities for the integrated photonics industry.

Program

15:00	Welcome introduction
15:10	Kick-off keynote by Carlo van de Weijer
15:30	Roadmap presentation by Carol de Vries
15:45	Interactive panel discussion
16:10	Q&A with audience
16:20	Virtual networking

A roadmap created by experts from the field

PhotonDelta, an independent industry accelerator for the integrated photonics industry, has created a roadmap that provides an overview of the different trends in the automotive sector and list the opportunities for integrated photonics. The roadmap was created together with various stakeholders from the industry as well as integrated photonics companies and will be made available for download after the event.

www.photondelta.com

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PhotonDelta
Gateway to Integrated Photonics

In collaboration with:

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Innovative sensing with **integrated photonics**

In the last decades, silicon-based photonic has become a key technology for innovative sensing devices because of the growing potential in spectroscopy, process control, emission monitoring, chemical sensing, medical and biological applications.

BY CEA LETI

FIRST PROPOSED by Soref in the late eighties, Si – based photonics is now a mature technology covering the full spectral range from visible to Mid-IR and direct access to prototyping and mass production of photonics integrated circuits is now available by many foundries. The availability of PDK tools for fast access to design and fabrication shows that the science and technology of generating, controlling, and detecting light is quickly moving into mainstream electronic designs.

The power of integrated photonics is in the capability to combine on a single chip the reliability and the intrinsic robustness of IC/MEMS technologies with a precise control over wavelength, linewidth, phase pulse duration and power, brought by the heterogeneous integration of the lasers sources directly on Si technological platform. The main driven for these developments is the strong need for high-performance communications hardware, where photonic ICs is the sole technology offering viable solutions to address technical manufacturability and cost challenges.

However, all major technical achievements designed for Datacom can also profit to other applications, and integrated photonics for optical sensing will be to be a key technology in many field starting from wearable and healthcare applications. In particular, the developments made for Datacom span out to sensing using Visible or Near IR PICs. In this wavelength region, typically the transduction mechanism used is the modulation of the refractive index induced by local modifications of the environment either by chemical or mechanical stimuli. In chemical sensors, the light can interact with surrounding environment via the evanescent field generated out of the waveguides. However, direct detection in gaseous phase generally

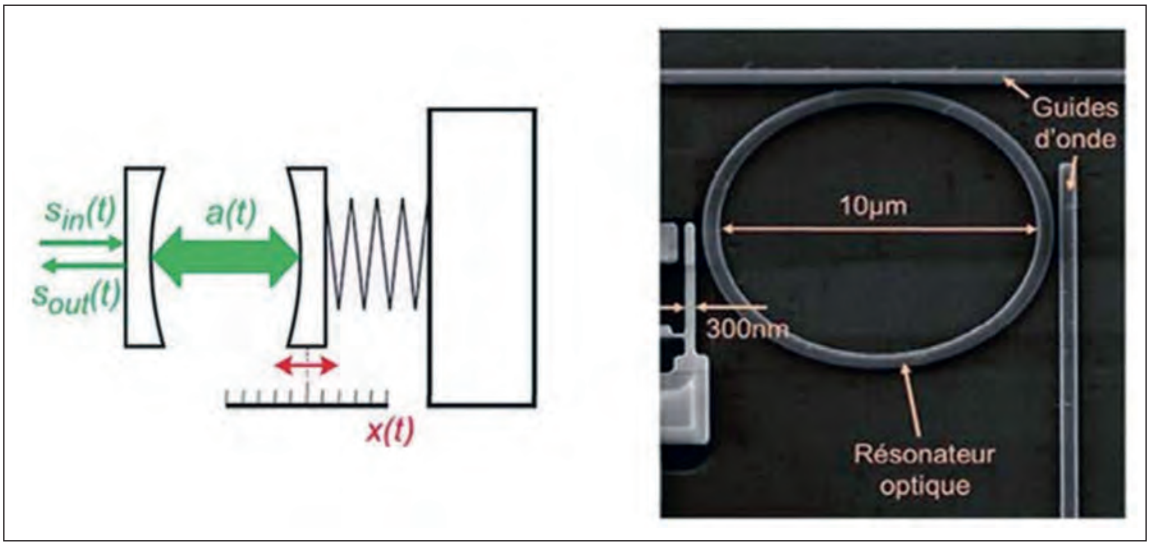

Figure 1: Schematics of a optomechanic cavity and example of an optomechanic device made of a resonant ring

gives very low signals, too low to allow reliable measurement. In biological applications, the shifts in refractive index can neither differentiate, nor identify unlabeled analytes due to the complexity of the sample. For this reason, the sensors require an additional process of surface functionalization of the optical device in order to unequivocally identify specific chemicals. As a result, parallel monitoring of multiple analytes need specific functionalization with different receptors (specific polymers, antibodies or markers). The specific receptor interacts with the chemical to be detected, changing the optical properties and the shift of the refractive index can be detected out of the PIC.

In the case of a mechanical stimulus, the mechanical elements is generally a suspended element, such as a waveguide or a resonant ring, externally actuated at the resonance frequency by an optical force. As presented in Figure 1, the resonant device is coupled via evanescent field to a waveguide at one end and to a mobile beam at the other end. The optical force depends, nonlinearly, on the gap separating the waveguides from the structure and is proportional to the optical power injected in the waveguide. When the mobile beam is set in motion by external physical stimuli – force, pressure, temperature, magnetic field or other – the gap between the beam and the resonator changes modulating the coupling and the variation can be detected out of the waveguides.

The idea of translating and adapting key building blocks to Mid-IR wavelength band was proposed by Soref and co-workers in 2006. Even if many other applications can addressed by Mid-IR technologies, the most mature field of usage is the detection of chemicals in traces either in gaseous, liquid or solid phase. Optical chemical sensing is a fast growing market, driving the technical developments and addressing more and more applications. The main challenge is the co-integration of group IV photonics and III-V heterostructures that allows the development of chemical sensors fully integrated on a single chip. Measuring in the Mid-IR wavelength region, also called fingerprint region, allows addressing a unique combination of fundamental absorption bands order of magnitude stronger than overtone and combination bands in the near IR that can allow high selective, high sensitive unequivocal identification of the chemicals. In fact, a multitude of molecules present strong and distinct absorption lines in the Mid-IR giving much interest for spectroscopic detection.

Spectroscopic sensing in the Mid-IR wavelength band has become commercially available with the advent of unipolar sources based on multiple quantum well stacks. With the recent progress in Quantum Cascade Laser (QCL) and Interband Cascade Laser (ICL) technology, compact and reliable Mid-IR light sources available are nowadays available. In particular, Distributed FeedBack (DFB) sources allow selecting specific emission wavelengths to target the detection of the chemicals of interest. With these sources, a novel generation of sensing tools suitable for real-time in-situ detection of gasses down to traces is nowadays available. In spite of the recent advancements, these tools relying on the assembly of discrete optical components still fail to meet some key requirements required for a large number of applications. In details, DFB sources are weakly tunable (typically few cm-1) and for a large majority of the applications a laser can be used to detect only one chemical. Furthermore, multispecies detection requires a massive use of optics which are intrinsically subject to mechanical and thermal drift. Additionally, the architecture of a typical sensing tool uses of multipass or resonant cavities and cooled IR sensors to measure the relative absorption of the gas mixture: these architectures can be barely miniaturized down to a size compatible with portable applications.

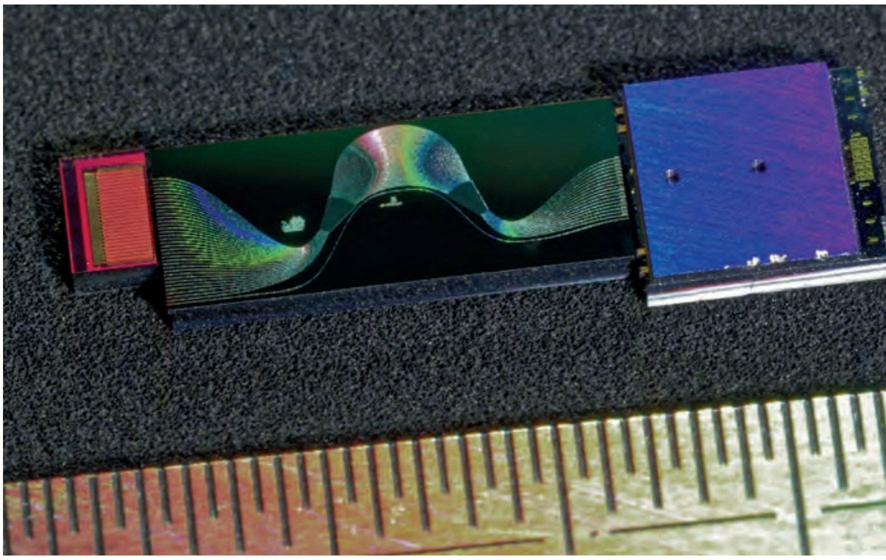

Figure 2: Array of QCL sources coupled to a miniaturized Photoacoustic cell via a PIC circuit allowing combining all the sources in a single output. All the devices are fabricated on Si on a 200 mm IC/MEMS platform at CEA-Leti.

The main focus of the current developments is on i) the extension of the of wavelength range available within a single source, ii) move beam handling and routing from discrete optics to photonics integrated circuits and iii) investigate alternative detection schemes allowing fully integrated on-chip sensing. This approach is presented in Figure 2, where a mockup of a fully integrated optical chemical sensor is shown: an array of QCL sources is coupled to a miniaturized Photoacoustic cell via a PIC circuit allowing combining all the sources in a single output. All the devices are fabricated on Si.

Leti, an institute of CEA-Tech, has been working on these technologies since more than 10 years developing state of the sensors based on photonics devices. Available on CEA-Leti's 200 mm platform in a multi-project-wafer program, these advanced technologies target designers & developers in integrated photonics, LiDAR, chemical and biochemical sensing, and imaging whose projects require chip-level miniaturization and high performance sensing capability.

Membranes underpin masterful modulation

SiC membrane supports record-breaking modulation rates for InP lasers

BY SUGURU YAMAOKA, NIKOLAOS-PANTELEIMON DIAMANTOPOULOS, HIDETAKA NISHI, TAKAAKI KAKITSUKA AND SHINJI MATSUO FROM NTT AND FUMIO KOYAMA FROM TOKYO INSTITUTE OF TECHNOLOGY

GLOBAL DATA TRAFFIC is continuing on a strong upward trajectory, due to growth in various internet services, such as smartphones, cloud services, and the Internet of Things. This growth comes with a cost, the substantial increase in power consumption at data centres. To try and address this, and reduce the associated carbon footprint, there is much interest in trimming the power consumption of the optical transmitters and increasing their modulation speed.

Directly modulated lasers (DMLs) are attractive contenders for optical transmitters, combining a small footprint with a low cost and a frugal power consumption. These strengths stem from the simple data transmission principle of the DML, with modulation of the injection current encoding data on the laser's output power. In the form of a VCSEL, DMLs are widely used in short-reach optical interconnects. However, they are up against a barrier – for the last 30 years they have been limited to a 3 dB modulation bandwidth of around 30 GHz, which has prevented them from realising the desirable symbol rate of 100 GBaud for beyond 400 Gbit-Ethernet (400GbE) applications.

For such applications, those that build today's networks combine CW lasers with external modulators, such as electro-absorption modulators and Mach–Zehnder modulators. Both these pairings can already provide 100 GBaud modulation.

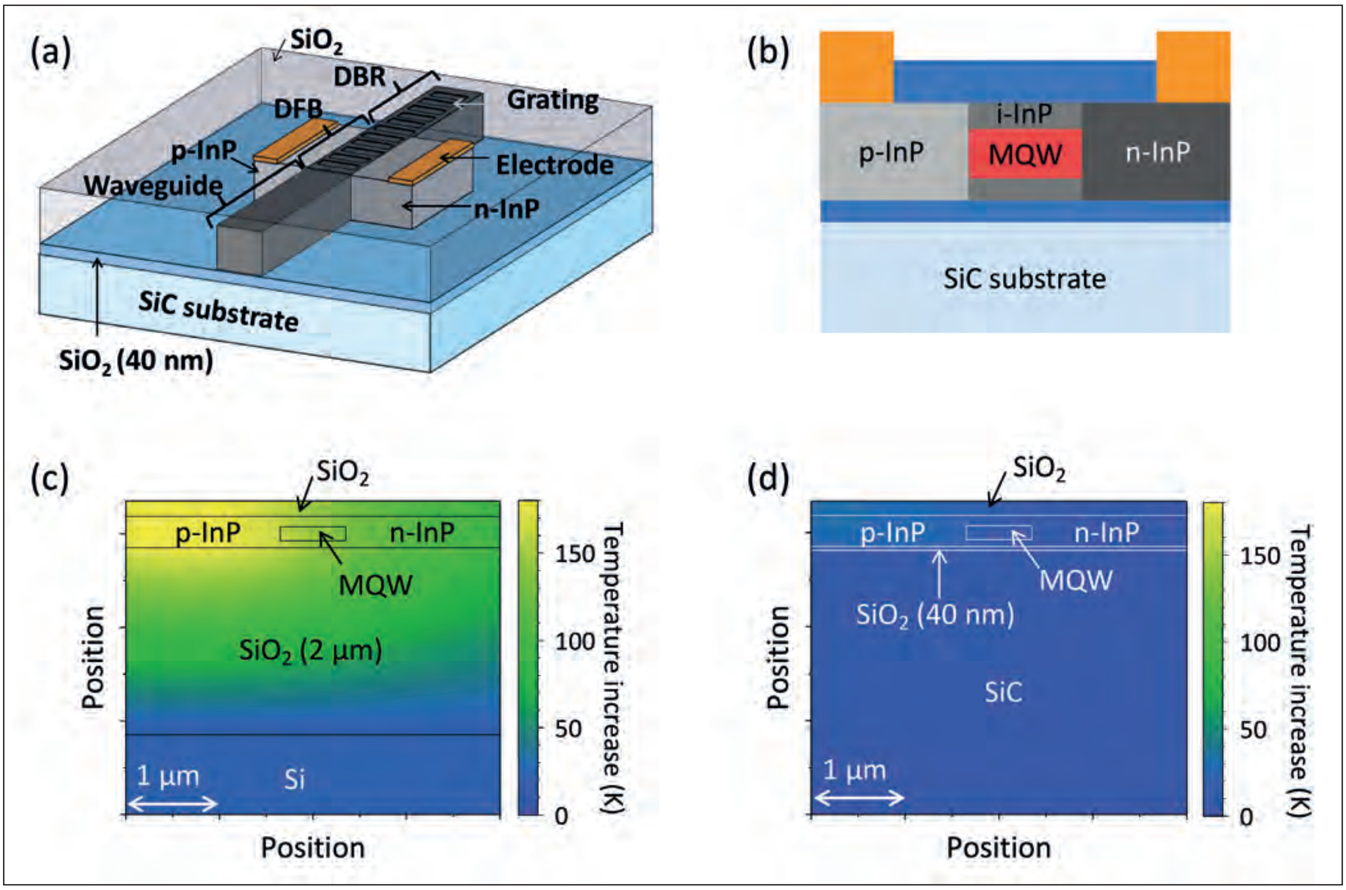

Figure 1. (a) NTT's membrane distributed-reflector laser on 40 nm-thick SiO_2-on-SiC. (b) Cross-section of the DFB section. (c) Calculated temperature increase for the laser on 2 μm-thick SiO_2-on-silicon. (d) Calculated temperature increase for the laser on 40 nm-thick SiO_2-on-SiC. Calculations assume a 50 μm by 0.7 μm by 0.15 μm multi-quantum-well region and a 100 mW heat source in the *p*-InP region. The InP slab thickness is 340 nm.

However, these solutions have a larger footprint than the DML, consume more power, and are more expensive, due to the requirement for more chips. With all these drawbacks, much research is directed at expanding the bandwidth of the DML.

When the injection current is varied in a DML, it induces a dynamical carrier-photon interaction, leading to a relaxation oscillation. The frequency of this oscillation governs the intrinsic modulation speed. Options for increasing this oscillation frequency, and thus the modulation speed, are to increase the optical confinement factor, the differential gain, the current density, and the internal quantum efficiency. Since the 1990s, many researchers have focused on differential gain, seeking improvements in the active regions in the O- and C-band that contain strained multi-quantum wells. However, the relaxation oscillation frequency has plateaued at around 20 GHz.

There are other strategies for increasing the 3 dB modulation bandwidth, such as the use of photon-photon resonance and detuned loading effects, which combine optical feedback with optical filtering. Photon-photon resonance can enhance the 3 dB modulation bandwidth, thanks to the introduction of an additional resonance frequency that corresponds to the difference between the main and side lasing modes. For example, a 55 GHz 3 dB modulation bandwidth has been realised by using a distributed reflector laser, with a photon-photon resonance effect at 50 GHz. Note that the relaxation oscillation frequency must be increased to ensure a flat frequency response with a large bandwidth. For that reason, detuned loading has been employed to enhance the effective relaxation oscillation frequency compared with its intrinsic value. An optical filter provides modulation of the cavity loss and volume.

For a further gain in the 3 dB modulation bandwidth, it is crucial to increase the intrinsic relaxation oscillation frequency. One promising way to do this is to boost the optical confinement factor.

At NTT, Japan, we have adopted this approach, beginning with the fabrication of membrane lasers on 2 μm-thick SiO_2-on-silicon. This combination ensures a high degree of optical confinement, with thin high-refractive-index multi-quantum wells sandwiched between low-refractive-index SiO_2 and air. Thanks to a high degree of optical confinement, the

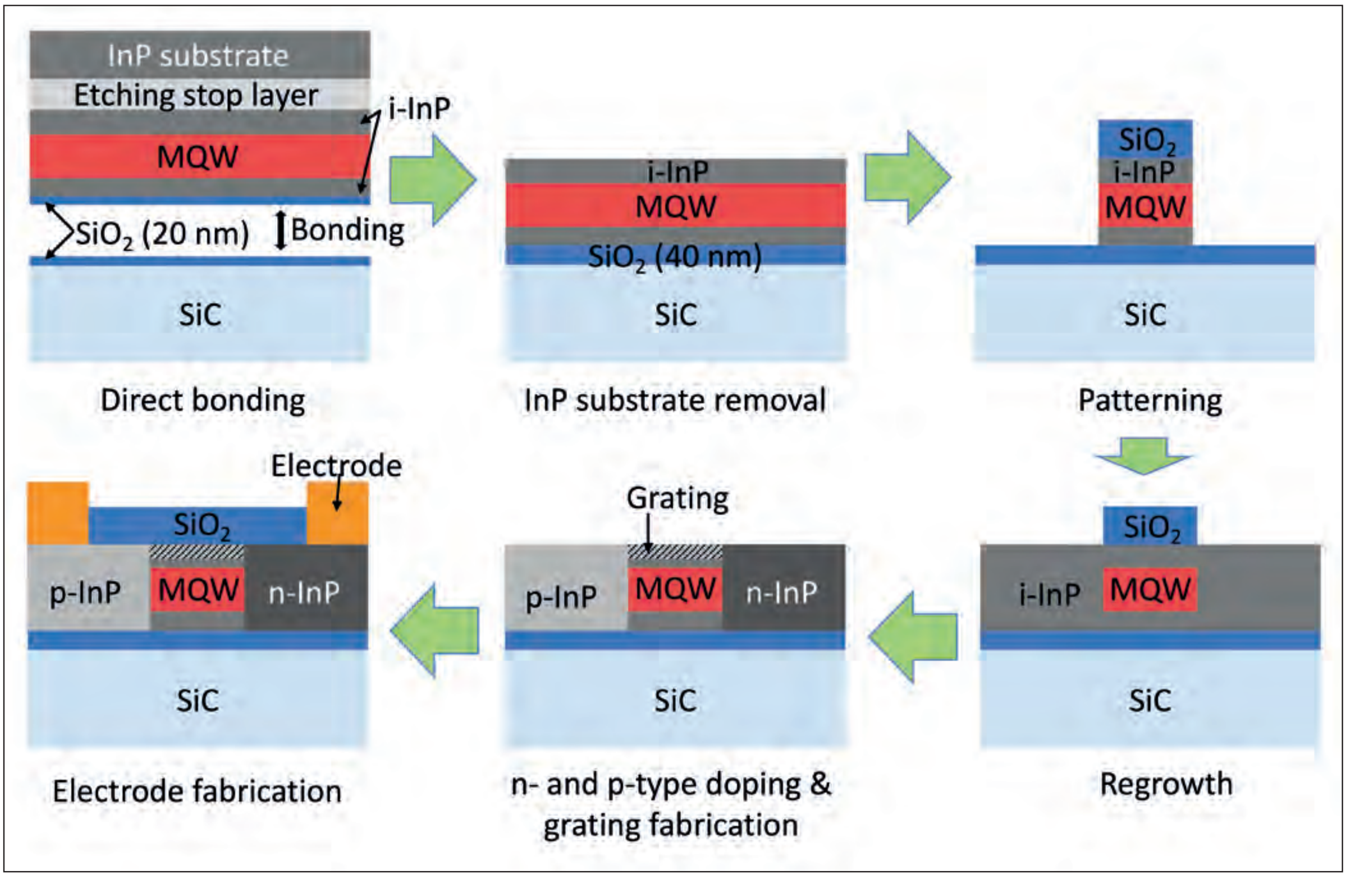

Figure 2. Fabrication procedure for membrane lasers on SiC.

threshold carrier density is low, leading to a reduction in power consumption. With this novel architecture, we have demonstrated 25.8-Gbit/s non-return-to-zero modulation. This is realised at an energy cost of just 132-fJ/bit, defined by the electrical power consumption divided by the modulati on speed.

While this result is promising, with the laser exhibiting a high modulation efficiency, it did not lead to any increase in the intrinsic relaxation oscillation frequency – this still had a value of around 20 GHz. The thick, low-thermal-conductivity layer of SiO_2 held back the laser, with the temperature of this device increasing relatively quickly with bias current, and hampering differential gain. Note that it would be folly to decrease the thickness of the SiO_2 layer to address this issue, as that would lead to more light entering the silicon substrate, and ultimately reduce optical confinement.

Introducing the SiC substrate

To prevent overheating of the laser, we have modified our architecture, moving to a high-thermal-conductivity material. When selecting this successor, we considered whether it would provide a low enough refractive index to realize high optical confinement in the active region, and whether it would be transparent in the O- and C-band. Attractive candidates for meeting these requirements are wide-bandgap semiconductors, such as diamond, GaN, AlN, and SiC.

From this class of material we selected SiC. Influencing our decision is the commercialisation of single-crystal SiC substrates by various companies. The growing market for high-power electronics has led to the availability of larger SiC wafers, up to 150 mm in diameter. This material has a very high thermal conductivity, with a value of 490 W m^{-1} K^{-1}, compared with just 1 W m^{-1} K^{-1} for SiO_2. The refractive index for SiC of around 2.6 is also suitable, ensuring comparable optical confinement to that on SiO_2-on-silicon.

Pairing an InP laser with a high-thermal-conductivity foundation breaks new ground. Success is not easy as there is the threat of degrading the quality of the active region during the fabrication process. The fundamental challenge is to thin the SiO_2 layer on the SiC substrate while not inflicting significant damage to the active region.

Our key process to realising our membrane laser on a SiC substrate (see Figures 1(a) and 1(b)) is the application of a low-damage oxygen-plasma-assisted direct-bonding technique with an ultrathin SiO_2 layer. Use of a 40 nm-thick SiO_2 layer increases heat dissipation in the active region and reduces plasma-induced damage to the multi-quantum wells.

According to our calculations, by switching from our previous design with the laser on a 2 μm-thick SiO_2-on-silicon foundation to our new architecture –

that is, a 40-nm-thick SiO_2 layer on SiC – slashes the increase in temperature by 88 percent (see Figures 1(c) and 1(d)). Thanks to this, we can increase bias current without degrading differential gain, and ultimately increase the relaxation oscillation frequency. The laser that we have fabricated has three sections: a distributed feedback (DFB) section, a rear distributed Bragg reflector (DBR) mirror, and a waveguide. Incorporating a distributed reflector structure enables single-mode lasing, using the DBR to select one side mode of the DFB grating. By altering the reflectivity at the facet of the output waveguide by changing its shape, we control the appearance of the photon-photon resonance effect.

By removing the limiting factor of the bandwidth of our laser structure, we can improve the damping factor and the time constant RC (the product of resistance and capacitance). It is essential to keep both these two factors as low as possible. When increasing the relaxation oscillation frequency, we must take into account the damping effect of the relaxation oscillation. As well as being proportional to the square of the relaxation oscillation frequency, the damping factor also depends directly on a factor known as *K*, which can be reduced with a grating design that decreases the photon lifetime. The danger with such a design is that it results in a large threshold current. However, that's not the case with our novel architecture, thanks to its high optical confinement factor. Addressing the second factor, our laser features a lateral *p-i-n* structure to enable lateral current injection. This lowers pad-electrode capacitances and the related RC time constant, leading to a higher bandwidth.

Fabrication of our laser begins with the growth, by MOCVD, of a 310 nm-thick InP-based membrane layer, including nine InGaAlAs quantum wells and an InGaAs etching stop layer, on 2-inch InP (001) substrates. This laser features more wells than that in our previous design – it had six – to ensure a higher differential gain.

We bond our InP epiwafers to 2-inch semi-insulating 6H-SiC substrates using oxygen-plasma-assisted direct bonding. This is carried out after sputtering a 20 nm-thick SiO_2 layer on both surfaces to yield a total thickness of 40 nm for the SiO_2 bonding layer. Note that one of the primary purposes of the 20 nm-thick SiO_2 layer is to provide a buffer to plasma damage.

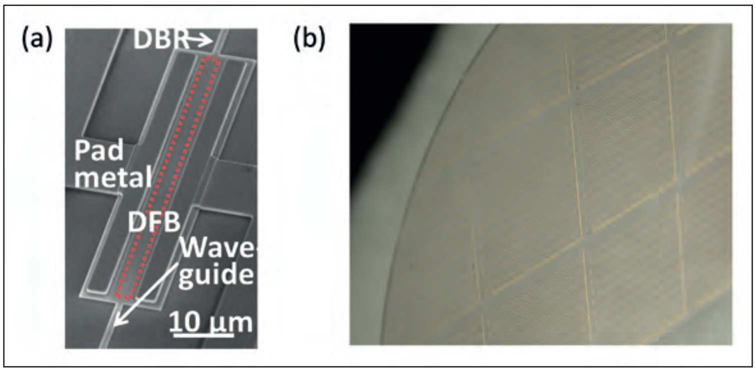

Figure 3. (a) Top-down view of NTT's fabricated distributed-reflector laser with a 50 μm-long active region on SiC. (b) Image of numerous membrane lasers fabricated on a transparent SiC wafer.

After bonding, we selectively remove the InP substrate, using a combination of an etch stop layer and mechanical and wet etching. Using a SiO_2 mask, we define a mesa-stripe structure by dry/wet etching. Burying the active region is followed by using epitaxial growth of undoped-InP, silicon-ion implantation and zinc thermal diffusion to produce a lateral *p-i-n* junction. Surface gratings are formed on the top, intrinsic InP layer, to define the DFB and DBR sections with lengths of 50 µm and 60 µm, respectively. The final step is to form electrodes on *n*-InP and *p*-InP.

Using this approach to fabricate our devices (see Figure 3 (a)), we ensure that the distance between the active region and the 40-nm thick SiO_2 layer on the SiC substrate is just 75 nm. This small separation, easy to realise with a thin membrane lateral-current-injection structure, enables effective heat dissipation in the active region. We have been able to fabricate numerous devices on SiC (see Figure 3(b)), indicating the capability of integrating the multi-channel laser array.

Record-breaking speeds

To evaluate intrinsic lasing characteristics without the photon-photon resonance effect, we have fabricated an inverse-taper waveguide, a configuration that ensures that there is no propagation mode in the InP waveguide. With this modification, the optical mode radiates into SiC in the inversely tapered region in InP,

Plans for the future are to increase the relaxation oscillation frequency and the 3 dB modulation bandwidth, through two strategies: increasing thermal dissipation, by decreasing the bonding SiO2 layer thickness; and increasing the number of quantum wells, to increase the differential gain

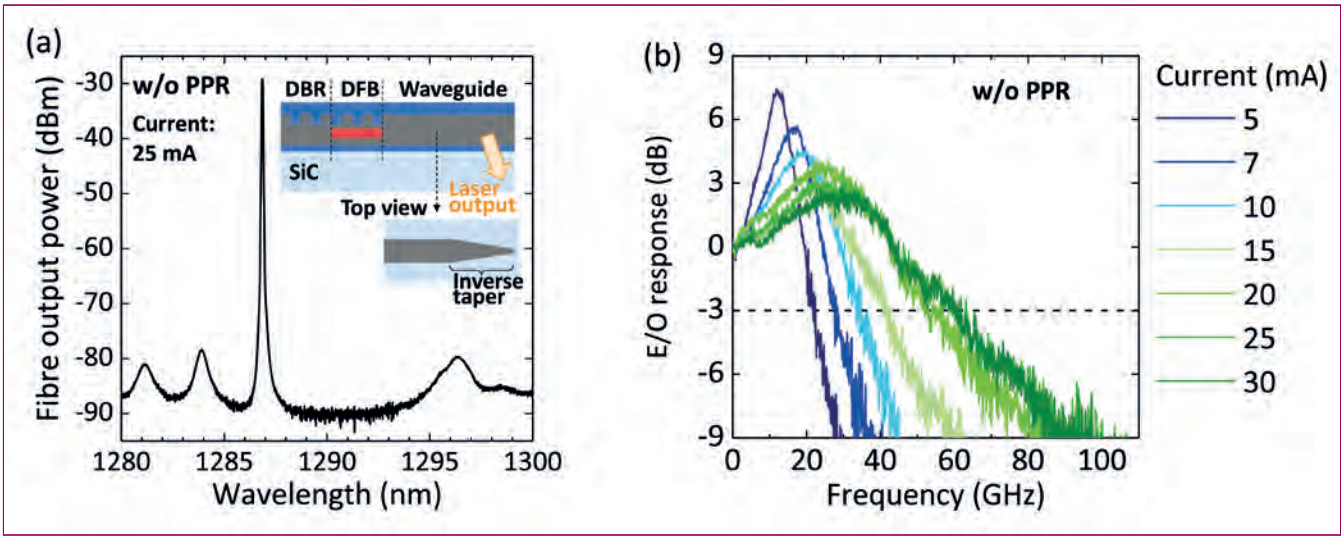

Figure 4. (a) Measured lasing spectrum at 25 mA without using photon-photon resonance. The inset illustrates the laser (cross-sectional view) and provides a top view of the inverse-tapered InP waveguide. The laser light goes through the SiC substrate in the tapered region, which suppresses the reflection at the edge of the waveguide. (b) Measured small-signal electro-optic responses of the laser at various bias currents without using photon-photon resonance.

resulting in a small-enough reflectivity to suppress the photon-photon resonance (see the inset of Figure 4(a)). This happens because the refractive index of the SiC substrate is higher than that of the SiO_2 overcladding layer.

Measurements with an optical fibre reveal single-mode lasing at 25 mA (see Figure 4(a)). This drive current produces a peak output power of 1.20 μW. We attribute this small output power to a large fibre coupling loss, noting that we could not fully detect the radiation mode into SiC. This laser's threshold current is 2.75 mA.

Encouragingly, our measurements of small-signal electro-optic responses of our laser reveal that the 3 dB modulation bandwidth linearly increases with the square root of the bias current, to reach 60 GHz at 30 mA (see Figure 4(b)). We estimate that the relaxation oscillation frequency is as high as 42 GHz at 30 mA. These are record values for DMLs without the photon-photon resonance effect, indicating that the membrane laser on SiC has an inherent advantage when it comes to increasing the 3 dB modulation bandwidth.

We have gone on exploit the photon-photon resonance effect and break more new ground for the 3 dB modulation bandwidth, using a 135 μm output waveguide (see the inset of Figure 5(a)). With this configuration, the output waveguide acts as part of the laser cavity, inducing Fabry–Pérot interference between the front of the DFB section and the edge of the waveguide.

A photon-photon resonance arises when the main lasing mode comes close enough to one of the Fabry–Pérot modes. When the device is running, it produces an increase in temperature in the active DFB region,

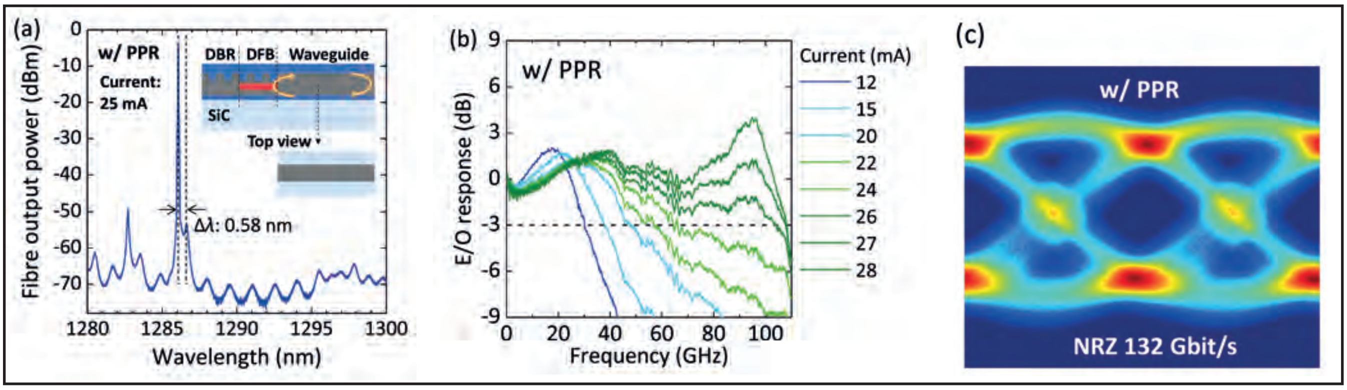

Figure 5. (a) Measured lasing spectrum at 25 mA using photon-photon resonance. The inset illustrates the cross section of the laser and the top view of the InP output waveguide. The waveguide is part of the laser cavity, inducing Fabry–Pérot interference between the front of the distributed feedback section and the edge of the waveguide. (b) Measured small-signal electro-optic responses of the laser without using photon-photon resonance at various bias currents. (c) Equalized optical eye diagram for 132 Gbit/s non-return-to-zero signal.


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where most of the heat is generated, that is larger than that in the output waveguide. Due to this, the bias current controls detuning, due to the red-shift of the main lasing mode exceeding that of the Fabry–Pérot mode.

Driven at 25 mA, this laser exhibits Fabry–Pérot modes in the DFB stopband (see Figure 5(a), and note the contrast with the spectrum shown in Figure 4 (a)). The free spectral range of the Fabry–Pérot modes is 1.48 nm, corresponding to 270 GHz. At 25 mA the maximum fibre output power is 0.37 mW, and the threshold current 2.54 mA. Based on fitting the spectrum, we estimate the reflectance at the facet of the output waveguide to be about 5 percent.

The photon-photon resonance effect enables far higher data rates. For drive current above 22 mA, small-signal electro-optic responses show a clear photon-photon resonance around 95 GHz, which is not far from the frequency separation of the main lasing and side modes: this is 105 GHz, equating to a value for $\Delta\lambda$ of 0.58 nm.

Thanks to the high relaxation oscillation frequency, along with a photon-photon resonance at 95 GHz, we obtained a flat frequency profile and a maximum bandwidth of 108 GHz.

FURTHER READING

S. Yamaoka et al. Nat. Photon. 15 28 (2021)
N. P. Diamantopoulos et al. J. Lightwave Technol. 39 771 (2021)
S. Matsuo et al. Opt. Express 22 12139 (2014)

We have directly modulated our laser with a 132-Gbit/s non-return-to-zero signal, using a back-to-back configuration. This produced a clear eye opening at a bias of 27.2 mA, after equalization with a 61-tap linear equalizer compensating for linear distortion (see Figure 5(c)). Energy cost is not as low as it has been with some of our earlier lasers, coming in at 911 fJ/bit. However, the bandwidth of 108 GHz and the symbol rate of 132 GBaud are more than twice as large as those of conventional DMLs.

Opening the door to applying DMLs to applications beyond 400GbE, our technology is already enabling this class of laser to provide an intrinsic 60 GHz and a photon-photon-resonance-assisted value of over 100 GHz.

Plans for the future are to increase the relaxation oscillation frequency and the 3 dB modulation bandwidth, through two strategies: increasing thermal dissipation, by decreasing the bonding SiO_2 layer thickness; and increasing the number of quantum wells, to increase the differential gain.

With the latter, it's also possible to reduce nonlinear optical phenomena, which could limit the 3 dB modulation bandwidth at a relaxation oscillation frequency of more than 40 GHz, thanks to a decrease in the photon density in the active region. Working towards this, our next goal is to develop DMLs for high-speed operation under uncooled conditions.

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T&M challenges & opportunities mirror overall IC, photonics 2022 market

As 2021's fourth quarter nears, it's fair to consider how long the challenges affecting semiconductor and photonic supply chains will continue. A business unusual climate remains as the world struggles to overcome the protracted pandemic recovery. Insiders and analysts affirm faith in recovery while at the same time everyone appreciates that some companies can't offer a timeline to 'normal' while others seem to think it could happen any day. PIC Magazine looks at the effects of the last 18 months and year to come through the perspective of EXFO's T&M experts. We spoke with **LEO LIN, THE COMPANY'S DIRECTOR OF MANUFACTURING, DESIGN & RESEARCH,** about ongoing impacts and how unparalleled demand combined with shortages and supply chain disruptions have shaped business and will likely impact manufacturing through 2022.

MA: *A recent Light Counting report indicated that the first half of 2021 was a good year for most optical / photonic manufacturers. However, they predict component and resource shortages may hamper future sales. How has 2021 challenged EXFO? What will drive testing requirements through 2022?*

LL: One of the sectors that has been adversely impacted by the global pandemic is the semiconductor industry. The Asian market is largely responsible for semiconductor production, and countries in Asia-Pacific have been hard-hit by COVID 19 and related restrictions, which has created

component supply chain issues. Forming the perfect storm, demand for semiconductors has been rising sharply, fueled by increased requirements in the automotive industry and other manufacturing sectors – including the telecommunications market.
At EXFO we have been able to weather the semiconductor supply chain storm by working diligently with our suppliers and finding multiple sources to meet our needs. In the short term, we have been fortunate that there has been minimal impact on our test equipment business.

Going forward, analysts are predicting recovery in the semiconductor industry which would relieve the pressures on manufacturers who are dependent on semiconductor availability. If, however, that recovery does not happen during 2022, many businesses will be facing adjustments – perhaps including creative redesigns of products to work around shortages.
In what has proven to be an unpredictable and unprecedented time, businesses – including EXFO – have had to be agile and adapt quickly to changing circumstances and we anticipate that will continue in the new year.

MA: *Product development around PIC/photonic-based sensors has grown due to device properties benefitting medical/diagnostic instrument developments. The pandemic showed we need faster, portable, more reliable testing that can rapidly reconfigure as new disease agents emerge. Light Counting also reported that it has tallied big sales tied to 400G transceivers, coherent modules, ROADMs, pump lasers and 3D sensing chips – Have these areas been 'hot' 2021 market drivers for you?*

LL: Definitely. A particularly hot area for EXFO in view of current demand is PIC testing to support a new generation of transceivers including 5G wireless transceivers, 400G transceivers and coherent modules for high-speed networking. PIC technology has also increased in importance for diverse industry segments, especially optical communications, automotive LiDAR, and medical applications where large volume, precise production is required.

By using PIC technology to consolidate and integrate various components on a single chip, functionality can be increased while increasing density, reducing cost of production and lowering energy requirements. These improvements are attractive where manufacturers are striving to cost-effectively produce high volumes of photonic components with consistent performance and quality.

Component manufacturing testing in this production pressure-cooker is critical to ensure end-to-end compliance and reliability throughout the design, foundries, and packaging stage. There are often production bottlenecks due to the sheer volume of units and even multiple ports-per- unit needing testing. Fortunately, innovation in light coupling methods has made wafer-level testing possible for mass production. Now testing must be a consideration from the design stage through production to ensure that the test process is simplified, test time per unit is reduced, and bottlenecks are avoided.

Innovation in PIC testing is being driven largely by the demands of high-speed networking, with up to 800G transceivers and data center consolidation relying on coherent modules today. With more functionalities being integrated into a single PIC, new functional tests like bit-error-rate (BER) or eye diagram are needed in addition to the conventional parametric tests – even at the wafer and die levels – in order to fully characterize these increasingly more complex PIC devices.

Beyond PIC transceivers, we also see some growing R&D activities and testing requirements around co-packaged optics for next-generation high speeds, automotive LiDAR for autonomous vehicles, and quantum communications for AI or machine learning applications.

These new PIC applications use diversified technology platforms and PIC designs, and also bring new challenges to PIC fabrication and testing. More modular and scalable PIC production and testing solutions will be needed to support wide-ranging PIC designs and to create the economy of scale needed to ensure competitive cost structure and return on investment.

MA: *Bringing T&M automation to market for PICs has been a challenge. Yet in less than five years, a number of companies are now offering automated, production-*

Leo Lin, Director of Manufacturing, Design & Research at EXFO

These new PIC applications use diversified technology platforms and PIC designs, and also bring new challenges to PIC fabrication and testing. More modular and scalable PIC production and testing solutions will be needed to support wide-ranging PIC designs and to create the economy of scale needed to ensure competitive cost structure and return on investment

grade T&M instruments, or are making continual strides. What are major hurdles (or opportunities) that T&M companies are facing as products and customer interests diversify?

LL: Test & measurement companies are striving to leverage automation to create full control of end-to-end testing from wafer and die to packaging, as well as to simplify configuration and test processes, and reduce time required between various test stages. That's a challenge because each application demands a unique PIC solution that's readily customized and quickly reconfigurable to optimize testing. Manufacturers need a turn-key solution that enables end-to-end testing in volume production settings.

EXFO continues to invest in automation and has made advances with flexible PIC test solutions that can scale to meet future requirements. However, no one test solutions provider can meet all PIC testing needs – from basic parametric measurements to full functional characterization – in today's market.

To best respond to varied customers with diverse product lineups, latest technology in ultra-high precision alignment systems, collision avoidance sensors, temperature control, machine vision, and electronic testing and photonics often need to be combined to provide a simple-to-use interface. EXFO has collaborated with other industry innovators to deliver customized solutions.

An example is EXFO's collaboration with component manufacturer AEPONYX and integrated electro-photonics probe system developer Maple Leaf Photonics (MLP) that delivered a custom PIC testing solution.

EXFO has also worked with Hewlett Packard Enterprise (HPE) and MPI Corporation to create a unique turnkey PIC testing application.

MA: *Standards don't usually make headlines, but without them microelectronic device manufacturing would not be as foundational to today's competitive landscape as it remains. The uniformity and reliability of standards also enables interoperability, which is essential to a competitive landscape and product diversity. Are there emerging photonics standards that EXFO is advocating, and if so, could you please explain key benefits?*

LL: Standards have always been important to the fiber optics industry to ensure that components produced by diverse manufacturers will interoperate compatibly in networks globally. And standards development and implementation will have an even more important role in the future given the exponential rate of innovation taking place in high-speed networking, data center evolution, and mobile networking. The transceiver industry is a prime example where diverse types of transceivers are being produced within a complex ecosystem and supply chain, with hundreds of thousands of transceivers deployed in networks worldwide.

At this stage, there are no standards particularly related to PIC testing because it is such a new area, and PIC designs today are based on different technologies. However, as the industry evolves, we believe PIC technologies and designs will start to converge. And convergence in technology platforms typically leads to the evolution of standards over time.

As a key participant in the PIC ecosystem, EXFO will be a strong contributor to ongoing standards development. EXFO is currently a member of various industry associations and consortiums which are catalysts for collaboration. These include AIM Photonics, the European Photonics Industry Consortium (EPIC), and LUX Photonics all of which provide a constructive platform for discussion and cooperation between photonics industry participants.

MA: *2020 and 2021 have proven to be challenging periods for businesses all across the supply chain. What challenges does EXFO see lying ahead for T&M or the phonics industry as a whole through 2021 and 2022?*

LL: As mentioned earlier, the challenges of the past year have required agility and adaptability to meet unforeseen circumstances. The pandemic shone a light on the importance of flexibility: flexibility in sourcing components, flexibility to automate processes and testing to support remote applications, and even flexibility in increased employee work-from-home options.

Despite the challenges, network transformations continue around the world at a rapid pace. Demand for bandwidth has become even more apparent as more people are home-based and need reliable connectivity 24/7.

High-speed networking up to 800G and even 1.6 Terabits is rapidly approaching, and 5G deployments are well underway. The bandwidth surge is continuing and network equipment manufacturers, component manufacturers, and test and measurement equipment suppliers will all feel the demand growth.

As in all challenging times, the roadblocks of supply chain shortages and the need to adopt new business processes have fueled innovation. Trends that EXFO identified in an article in PIC Magazine's June 2021 issue will continue into 2022 and beyond. Those include automation, designing for end-to-end testing, customization, integration, and collaboration.

Further information on EXFO PIC Testing is available at: https://www.exfo.com/en/solutions/academic-research-institutions/pic-testing/

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