Scholars Journal of Physics, Mathematics and Statistics
Abbreviated Key Title: Sch J Phys Math Stat
ISSN 2393-8056 (Print) | ISSN 2393-8064 (Online)
Journal homepage: https://saspublishers.com

OPEN ACCESS

Optical Integrated Circuits: Review Study

Afrah Abdulridha Jumaah Kinanah[1*]

[1]Ministry of Education - Wasit Governorate Education Directorate

DOI: https://doi.org/10.36347/sjpms.2025.v12i04.004 | **Received:** 10.04.2025 | **Accepted:** 16.05.2025 | **Published:** 20.05.2025

***Corresponding author:** Afrah Abdulridha Jumaah Kinanah
Ministry of Education - Wasit Governorate Education Directorate

Abstract **Review Article**

Integrated optical circuit (IOC) is a multi-functional component of the display and electronic display on the same side, the main application of these devices is fiber optic communication networks, and now "IOC" can be used in the aviation, automotive, computer or medical device industry to manufacture data transmission networks, regulators or sensors. This study was to know the Integrated optical circuit. Photonic Integrated Circuits Industry Overview the photonic integrated circuits market is moderately competitive and consists of several major players such as Neophotonics Corporation, Poet Technologies, Cisco Systems Inc., and Infinera Corporation. In terms of market share, there are a few major players currently dominating the market. However, with innovations and technological advancements, several companies are increasing their presence in the market by securing new contracts and tapping new markets. Driving the development of high-speed networks and 5G, photonic integrated circuits (PICs) are a well-known technology in the telecom world—mainly thanks to the frantic development of transceivers and passive components that are smaller, faster, cheaper and greener than their bulk-optics counterparts.

Keywords: Integrated optical circuit, Neophotonics, Poet Technologies, IOC.

INTRODUCTION

Integrated Optical Circuit (IOC) is a multi-functional component of the display and electronic display on the same side, the main application of these devices is fiber optic communication networks, and now "IOC" can be used in the aviation, automotive, computer or medical device industry to manufacture data transmission networks, regulators or sensors. "IOC" is an abbreviation for "Integrated Optics Circuits Integrated optics: is a technology that aims to build what are called integrated optical devices or integrated optical circuits or planar optical wave circuits, which contain many or many optical components that are combined to achieve some complex functions in one way or another (Nishihara, 1980).

The original formation of integrated optics began with the technology of integrated electronic circuits, which showed rapid development over several decades and led to amazing achievements, such as complex and powerful microprocessors containing millions of transistors and specialized signal processors, and computer memory chips with huge data storage capacity. Unfortunately, integrated optics has not been able to match the progress of microelectronics in terms of the complexity of possible devices, and this also results from a number of technical limitations (Kaminow, 2008).

Photonic Integrated Circuits Industry Overview The photonic integrated circuits market is moderately competitive and consists of several major players such as Neophotonics Corporation, Poet Technologies, Cisco Systems Inc., and Infinera Corporation. In terms of market share, there are a few major players currently dominating the market. However, with innovations and technological advancements, several companies are increasing their presence in the market by securing new contracts and tapping new markets. Some of the recent developments in the market are: In March 2023, iPronics created a programmable photonic chip for wireless signal processing, data centers, machine learning, and other advanced computing applications (Li & Henry, 1996).

The company develops programmable photonic systems based on optical devices that can be adapted to meet the needs of different applications. In March 2022, EFFECT Photonics and Jabil Photonics announced a collaboration to develop a new generation of coherent photonic modules. The modules provide a unique solution for network operators and hyperscalers seeking to leverage QSFP high DD performance, small footprint, low power consumption cost, field replaceability, and vendor interoperability for cloud DCIs (data center communications). The next generation coherent optical modules address the growing demands for data flow, service continuity, security, global scalability, and sustainability (Nishihara *et al*., 2000).

Driving the development of high-speed networks and 5G, photonic integrated circuits (PICs) are a well-known technology in the telecom world—mainly thanks to the frantic development of transceivers and passive components that are smaller, faster, cheaper and greener than their bulk-optics counterparts. PICs are also getting traction—both from a commercial and research perspective—in other sectors too (e.g., lab-on-a-chip, LIDAR technology or quantum computing) (Razavi, 2012).

EXFO

It has worked closely with this fast-paced PIC industry and community over the years to develop test and measurement (T&M) hardware and software solutions that are automated, scalable, fast, accurate and cost-optimized. These solutions range from simple optical testing to spectral optical characterization or traffic analysis. EXFO also offers an extensive selection of probe stations for wafer, bar, multi-die or single die configurations, and a powerful automation software suite. Through memberships in consortiums, EXFO has partnered with major vendors worldwide to offer integrated solutions for testing PICs (Hunsperger, 1995).

New technology, new challenges

The rise of integrated photonics brings complex, new challenges in R&D and in the maturation iterations towards the commercial success of a product. Testing is a critical aspect, as it represents most of the cost of the product and its outputs are consumed at all life cycle stages—from design and development, through qualification and validation to production. Automation is key in this regard. However, repeatability, scalability and parallelization of the testing processes are also needed for the massive volume of circuits and ports, in view of meeting the profitability of economies of scale that photolithography fabrication promises (Circuits, 1997).

It can also be tricky to keep up with evolving optical test requirements and to equip photonics labs accordingly for testing active (i.e., emitting light) or passive (i.e., guiding light) optical components. You may be asking yourself: what spectral testing capabilities should I be looking for right now or in the near future? How can I obtain traffic analysis for PICs? Read on to explore solution avenues. Automate and accelerate testing for PIC and optical components, from design to test and validation (Bêche *et al*., 2006).

Design and manufacturing of PIC dies is maturing fast, with photonic wafers now containing thousands of components made available by foundries through process design kits (PDKs). To create and update these PDKs, wafer manufacturers require reliable testing solutions to optimize the different parameters of interest for a given optical component (Figure 1).

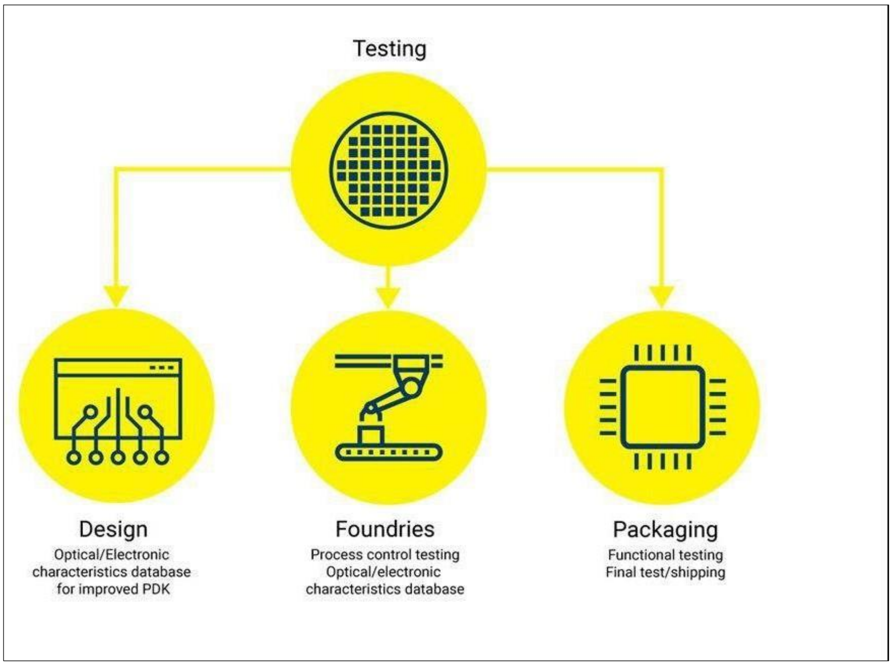

Figure 1: PIC dies

Testing is a crucial step after design and manufacturing to provide feedback to the design tools and help optimize them. It is also needed for process control, to ensure that devices operate as expected throughout the assembly and packaging of the PIC chips. The PIC devices are usually tested at the wafer level prior to dicing so as to detect defects as early as possible and to avoid packaging defective dies. Using a PIC wafer probe station, light can be coupled in and out of each chip using specially designed optical fiber hardware and high-precision alignment software. It is also possible to couple several components simultaneously using a fiber array. Precision alignment and speed allow coupling optimization within a fraction of a second (Murphy, 2020).

ILOT software view:

The PILOT Station App orchestrate full testing automation for wafers or multiple dies Once the light is coupled into the wafer, the optical characteristics of the DUT can be measured. Testing photonic devices is at the heart of EXFO's expertise; the CTP10 specifically addresses key PIC measurement challenges. EXFO's PIC testing solutions can measure optical components quickly, reliably and accurately Accelerating photonics lab to fab(McLevige *et al*., 1975).

The OPAL

series of probe stations deliver industry-leading performance for testing wafers, multiple dies or single dies relating to integrated photonics. With possibilities to perform trench coupling on wafer and flexibility of reconfiguration, the stations enable accurate, repeatable and fast measurement. The PILOT software suite enhances each station by offering automation capabilities that support the full test flow (preparation through measurement to results analysis), using EXFO's or third-party T&M instruments (Figure 2).

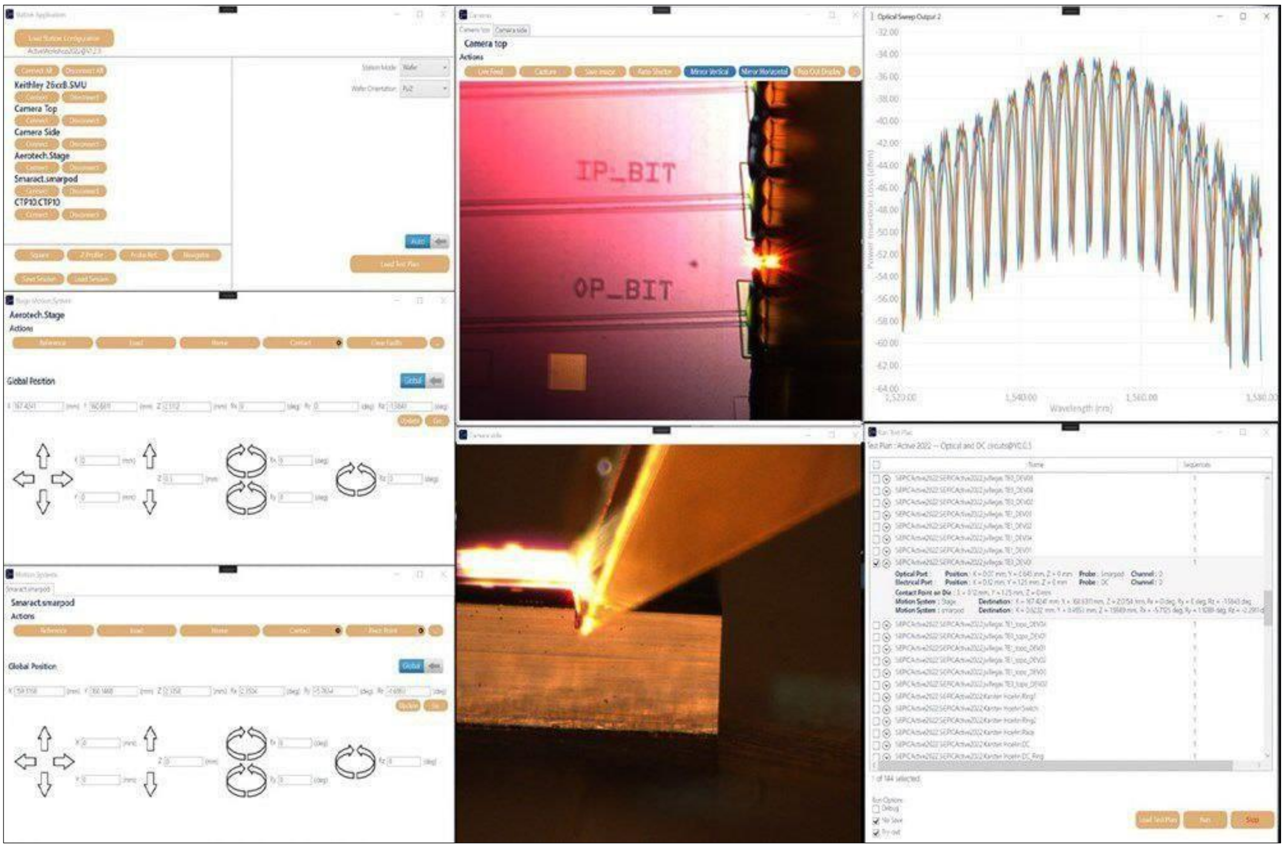

Figure 2: the OPAL instruments

Related resources:

*Product page OPAL-SD

*Spec sheet OPAL-EC Automated PIC testing

The OPAL single die test station for integrated photonics consists of a 4-axis stage and chuck with probe heads both for optical testing (optical fibre array) and electrical testing (DC/RF probes). The station includes a top and side vision system as well as a server- grade PC and a license to an automation software suite that links directly to a database. It offers fully automated optical probe navigation at the die level and manual electrical probing. When combined with the advanced optical measurements capabilities of EXFO's product line of optical instrumentation, this system provides an unmatched solution for optical spectrum analysis as well as electrooptic testing such as BER. Together with the PILOT automation software suite, the OPAL-SD station becomes a complete, flexible and scalable solution. The OPAL single-die station is part of a larger family of test stations and can be used as a stepping stone to increase throughput capabilities. EXFO's multi-die and wafer stations share many of the OPAL-SD elements, particularly the probe heads, vision system and more importantly, the PILOT software-allowing flexible migration from single-die testing to wafer characterization (Debrégeas-Sillard & Kazmierski, 2008).

CHALLENGES

Accuracy/repeatability: Obtaining traceable results—through high-precision alignment and measurement—for tighter acceptance thresholds and greater yield of known good dies, with more confidence in design and process optimization decisions.

Dynamic range: Seeing full optical spectral contrast in a single measurement (Figure 3).

Figure 3: Accelerating photonics lab to fab

Speed: Keeping alignment and measurement time to a minimum, but also accelerating the ease of the test and analysis iterative flow. From data to insight: Generating and managing structured data that is ready for artificial intelligence and business intelligence. Flexible/scalable: Leveraging test station modularity and third-party compatibility of software to improve test throughput and complexity over time or swap equipment as needed. Automation: Leveraging automated chip and wafer advanced navigation, coupled with the freedom of controlling any instrument and executing data analysis in user-defined test routines to test massive circuit amounts with minimized cost of ownership Active optical components (Chu *et al.*, 1991).

Testing active components such as lasers and amplifiers found on PICs is usually done using an optical spectrum analyzer (OSA). This general-purpose test instrument measures the spectral signal of the sources, as shown below. Industr y-leading OSAs, such as the OSA20, have the advantage of being very fast, performing up to five scans per second at speeds of 2000 nm/s, fast enough for real-time component alignment and with a high enough resolution to allow measurement of key parameters such as OSNR and SMSR.

Testing Passive Components

Testing PIC-based passive components is often challenging due to the high port count of some components like arrayed waveguide grating (AWG) or the sheer number of components to test on a single die. A component test platform is a multiport detection system that operates in conjunction with a continuously tunable laser to measure optical insertion loss, return loss and polarization-dependent loss across the laser's spectral range. The method yields optical spectrum quickly and with a high wavelength resolution, typically on the order of a picometer (Chen, 1993).

The CTP10 is a modular component test platform that operates together with the T200S or T500S continuously tunable lasers. The CTP10 characterizes the spectral properties of high port count devices in one single scan with high spectral resolution and a 70-dB dynamic range, even at a sweep speed of 200 nm/s. The CTP10 operates from 1240 to 1680 nm and covers a wide range of applications, including telecom, sensing and LIDAR. The instrument allows for both optical and photocurrent measurements with analog output possible for PIC first-light search and coupling optimization. Its electronics and internal processor make data transfer a breeze. The CTP10 can be remotely controlled using SCPI commands, facilitating integration as part of an automated PIC testing setup, increasing PIC testing throughput while reducing test time. The high sampling resolution down to 20 fm of the CTP10 enables the accurate measurement of narrow spectral features, such as the resonances of high-Q ring resonators (see example below), that have applications in modulators and sensors (Son *et al.*, 2018).

For the characterization of PIC components with a limited number of outputs, the CT440 is a more compact solution. The CT440 has the same wavelength accuracy and spectral coverage as the CTP10 and can perform IL/PDL measurements. Reconfigurable tests when testing hundreds or even thousands of components on a single wafer, automation quickly becomes essential. This is particularly the case considering that optical functionalities may vary from device to device or from die to die. As a result, PIC test solutions need to address fast reconfiguration of port connectivity using automated optical switches. Additionally, simpler, single-point tests may also be beneficial to the overall speed of the test and measurement (T&M) process (Heck, 2017).

EXFO's solutions address this challenge from two angles. First, through optical testing building blocks (FTBx modules) for a simple laser + power meter test configuration with the possibility of adding attenuators, switches or different types of optical sources. Second, rapid yet repeatable reconfiguration with the MXS matrix switch (Horikawa *et al*., 2016).

Modular Optical Test Solution

PIC-based transceivers: Traffic analysis Photonic integrated circuits are currently being deployed to tackle the bandwidth stress taking place in the transceiver industry. This stress is due to ever-increasing performance demands and costs pressures experienced by data centers and 5G applications.

Solution

PIC-based transceivers: Traffic analysis

Photonic integrated circuits are currently being deployed to tackle the bandwidth stress taking place in the transceiver industry. This stress is due to ever-increasing performance demands and costs pressures experienced by data centers and 5G applications (Kimerling *et al*., 2006)

End-to-end transceiver qualification requires an entire range of high-end optical and electrical testers. To help transceiver vendors ensure compliance throughout the transceiver lifecycle, EXFO offers a range of electrical and optical testing solutions from wafer-level to packaged devices, including the EA-4000 sampling scope and the BA-4000 bit error rate tester (Figure 4).

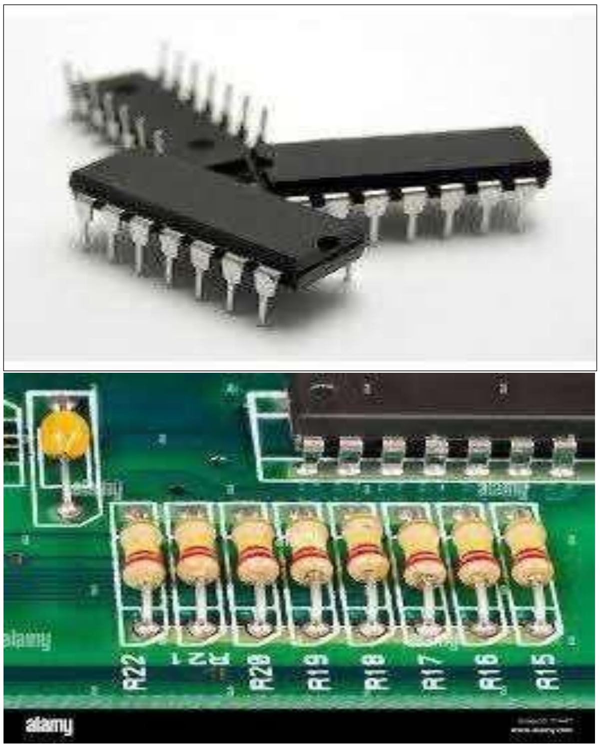

Figure 4: Traffic analysis

Flexibility

Integration and automation

Improve production yield with R&D-grade solutions that rapidly provide best-in-class measurements. Applications Active and passive component testing Mach-Zehnder modulator characterization In March 2022, ColorChip Group and Skorpios Technologies Inc., a leading vertical integrator in the field of heterogeneously integrated silicon (Figure 5).

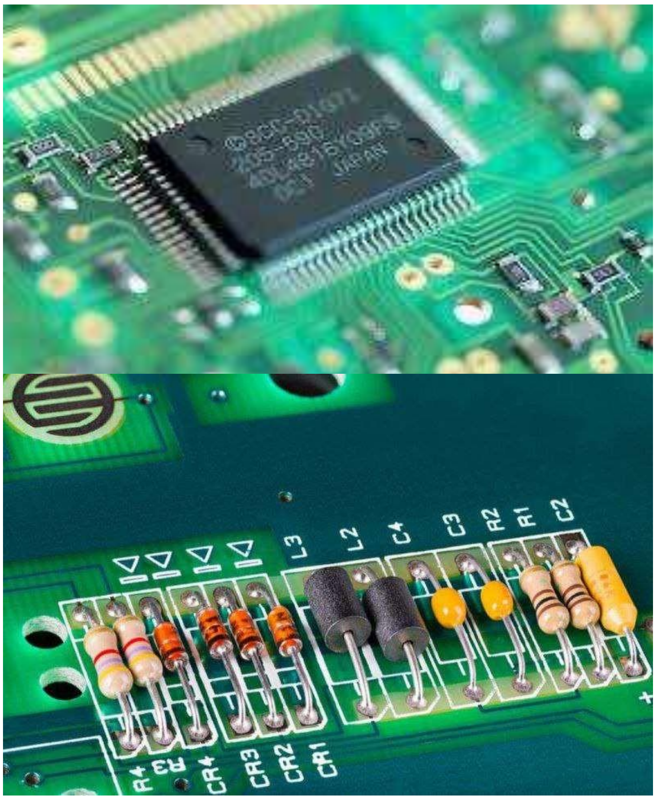

Figure 5: Integration and automation

photonics, formed a strategic partnership to leverage Skorpios' disruptive optical technology to produce optical modules at previously unheard-of prices. ColorChip will sell its own brand of modules and private label modules to Skorpios to sell at various speeds and performance levels. Future products, such as bundled optics and coherent modules will be developed collaboratively AlMl(Wada *et al.*, 1986).

CONCLUSIONS

The study concludes that photonic Integrated Circuits Industry Overview the photonic integrated circuits market is moderately competitive and consists of several major players such as Neophotonics Corporation, Poet Technologies, Cisco Systems Inc., and Infinera Corporation. In terms of market share, there are a few major players currently dominating the market. However, with innovations and technological advancements, several companies are increasing their presence in the market by securing new contracts and tapping new markets.

REFERENCES

- Bêche, B., Pelletier, N., Gaviot, E., Hierle, R., Goullet, A., Landesman, J.-P., & Zyss, J. (2006). Conception of optical integrated circuits on polymers. Microelectronics Journal, 37(5), 421-427.
- Chen, R. T. (1993). Polymer-based photonic integrated circuits. Optics & Laser Technology, 25(6), 347-365.
- Chu, S., Huang, W., & Chaudhuri, S. (1991). Simulation and analysis of waveguide based optical integrated circuits. Computer Physics Communications, 68(1-3), 451-484.
- Circuits, I. (1997). Integrated Circuits. A CASCADABLE, MONOLITHIC LASER/MODULATOR/AMPLIFIER TRANSMITTER, 39.
- Debrégeas-Sillard, H., & Kazmierski, C. (2008). Challenges and advances of photonic integrated circuits. Comptes rendus. Physique, 9(9-10), 1055-1066.
- Heck, M. J. (2017). Highly integrated optical phased arrays: photonic integrated circuits for optical beam shaping and beam steering. Nanophotonics, 6(1), 93-107.
- Horikawa, T., Shimura, D., & Mogami, T. (2016). Low-loss silicon wire waveguides for optical integrated circuits. MRS Communications, 6(1), 9-15.
- Hunsperger, R. G. (1995). Integrated optics (Vol. 4). Springer.
- Kaminow, I. P. (2008). Optical integrated circuits: A personal perspective. Journal of Lightwave Technology, 26(9), 994-1004.
- Kimerling, L., Ahn, D., Apsel, A., Beals, M., Carothers, D., Chen, Y.-K., Conway, T., Gill, D., Grove, M., & Hong, C.-Y. (2006). Electronic-photonic integrated circuits on the CMOS platform. Silicon photonics,
- Li, Y. P., & Henry, C. (1996). Silica-based optical integrated circuits. IEE Proceedings-Optoelectronics, 143(5), 263-280.
- McLevige, W. V., Itoh, T., & Mittra, R. (1975). New

waveguide structures for millimeter-wave and optical integrated circuits. IEEE Transactions on microwave theory and techniques, 23(10), 788-794.

- Murphy, E. J. (2020). Integrated optical circuits and components: Design and applications. CRC press.
- Nishihara, H. (1980). Optical integrated circuits. The Review of Laser Engineering, 8(4), 632-643.
- Nishihara, H., Haruna, M., & Suhara, T. (2000). Optical integrated circuits. Electro-Optics Handbook.
- Razavi, B. (2012). Design of integrated circuits for optical communications. John Wiley & Sons.
- Son, G., Han, S., Park, J., Kwon, K., & Yu, K. (2018). High-efficiency broadband light coupling between optical fibers and photonic integrated circuits. Nanophotonics, 7(12), 1845-1864.
- Wada, O., Sakurai, T., & Nakagami, T. (1986). Recent progress in optoelectric integrated circuits (OEIC's). IEEE journal of quantum electronics, 22(6), 805-821.