Beaming with Potential – Why Integrated Photonics is Worth It

In today's rapidly evolving world, traditional technologies such as microelectronics are increasingly struggling to match the rising demands of sectors such as communication, healthcare, energy, and manufacturing. These struggles can result in slower data transmission, more invasive diagnostics, or excessive energy consumption. Amidst these challenges, there is a ray of hope: photonics.

Photonics is the study and application of light generation, manipulation, and detection, often aiming to transmit, control, and sense light signals. Its goals and even the name "photonics" are born from its analogy with electronics: photonics aims to transmit, control, and sense photons (the particles of light) in similar ways to how electronics do with electrons (the particles of electricity).

Photons can travel more quickly and efficiently than electrons, especially over long distances. Photonic devices can be manufactured on a semiconductor process similar to the one used by microelectronics, so they have the potential to be manufactured in small packages at high volumes. Due to these properties, photonics can drive change across multiple industries and technologies by enabling faster and more sustainable solutions manufactured at scale.

Integrated Photonics Enables New Networks and Sensors

Two of the biggest sectors photonics can impact are communications and sensing.

Light is the fastest information carrier in the universe and can transmit this information while dissipating less heat and energy than electrical signals. Thus, photonics can dramatically increase communication networks' speed, reach, and flexibility and cope with the ever-growing demand for more data. And it will do so at a lower energy cost, decreasing the Internet's carbon footprint.

The webpage you are reading was originally a stream of 0 and 1s that traveled through an optical fiber to reach you. Fiber networks need some optical transceiver that transmits and receives the light signal through the fiber. These transceivers were initially bulky and inefficient, but advances in integrated photonics and electronics have miniaturized these transceivers into the size of a large USB stick.

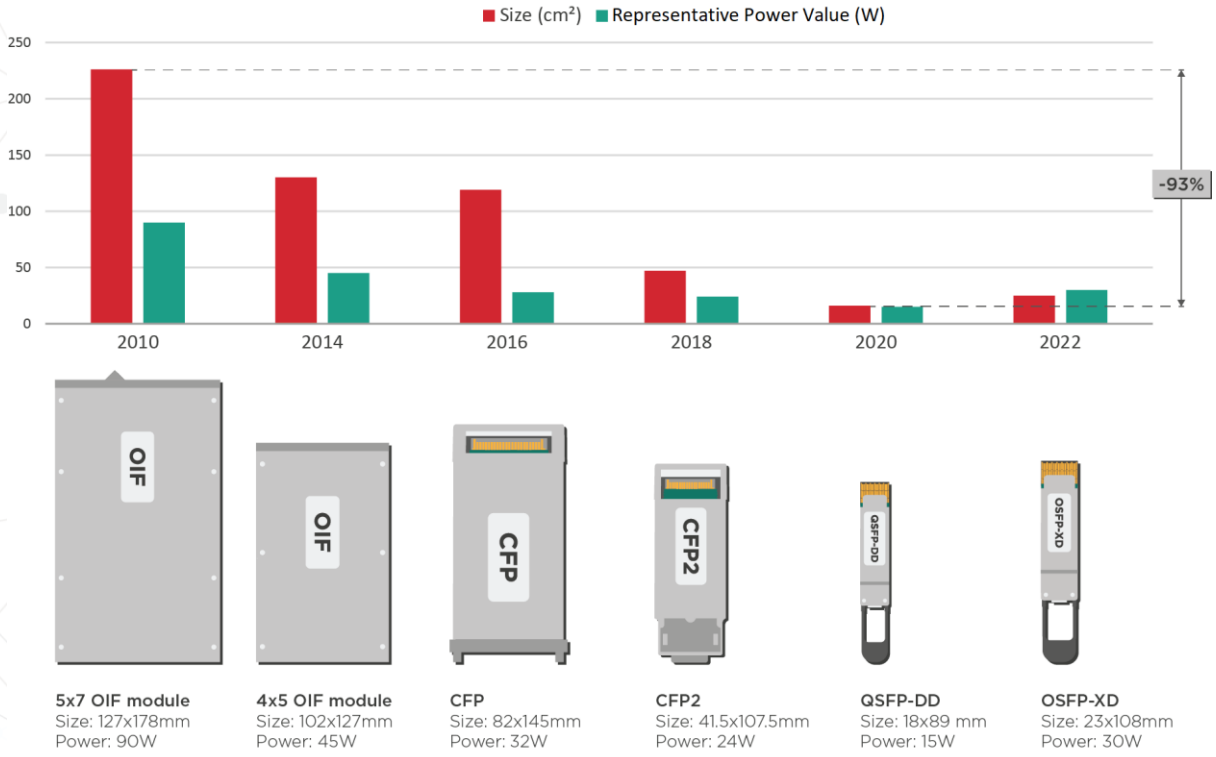

Figure 1: Coherent module size and power consumption evolution from OIF MSA line card modules to pluggable modules like CFP and QSFP.

Aside from fiber communications, photonics can also deliver solutions beyond traditional radio communications. For example, optical transmission over the air or space could handle links between different mobile network sites, cars, or satellites.

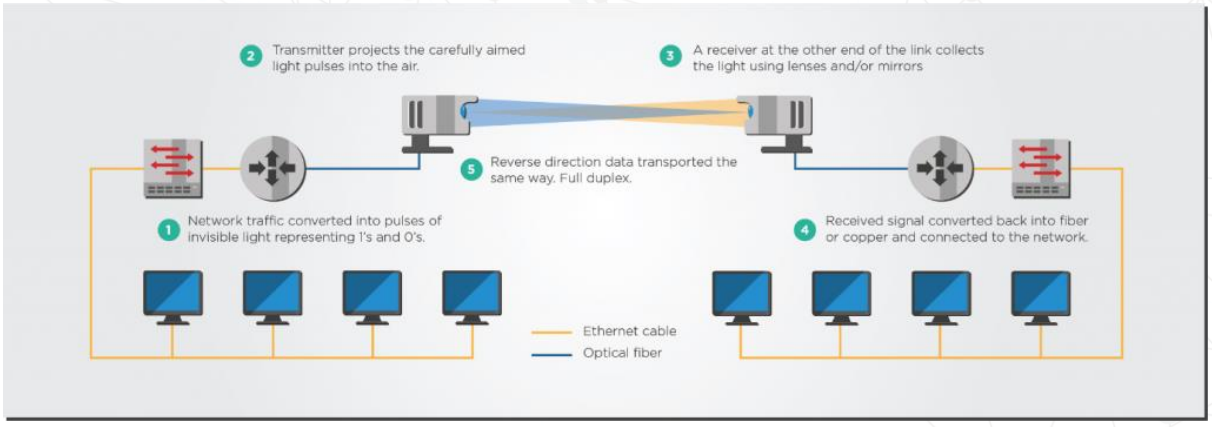

Figure 2: Simplified wireless optical system diagram

There are multiple sensing application markets but their core technology is the same. They need a small device that sends out a known pulse of light, accurately detects how the light comes back, and calculates the properties of the environment from that information. It's a simple but quite powerful concept.

This concept is already being used to implement LIDAR systems that help self-driving cars determine the location and distance of people and objects. However, there is also potential to use this concept in medical and agrifood applications, such as looking for undesired growths in the human eye or knowing how ripe an apple is.

Integrated Photonics Drives Down Power Consumption

Photonics can make many industries more energy efficient. One of the photonics' success stories is light-emitting diodes (LEDs) manufactured at scale through semiconductor processes. LED lighting sales have experienced explosive growth in the past decade, quickly replacing traditional incandescent and fluorescent light bulbs that are less energy efficient. The International Energy Agency (IEA) estimates that residential LED sales have risen from around 5% of the market in 2013 to about 50% in 2022.

Greater integration is also vital for energy efficiency. In many electronic and photonic devices, the interconnections between different components are often sources of losses and inefficiency. A more compact, integrated device will have shorter and more energy-efficient interconnections. For example, Apple's system-on-chip processors fully integrate all electronic processing functions on a single chip. As shown in the table below, these processors are significantly more energy efficient than the previous generations of Apple processors.

Mac Mini Model	Power Consumption (Watts)	
	Idle	Max
2023, M2	7	5
2020, M1	7	39
2018, Core i7	20	122
2014, Core i5	6	85
2010, Core 2 Duo	10	85
2006, Core Solo or Duo	23	110
2005, PowerPC G4	32	85

Table 1: Comparing the power consumption of a Mac Mini with an M1 and M2 SoC chips to previous generations of Mac Minis. [Source: Apple's website]

The photonics industry can set a similar goal to Apple's system-on-chip. By integrating all the optical components (lasers, detectors, modulators, etc.) on a single chip can minimize the losses and make devices such as optical transceivers more efficient.

There are other ways for photonics to aid energy efficiency goals. For example, photonics enables a more decentralized system of data centers with branches in different geographical areas connected through high-speed optical fiber links to cope with the strain of data center clusters on power grids. The Dutch government has already proposed this kind of decentralization as part of its spatial strategy for data centers.

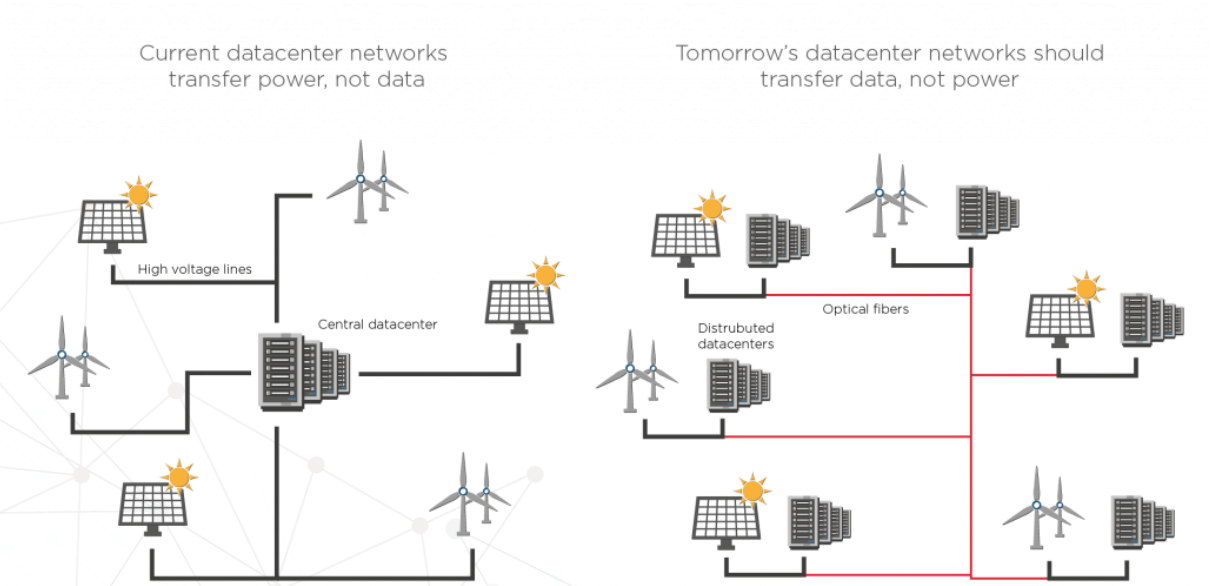

Figure 3: High-speed fiber-optic connections allow data processing and storage to be moved to locations where excess (green) energy is available. Data can be moved elsewhere if power is needed for other purposes, such as charging electric vehicles.

More Investment is Needed for Photonics to Scale like Electronics

Photonics can have an even greater impact on the world if it becomes as readily available and easy to use as electronics.

We need to buy photonics from a catalog as we do with electronics, have datasheets that work consistently, be able to solder it to a board and integrate it easily with the rest of the product design flow.

Tim Koene – Chief Technology Officer, EFFECT Photonics

Today, photonics is still a ways off from achieving this goal. Photonics manufacturing chains are not at a point where they can quickly produce millions of integrated photonic devices per year. While packaging, assembly, and testing are only a small part of the cost of electronic systems, they are 80% of the total module cost in photonics, as shown in the figure below.

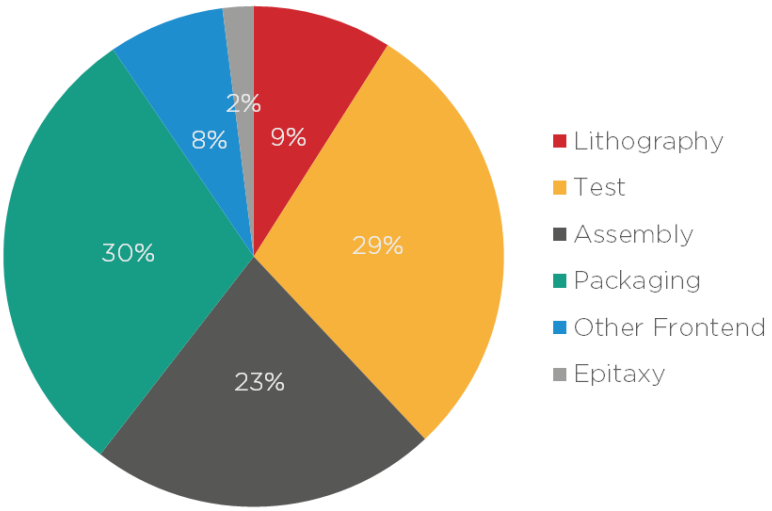

Figure 4. Process cost breakdown of an indium phosphide (InP) photonic integrated circuit (PIC) module as a percentage of the overall manufacturing cost. Source: Latkowski et al., 2019

To scale and become more affordable, the photonics manufacturing chains must become more automated and leverage existing electronic packaging, assembly, and testing methods that are already well-known and standardized. Technologies like BGA-style packaging and flip-chip bonding might be novel for photonics developers who started implementing them in the last five or ten years, but electronics embraced these technologies 20 or 30 years ago. Making these techniques more widespread will make a massive difference in photonics' ability to scale up and become as available as electronics.

The roadmap of scaling integrated photonics and making it more accessible is clear: it must leverage existing electronics manufacturing processes and ecosystems and tap into the same economy-of-scale principles as electronics. Implementing this roadmap, however, requires more investment in photonics. While such high-volume photonics manufacturing demands a higher upfront investment, the resulting high-volume production line will drive down the cost per device and opens them up to a much larger market. That's the process by which electronics revolutionized the world.

Conclusion

By harnessing the power of light, integrated photonics can offer faster and more sustainable solutions to address the evolving challenges faced by various sectors, including communication, healthcare, energy, and manufacturing. However, for photonics to truly scale and become as accessible as electronics, more investment is necessary to scale production and adapt existing electronics processes to photonics. This scaling will drive down production costs, making integrated photonics more widely available and paving the way for its impactful integration into numerous technologies across the globe.

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