Building a Sustainable Future with Fully Integrated PICs

The World Needs Greener Telecommunications

The demand for data and other digital services is rising exponentially. From 2010 to 2020, the number of Internet users worldwide doubled, and global internet traffic increased 12-fold. By 2022, internet traffic will likely double yet again. Mobile wireless networks will significantly drive this energy consumption upwards despite 5G being the most energy-aware mobile communication standard ever released. In a March 2020 report, Ericsson states that some communications service providers have estimated doubling their energy consumption to meet the increasing traffic demands after rolling out 5G.
Keeping up with the increasing data demand of future networks in a sustainable way will require operators to deploy more optical technologies, such as photonic integrated circuits (PICs), in their access and fronthaul networks. By replacing the inefficient copper and coaxial links that use electrical signals, operators can provide their customers and mobile sites with more data while reducing the required power per bit.

Integration Impacts Energy Efficiency and Optical Losses

Lately, we have seen many efforts to increase further the integration on a component level across the electronics industry. For example, moving towards greater integration of components in a single chip has yielded significant efficiency benefits in electronics processors. Apple's M1 processor integrates all electronic functions in a single system-on-chip (SoC) and consumes a third of the power compared to the processors with discrete components used in their previous generations of computers.

Mac Mini Model	Power Consumption (Watts)	
	Idle	Max
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 SoC chip to previous generations of Mac Minis. [Source: Apple's website]

Photonics is also achieving greater efficiency gains by following a similar approach to integration. The more active and passive optical components (lasers, modulators, detectors, etc.) manufacturers can integrate on a single chip, the more energy they can save since they avoid coupling losses between discrete components and allow for interactive optimization.

Transceiver manufacturers have three choices in terms of design:

- Discrete build – The transceiver components are manufactured through separate processes. The components are then assembled into a single package using different types of interconnections.
- Partial integration – Some components are manufactured and integrated on the same chip, but others are manufactured or sourced separately. For example, the transceiver laser can be manufactured separately on a different material and then interconnected to a chip with the other transceiver components.
- Full integration – All the components are manufactured on a single chip from a single material simultaneously.

While discrete builds and partial integration have advantages in managing the yield of the individual components, full integration has fewer losses and more efficient packaging and testing processes, making them a much better fit in terms of sustainability.

The interconnects required to couple discrete components result in electrical and optical losses that must be compensated with higher transmitter power and more energy consumption. The more interconnects between different components, the higher the losses become. Discrete builds will have the most interconnect points and highest losses. Partial integration reduces the number of interconnect points and losses compared to discrete builds. If these components are made from different optical materials, the interconnections will suffer additional losses.

On the other hand, full integration uses a single chip of the same base material. It does not require lossy interconnections between chips, minimizing optical losses and significantly reducing the energy consumption and footprint of the transceiver device.

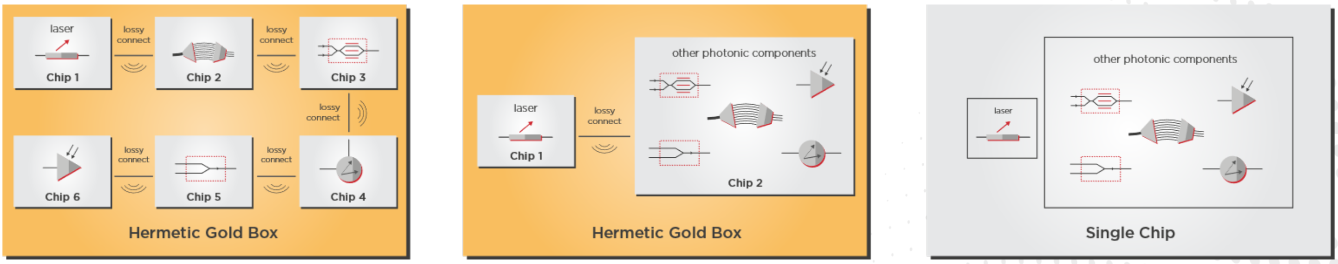

Figure 1: Example of integrating a laser to other photonic components through different integration approaches.

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More Integration Saves Scarce Resources

When it comes to energy consumption and sustainability, we shouldn't just think about the energy the PIC consumes but also the energy and carbon footprint of fabricating the chip and assembling the transceiver. To give an example from the electronics sector, a Harvard and Facebook study estimated that for Apple, manufacturing accounts for 74% of their carbon emissions, with integrated circuit manufacturing comprising roughly 33% of Apple's carbon output. That's higher than the emissions from product use.

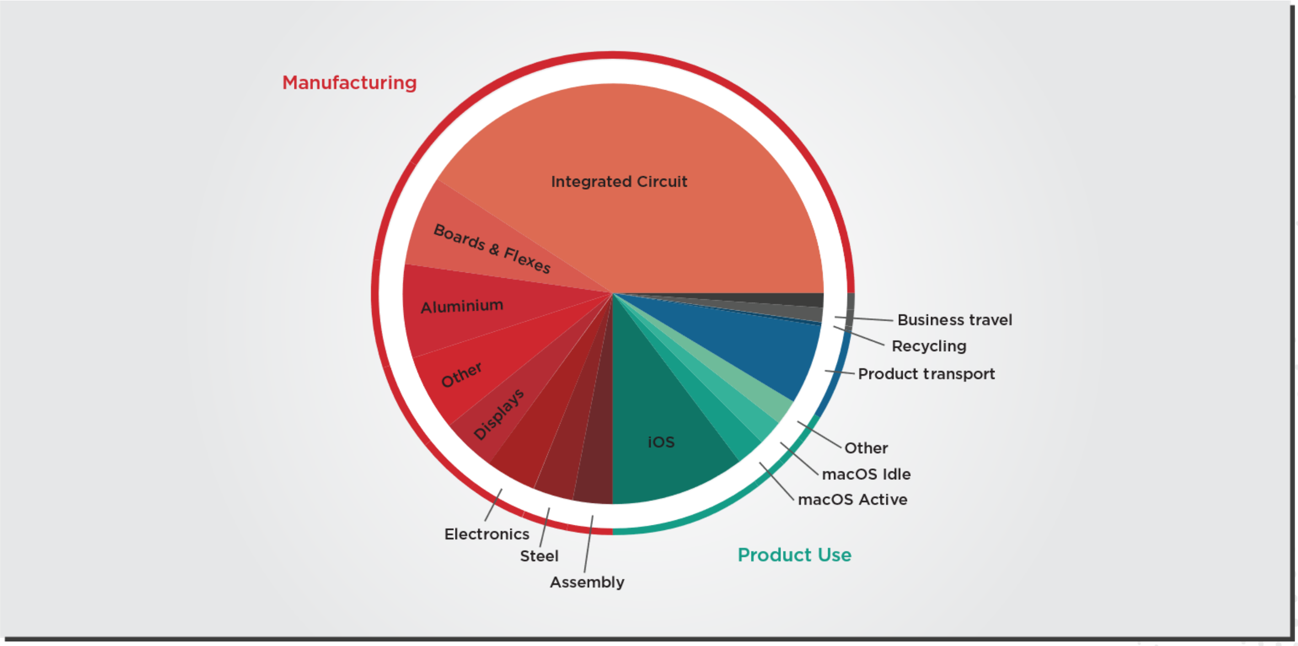


Figure 2: Apple's carbon-emission breakdown. Manufacturing accounts for 74% of total emissions, and hardware use accounts for 19%. Carbon output from manufacturing integrated circuits (i.e., SoCs, DRAM, and NAND flash memory) is higher than that of hardware use. [Source: https://doi.org/10.1109/HPCA51647.2021.00076]

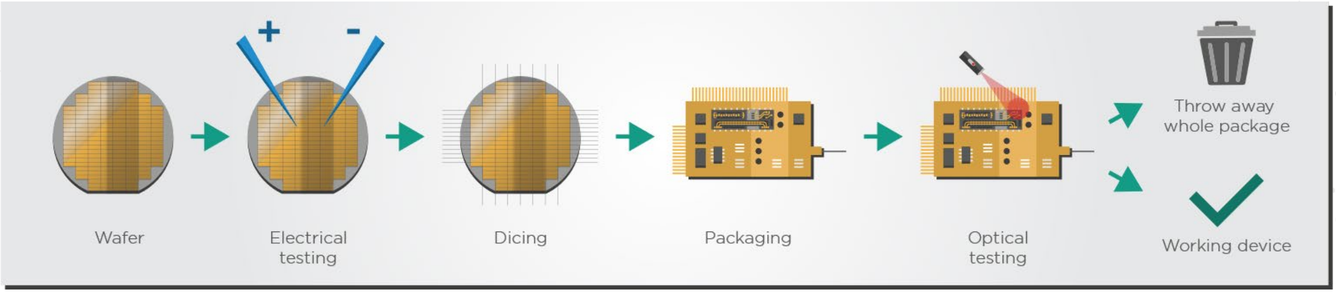
Chip manufacturing processes consume an immense amount of resources. A typical electronics semiconductor chip fab uses between 2 and 4 million gallons of water per day (that's roughly between 7 and 15 million liters of water per day). Chips often need rare metals such as gold, cobalt, and silver or rare earths such as erbium yttrium, neodymium, or thulium. Mining and processing these materials are among the activities that produce the most waste and damage to the environment. To make things worse, we only recycle a small fraction of these materials. For example, the Global Enabling Sustainability Initiative estimates that high-tech products use 320 tons of gold every year and that less than 15% of the gold in e-waste is recovered for reuse.

The choice of integration approach has implications on the complexity of fabrication and packaging of the transceivers, which in turn has implications on their level of sustainability. For example, discrete integration requires a hermetically sealed gold box package to protect the interconnections from moisture. This packaging process also consumes more energy to create an airtight seal and consumes rare gold material. Partial integration reduces the number of interconnects and requires a smaller gold box, which reduces the cost and complexity of the packaging. However, this approach still requires separate fabrication processes for its components and interconnects, which increases the energy consumption of the assembly process. On the other hand, fully integrated transceivers can do away with the gold box and minimize energy consumption by avoiding the extra fabrication and packaging steps.

Early Testing Avoids Wastage

Testing is another aspect of the manufacturing process that impacts sustainability. The earlier faults can be found in the testing process, the greater the impact on the use of materials and the energy used to process defective chips. Ideally, testing should happen not only on the final, packaged transceiver but in the earlier stages of PIC fabrication, such as measuring after wafer processing or cutting the wafer into smaller dies.

Package level testing



Wafer level testing

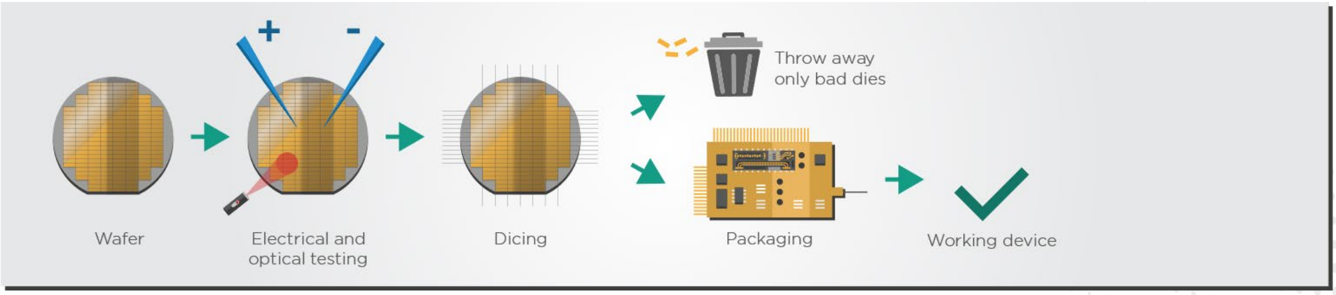


Figure 3: Package vs. die level testing. Manufacturers can find faults earlier by testing at the die level, which avoids wasting packaging materials.

Discrete and partial integration approaches do more of their optical testing on the finalized package, after connecting all the different components together. Should just one of the components not pass the testing process, the complete packaged transceiver would need to be discarded, potentially leading to a massive waste of materials as nothing can be "fixed" or reused at this stage of the manufacturing process.

Full integration enables earlier optical testing on the semiconductor wafer and dies. By testing the dies and wafers directly before packaging, manufacturers need only discard the bad dies rather than the whole package, which saves valuable energy and materials.
For example, EFFECT Photonics reaps these benefits in its production processes. 100% of electrical testing on the PICs happens at the wafer level, and our unique integration technology allows for 90% of optical testing to also happen on the wafer.

Full Integration Drives Sustainability

While communication networks have become more energy-efficient, further technological improvements must continue decreasing the cost of energy per bit and keeping up with the exponential increase in Internet traffic. At the same time, a greater focus is being placed on the importance of sustainability and responsible manufacturing. All the photonic integration approaches we have touched on will play a role in reducing the energy consumption of future networks. However, out of all of them, only full integration is in a position to make a significant contribution to the goals of sustainability and environmentally friendly manufacturing. A fully integrated system-on-chip minimizes optical losses, transceiver energy consumption, power usage, and materials wastage while at the same time ensuring increased energy efficiency of the manufacturing, packaging, and testing process.