Past and Future of InP-based Photonic Integration

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Abstract. In the last decades the complexity of InP-based Photonic Integrated Circuits has increased by almost two orders. In this paper past and future developments in Photonic Integration will be discussed.

1. Moore's law in Photonics

The introduction of WDM-technology in telecommunication links and networks has been the driving force behind the development of photonic integration for more than a decade. A large number of Photonic ICs have been reported, including WDM receivers and transmitters, wavelength converters, and add-drop multiplexers (OADMs). Figure 1 shows an example of a complex PIC, reported by Infinera [1], integrating more than 50 components on a single chip.

Figure 2 shows the development of the complexity of reported Photonic ICs for WDM applications measured as the number of components per chip. Most points in the figure can be traced in Smit [2] and Nagarajan [3]. The complexity of Photonic ICs clearly shows a similar pattern as that of electronic ICs in their early days, but the market development does not follow. So far the only commercial complex PIC is the one reported by Infinera [1] and there are no signs of a breakthrough for many other devices.

Fig.1 Example of a complex PIC: a WDM transmitter. The example is from Infinera [1]

Fig. 2 Moore's law in Photonics: the development of WDM PIC complexity, measured as the number of components per chip.

2. Generic Integration Technology

The success of microelectronics has been caused by a steady increase in functionality at an essentially constant price as a result of technological innovation and scaling of production in combination with a steadily increasing number of applications, which provide a market for large investments in technology development, which in turn leads to better performance, and so on ... This is the well-known dynamics of Moore's law. It became possible because micro-electronic integration processes show a very generic character: they support integration of a set of basic building blocks, from which a large number of different circuits can be realised by connecting them in different circuit configurations. A few flavors of generic processes, e.g. for lowest cost, low-power, high voltage and high speed, can serve a large part of the market so that the development costs of these technologies can be shared by large markets and the charge of process R&D costs per chip can be small.

In InP technology generic integration technologies are not available. This situation has its roots in the abundance of different devices, device principles, materials and technologies that are available in photonics, and that make that without coordination or standardization almost any application gets its own specific technology. Even a simple DFB laser can and has been made in at least 10 different ways! On inspection of the functionality of Photonic ICs reported in the literature, we see that many of them contain only a rather small set of basic components: 1) waveguides (which can be used as interconnects or in components like MMI-couplers and AWG or ring filters and demultiplexers), 2) amplifiers (SOAs), 3) reflectors (DBR or DFB), 4) modulators (either EAM or MZI), and 5) an integrated fibre mode adapter (Spot Size Converter). This strongly suggests that a large part of today's applications can be covered with a few generic technologies.

3. The future

The reason that Photonics does not yet have generic integration technologies are mainly historic. In the presentation the properties and economics of generic integration technologies will be discussed. Once such technologies become available, the first step will be the introduction of low-cost PICs with a small complexity (<100 components per chip) in a large number of applications, both in telecom and non-telecom applications. This step will form the starting point for a development towards increasing performance of the integration technology and increasing complexity of the PICs. At a certain point, probably below 110 components per chip, larger complexities will require digital operation because of the inherent signal regeneration properties of digital signal processing, and further it requires small and low-power building blocks. Nano-lasers are the most promising candidate as building block for digital photonic ICs. Research reported by Hill [4] indicates that by using metallic cavities the size of lasers can become comparable with that of modern transistors. Due to their small size, these lasers would operate at very low powers, and their predicted operation speeds are well into the THz domain. Such lasers would pave the way for VLSI digital photonic ICs, containing more than 100.000 lasers operating at multi-TeraHz clock rates.

Fig.3 Schematic structure, simulated intensity of the lasing mode, electron microscope photo and measured laser spectrum for a metallic nanocavity laser operating at 77K with 6 μ A threshold current [4].

References

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