Moore's law in photonics

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Abstract—**Similarities and differences between photonic and microelectronic integration technology will be discussed and a vision on the development of photonic integration in the coming decade will be given**

Keywords-photonic integration; integrated optics

I. THE DEVELOPMENT OF CHIP COMPLEXITY

Figure 1 shows the complexity development of InP-based Photonic ICs (PICs), measured as the number of components integrated on a single chip [1,2]. The PICs based on Arrayed Waveguide Grating based wavelength demultiplexers, which play a key role in WDM systems, show a clear exponential trend, similar to Moore's law in micro-electronics, which suggests that photonics is following the technology driven development of microelectronics, albeit with a time lag of more than thirty years, and at a slower pace: doubling each 30 months.

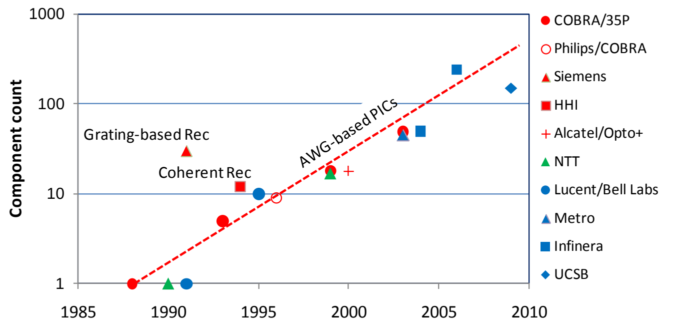

Figure 1 Development of chip complexity measured as the number of components per chip.

II. DIFFERENCES BETWEEN PHOTONICS AND MICROELECTRONICS

There is an important difference, however, between de well know Moore plot of Intel and the graph shown in Figure 1. The Intel plot lists the complexity development of commercially applied ICs, whereas most of the points in Figure 1 are about research devices. Only one of the reported devices, the chip of Infinera (■, 2004) is applied in a commercial product. It is an interesting question why so few of the advanced PICs reported in the literature have made it to the market, despite the fact that in the last two decades there has been substantial investment in the development of integration technologies in national and international projects in Europe, America and the Far East.

The problem with current project funding models is that they tie the technology development closely to an application: you get no money without a clear and challenging application. In order to meet the challenging specifications the technology has to be fully optimized for that application and, as a result, we have almost as many technologies as applications. Owing to this huge fragmentation, the market for these application-specific technologies is usually too small to justify their further development into an industrial volume manufacturing process that would really lead to low chip costs. This is quite different from the situation in micro-electronics where a huge market is served by a relatively small set of integration technologies (most of them CMOS technologies).

III. TOWARDS GENERIC PHOTONIC INTEGRATION TECHNOLOGIES

The solution to this problem seems obvious: introduce the same methodology to photonics that allowed microelectronics to change the world. This can be done by moving from application specific integration technologies to generic integration technologies. These are technologies that support integration of a small set of high performance building blocks, like passive waveguide devices (MMIs, AWGs), modulators and optical amplifiers, in different circuit configurations that support a broad range of functionalities. And by making such technologies available to a broad group of customers via foundries, similar to the foundry model in microelectronics. Reducing the huge variety of different technologies to a few generic technologies will make it attractive for Photonic CAD companies to develop dedicated design kits that will enable much faster design in the generic process. And it will allow for building a steadily growing component library that will release designers from having to develop each part of their circuit themselves. Another important advantage of a generic foundry process is that it will lead to a large reduction of the costs of product qualification. If the process is qualified than each component that is designed within the design rules should automatically qualify too.

Generic foundries are well known in micorelectronics, in Photonics they do not exist, however. Within the European FP6 Network of Excellence ePIXnet (www.epixnet.org) research platforms for foundry access to three major technologies have been established: InP-based monolithic integration technology (JePPIX), Silicon Photonics technology (ePIXfab) and a glass-based platform that covers the whole wavelength range from visible to IR (TriPleX).

The COBRA research institute of TU Eindhoven has pioneered with providing small scale foundry access to an InP-based monolithic integration process for research purposes in the framework of the JePPIX platform. Transfer of the model to industrial foundries is presently investigated in large European and Dutch research projects.

IV. Limits to Integration Complexity

Once generic integration technologies are introduced in photonics we expect a development similar to what happened in micro-electronics: a dramatic reduction of the cost of R&D and chip manufacturing and a correspondingly expansion of the application market, both in volume and diversity. Applications will follow in many fields where PICs are presently too expensive, such as sensors, health care, interconnect, metrology etc.

We do not expect, however, that the complexity supported by the generic processes as described above will exceed a component count of 1000 for a number of reasons. In passive devices the complexity will be restricted due to unavoidable component losses which restrict the total number of components that can be cascaded. But in active PICs SOAs and lasers typically have a power dissipation of 100 mW or more. So their number is restricted to several tens up to a maximum of a few hundreds, because of heat sinking limitations. Secondly, although today's PICs often carry digitally modulated signals, the basic building blocks and the circuits built from them essentially operate in an analog mode, which means that on passing a number of components the signal will accumulate noise and distortion and needs to be regenerated. Regenerators can be integrated too, but they consume space and dissipate heat.

This is quite similar to the development path in microelectronic ICs, where analog circuits usually do not contain more than a few hundred transistors per circuit block. The breakthrough to VLSI did not occur in analog electronics but in digital electronics, where signal regeneration inherently occurs after each processing step, so that operations can be concatenated endlessly.

V. Silicon Photonics

A larger complexity can be supported, in principle, in membrane based circuits, where component dimensions and power dissipation can be significantly smaller due to the strong light confinement in thin membranes with a high vertical index contrast, as they are presently applied in Silicon Photonics. This will allow lasers and amplifiers to operate with significantly lower injection currents and heat dissipation. Unfortunately silicon does not support integration of efficient lasers and amplifiers because of its indirect bandgap structure. Solutions are sought in heterogeneous integration of active InP-based layers on silicon waveguide layers. Efficient coupling of light from the III-V layers to the silicon layers is difficult, however. A promising novel solution is the integration of active and passive functionality in InP-based membranes with locally active regions which are created with nanoscale selective area epitaxy [3]. With this technology, which is called IMOS (InP Membrane on Silicon) a complexity increase of one order might be feasible, as depicted in figure 2.

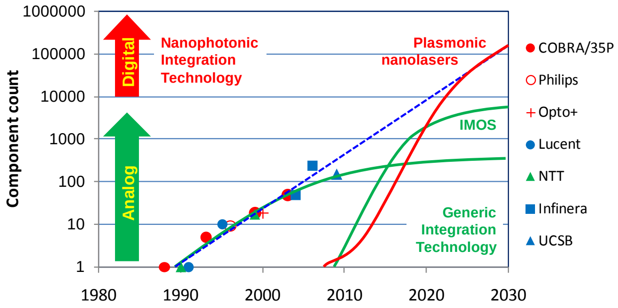

Figure 2 Vision on the future complexity development of InP-based photonic ICs

VI. Towards Digital Photonics

For moving towards LSI or VLSI circuit complexity a change from analog to digital signal processing will be necessary. Digital Photonics is receiving increasing interest. In particular, digital photonics based on coupled micro or nanolasers is a promising candidate for integrating large numbers of digital circuits. The recent breakthrough in plasmonic lasers [4, 5], which are no larger than modern transistors and can operate with low switching energies at very high switching speeds, holds the promise that digital photonic circuits with more than 100,000 lasers operating at THz clock rate will become reality. Such circuits can avoid a lot of power-hungry electro-optic conversions in high speed internet routers and they may be used in ultrafast digital photonic signal processors.

VII. Conclusions

It is often argued that Moore's law does not apply to photonics because of the large differences between microelectronic and photonic integration technology. This is indeed true for today's R&D model in photonic integration. But as these differences are at the same time the major reason that photonic ICs have not succeeded in large scale penetration into the photonics components market, an obvious conclusion is that we have to get rid of these differences as soon as possible. By applying the methodology of microelectronics to photonics we expect a dramatic reduction of the costs of R&D and manufacturing of photonic ICs and a breakthrough to applications in telecommunications and datacommunications, as well as in sensors, medical equipment, metrology and consumer photonics.

References

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