Equipment needs for efficient and reliable production of integrated photonics

A short survey in the photonic production world

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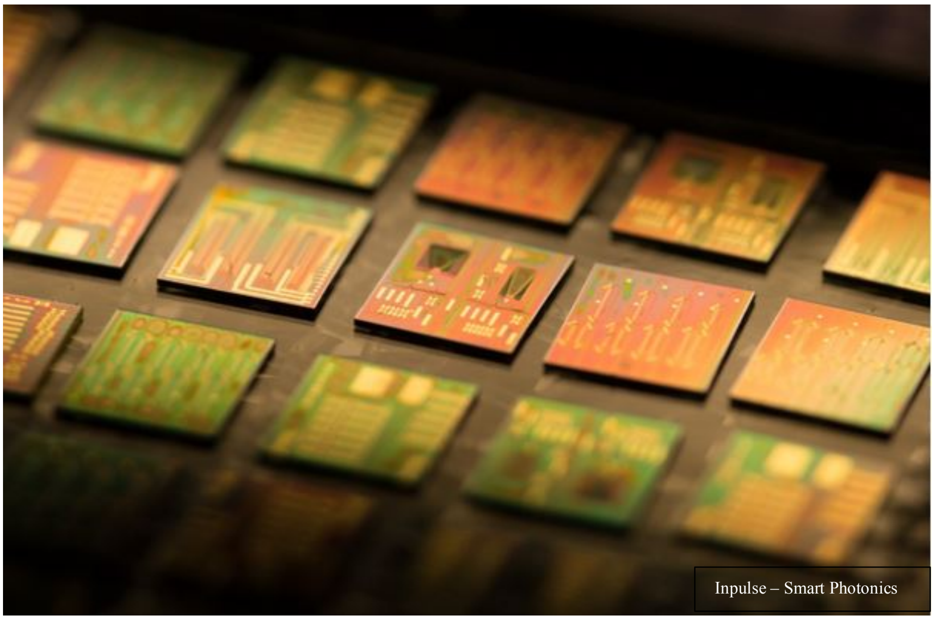

Inpulse – Smart Photonics

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Introduction

Although some similarities seem to exist between semicon and photonic production there are major differences. First Photonics, in her upcoming phase requires high quality but low volumes whereas semicon requires next to high quality also very high volume and has over the years introduced many standards. Hence, OEM equipment suppliers for semicon (having ample means for new developments) are not yet inclined to execute major equipment developments as the outlook for the large series of equipment they need to produce to be profitable is still far away. For the photonics companies this means that they have to initiate, drive and fund the equipment developments matching their needs themselves, implying that a different part (mainly the 1st tier companies) of the equipment developing and producing community needs to be addressed towards engagement in the developments. This survey is the first step in this engagement process! Bringing the photonic community in contact with the machine building community will also introduce photonics in more detail to the machine building community and show the benefits of photonics in machine building (e.g. advanced sensor systems).
The first incentive to pay attention to further tuning and specialisation for packaging and testing of photonic chips has been made by Photon Delta via the project plan Standardised Packaging & Testing of photonic chips (Photon Delta Office October 7, 2016). All issues mentioned in this document are still actual as is found in the current reported survey.

Next steps

A physical or virtual Photonics Equipment matchmaking event will be organized by Photon Delta, TU/e, HTNL in 2020Q2/Q3, to hone in on most important innovation areas highlighted in the survey. During this session 2 to 3 topics will be selected (based on importance and available capabilities and interest) for which collaborations for joint research & development & engineering can be formed (2020Q3).
The following step is as follows. Together with the collaborative teams (which will have both problem owners and problem solvers onboard) the collaborative projects will be defined and further detailed to a level that development can be started and that funding for the development can be raised (preferably in a Dutch context with e.g. Photon Delta, NWO/TTW, Eindhoven Engine, PITC-CITC, regional investment/development agencies etc., etc, …). These teams can also apply for European H2020 photonic equipment calls, which are expected shortly.

The relevant audience for this event and the consequent steps include:

- Interested OEMs
- Interested photonics companies
- Interested equipment and sub-system suppliers
- Interested researchers from 4TU and institutes like TNO (DOC)
- Representatives from regional/national administrations

1. Overview

The need for specific equipment hinges on three driving aspects:

- Growth of market demand for integrated photonics products and systems.
- The inefficiency by using top grade semiconductor production equipment as this equipment is on aspects over specified (e.g. production capacity, wafer capability) and hence too expensive.
- Insufficient standardisation of processes hence standardized equipment (modules) are not yet available or need very specific engineering. This is especially true for the backend. For the front end there are (smaller) companies specializing in III/IV tools, however the smaller wafer size and lower volumes are different indeed.

Like in the semicon production world also in the production of integrated photonic devices is split in a front-end section (wafer production) and a back-end section (integration, assembly and packaging). Test is typically part of the backend process, as is the binning of products based on certain characteristics. However, wafer level testing becomes more and more needed to avoid expensive scrap at the end of the production. A specific difference is that in InP you have edge emiting devices which means tests are also done on “bars” (wafer scribed into bars to reveal output facets).

The front end comes in different “flavours”. First the processes to produce SiN based photonic chips and secondly the processes to produce InP based photonic chips. Outside of Europe also the Si-platform is widely used. The SiN production relies largely on the proven Si-production processes from the semiconductor industry. The main discriminator between Si-based and InP-based photonics lies in the fact that in silicon currently only passive structures can be built and that active elements have to be integrated afterwards. In InP technology both the passive and the active elements can be produced on one chip. Hence, in the InP case back-end production can be largely reduced to providing connections to the outside world and providing proper housing and shielding, whereas in the SiN case a high precision assembly step to connect the active elements to the passive infrastructure is required (*multi-chip packaging*). Currently most photonic devices are produced with semiconductor production equipment that can handle or is refurbished to handle small (3” and) 4” wafers and is therefore inefficient in terms of equipment/refurbishment costs and production costs. To lift integrated photonics out of her adolescence, production chains/equipment must be made available that is tuned to both the performance and economical needs of the production of integrated photonics and will provide highly reliable products at competitive prices, something akin to what happened in LED production some 20 years ago. Hence, there will be a path to larger wafer sizes which must be considered!

Over the years, the Dutch equipment builders have worked and improved their performance alongside Moore’s law, making them currently very well positioned to cater for challenging markets with complex production equipment needs like photonics. In the current popularity and stimulus for integrated photonic activities in The Netherlands appeals to the high-tech equipment building ecosystem as it is looking for opportunities for new types of equipment challenges like production equipment for integrated photonic products and/or systems.

This survey presents a summary of equipment needs of the photonic community, as obtained from a number of Dutch photonic key players. In dialogue with the equipment building society in the Netherlands these needs can be satisfied. This action may conclude in the near future in an acceleration of the photonic activities in the Netherlands through dedicated production equipment developments.

The next chapter presents the findings as summary of the interviews that have been conducted.

2. Findings

From all interviews it appeared that, for the shorter term, production speed is not the main issue to solve (a production rate of 10k/month is often mentioned). Providing reliable products of excellent and constant quality and performance are the main issues to solve.

Typically, three buckets of volume are recognized by the various companies:

- 5,000 parts per year.
- 50,000 - 250,000 parts per year.
- 500,000 and above.

The area up to 10k and slightly above, products per year can be handled with largely manually operated or semi-automated tools. Up to 250k products peer year partial production automation is needed. So, the first step will be to arrange for production equipment that can cater for the <250k products/year. The following paragraphs describe the findings.

2.1. Frontend; chip production

Front-end processes yield chips that contain passive or active optics, or a combination of optical and electrical components, depending on the capabilities of the specific material.

2.1.1. Silicon Nitride

Production of chips for Integrated Photonics on Silicon Nitride does in general not give problems as the production is done with the matured semicon silicon production processes. Chips can reliably be obtained from various suppliers like MESA+, LETI or IMEC. However, these producers are not real commercial fabs as they are heavily linked to research institutes. Therefore, seamless commercial collaboration is not always possible due to other commitments etc. However, this concept is easily scalable to 200-300 mm equipment.

Having a commercial SiN fab for photonic devices available in the Netherlands is seen as a major step forward in particular to guarantee short cycle times of the full range of chip/wafer production steps. Short iteration times are essential for optimisation of the quality and performance of the chips. It must be noted that the wafer size must increase to 150 mm or even 200 mm as the smaller wafers (3” and 4”) are becoming obsolete.

2.1.2. Indium Phosphide

The production of Indium Phosphide photonic chips is done by Smart Photonics. Today the production line of Smart Photonics is still scattered over various locations which makes it quite difficult to have a tight grip on the production processes resulting in unpredictable production performance. Having all production processes in one house would enable Smart Photonics to perform much better on constant and high-quality products with shorter lead times. In principle production equipment is readily available from the semiconductor business as the top-quality processes are needed for photonics. However, such equipment is geared for high volume production on large wafers which would be an overkill for photonic production. Tailoring this equipment to the needs (performance and economic) of photonics production is needed. A major investment to fund this tailoring is currently pursued.

2.1.3. Logistics

High and constant quality production requires a properly working logistic system that connects the various processes. The production of photonic chips is mainly done on 3" wafers and Smart Photonics considers 4" or 6" for the (near) future. However, 6" wafers do exist but are or inferior quality as low production volumes do not invite for significant quality improvement development. The mechanical solution (wafer handling, foops etc) for the logistics must be engineered from scratch whereas the logical part might be copied from the semicon solutions (seamless wafer solutions for up to 8" are available on the market).

2.1.4. On-wafer test

On-wafer evaluation of electro-optical properties will allow for more efficient down-stream processing, since out-of-spec dies can be marked and rejected, and other parameters are known to allow for binning of devices down-stream. Delivering 100% "known good die" will eliminate tedious test procedures at the user side and hence save significant costs. Optical probes are required to do full evaluation of relevant parameters and are not yet available. On-wafer evaluation will enable better process control of front-end manufacturing. Research on this topic is done at the TU/e[1] and within the PITC (Photonic Integration Technology Centre) a project on testing is defined and expected to start soon.

The companies that build systems from individual chips very much welcome the fact that chips are delivered from the fabs in a fully tested fashion. To-day, they need to do the "incoming goods tests" themselves in not always the most optimal setting.

Electrical testing is available from the semicon market. Test structures are included in the photonic chips to allow for electrical interfacing to the electro-optical processes for evaluation. Direct evaluation of the photonic parameters requires possibilities to couple light from and to the chip or requires active test circuits on the wafer/chip. Combining electrical and optical testing is a yet unprocessed area but essential as metrology tool enabling high yields.

[1] Dzmitry Pustakhod: 'Process Control Modules for Photonic Integration Technology', PhD Thesis, July 2018.

2.2. Backend; assembly, integration and packaging

Not all functional semiconductor materials are suitable for converting light into electricity and vice versa, so most integrated photonic circuits will consist of multiple chips in a package (PIC (Photonic Integrated Circuit)). Connecting multiple chips, as well as connecting the assemblies to fibers for optical interfaces, are part of the so-called back-end process. This back-end process claims a major portion of the costs of a PIC (up to 80%!)) as it requires (sub-) µm alignment of the components and inclusion of thermal management components.

2.2.1. General

The growth of photonics is hampered by, amongst others, the lack of standardization in back-end production of integrated photonics packages. That is why every new product demands an innovation in assembly and packaging. This leads to high costs and technological risks. Many of the assembly steps are done manually. As soon as production volumes cross the 10k/month, (partial) automation of the integration, assembly and packaging becomes inevitable but also require product specific automation as there is little to no standardisation and virtually every package is unique in design and production. Therefore, it is hard to find generic processes for all integration, assembly and packaging processes needed and that will hold for all products produced.

2.2.2. Fiber alignment

However, one process step is found in almost all products: single and/or multi fibre alignment where optical fibers are connected to the chips and optimal light transmission must be guaranteed. Alignment and fixation are typically done using active feedback control based on electro-optical signals. Especially the alignment of multiple fibers is time consuming. To improve this assembly step, several initiatives are already in place (Fraunhofer IPT, Tegema, TU/e). It is also mentioned that in the design of optical chips the integration with fibers must be taken at hand to balance the effort of the integration between chip properties and alignment approaches. Processes like Spot-size converters are necessary components to convert optical spot size between on-chip waveguides and optical fibers and may be a welcome step in this respect.

2.2.3. Generic photonic backend processes

Generic photonic backend processes include wire bonding, chip2chip alignment and recently also flip-chip and are readily available from the semicon market and require little attention as this equipment show good process quality and acceptable production speeds. Here it must be noted that alignment requirements supersede the semicon requirements in many cases, so attention is needed here.

2.3. PITC/CITC; Application, Process, Technology and Equipment development

Photonic technology has, till now, been an excellent academic activity. To materialise this excellent knowledge a strong link must be established between the academia, the industry and markets. To this end the **Photonic Integration Technology Centre** (PITC) has been conceived in 2017 as a PhotonDelta - TU/Eindhoven subsidiary with R&D&E support from TNO and the Twente University. It is expected that the PITC will be operational by the end of 2020. The PITC (www.pitc.eu) aims at providing an environment where sharing of relevant high-end facilities and equipment- reducing individual company's financial risks, accelerating product and system development, earlier time to market, getting R&D support of leading research organizations, achieving results they could not do alone, early access to IP before that intellectual property is published gives competitive advantage cooperating and sharing knowledge with other companies as well as the opportunity to build strong strategic collaborations. The main focus areas of the PITC are front-end process development and application development.

To cater for the back-end part, assembly, integration and packaging, of photonic parts it is chosen to collaborate in the **Chip Integration Technology Centre** (CITC) recently opened in Nijmegen and strongly supported via the "Twente Investeringsfonds" enabling equipment developments. This CITC budget could very well be used for the development of dedicated assembly equipment for the specific PITC needs. This would render two major advantages. It enables photonic assembly companies to develop and use such equipment. And once in use it will create the need for scaling up in volumes requiring more equipment to be produced by such suppliers.

The CITC started initially for the semicon integration, assembly and packaging and specializes in heterogeneous integration and advanced packaging technology. It is a place where companies, research and educational institutes work together on bridging the gap from academics to industry and create new and better solutions. CITC offers access to innovation, infrastructure and education. Next to the semicon backend activities, the CITC will also cater for photonic integration, assembly and packaging technology to make optimal use for photonics of the in-house packaging and integration knowledge.
As a first action towards equipment development for photonic integration, the CITC and TEGEMA have joined forces to develop micro-assembly processes for integrated photonics based on the micro assembly concept platform developed by TEGEMA as well as the TEGEMA knowledge and experience in fibre alignment and fixation.

Together, the PITC and the CITC establish the experimental market/technology playground that is typical for Digital Innovation Hubs.

2.4. Identified developments in summary

During the survey a number of concrete issues related to the production of photonic devices have been identified that have a more or less generic character and are applicable to a manifold of products. The list below presents these issues. In consequent steps these issues need to be further elaborated towards research/development/engineering projects.

- Fibre alignment and assembly:
    - Active (multi fibre) alignment,
    - Chip design for fibre connection,
    - Thermally stable Fibre fixation.
- On chip/wafer electrical/optical probing:
    - On chip test structures.
- Material/wafer/die handling:
    - Standardisation of transport/storage means.
- Automated binning support.
- Defect mechanism determination and mitigation (extensive process knowledge) for InP chip production[2].
- Production chain logistics (like IDRS Factory Integration, industry 4.0).
- Optimised Litho tools (lower costs, lower volume).
- Layer technology (thick oxide layers, anti-reflective coatings, barrier coatings)[3].

The topics marked with [1, 2] (application specific) do apply to a subset of companies and/or processes, and may not be suitable for multilateral development agreements.

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Boudewijn Docter (Effect Photonics), Pim Kat (Technobis), René Heideman (LioniX), Albert Hasper (PHIX), Wilhelm Claussen (Smart Photonics), Carol de Vries (Photon Delta).

[2] Application specific for one technology only; can be taken at hand by the problem owner.
[3] Seems application specific but may be brought to a broader context