FLOIM

Flexible Optical Injection Moulding of optoelectronic devices

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Benchmarking analysis

Work Package 1

Analysis of industrial constrains and specifications

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Executive Summary

This report is part of the deliverables of Work Package 1, Analysis of industrial constraints & specifications. Firstly, the report briefly presents the three demonstrators that will be manufactured throughout the project and highlights the achieved relevant improvements. These improvements in the demonstrators will be provided through optical designs and also through the manufacturing processes involved. For this reason, this deliverable includes a review on the competing technologies used in the manufacturing processes of the three different demonstrators and their main advantages over other technologies that will be summarized following:

Laser machining will improve the manufacturing process of moulds for microoptics, like the diffractive gratings of the optical encoder and the optically dispersive surfaces of the backlight unit demonstrators. This technique increases the flexibility of the tools and patterns with high fidelity features, ranging from 10’s nm^3 to 10’s mm^3 which can be added directly to the mould over millimetre scale areas at critical locations.

In addition, the manufacturing process of the fibre optic transceiver will be also improved both in costs and in technical performance due to the application of the encapsulation technology with thermoplastics using microinjection. Said manufacturing process will be of high optical quality and more efficiency resulting in higher quality injected parts.

Finally, the OCT inspection technology will be novelty introduced as a part of the in-mould inspection through adapted design of the mould inserts as observation windows. This technique will enable up to 100 cross sections per second in a control volume of tens of mm^3.

Table of Contents

1 PRESENTATION OF THE DEMONSTRATORS

1.1 Fiber Optic Transceiver (FOT)

An extremely compact optical transceiver is devised for high data density Datacom. It includes a transmitter and receiver in a single module. FLOIM will provide low cost, direct embedding of high performance optics with the emitter die, with high alignment precision between the light source and the optics. This will improve light coupling performance to the fibre, resulting in high energy efficiency of the device, minimizing the losses in the transmitted signal. This coupling is also affected by the geometry of the optics. In that sense, FLOIM capability of manufacturing free-form optics opens the door for improving the design and obtaining a better behaviour within the refracting light of the emitter to a Numerical Aperture of 0.3, matching that of the Fibre.

1.1.1 Current market competitors

There is one major competitor that copes the market with its device launched 9 years ago. It is a multibillion transnational company, in which this device is part of its portfolio, with factories located mainly in Far East and USA.

1.1.2 Relevant improvements provided by FLOIM

The most relevant improvements provided by FLOIM would be the use of a new material for optics and encapsulation that provides good light transmission (reduced losses) which is cheaper than the used actually for most LEDs manufacturers and provides a faster manufacturing time through the proper development of the mould and the manufacturing techniques of the demonstrator included in FLOIM. The optimisation of the lens design will also provide a significant reduction of the losses in the light transmitted to the fibre.

The material studied for the leadframe will allow a material cost reduction in the device prior to the optics injection, with a definitive reduction of expensive metals involved in the process and a bigger recycling capacity than the actual devices.

The combination of the items mentioned above together with the improved manufacturing based in the demonstrator will provide a significant cost reduction of this device, which is critical for optic fibre transmission in their main markets: FTTH, Automotive, Industrial control and Telecom Interconnect.

1.2 Miniaturized scanning head for optical encoders (OEH)

A linear encoder is a device that sense linear position changes in industrial machines. Among the different kinds of linear encoders, Optical encoders are the most accurate of the standard styles of encoders, and the most commonly used in industrial automation applications as feedback units in control systems. Generally, every optical encoder includes two parts: One fixed (Scale) and other mobile (scanning head). The scanning head contains a diffraction grating (Analyzer), a light source (Led) and a set of Photodiodes.

The light interaction between the Analyzer and the scale provides a periodical fringe pattern in a certain plane of the space. As the scanning head moves respect to the fixed scale, such fringe pattern moves accordingly too. This movement is used to determine the relative displacement between the two parts. By placing a photodiode over the plane where the fringe patter is produced, a physical optical modulation is converted in electrical signals that are sent to the control system.

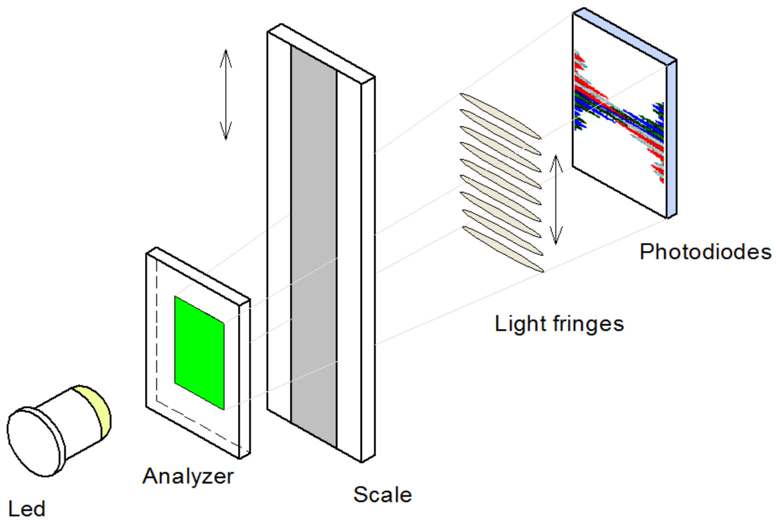


Figure 1. Performance of a linear optical encoder.

1.2.1 Current market competitors

In industrial environments, the market requires miniature, precise, and easy to install optical encoders. It means that the designers face everyday the challenge of designing devices that contemplate the integration of components into optimized assemblies. For that, it is necessary to minimize the size and weight of all components, without forgetting the final device's target cost as well as the ease and viability of mounting the device in massive production.

With the non-contact exposed encoder series, FAGOR is fitting the market requirements. However, the FLOIM project will improve the miniaturization of the optics-core of these devices. Therefore, it will be possible to create future smaller reading heads to be assembled in industrial environments, where FAGOR competitors are currently present due to their reduced optical encoder sizes.

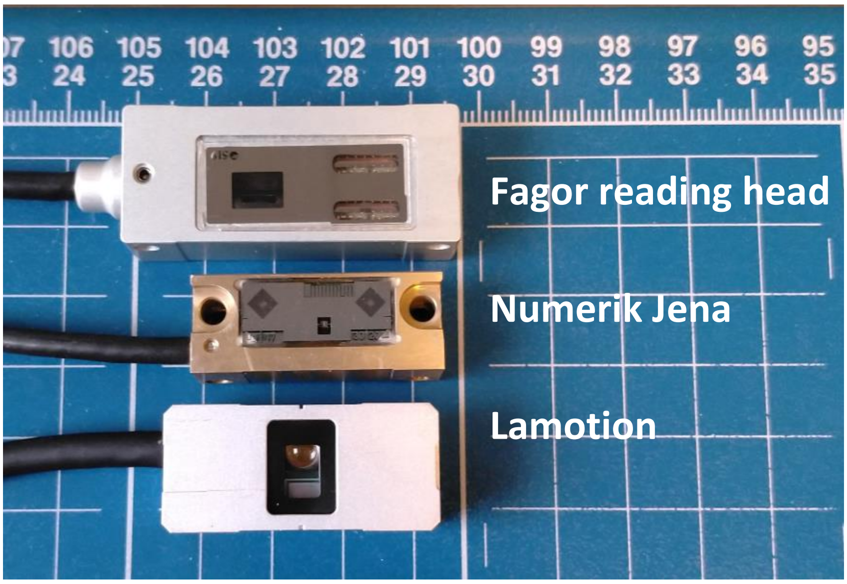


Figure 2. Current industrial encoders competitors.

1.2.2 Relevant improvements provided by FLOIM

FLOIM will allow the testing of a new optical scanning head arrangement, which incorporates the diffractive element directly in the encapsulation through microreplication. The illumination LED will be provided with a catadioptric beamforming surface for further miniaturization and weight saving. The current manufacturing approach requires to manually assemble and adjust all the main optical and optoelectronic components. FLOIM simplifies the fabrication process and has the ability to include the complete assembly in a single fabrication process, while providing product advantages: more compact design, freeform beamforming optics that will increase the efficiency of illumination, and subwavelength (polarization) structures will improve the signal/noise ratio, all reducing the total cost of the component.

1.3 Direct backlight unit for flexible OLCD (OLCD)

FlexEnable are specialists in conformable and flexible electronics and have developed organic thin film transistor (OTFT) backplanes that can be used in combination with a number of different front planes, for example as the driving electronics in liquid crystal displays (LCDs). LCDs require a backlight which can either be edge-lit or direct-lit (Figure 3) depending on the display requirements, the latter offering better contrast and the ability to offer local dimming. FlexEnable’s organic LCDs (OLCDS) are flexible and can be curved or conformed to different surfaces, however currently there are no commercially available curved direct-lit backlights.

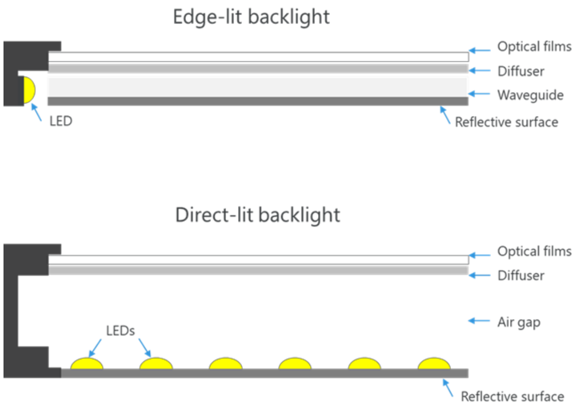


Figure 3. cross-section of direct-lit and edge-lit backlights.

For 12.1" OLCDs developed at FlexEnable, an array of light emitting diodes (LEDs) on a printed circuit board (PCB) are used and can be curved to different bend radii, see Figure 4. However, neither the optical function of the backlight itself nor the subsequent optical layers; diffusers, recycling polarisers etc. are designed specifically for a curved display. FlexEnable's demonstrator as part of the FLOIM project is a novel direct-lit curved backlight unit manufactured through injection moulding of light management optics on an array of LEDs to reduce the air gap between the backlight and the OLCD. The aim is to optimise the backlight unit for improved off-axis viewing angles, higher brightness and efficiency while meeting automotive specifications. Using FLOIM's injection moulding process should simplify the assembly process of large-area OLCDs by integrating light guiding plates and diffusers.

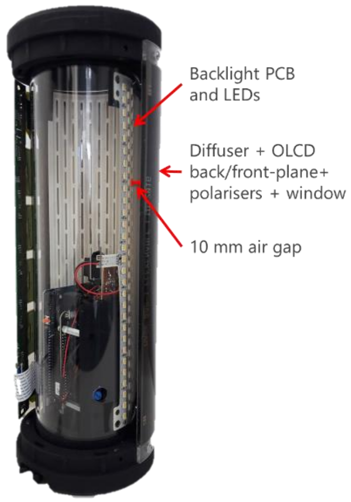


Figure 4. current curved OLCD module including backlight unit.

1.3.1 Current market competitors

There are no direct competitors with regards to the FlexEnable's OLCD demonstrator in terms of commercially available curved direct-lit backlights for large area displays. The current state-of-the-art for benchmarking activities of optical performance would be to compare to an array of LEDs mounted onto a PCB, such as the units designed by FlexEnable but outsourced to commercial providers of PCBs.

The key competing technology to consider in relation to conformed OLCD are curved OLED displays, thus the subsequent benchmarking analysis will focus on this comparison:

Technological:

OLED displays yield very good performance in terms of contrast, colour gamut and refresh rate. OLED displays can be made on plastic substrates to make them more flexible, conformable and thinner than glass OLEDs. As a result of these features, new designs can be seen on the market, for example:

- Samsung Galaxy Edge (Samsung: https: https://www.samsung.com/uk/smartphones/galaxy-s7/overview/)
- Apple X phones (Apple: https: https://www.apple.com/uk/iphone/)
- Huawei mate-X (foldable): https://consumer.huawei.com/uk/phones/mate-x/

Figure 5. Huawei mate-X foldable phone.

- LG (roll-able OLED TV): https://www.lg.com/uk/lg-magazine/tech-story/rollable-tv-ces-2019

For consumer electronics the lifetime of OLED displays on flexible substrates is good enough, however for applications with higher specifications on lifetime such as in the automotive industry, OLED is not good enough. For automotive applications the requirement is both high brightness and long lifetime, but for OLEDs the lifetime is reduced with increasing pixel brightness (more specifically it is inversely proportional to the square of the pixel brightness.)

In contrast to OLED displays, OLCDs can be very bright without a negative impact on the lifetime. This is a result of OLCDs using a separate light source rather than emitting its own light.

Flexible OLED and OLCD technology are both well suited to applications that require conformability, unbreakability and light-weight displays. However, OLCD is better suited to applications that also require a large area display, long lifetime or high brightness, for example in automotive or digital signage applications.

Economical:

- OLCD is 3-4X lower cost than flexible OLED, and the difference will increase further at larger display sizes.
- OLCD makes use of many of the same components as glass LCD – which are themselves already cost-optimised (driver IC, BLU, polarisers, etc. depending on the use case).
- For flex OLED, DSCC (Display Supply Chain Consultants) recently reports flex OLED production costs of around $80+/unit. This is for flexible OLED when put into rigid phones. That equates to around $10,000/m^2
- Another example of flexible OLED costs being high is the $2600 price tag of the new foldable Huawei Mate X phone.

Manufacturing and quality:

The flexible OLED manufacturing process is currently very expensive because the material cost and process complexity is high, thus the yield is relatively low and as the display area increases the yield drops further.

The manufacturing process of OLCD is relatively simple with regards to the number of steps. The process is also scalable using existing production lines for glass LCDs, for example the largest LCD lines currently can process substrates up to 2.9 m x 3.4 m. The OTFT backplane only requires low temperature processes, therefore low cost plastic substrates such as TAC can be used.

1.3.2 Relevant improvements provided by FLOIM

Conventional backlights are formed from many separate layers/films which combine to provide the desired optical effect. Using FLOIM’s injection moulding process would directly integrate the optical light management components, enabling a single part to perform all the required functions.

The FLOIM injection moulded component will also be designed specifically for a particular radius of curvature, thus tuning the optical function for a conformed display to optimise for improved off-axis viewing angles, higher brightness and efficiency. The expectation is that the FLOIM technology will not only improve the optical performance of the backlight unit, but also reduce the airgap between the backlight unit and the display, thus improving the form factor of the OLCD module by reducing the thickness.

2 Techniques involved in the manufacturing processes

The techniques used by the consortium of FLOIM involved in the manufacturing process of the different demonstrators will be: Tooling technology, optical quality injection moulding as well as inspection and advanced control of the demonstrators functionality and the manufacturing process.

In this section, the different solutions offered by the consortium will be reviewed, while highlighting the most relevant features and advantages that each technique provide to the manufacturing processes, comparing them with the current available solutions in the market.

2.1 Tooling technologies

2.1.1 Laser Micro machining

One of the tooling technologies used during FLOIM project will be the micro/nano-structuring of the surface of moulds by laser in order to grant the desired optical properties to the final injected parts. This technology will be complementary to the ion implant nanolithography by ADAMA, and both will be compared regarding the processing time, cost and precision.

For that purpose, the consortium partners AIMEN and CEIT provide ultrafast laser stations, including femtosecond (Ti:Sapphire and Yb:Fibre) and picosecond lasers. Ti:Sapphire lasers emit at 800 nm, providing high energy per pulse and very short pulses, these lasers are limited in repetition rate and thus, in productivity. In the case of the Coherent Libra Ti:Sapphire laser available at CEIT, the laser system consists of a mode-locked oscillator and a regenerative amplifier, to deliver up to 2 mJ, 130 fs pulses, with a 1 kHz repetition rate. The system includes a Second (400nm) and Third (267nm) harmonic generators. This will allow studying the influence of the wavelength on the main nanostructuring mechanism, the generation of LIPSS (Laser Induced Periodic Surface Structures). The periodicity of these structures depends on the wavelength of the irradiating source, and the use of the different wavelengths is known to yield different LIPSS periods. Furthermore, concerning the generation of the microstructures by ablation, the variation of the wavelength will yield different penetration rates into the substrate, which could vary the processing time.

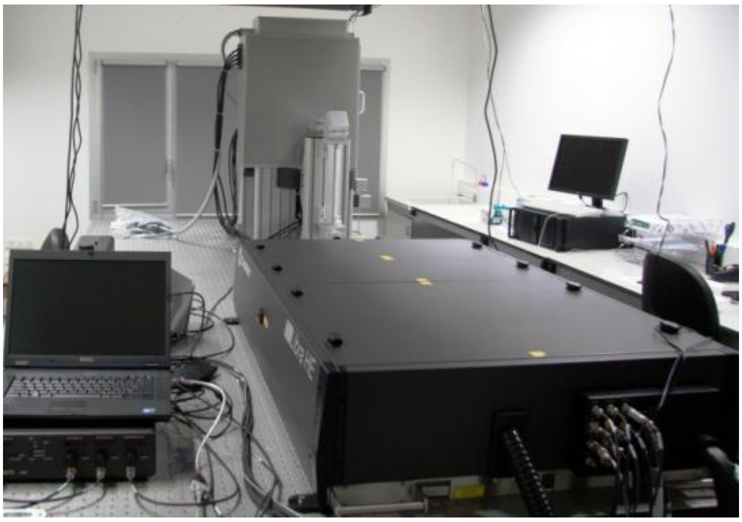


Figure 6. Coherent Libra Ti:Sapphire femtosecond laser

The second type of femotosecond laser system is the fibre amplified Amplitude Satsuma HP. This laser delivers 350 fs pulses at a central wavelength of 1030 nm (IR), with a 500 kHz as typical repetition rate, but able to reach up to 2 MHz. It is available in both CEIT and AIMEN, and in the second case, with a Second (515nm) and Third (343nm) Harmonic generator. The lasers are integrated in galvoscanner+translation stages hybrid systems for high precision and high speed machining. Its high repetition rate allows high machining speed, at the expense of higher heat accumulation, allowing different machining regimes.

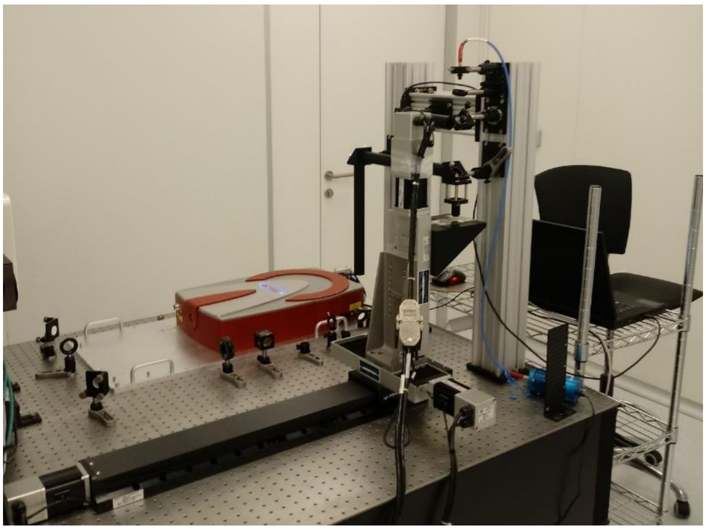


Figure 7. Amplitude Satsuma laser system

To fulfil the design specifications, different mould manufacturing technologies from centimetre to submicron scale can be united in a combined process. Flat areas and features with the lateral dimensions of hundreds of micrometres are typically manufactured using micro milling. A following laser beam machining could be used for production of very small structural details with the lateral size of tens of micrometres. Laser polishing reduces the surface roughness and harmonizes the surface quality on different machined structures. Finally, the mould insert surface can be coated with a layer of diamond like carbon (DLC), which improves replication processes due to its ability to reduce de-moulding forces, improved feature integrity and enhanced die lifetime and reusability. This approach allows placing micro and nano patterns in the selected areas of non-planar surfaces of irregular shape such as moulds for HE or IM. Applying structure specific technologies only where they are needed saves cost in mould manufacturing and allows flexible building, eliminating and rebuilding of features in moulds to realize reconfigurable tools.

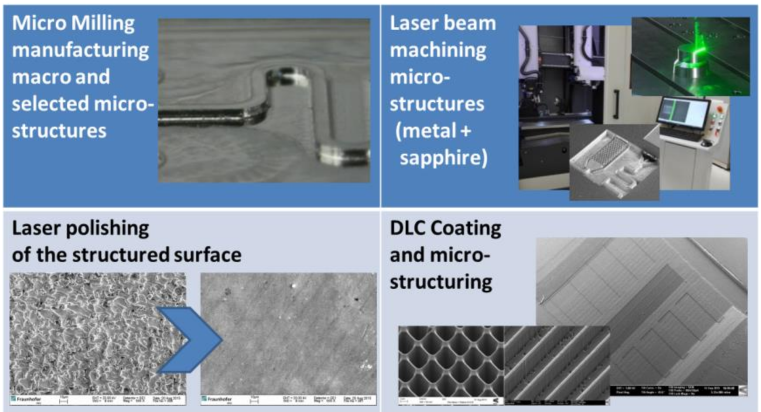
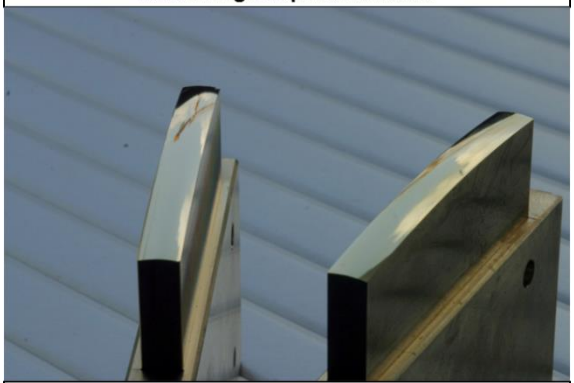


Figure 8. Structuring technologies for mould fabrication

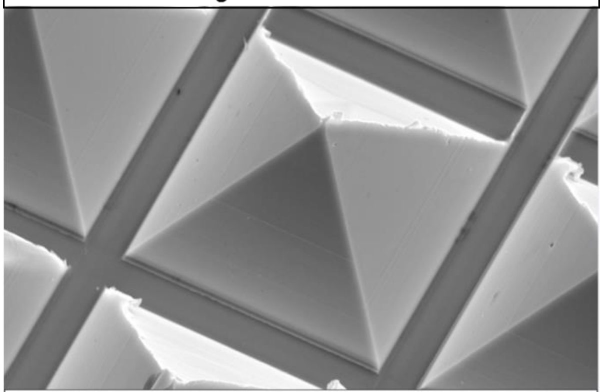
Especially for machining of optical surfaces on mould inserts, typically competencies and experiences in diamond machining are required using brass or other non-ferrous metals as mould material. Special equipment on a micromachining center as well as the use of monocrystalline diamond tools and high precise balanced air bearing spindle system are needed to machine a geometrical variety of shapes.

Machining of optical surfaces



F-theta lense, double curvature surface, Ra 15nm

Machining of small structure details



2µm pyramid structure 25 µm x 25 µm

The combination of different structuring technologies enables manufacturing of cost-efficient mould inserts for replication in polymers. This allows functional surface modification by combined meso-micro-nano structures using simple and profitable replication technologies.

In the FLOIM project, the development of optical quality micro/nanostructuring of mould is based on an advanced manufacturing technique pioneered by ADAMA. This technology benefits from the combination of Ion Implant Lithography (IIL) and dry-etching on a DLC coated film (*Figure 9*). IIL is a direct-write, resist-less patterning procedure that is not subject to the high costs and planar geometry limitations of typical photolithograpy. It is versatile so that patterns with high fidelity features ranging from 10’s nm to 10’s µm can be added directly to the mould over millimetre scale areas at critical locations, as a last step of finishing.

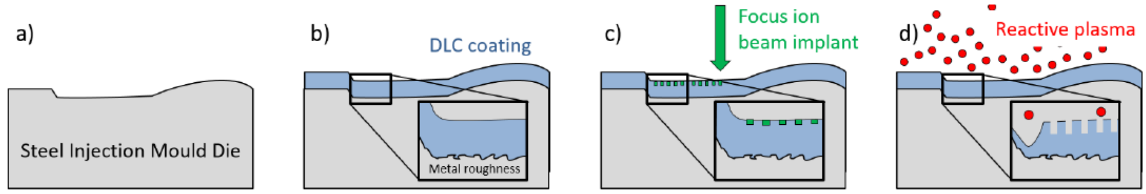


Figure 9. Schematic diagram showing the diamond nanopatterning process. (a) Ga implantation in arbitrary shapes using IBL. (b) Plasma etching to create diamond nanopatterns

Direct-write, ion implant top surface imaging is a two-step fabrication method that simplifies and improves processing of DLC at the nanoscale, harnessing the extraordinary material properties in a simple cost-efficient method. It utilizes a low-dose gallium (Ga) ion implant in a specific patterns and subsequent plasma etching for nanopatterning (see Figure 10). Focused Ion Beam (FIB) is a powerful and indispensable tool for fabrication of prototype micro/nano structures. Conventionally, for nanofabrication, it utilizes two basic phenomena, namely sputtering and molecular cracking, leading to material removal and material deposition, respectively. However, in the process developed by ADAMA we use a new ion beam platform developed for ion beam lithography (IBL), which is specialized to perform low-dose Ga implantation into the first few nanometers of diamond surface with high precision. The implanted regions form a hard mask to plasma etching, allowing production of well-controlled high relief structures over the exposed surface of the substrate. For large area patterning of DLC, the two step process is orders of magnitude faster than conventional FIB processes. The process has the capability to fabricate high aspect ratio, high-resolution patterns over millimeter-size areas.

Figure 10: The Carl ZEISS Focused Ion Beam Scanning Electron **Microscopes(**FIB-SEMs) used for the nanopatterning process.

The Ga implantation experiments are carried out using a Raith ionLiNE, a dedicated system for IBL. The energy and current of the Ga FIB can be varied up to 40 kV and from 0.5 pA to 15 nA, respectively. The system is equipped with a new derivative of the NanoFIBTM ion optics, which provide beam current stability over several days. This is required for advanced and automated large area patterning with low beam tails and high selectivity. The system includes a high precision laser interferometer controlled stage which provides highly accurate navigation and field stitching across large distances allowing large area patterning of a substrate, with pattern placement accuracies within a few nanometers. The plasma etching of the implanted diamond samples is performed in an Oxford Instruments Plasmalab 100 ICP 180 etching tool (Figure 14) using O2/SF6 gas chemistries. The fabricated nanostructures were analysed using Zeiss Ultra Plus scanning electron microscope (SEM).

Figure 11. Plasmalab 100 ICP 180 etching tool used for our process.

Mould inserts requires micro machining for the free-form optics manufacturing. A suitable alternative to conventional micromachining (like diamond milling or EDM) is laser machining. Depending on the laser source and optics used, features resolution in the micron scale can be achieved. This resolution can be further improved by using techniques like beam interference, making it possible to reduce the features size down to the laser wavelength (sub-micron resolution).

Inserts for optical injection must have high resistance, conductivity, hardness and dimensional accuracy under process temperature and pressure. In addition, they must use a fine-grained material, as defect-free as possible, for high accuracy structuring and low r_a. These conditions make it necessary to machine the mould mainly through cold-ablation processes, avoiding any heat induced damage.

In cases where a better resolution is required than what laser micro machining can provide, this technology can still be useful. Multilevel micromachining consists on doing several micromachining steps, being the last steps the ones with the best resolution. This way, larger features can be machined by laser micromachining, while a final step by, for example, Ion Implant Lithography pattern smaller features (Figure 12).

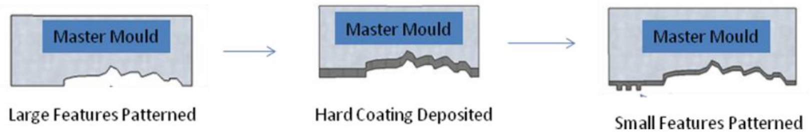


Figure 12. Example of multilevel micromachining, first step can be laser micromachining and last step Ion Implant Lithography

2.1.2 Viewport machining

In FLOIM, the mould cavity will include sensors to control the injection process. The project aims to develop innovative optical inspection and monitoring techniques, in particular OCT and IR sensing.

The active optical inspection technologies require the illumination of the workpiece, which has been done in the past using optical fibres and similar arrangements, which give very limited field of view. In FLOIM, the proposed route is the use of optically transparent viewports, of significant field of view, which are at the same time integral part of the injection moulding cavity.

Adequate structuring of the integrated optical viewport poses a challenge to conventional toolmaking technologies, and laser micromachining will be used in this project. Ultrafast laser machining of complex geometries on Sapphire glass has proven effective in the past, as shown in Figure 13. However, thorough testing will be required to evaluate the best resolution that can be achieved and the limitations of the process. Improved surface quality will be attained through chemical and thermal postprocessing.

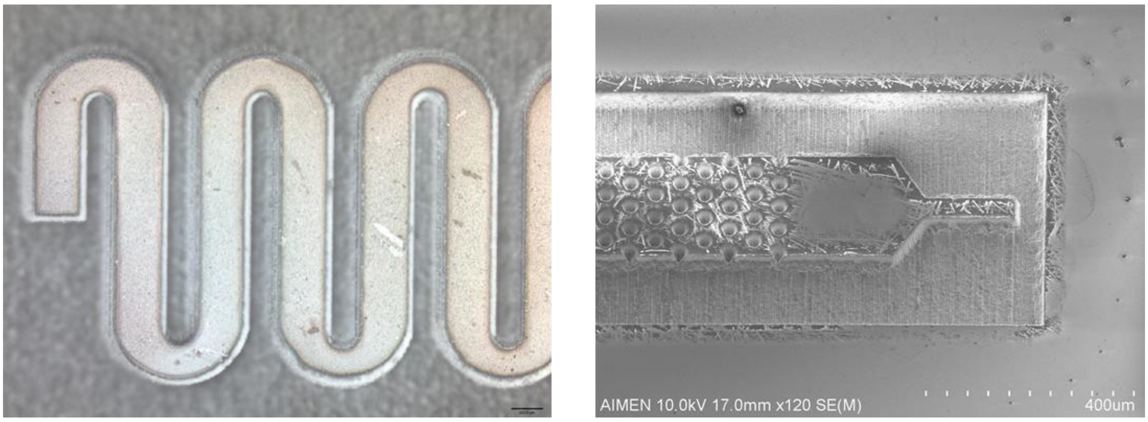


Figure 13. Micromachined complex geometries on Sapphire with pulsed laser

2.1.3 Laser Photopolymerization

As an innovative route for micron-precision toolmaking, FLOIM will develop the use of laser multiphoton polymerization (MPP). This technology exploits the effect of multiphoton absorption inside the volume of a photocurable resist, to result in a full 3D printing with super-resolution (details smaller than the laser wavelength). This allows generating complex 3D structures with sub-micron accuracy and resolution.

In the FLOIM project, this technology can be used together with a hybrid organic-ceramic photoresist (silica based OrmoCers). When cured, this resin hardens enough to be used for nanoimprinting, so it is possible to use it as well to manufacture an insert in an injection moulding cavity, taking advantage of the high resolution provided by the MPP technology, while eliminating the low productivity handicap inherent to direct manufacturing.

The Optical Encoder demonstrator incorporates two diffractive gratings in its making, demanding a resolution well below the micron, in the range where MPP makes more sense. The mould for a phase grating can be manufactured using an adequate commercial OrmoCer like OrmoStamp®, which has the right mechanical properties to replicate the gratings through moulding.

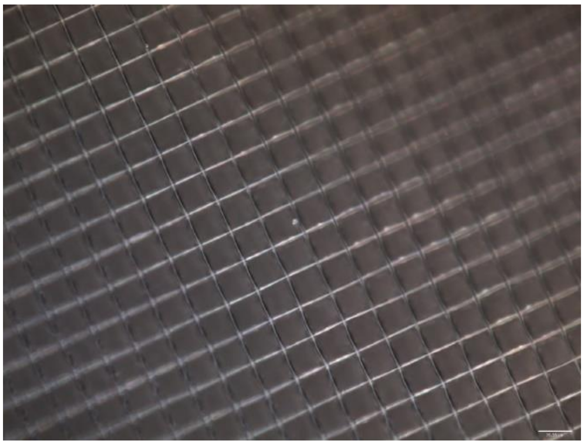


Figure 14. Grating made at AIMEN by TPP with a femtosecond pulsed laser and galvoscanner optics.

TPP is a particular case of laser scanning that allows writing 3D patterns inside the photoresist. However, this is still a serial fabrication technique that writes voxel by voxel the 3D pattern, meaning that, despite its huge flexibility for the fabrication of different 3D patterns, TPP has a lower fabrication speed than other fabrication techniques. However, the efficiency of TPP can be improved through the parallelization of the writing process. In this way, the use of Diffractive Optical Elements (DOEs), splitting the laser beam into multiple parallel beams would allow the fabrication of multiple motives at the same time. In the case of diffraction gratings, the DOEs can be shaped as a line of multiple dots, or as parallel lines, depending on the photoresist sensitivity.

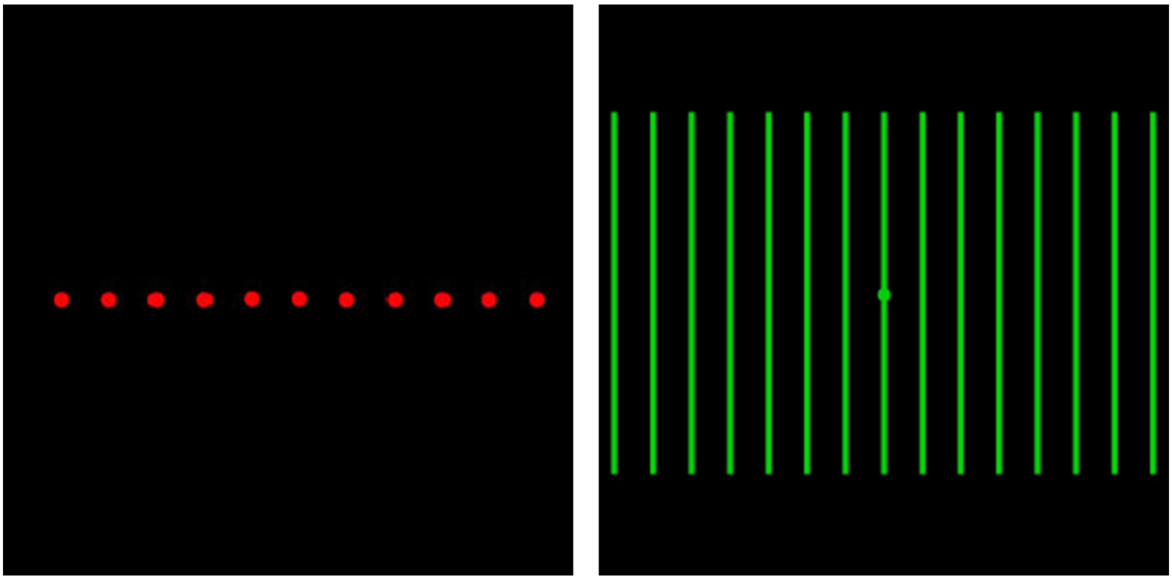


Figure 15. Example of dotted lines and line matrix DOEs. Images taken from https://holoeye.com/

2.1.4 Dispersive patterns

FLEXENABLE's demonstrator consists of a direct Backlight Unit (BLU) for flexible Organic Liquid Crystal Displays (OLCD). With current systems, the number of parts required to assembly a complete BLU is high (as well as the number of operations, and the sources of possible defects), and the size of the system is compromised due to the need of an air gap. By directly integrating light manipulating features on the grid array where the LED will be mounted, FLOIM project aims to reduce the required air gap of the BLU and increase the minimum distance between LEDs.

Laser machining is an effective method for direct production of optically dispersive surfaces which can be replicated on polymer through moulding. In this way, the cost and footprint of the BLU will be further reduced by integrating the diffuser function directly in the display window which also incorporate the beamforming lenses.

2.2 Optical quality injection moulding

2.2.1 Injection machines

There is currently available a wide variety of companies specialized in injection moulding but not all of them are familiar with microinjection processes.

For the overmoulding of very small LED's and other opto-electronic devices specialised micro injection moulding machines can provide higher accuracy than larger injection moulding machines and prevent degradation of the material caused by long residence times.

For overmoulding of electronics and wiring often vertical machines are used. In this case the mould opens vertically, which has as advantage that the part that needs to be overmoulded stays in place by gravity, in horizontal machines other methods like vacuum or magnets should be used.

Here, the most relevant companies in the microinjection area will be highlighted, since it plays an important role in the manufacturing process of one of the demonstrators. Microinjection moulding machines provide high quality injected parts and allow to adapt the injection parameters to over mould photonic component without modifying its performance.

Figure 16. Babyplast 6/10VP Vertical from Cronoplast (Rambaldi Group Spain)

The **Rambaldi Group** is a holding company composed of three European companies that collaborate in the development of babyplast products and applications in the field of micro-injection. The main partner, Rambaldi + Co it srl (Italy), is in charge of international marketing; Cronoplast SL (Spain) produces and develops the Babyplast machines; and CKT Gmbh (Germany) markets the Babyplast in the German market. Each company of the group, since its creation, has devoted all its efforts in Research and Development applied to the sector of MICRO-INJECTION of technical plastics.

Since 1978, **Centrotécnica** is a Spanish company dedicated to the commercialization and provision of after sales service, machinery and peripheral equipment for the plastic processing industry by injection, extrusion, blow molding, thermoforming and recycling lines.

Figure 17. Boy XS from Centrotécnica

In their portfolio, we can find the BOY company which offers the XS, XXS, and the vertical XSV injection molding machines. The BOY XXS is not equipped as usual with this size injection molding machines with a plunger type injection (such as Babyplast) but with a reciprocating plasticizing screw with diameters from 8 to 18 mm working after the "first in first out" principal and with specific injection pressures up to 2.750 bar. The intelligent design is ideally suited for the requirements of micro injection molding, since the 8 mm plasticizing unit assures shortest residence times.

Béwéplast is a French company with an important and recognized role in plastics since 1963. Their reputation has been based on the experience and knowledge accumulated over these years in the fields of injection and extrusion of plastic or rubber.

Their suppliers are true partners, from the beginning for the most part, and indisputable leaders each in their field. They provide the customers with sustainable solutions for the reliable development of their production tool: injection molding machines, drying materials and power plants, conveyor belts and conveyors, thermoregulation, dedusting of materials, grinding and cutting machines.

In 2011, Béwéplast joined the BMS group, expanded its teams considerably at a commercial, technical and service level, and now has the support of a group at a European level.

Figure 18. Nissei STX 10 2V from Nissei Plastic

Nissei Plastic is a Belgian company specialized in the field of injection molding, deepening and expanding the use of its technology for a wide variety of applications since its inauguration in 1947.

With their motto "Going Specific, Deeper, and Unlimited", they have been making a continuous effort in the research and development of injection molding machines, as well as their molds, molding support systems and mold processing technologies.

Arburg produces a micro injection unit combining an 8mm injection screw with a second screw for melting the material. With this technology also shot volumes under one gran can be reliably processed. The modular design means fits on a standard small injection moulding machine, so larger and micro parts can be produced on the same machine.

Wittmann-Battenfelt has the MicroPower 5 ton and 15 ton all electric machines using a combination of a 14 mm scerw and a plunger.

In the following table (Table 1), a summary of the microinjection machines that best suit the application required for the FOT demonstrator is shownTable 1.

Table 1. Summary table of the microinjection machines suitable for FOT demonstrator manufacturing process.

		Babyplast 6/10VP Vertical	Babyplast 6/10VP Horizontal	Arburg 170S	Boy XS V	Boy XS H	Mateu & Solé miniMat 6 H	Mateu & Solé miniMat 10 H	Sumitomo SE7M H	Nissei STX 10 2V
Piston diameter	Mínimo	10 mm	10 mm	18 mm	12 mm	12 mm	16 mm	16 mm		16 mm
	Máximo	18 mm	18 mm	25 mm	16 mm	16 mm	20 mm	20 mm		22 mm
Volume	Mínimo	4 cm^3	4 cm^3	23 cm^3	4,5 cm^3	4,5 cm^3	12 cm^3	12 cm^3		13 cm^3
	Máximo	15 cm^3	15 cm^3	44 cm^3	8 cm^3	8 cm^3	19 cm^3	19 cm^3	6,2 cm^3	25 cm^3
Injection pressure	Mínimo	796,3 Bar	796,3 Bar	1550 Bar	1760 Bar	1390 Bar				1390 Bar
	Máximo	1990,7 Bar	1990,7 Bar	2500 Bar	3128 Bar	3128 Bar	2680 Bar	2680 Bar	2000 Bar	2630 Bar
Closing force	kN	62,5	62	150/180	100	100	60	100	69	94
Minimum thickness of the mould	mm	119		150	100	100	100	100		130
Maximum aperture of the mould	mm	229	140	350	250	250	150	150	300	300
Length aperture	mm	110	110	200	150	150			130	170
Ejection force	kN	7,5	7,4	16	8,4	8,4	13	13	5	
Ejection length	mm	50	45	75	50	50	50	50	30	60
Oil reservoir capacity	l	16	16	120	28	28	50	50		60
Power	kW	3	3	3	3/4,83	3/4,83	6,55	7,35		7,5
Weight	kg	350	150	1360	457	422	760	760	900	1200
Tension		3ph-230/400V-50/60Hz	400 V 50 Hz	50 A	400V	400V				

The main advantage that these microinjection machines present compared to regular injection machines is that the injection process is more accurate, resulting in higher quality and consistency of the results. The screws or plungers melt only a small amount of material to prevent degradation due to long residence times. Furthermore, microinjection machines can save energy compared to larger injection machines. With these characteristics, the manufacturing process will be more efficient with resulting higher quality injected parts.

2.2.2 Injection materials

Liquid silicone rubber:

LSR (liquid silicone rubber) overmoulding) is often mentioned as a technology to overmould LED's, or to produces lenses and lightguides that are placed on top of LED's. The LSR process it makes use of a modified injection moulding process. Two liquid components are mixed and injected in a heated mould, in which the two components react to form a clear crosslinked elastomer with a hardness up to 80 shore A.

Advantages that are mentioned compared with thermoplastic resins are: less yellowing by UV light, high temperature resistance, large variations in wall thickness are no issue, no moulded in stresses like thermoplastics, very low viscosity so low stress on the LED during overmoulding and accurate replication of the finest details. Disadvantages are the need for a high tool temperature and the need for very accurate moulds since the liquid can easily create flash.

Another possible advantage of the low modulus of LSR is that this leads to a low stress on the overmolded PCB, while the shrinkage of rigid polymers can create large stresses on the components and deformations of the PCB, especially on large areas like the Flexenable case.

Some links to LSR lenses for LED's:

http://www.polymerjournals.com/pdfdownload/1252586.pdf

https://consumer.dow.com/content/dam/dcc/documents/en-us/train-seminar/11/11-39/11-3945-01-multi-functional-led-lighting.pdf?iframe=true

https://www.engelglobal.com/nl/nl/nieuws-en-pers/nieuws-en-persberichten/detail/news/detail/News/fakuma-2018-sophisticated-led-lenses-made-of-lsr.html

https://albrightsilicone.com/liquid-silicone-overmolding/

Clear TPE:

As a thermoplastic alternative to LSR clear TPE's based on SEBS could be considered as overmolding materials. They have the advantage of the low modulus and therefore low stress on the part, but the viscosity is higher tan liquid silicones. No current optical applications were found.

Producers of clear TPE's:

Dryflex T: https://www.hexpoltpe.com/en/dryflex-t.htm

Versaflex CL series: http://www.polyone.com/products/thermoplastic-elastomers/gls-versaflex-thermoplastic-elastomers

2.3 Sensing technologies

2.3.1 Inspection and advanced control of the demonstrators

Optical coherence tomography is a widely used characterization method for biomedical application e.g. In-vivo cross sectional imaging of retinal structures or dermatology applications. This method allows for depth-resolved imaging within turbid media. It is based on the concept of low-coherence interferometry and has gained importance in alternative fields of application, like non-destructive testing, contactless material characterization or art diagnostics, in the last years[1].

For OCT in the field of material characterization one can find two main approaches: versatile desktop devices and production integrated systems tailored to a very specific application. The versatile desktop devices, like the one offered from Thorlabs (see figure below), are operated like a microscope. The sample is manually positioned under the measurement head and aligned to show the region of interest. In most cases, the appropriate software offers basic functionality for manual image evaluation (overlay of rulers…).

[1] „Beyond biomedicine: a review of alternative applications and developments for optical coherence tomography", D. Stifter, Appl. Phys. B 88, 337–357 (2007)

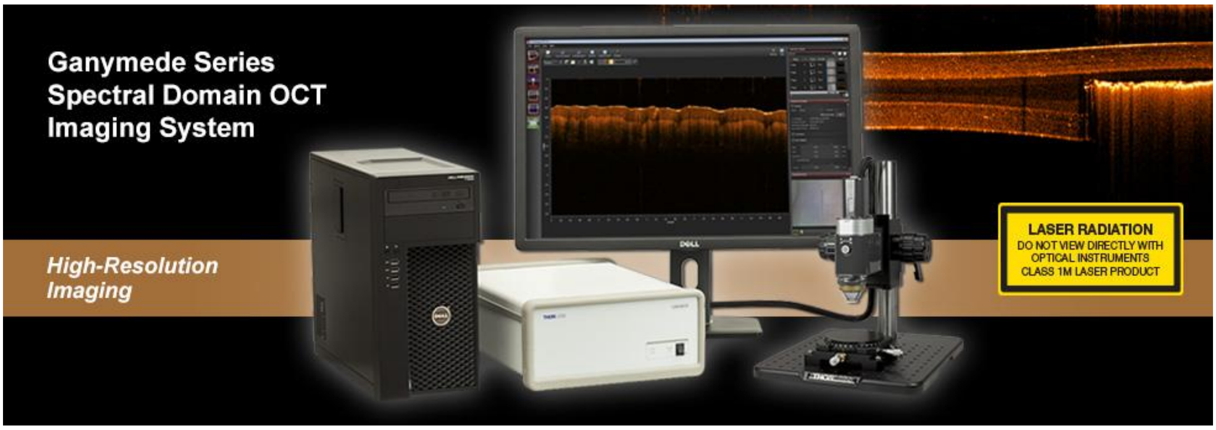


Figure 19. Desktop OCT System from Thorlabs

Some companies use OCT as production integrated measurement systems for quality assurance, but only for very specific applications. The german company Sentronics Metrology GmbH[2] uses this technology for semiconductor industry and for the film production sector. For the first user group they measure layer thicknesses and also other 3D surface parameters of wafers. The films / coating division of sentronics metrology offers a selection of sensors used for quality assurance of coatings (Adhesive layer thickness, Barrier layer, Application of oil ...) and film/ composite systems (multiple layers in cast film plant, thickness of adhesives in composites, composite films...).

Another very specific solution using OCT technology is an inline coating characterization system for pharmaceutical tablets offered by Phyllon[3]. During the coating process in e.g. a drum coater, the layer thickness of the tablets passing a viewing window is continuously determined, thus enabling optimized process control.

[2] http://sentronics-metrology.de/

[3] http://www.phyllon.at

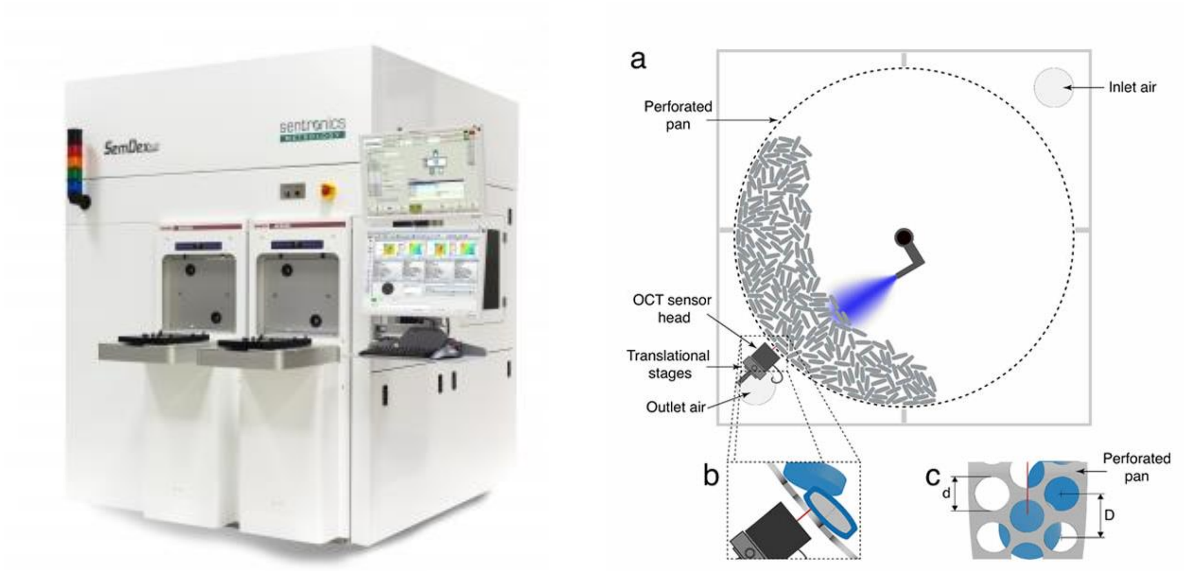


Figure 20. Production integrated OCT systems tailored to a very specific application. Left: fully automated wafer inspection system from sentronics metrology GmbH, right: schematic of an OCT based measurement system for the inline characterisation of coatings of tablets or pellets, produced by Phyllon.

It was not possible to find a company offering an off-the-shelf inspection solution for the quality assurance of polymer optics for photonic components.

In the manufacturing environment of photonic components, the production times are within a few seconds per piece[4]. In these conditions, due to the small time window of action, commercial systems that exist are mainly validation systems that perform the direct comparison of values with respect to a reference element that is considered valid, and very few are characterization systems, in which the goodness of the element is analyzed from the measured values, without mediating the reference element.

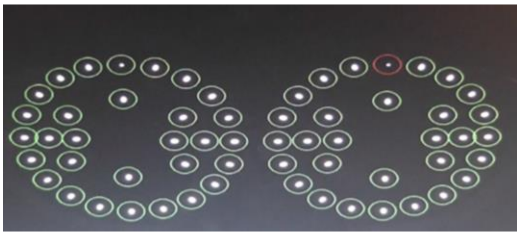
There are several companies in the field of test systems in the online environment, such as Averna Techologies[5], Pruftechnik[6], Maxim Integrated[7], A.T.E Solutions[8] and Chroma ATE[9]. These companies, in addition to the sale of their products, offer customized online test solutions, especially in the field of

[4] https://www.besi.com/products-technology/product-details/product/fico-ams-w/#tabs-97
[5] https://www.averna.com/en/home/
[6] https://www.pruftechnik.com/
[7] https://www.maximintegrated.com/en.html
[8] https://atesolutions.co.uk/
[9] http://www.chromaate.com/

mechanics, electronics and software. However, only the last two, A.T.E Solutions and Chroma ATE have developed inline validation systems for photonic components.

ATE Solutions is a company specialized in designing and manufacturing automated test devices, mainly for the electronics industry. In 2016, at the request of ASD Lighting PLC, it developed a system to analyse the ignition and colour temperature of LEDs mounted on streetlights, fully automated in-line test system for testing LED light engines[10], Figure 21(a). This system consists of an automated line that displaces the components and an artificial vision system. The camera of the system takes an image and the software is able to recognize the position of the individual photonic components, detecting the absence of a photonic component or that it does not emit enough radiant flow, Figure 21 (b).

(a)

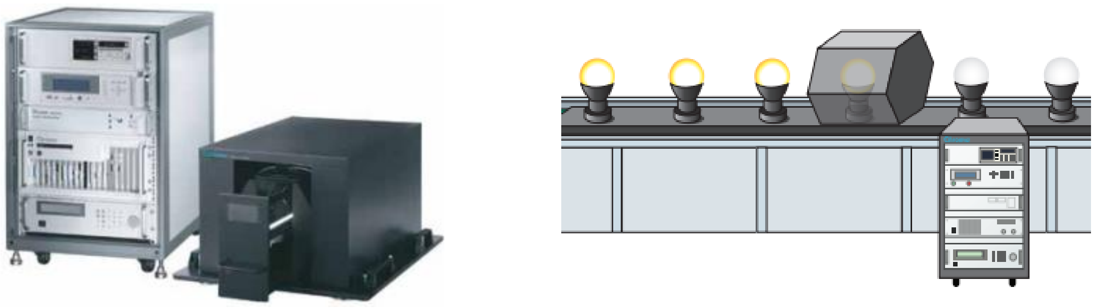


(b)

Figure 21 (a) Fully automated in-line test system for testing LED light engines developed by ATE Solutions. This system of in-line validation of photonic components evaluates the absence or if the photonic component does not emit enough luminous flux. (b) Appearance of the record that assesses the ATE Solutions system, where it is indicated by a red circle that the photonic component does not emit enough luminous flux.

Chroma A.T.E. is a provider of measuring devices and automatic test systems. Its products are applied to different sectors, although it is mainly the electronic sector, as well as lighting. They currently have an online test of photonic components for an illumination, model 58158-SC[11]. The model 58158-SC, Figure 22(a) and (b), provides a measure of the total luminous flux emitted, and the priority parameters in the components applied to the illumination as the correlated colour temperature and the colour rendering index (CRI).

[10] https://atesolutions.co.uk/fully-automated-in-line-test-system-for-led-light-engines/
[11] https://www.chromaus.com/datasheet/58158-SC.pdf



(a) (b)

Figure 22 (a) View of the online test of photonic components for lighting, model 58158-SC developed by Chroma A.T.E. This model offers measurements of the total luminous flux emitted, and priority parameters in the components applied to lighting such as the correlated color temperature and the chromatic reproduction index. (b) Illustration where model 58158-SC operating line is indicated

UPC will design and manufacture an in-line optical test that will allow the inspection of radiometric and photometric parameters that are currently measured off-line. The new equipment will give the possibility to measure the light distribution of the component, as well as lighting related parameters, so it will be valid for lighting, telecom and automotive among other applications, with a significant reduction on costs and time consumed. It is based on an image sensor which allows us to obtain lot and valuable information from a picture in a short period of time.

2.3.2 Sensing and control manufacturing process

As far as we know, nobody has ever tried to use OCT directly as a measuring method inside moulds of injection moulding machines. Alternative approaches that might be seen as a benchmark could be standard cameras with digital image processing or 2D/3D distance measurement sensors (e.g. laser displacement sensors…).

Different vision systems are available on the market, ranging from low cost cameras to sophisticated products offered by e.g. Matrix Vision[12] or Vision & Control GmbH[13]. The disadvantage of using such camera-based systems to align the active optical components in the mould is that no real 3D information is available, making it difficult to correct misalignments in all dimensions. In addition, an initial quality control of the injection moulded part is only possible to a limited extent because defects can only be identified if they are visible by means of a 2D image.

[12] https://www.matrix-vision.com/industrial-cameras.html
[13] http://vicosys.com/en/

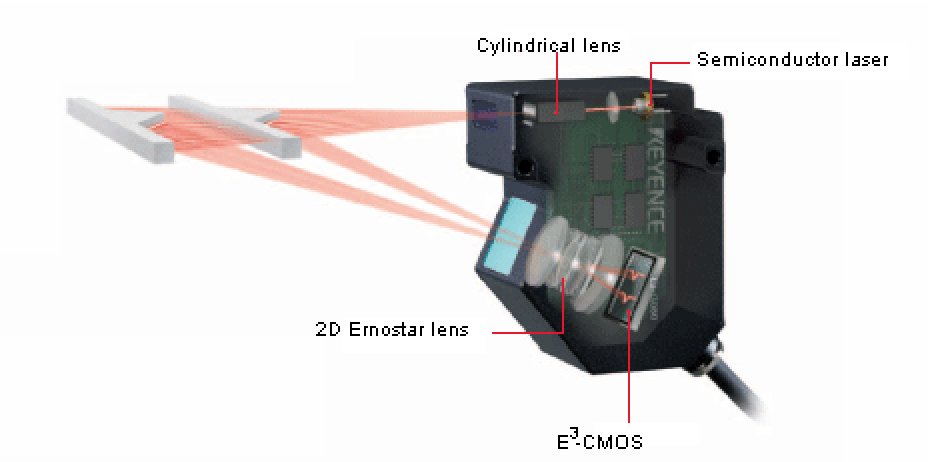


Figure 23: KEYENCE laser displacement sensor

2D/3D distance measurement sensors are widely used in industry and available in different configurations and prize segments (e.g. Micro-Epsilon Messtechnik GmbH[14] or Keyence[15]). These sensors raise the question of the extent to which 3D information can be obtained without moving the sensor and whether the space required can be matched to the application. In addition, the measuring systems are limited to surface measurements, so that the inspection of the interior of the manufactured components (e.g. finding air bubbles) is not possible.

[14] www.micro-epsilon.de
[15] https://www.keyence.com/

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