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FABRICATION OF SENSOR PACKAGES ENABLED BY ADDITIVE MANUFACTURING

= Deliverable D5.1 =

Prototype NIL equipment and tools

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TINKER

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= Deliverable D5.1 =

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Executive Summary

Miniaturization for autonomous driving

Autonomous driving and self-driving cars represent one prominent example for the use of microelectronics and sensors, most importantly RADAR and LiDAR sensors. Their respective markets have a big potential, e.g. it is estimated that the market size of LiDAR in automotive will double itself in the next two years (within 2020 to 2022). The public awareness and the industrial need for further miniaturization of such sensor packages is the main driver of ongoing efforts in the automotive sector to be able to integrate such devices into the car body like in the bumpers, grilles and exterior lamps (headlights & rear lamps) instead of attaching them (e.g. on top of the car in case of LiDAR device). Safety (for the driver and others) is the most important key aspect of the automotive sector. Therefore, highly-value and high-performance RADAR and LiDAR systems are required for advanced driver-assistance systems (ADAS) as well as autonomous cars. Current bottlenecks are relevantly large size of such sensor devices, their weight and power consumption. Since these factors are highly limited within cars, further miniaturization and improving functionality and efficient use of resources is highly demanded.

In the period of 3 years, starting from 1st of October 2020, European Union´s H2020 funded TINKER project is set to develop a new reliable, accurate, functional, cost- and resource efficient pathway for RADAR and LiDAR sensor package fabrication, following 2 main objectives: *Establishing the TINKER platform based on Additive Manufacturing {AM}* and *Fabrication of RADAR and LiDAR sensor packages as use cases.* TINKER's approaches to use "*key enabling technologies, especially inkjet printing and nanoimprint lithography"*, as disruptive and flexible manufacturing techniques in micro-part assembling is in alliance with the overall scope of the call Transforming European Industry. The proposed TINKER pilot represents a high degree of flexibility and reliability due to its modular character.

According to the work program, TINKER addresses the expected impacts, such as decrease of production time, measurable increase of automation level, higher or similar precision level and reduction in rejection rates during the production process. The main purposes of this project is to widen the range of available miniaturization and microelectronic fabrication possibilities including the novel approaches in assembly processes directly in production steps. This supports the constitution of a resilient economy of Europe and enhances resource efficiency. In addition, this enhances the competitiveness by creating jobs, new business models and new innovative production methods in various industries. TINKER will contribute to European innovation capacity on the one hand with patents, training of PhD and Diploma students, more scientific papers, protection of intellectual property, on the other hand by strengthening the European competitiveness with the development of design-driven and market demanding sensor packages. Similarly, new knowledge created by the TINKER research is the source of innovation and in return, new market prospects for innovation identified by the industrial partners can point towards new avenues for research.

This article presents the nanoimprint lithography infrastructure and tools available as well as developed for the TINKER project. For the realisation of a LIDAR sensors, the TINKER consortium is developing a nanoimprint lithography-based fabrication method for photonic integrated circuits. The photonic integrated circuit is the very precise core element necessary for the manipulation of light for each LIDAR sensor.

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1. Introduction

The vision of TINKER is to provide a new cost- and resource efficient pathway for RADAR and LIDAR sensor package fabrication with high throughput up to 250units/min, improved automation by 20%, improved accuracy by 50% and reliability by a factor of 100 to the European automotive and microelectronic industry via additive manufacturing and inline feedback control mechanisms. Autonomous driving and self-driving cars represent one prominent example for the use of microelectronics and sensor, most importantly RADAR and LIDAR sensors. Their respective markets have a big potential, e.g. it is estimated that the market size of LIDAR in automotive will double itself in the next two years (within 2020 to 2022).

Figure 1: TINKER overview

The public awareness and the industrial need for further miniaturization of such sensor packages is the main driver of ongoing efforts in the automotive sector to be able to integrate such devices into the car body like in the bumpers and head lamps instead of attaching them (e.g. on top of the car in case of LIDAR device). Safety (for the driver and others) is the most important key aspect of the automotive sector. Therefore, high-value and high-performance RADAR and LIDAR systems are required for advanced driver-assistance systems (ADAS) as well as robotic cars. Current bottlenecks are the relatively large size of such sensor devices, their weight and power consumption. Since these factors are highly limited within cars, further miniaturization and improving functionality and efficient use of resources is highly demanded.

1.1. Description of deliverable

Within the TINKER consortium a Nanoimprint Lithography (NIL) based process will be developed to serve the manufacturing need of the photonic integrated circuit (PIC). This PIC, one of the core components in a LIDAR system, will be fabricated directly by NIL and the use of novel high refractive index materials. In the following deliverable the NIL hardware and process setup based on set requirements is presented to serve the manufacturing of the PIC. The key development aims for the direct imprinting of functional optical materials and the implementation of novel materials into the PIC fabrication process.

1.2. Short description of TINKER Partners working on Nanoimprint Lithography

CEA-LETI (Laboratoire d'électronique et de technologie de l'information) is a research institute for electronics and information technology based in Grenoble. It is one of the largest institutes for applied research in microelectronics and nanotechnologies in France. Within the TINKER project LETI is evaluating a PIC fabrication process based on NIL by considering two approaches. The first one targets to substitute optical lithography steps by NIL of the actual process flow. The second one aims to directly integrate a novel high refractive index material imprinted by NIL. These two ways lead to an easier fabrication process with less involved fabrication steps which finally will reduce the price of the next generation LIDAR sensors.

EV Group (EVG) is a leading supplier of high-volume production equipment and process solutions for the manufacture of semiconductors, MEMS, compound semiconductors, power devices and nanotechnology devices. Products include manual and fully automated photolithography systems, systems for nanoimprint lithography, wafer bonders and inspection systems that can be used for research and development as well as industrial mass production. Within TINKER EVG further develops the Nanoimprint equipment and process solutions for photonic integration. In particular it is targeted to enable automated production on fully integrated systems up to 300mm. Therefore, improvements for equipment, process and materials know-how will contribute to establish a viable solution for mass manufacturing of photonic integrated chips by means of additive manufacturing utilizing nanoimprint lithography.

PROFACTOR GmbH is a non-university research institute in Upper Austria based in Steyr. Profactor conducts applied research in the areas of Industrial Assistance Systems and Additive Micro- and Nano fabrication. With more than 15 years of experience, PROFACTOR has gained considerable expertise in the field of Nanoimprint Lithography. As a project leader PROFACTOR is coordinating the developments in the TINKER project. In technical terms, PROFACTOR is developing an R&D step and repeat nanoimprint tool for automated nanoimprinting with the aim of resource-saving material testing. Further PROFACTOR develops respective NIL processes on lab-level within TINKER to then allow upscaling to higher TRL.

INKRON, a Nagase Group Company, develops and manufactures advanced siloxane-based formulations and resin systems for optical devices, Opto packaging and printed electronics. INKRONs core technology is centred around siloxane resins designed and synthesized in-house with advanced formulation knowhow. These optically clear resins are thermally and optically stable providing a perfect platform for the targeted applications. Advanced formulation steps facilitate meeting the various application-specific needs. Within TINKER INKRON focuses on developing optical coatings with ultrahigh refractive index, suitable for NIL processing. Simultaneously INKRON is working on making these materials compatible for inkjet printing.

2. Results and Discussion

2.1. Fabrication process for photonic integrated circuits

TINKER's goal is to replace certain manufacturing steps in PIC fabrication with NIL steps to achieve fast and reliable direct fabrication of the required passive optical elements such as the waveguides and optical coupling structures. Therefore, two approaches are considered in TINKER. The first one is based on classical litho-etch integration by using the NIL resist material as a mask for etching. This is schematically shown in Figure 2. The second more demanding approach consists to use novel high refractive index NIL resist as a functional material as shown below. Here, novel high refractive index materials get developed during the project by INKRON. In parallel LETI, EVG and PROFACTOR are working on the development of NIL processes and tools which are explained in the next part.

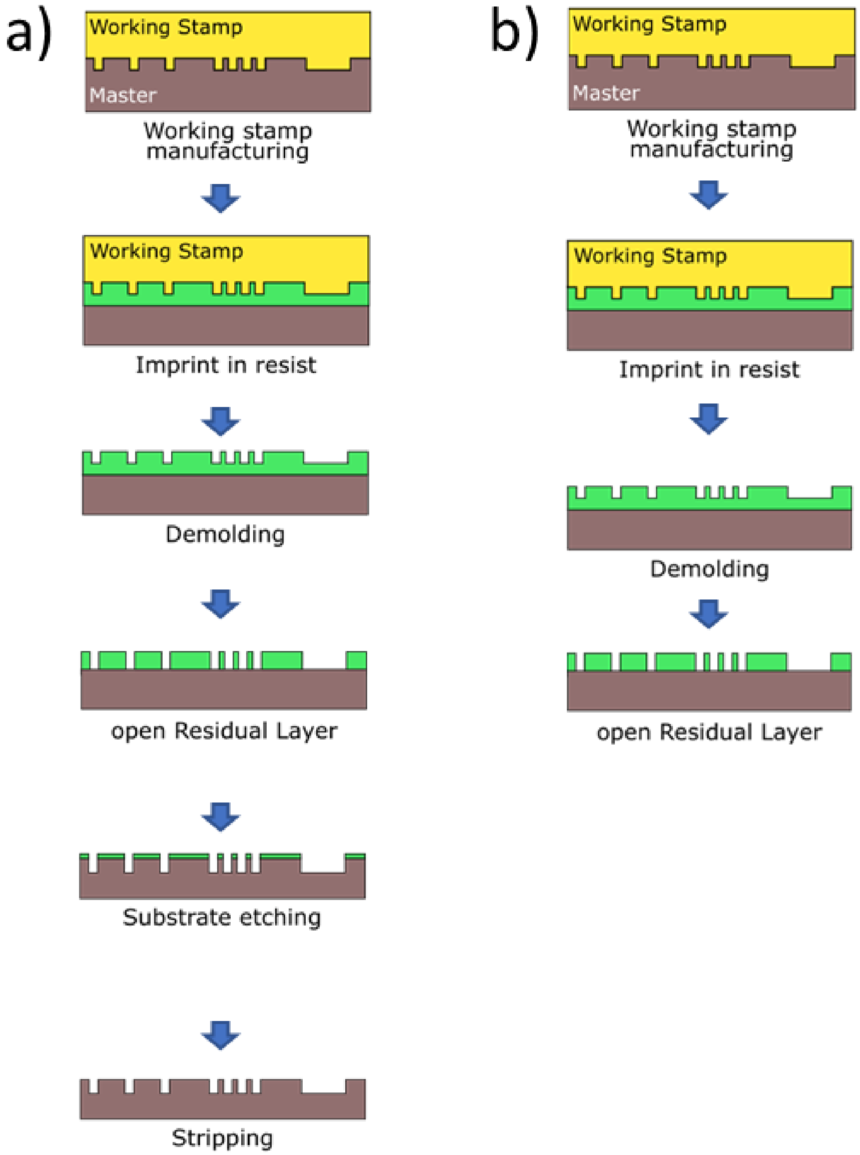


Figure 2 NIL approach where the NIL step serves as etching mask to etch the underlying substrate. (a) NIL approach where the NIL step directly patterns a functional resist and stays on the device. (b)

2.2. EVG tools capable of high volume photonic integrated circuit fabrication

For the TINKER pilot line EVG prepared the nanoimprint infrastructure to support the needed developments from R&D to high volume.

EVG's core technology platforms, span the entire manufacturing chain from R&D all the way to small-scale and high-volume production. The semi-automated system is designed to support different process requirements with high flexibility and fast interchangeability. Full software and recipe compatibility between R&D and full-scale production systems enables researchers to migrate their processes to volume-production environments.

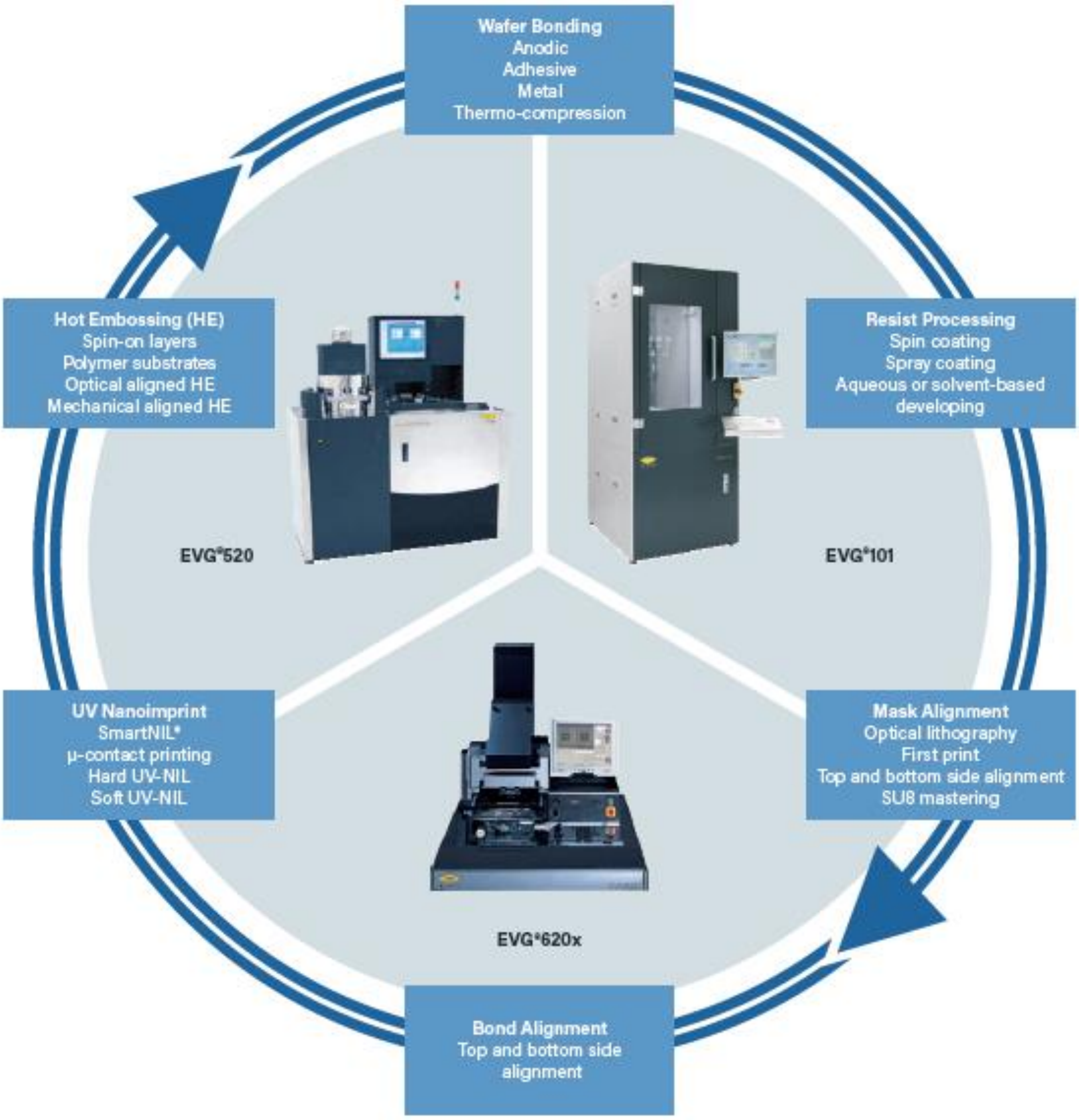


Figure 3 EVG's core technology platforms

For the particular NIL development within TINKER it is the goal to define all key aspects for automated volume manufacturing up to 300mm substrate size and provide a dedicated pilot line. Even though in the first steps the R&D equipment is used for facilitated feasibility tests and quick turn around times for material evaluation it is already considered to leverage the learning to automated equipment by migrating the process recipes. Therefore, the EVG101 and EVG7200 systems, shown in Figure 4 will be utilized and the imprint process will be performed in a fully automated fashion.

Figure 4 R&D equipment EVG101 and EVG7200

To enable this fully automated manufacturing, dedicated chucks were designed and manufactured. Key considerations for the project were adaptions regarding optimized vacuum lines and proper cut out to support the layout properly. Additionally, the chuck can be heated up to 60°C in order to change the resist viscosity and enable improved filling of nanostructures. This is actually a key aspect for the newly developed materials which are to be implemented during the project. While for R&D non-optimum filling times can be easily compensated by longer delay times, this is obviously not wanted for a volume production environment. With the heated chuck option is possible to address this topic and provide a technically and economically viable solution if needed. For the imprint itself the system different tooling are prepared to adapt imprint pressure and compliant layers.

Further preparations for the pilot line have been done to flexibly support the coating of the new materials. Therefore, syringe systems, new dispense lines and adequate pumps were installed. Additionally, HMDS (hexamethyldisilizane)priming, baking in controlled atmosphere and oxygen free curing can be supported.

All processes developed in this fashion can be easily transferred to the Hercules system which combines the coating, baking and imprinting in a modular platform. In this way the standalone systems of the 1xx and 7xx series are combined and allow volume manufacturing with a minimum of operator interference.

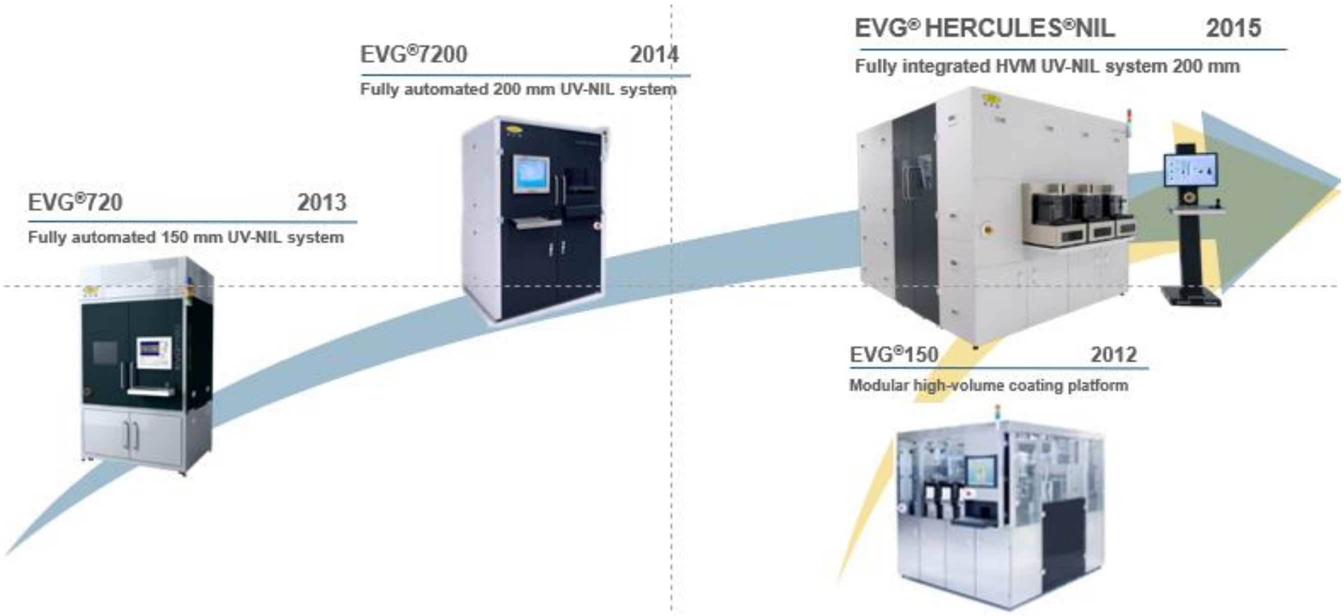


Figure 5 Standalone systems of the 1xx and 7xx series can be combined and allow volume manufacturing.

For the first phase it is considered to handle everything on 200mm systems for easier transfer of substrates and results with the partners and 300mm processing is considered for the last phase of the project. The EVG7300 system is readily available and will be then adapted according to the needs of the pilot line.

Figure 6 EVG7300 system

2.3. NIL hardware at LETI for PIC fabrication

The TINKER NIL process is developed at LETI by using an HERUCLES series tool from EVG (Figure 7). This automatic equipment is able to handle 200 mm diameter Si wafers and to achieve the entire NIL process (from working stamp manufacturing until wafer imprinting) respecting cleanliness standards. A first module is dedicated to the working stamp and the NIL resist material deposition (spin-coating and bake). A second one allows to achieve the imprinting of the working stamp and the NIL resist by using UV wavelength for material curing.

Figure 7 EVG HERKULES NIL tool in use at LETI

Masters (200mm diameter Si wafers) used during NIL process are manufactured by using a litho-etch process. Design of master is adapted depending on the approach. Optical lithography (193nm or 248nm wavelength) is applied for the more critical patterns resolution.

Furthermore, advanced metrology equipment is used for the master manufacturing process flow and the NIL process characterization. The most used methods, to extract morphological and dimensional data is the SEM (Scanning Electron Microscope) cross-section, the AFM (Atomic force microscopy) and the CD-SEM (fast SEM top-view providing statistical data).

2.4. Novel high refractive index materials

INKRON contributes by developing and manufacturing nanoimprintable optical materials with ultrahigh refractive index (RI) for use as waveguides. These materials are developed to be compatible with the EVG nanoimprinting process and during development tested at INKRON with an EVG7200 system.

The development workflow comprises the following iterations:

- a novel polysiloxane-based printable base matrix material specifically tuned to the application requirements is developed and tested.
- Nanosized solids are blended with this matrix to reach the specified refractive properties. Material type, particle size distribution (PSD), concentration and solvent composition are the variables to be optimized. As the solid content directly affects the viscosity, this must be compensated through the solvent composition, while keeping the surface tension within the window required by the deposition method.
- Characterization of the optical and physical properties: measurement of the viscosity, surface tension, transmittivity, particle separation. Also curing behavior and its impact on film formation is tested. Also, long-term behavior is followed where necessary including colour shifts under environmental stress.
- Testing and characterization of the new blend further including investigation of its nanoimprinting properties and behavior in several deposition technologies according to need: spin-coating, inkjet printing, and spray-coating.

At this stage of the project, developed materials have been distributed to the respective partners for the application testing.

2.5. Equipment for resource-saving material testing and stamp degradation investigation

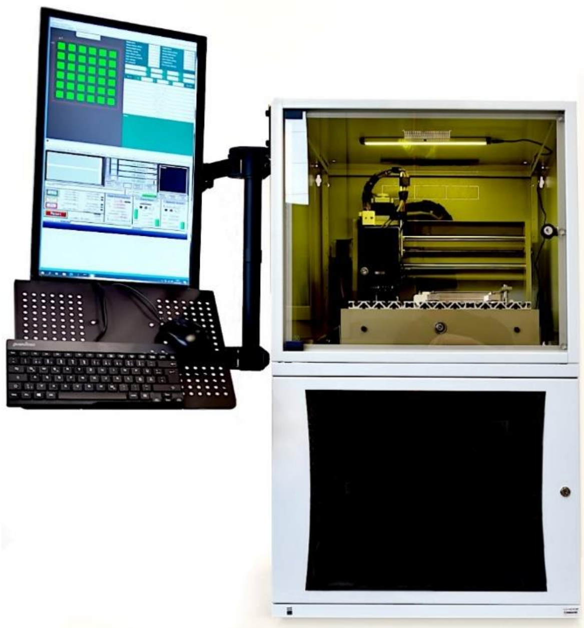
As part of TINKER, PROFACTOR is developing an R&D step and repeat nanoimprint tool for automated imprinting with the aim for resource-saving material testing. For new materials a proper testing of compatibility between imprint material and stamp material is necessary in order to know when and how changes of the stamp during a fabrication process is necessary. Within TINKER the existing stepper at PROFACTOR was upgraded to allow fully automated data capturing during the imprint process. Therefore, new sensors for measuring stamp transmission, humidity, temperature as well a microscope camera and illumination system for monitoring the first order diffraction on the stamp were integrated. The current stepper design including some highlights is shown in chapter 2.5.1. In the further course of TINKER, the stepper system and the software will be further developed. With inline control, it will be possible to detect defects on the stamp at an early stage and take appropriate countermeasures.

2.5.1. PROFACTORS SOFT-NIL-STEPPER

The desktop Soft-NIL-Stepper is a versatile R&D tool for Nanoimprint Lithography to perform imprinting in a step and repeat manner. The Soft-NIL-Stepper is well suited for performing automated material test and producing small series of imprints.

Highlights:

- Fully automated nanoimprint process
- Easy handling and stamp exchange
- Up to 600 imprints per hour
- Ideal for material testing and lab scale imprinting
- Intuitive software for pattern generation
- Substrate size up to 8 inches
- Automated measurements
  - Separation force
  - Stamp transmission
  - First order diffraction



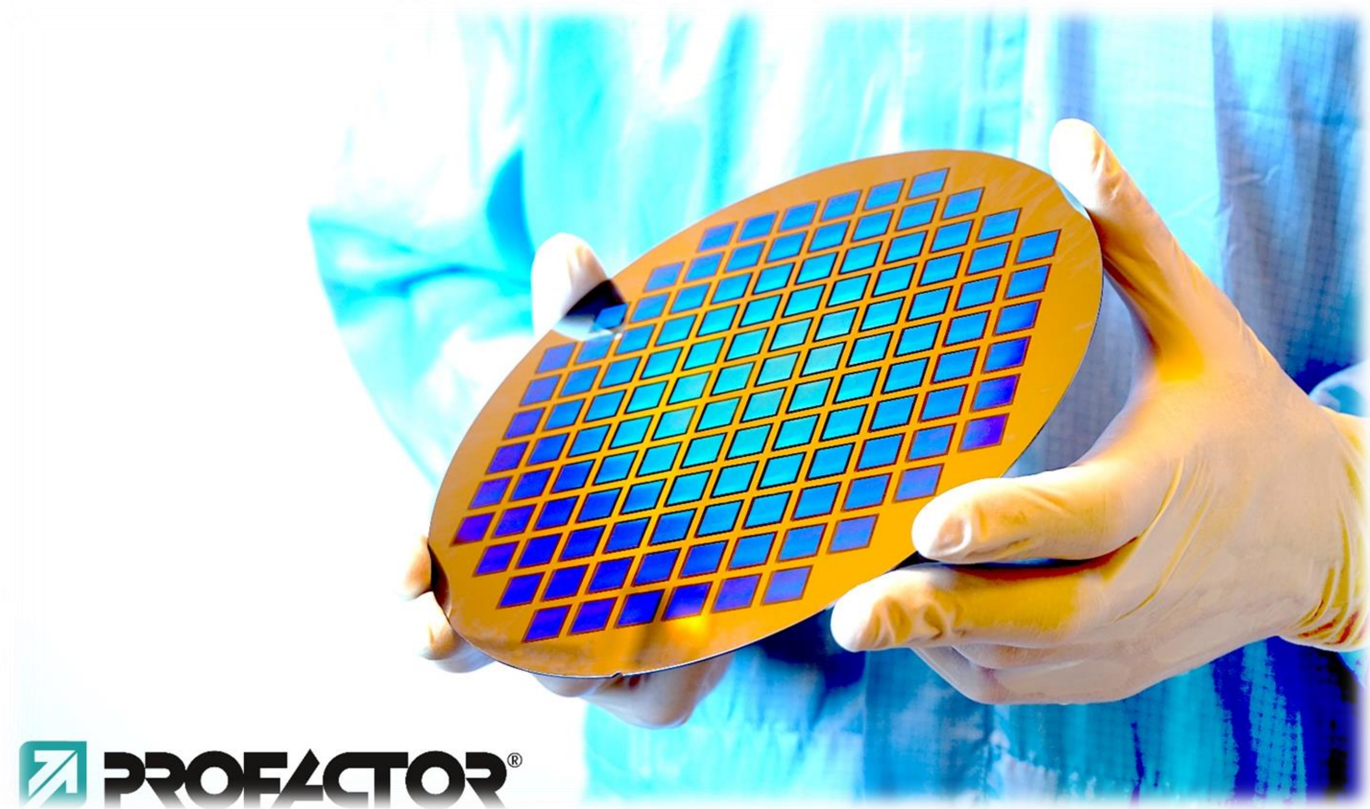


Figure 8 Imprint example on a 200mm Si substrate performed in a SOFT-NIL-Stepper at PROFACTOR

Within Tinker, the Soft-NIL Stepper was upgraded at PROFACTOR to be able to precisely measure imprint conditions. Such as separation force during an imprint process, UV transmission evolution and the stamp surface. These data can be used to monitor the wear on the stamp and allow conclusions to be drawn about the compatibility between stamp material, structure size and imprint material.

To test material compatibility, imprint patterns are generated with the help of the stepper software. In order to perform these tests in the most resource-saving way possible, placing as many imprints as possible on one substrate is necessary. Typical pattern substrate sizes from 100mm to 200mm are shown in Figure 9. With the Soft-NIL-Stepper, it is easy to find the best imprint parameters for each material and then to use the best settings to make as many imprints as possible with one stamp. In the second step and with the help of the inline control, the stamp can be closely observed, and the imprint conditions get monitored.

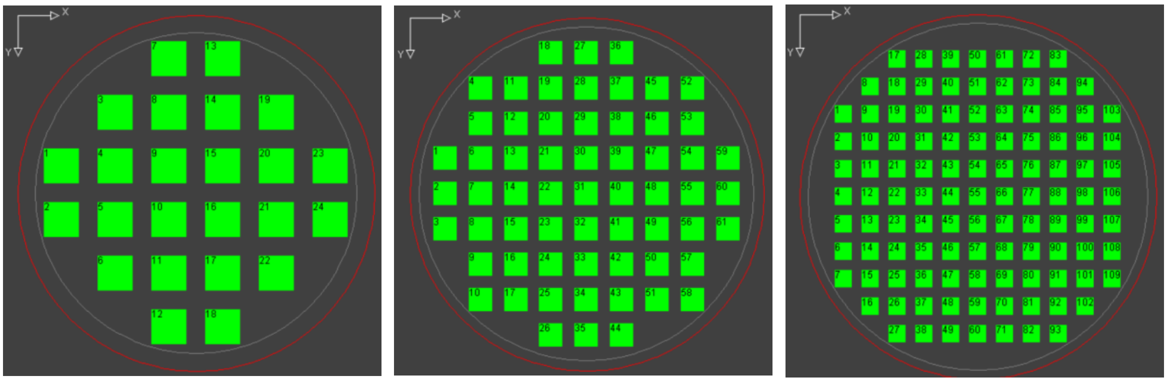


Figure 9 Pattern generator showing generated imprint pattern of a 10x10mm² stamp with a large 5mm spacing on 100 mm (left), 150 mm (centre) and 200 mm wafer substrate (right). The imprinted substrates will have 24, 61 and 109 imprints with this specific stamp size and spacing.

A typical example of imprints performed in the Soft-NIL-Stepper on 150 mm as well as on 100 mm substrate is shown in Figure 10. The curing time was around 5 sec with an imprint cycle time of around 25 seconds per imprint. The nanopattern with a unit cell size in the range of 500 nm has a size of 1x1cm². In the shown examples, there was no degradation on the nanopattern visible. A 200 mm substrate is shown in Figure 8.

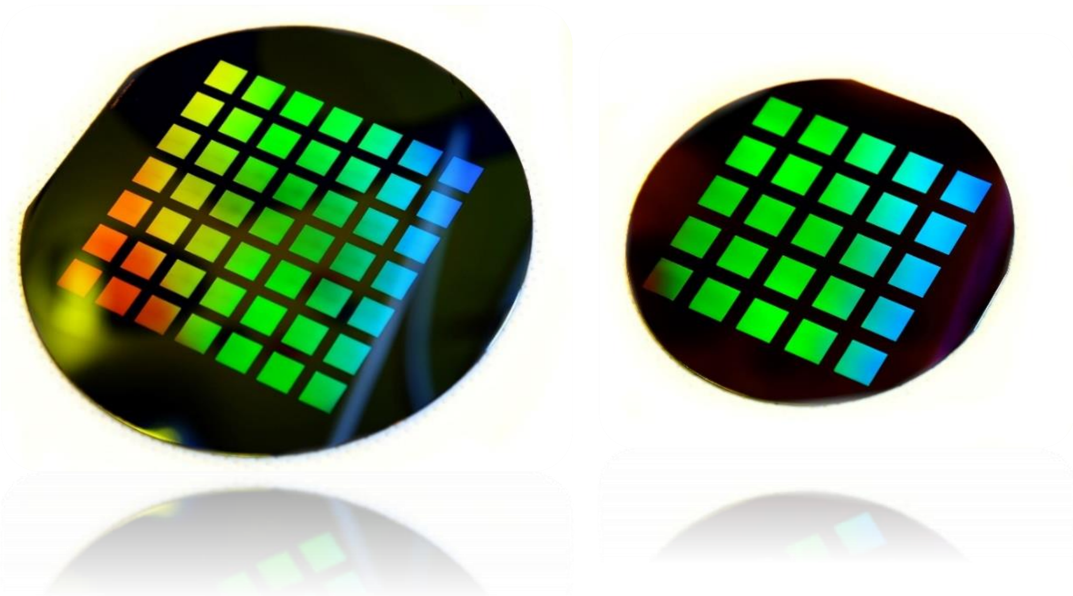


Figure 10 Imprints performed in the Soft-NIL-Stepper on 150mm (left) and 100 mm silicon substrate (right)

3. Conclusions and outlook

The aim of TINKER is, to replace certain fabrication steps in an OPA fabrication steps with Nanoimprint Lithography (NIL) in order to achieve fast and reliable direct manufacturing of the needed passive optical elements as the waveguides and optical coupling structures. This will reduce the size of the PIC, the costs of fabrication and increase the throughput. With the completion of this deliverable, the Tinker consortium has now completed the equipment and tools development for the use case in TINKER. As the project progresses, even as work on prototype NIL devices and tools is completed, the devices will be continually adapted to meet new requirements that may be necessitated by new materials or designs.

INKRON is constantly developing its materials for direct use in PIC to achieve very high refractive indices with excellent material properties.

PROFACTOR has the capability to test the materials and will continue to develop its RND stepper platform.

EVG is able to supply the complete manufacturing equipment for the entire production and large-scale production and will continue to develop the products.

LETI is developing new LIDAR sensors using NIL as a manufacturing step to offer lower cost LIDAR sensors for autonomous driving in the future.

To achieve the ambitious goals in TINKER all partners will work together in the further course of the project.