COOP-CT- 2004 - 512667

3D NanoPrint

Nanoimprint Lithography for novel 2- and 3-dimensional Nanostructures

Co-operative Research Project

FP6-2002-SME-1

D0.6B

PUBLISHABLE FINAL ACTIVITY REPORT

Period covered:
from 01/11/2004 to 30/04/2007

Date of preparation:
26 July 2007

Start date of project: November 1st, 2004

Duration: 30 months

Project coordinator name: DI Dr. Michael Mühlberger
Project coordinator organisation name: Profactor Produktionsforschungs GmbH

Table of Content

1 Project Execution

3D NANOPRINT

www.3dnanoprint.org

1.1 Summary description of project objectives

One of the main problems in nanotechnology is the lack of methods for mass production. This is especially true for SMEs, which do not have the ability to invest in expensive equipment for large-scale production of nanostructures. Nanoimprint lithography (NIL) is a tool that is comparably cheap and suited for mass production. The project 3DNANOPRINT aims at the development of a complete process technology with the necessary tools to produce 3-dimensional nanostructures with ultra high precision. In comparison to deep or extreme ultra violet lithography (abbreviated as DUV and EUV lithography respectively) this research paves the way for the widespread use of a nanoscale production technology also by smaller companies, since the investment costs of nanoimprint production lines are significantly less than the ones for DUV or EUV lithography.

In nanoimprint lithography a micro- and/or nano-structured stamp is used to pattern a polymer. If necessary this polymer can then be used to transfer this pattern into a substrate by an etching process. The pattern replication is done under well controlled conditions by hardening the initially liquid polymer, while the stamp is still pressed into it, and subsequent separation of stamp and then hard polymer.

The project consisted of two levels, a directly process oriented part dealing with nanoimprint lithography itself, nanoimprint resists, reactive ion etching and alignment problems and a second more application oriented part.

In the second part requirements for nanoimprint lithography as production tool are defined, assuring that the final result of the project is a cost effective, high throughput, ultraprecise tool for the production of 3-dimensional nanostructures.

As a reference application 3-dimensional photonic crystals have been chosen, since such devices are extremely difficult to fabricate and therefore serve as an excellent indicator for the quality and suitability of the fabrication process. Other applications considered are micro- and nano-optical devices and glass scales and discs for position encoding and measurement.

The photonic crystal was built up in a woodpile structure, which requires that the 3^{rd} layer is shifted by half the period d with respect ot the first layer and layer 5 sits just atop layer 1 again (see Figure 1). This leads to very stringent alignment requirements, since the periodicity is in the range of a few 100nm.

Additional critical issues are the residual layer thickness, the sidewall roughness and the imprinting polymer itself.

The residual layer after imprinting is the layer of imprint polymer, which remains after imprinting in the areas where the imprint polymer has been pressed down by the stamp. It cannot be avoided but has to be as thin and as homogeneous as possible over the whole imprinting area to make a perfect pattern transfer in a subsequent etching process feasible.

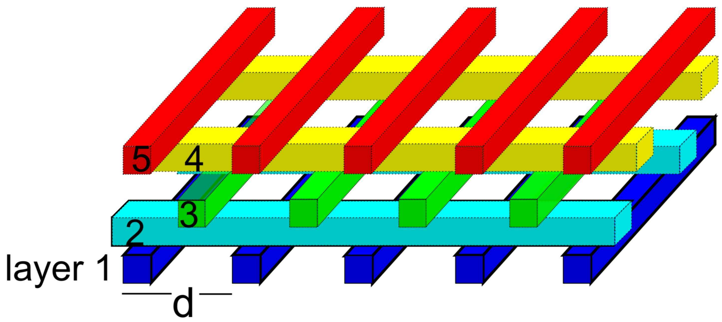

Figure 1 photonic crystal in woodpile structure

In our imprint experiments we mainly used hard quartz stamps (25x25mm²) to imprint spin coated layers on Si wafers.

The main objectives of the project were the following:

- Development of a nanoimprint tool which allows the production of 3-dimensional nanostructures
- Development of the process technology to produce these nanostructures, which includes:
    - Improvement of layer-to-layer alignment accuracy
    - Improvement of NIL resists
    - Improvement of reactive ion etching

This project should help to pave the way for the use of NIL as a production technology.

1.2 Contractors involved

The consortium of 3D NANOPRINT consists of 4 research partners and 5 industrial partners (3 of which are small or medium sized enterprises (SMEs)) from 4 different countries.
The companies involved are **microresist technology GmbH** (www.microresist.de) from Germany, dealing with nanoimprint polymers, **SENTECH Instruments GmbH** (www.sentech.de) also from Germany providing reactive ion etching equipment and know-how. Furthermore **Heptagon Oy** (www.heptagon.fi) from Finland is a member of the 3D NANOPRINT consortium. They produce micro- and nano-optical devices using UV embossing in their production facilities..
Additionally **EV Group** (www.evgroup.com) from Austria, a producer of nanoimprint and wafer processing equipment, and **Brown&Sharpe Precizika** (www.bsp.lt) from Lithuania specialized in high quality metrology equipment contribute to the project.

The research partners are 3 universities and one privately owned research company. The universities are the **Johannes Kepler University Linz** (www.jku.at) in Austria, the **Institute of Physical Electronics of Kaunas Technical University** (www.fei.lt) in Lithuania and the **Friedrich Schiller University Jena** (www.uni-jena.de) in Germany. Furthermore **Profactor GmbH** (www.profactor.at) in Austria is one of the research partners and also the co-ordinator of the project..
The following table summarizes the contact details:

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1.3 Co-ordinator contact details

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1.4 Work performed

At the beginning of the project at first a review of the status of the technological components for the NIL process was started. This lead to a definition of requirements especially as far as resist properties and etching requirements are concerned but also regarding the necessary alignment accuracy.

Starting form this point the work carried on in parallel in several workpackages, all of them interacting strongly.

One major workpackage dealt with the **development of a new UV-curable polymer**, to be suited for the use in UV-NIL and to be applied by spin coating (as compared to droplet dispensing of the polymer). In coordination with imprint process development the properties of this new polymer material were finetuned to guarantee optimium imprint performance.

Using this polymer the **imprinting process for the 3D photonic crystal** as well as the relevant **etching procedures** were developed, giving feedback to the resist development workpackage.

Figure 2: EVG®620 Nanoimprint equipment at Profactor

Additionally a simple yet extremely precise **alignment** mechanism has been implemented in the nanoimprint equipment used during the project, which is an EVG®620 nanoimprinter (see Figure 2 on the right).

These 4 main ingredients (new resist, imprinting process and etching process and alignment procedure) were all combined to fabricate the photonic crystal in woodpile structure.

Since adhesion between the stamp and the substrate is always an issue in NIL accompanying work has also be done in this field. Here also investigations of **diamond-like carbon** (DLC) coatings of the imprint stamps were performed.

To address thermal expansion issues in the hot embossing process laser irradiation was used to heat the thermoplastic polymer and a protype process was developed.

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Besides the **3D photonic crystals** there were **2 other applications** that were investigated during the project. On the one hand there are the micro- and nano-optical components of Heptagon and linear and angular encoders of Brown&Sharp Prezizika (glass scales and disks). These types of applications have very different requirements as far as the imprinting process is concerned but nevertheless gave important input to the overall project goal which was the improvement of UV-NIL.

In general all the project partners have made significant advances in their various fields, which would not have been possible without the collaboration within this project.

1.5 End Results

Due to the combined efforts of research and high tech industry partners several important achievements could be made during the project.

a)
Moiré alignment
A simple and purely optical alignment mrocedure has been established in the UV-NIL process, which allows layer-to-layer alignment with an accuracy below 100nm. This is achieved by a Moiré technique and does not require expensive modifications of the nanoimprint equipment. [1] The advantage is that no expensive interferometric alignment stages are needed and that it is also suited for machine vision processing.

b)
mr-UVCur06
A new nanoimprint polymer has been developed tested and implemented in the NIL process chain. It can be applied by spin coating and offers ultra-thin residual layers (see e.g. Figure 3) and excellent etching characteristics in the RIE process. [2] The relevant etching procedures have been established. This polymer offers very good layer properties when spin coated, low curing dose and optimized etching stability and therefore is ideally suited for the imprinting process with a subsequent pattern transfer step. The viscosity is low which guarantees instant and complete filling of the stamp in the NIL process. The low curing dose keeps the process time minimal.

c)
UV-NIL with quartz stamps on spin coated substrates
To our knowledge it is one of the first times that rigid quartz stamps have been successfully used to imprint spin-coated resist layers on a large area using this equipment. The stamp area for our experiments was 25x25mm², a size compatible with step-and-repeat imprinting processes. This is important since it establishes a process which is basically compatible with standard semiconductor processes and is also suitable for wafer scale imprinting.

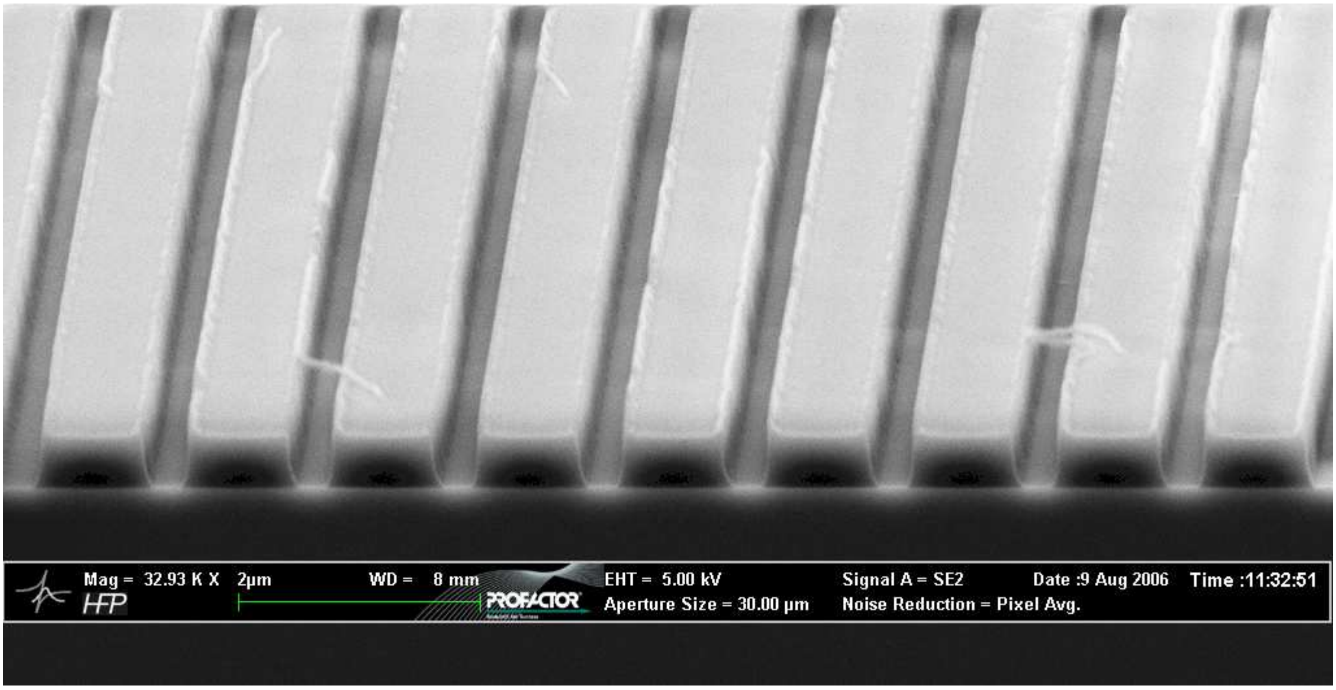

Figure 3 cross section scanning elcectron micrograph of an structured polymer layer. The ultra-thin residual layer after imprinting can be seen.

d)
NIL for glass scales and discs
To asses the applicability of NIL for the fabrication of scales and discs for linear and rotary encoders hot embossing and UV-NIL have been compared. Functioning devices have been fabricated. [3] Devices have been fabricated and there performance has been assessed.

e)
laser assisted NIL prototype process
As already mentioned above a laser assisted hot embossing process was developed. The advantage is the reduction of the thermal cycles in hot embossing due to shorter heating times. [4]

f)
UV Embossing for micro-/nano-optics
Heptagon established a UV embossing process for their products in the micro- and nano optics field [5]. This process is working on EVG equipment [6].

g)
improvements to the equipment used within the project
During the project modifications to the equipment in use have been made. Mainly the nanoimprint equipment but also the reactive ion etching equipment was modified to meet the demands of the process and to incorporate improved features. This work has been performed by the project partners EVG and Sentech respectively.

h)

3D photonic crystal capability

Taking together all achievements mentioned above and combining them the 3D photonic crystal process has been established. Using the alignment procedure, the new UV-NIL polymer, the corresponding etching procedures with standard semiconductor process technology like chemical mechanical polishing it has been demonstrated [7], that using UV-NIL a 3D photonic crystal in woodpile structure can be successfully fabricated.. Figure 4 shows a scanning electron micrograph of a cross section of such a sample. It consists for the purposes of this image of layers of imprint polymer and aluminium and demonstrates especially nicely the multi layer alignment capabilities of the process (and gives a better contrast in the SEM than Si/SiO_2).

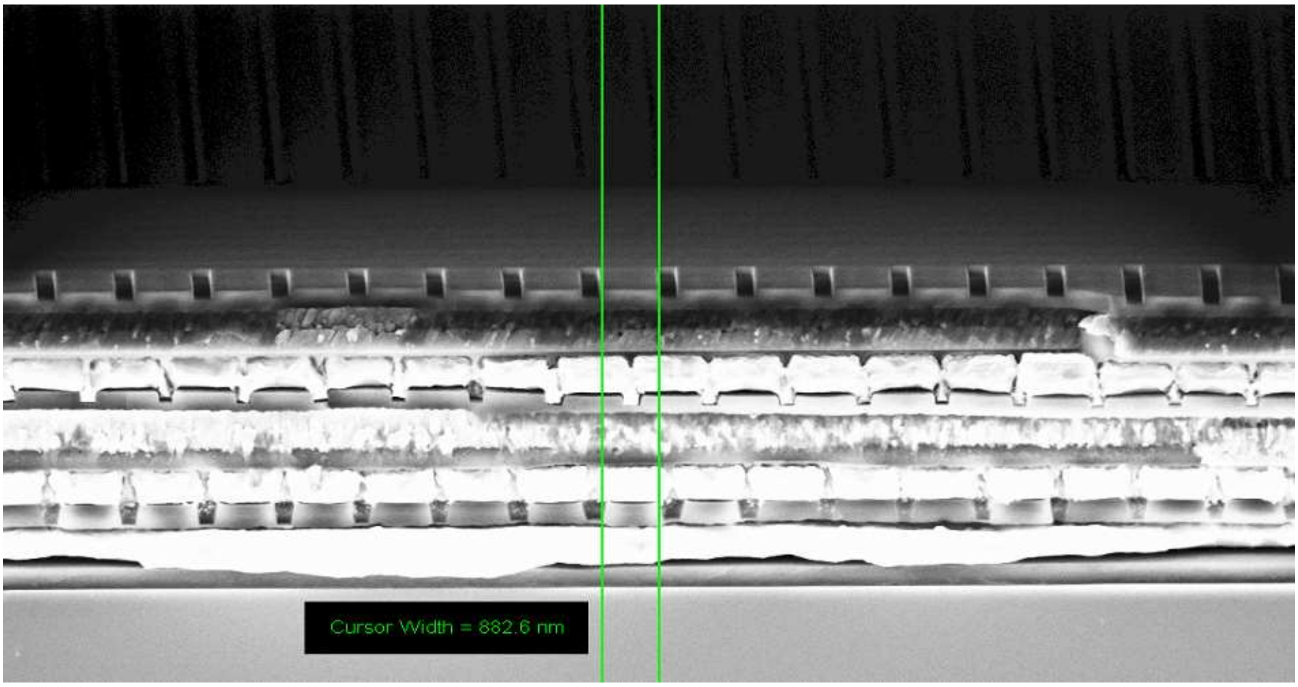

Figure 4 photonic crystal layer stack showing the perfect alignment of the layers 1, 3 and 5 as needed for the woodpile structure

1.6 Impact on industry and research

The intention of the consortium was to improve nanoimprint lithography and the accompanying technologies (resists, reactive ion etching) to be able to provide a comprehensive package of technological and process know how for a low cost high volume nanoscale production technology.

This goal has been successfully achieved. A highly challenging demonstrator process has been implemented on a relatively inexpensive equipment using a new imprint polymer.

This has definitively strengthened each participant's market position and ensures further development and growth.
During the project constantly improvements have been implemented and new solutions have been found for some of the most challenging aspects of nanoimprint lithography.
The improvement will not only be for the benefit of the technology providers EVG, SENTECH and microresist technology, but furthermore also help Heptagon and Brown&Sharpe Precizika to improve their production technology for micro- and nanooptical elements and glass scales respectively.

But not only will the direct project participant strongly profit from the project outcomes, but nanotechnology SMEs in general will benefit significantly. The impact on industry in general is such that it has been shown that UV-NIL can successfully be used as a production tool. This will in the end enable the fast and cost efficient production of new high quality "nano"products. A process package is now available, which has been shown to be able to produce high quality results.

For the research area similar issues are of importance. UV-NIL is able to produce highest quality nanostructures in a flexible, fast and cost-efficient way. E-beam lithography is only necessary to fabricate the stamps.

1.7 Conclusions

3DNanoPrint has successfully highlighted the enormous potential of nanoimprint lithography. The consortium is optimistic that the results achieved will have significant economic impact. Further collaborations within the consortium are planned.

1.8 References

1. Mühlberger, M., et al., *A Moire method for high accuracy alignment in nanoimprint lithography.* Microelectronic Engineering, 2007. **84**: p. 925-927.
2. Vogler, M., et al., *Development of a novel, low-viscosity UV-curable polymer system for UV-nanoimprint lithography.* Microelectronic Engineering, 2007. **84**: p. 984-988.
3. Grigaliūnas, V., et al., *Imprint Lithography for Large Scale Angular Encoders.* MATERIALS SCIENCE, 2007. **13**(2): p. 103-106.
4. Grigaliūnas, V., et al., *Nanoimprint lithography using IR laser irradiation.* Applied Surface Science, 2006. **253**(2): p. 646-650.
5. Heptagon. *Heptagon*. 2007 [cited; Available from: www.heptagon.fi.
6. EVG. *EV Group Wins Order from Heptagon for Nanoimprint Lithography Production Equipment for Micro Optic Devices*. 2005 [cited; Available from: http://www.evgroup.com/pressrelease_sub1.asp?pr_id=90.
7. Glinsner, T., et al. *Fabrication process of 3D-photonic crystals via UV-nanoimprint lithography*. 2007: SPIE.

2 Dissemination and Use

This section provides a publishable summary of **each exploitable result** the project has generated, and should therefore be included **only when** the consortium is ready to publicise and have taken the appropriate measures to protect their IPR[1].

Result #1:
mr-UVCur06
UV-curable polymer for Nanopimprint Lithography

- Result description :
  - UV-curable polymer for Nanoimprint Lithography. The new UV-NIL polymer mr-UVCur06 has been designed for the fabrication of nanostructures and pattern transfer. It is applied by spin-coating giving 150 nm – 500 nm films with excellent quality and uniformity. The low viscosity of mr-UVCur06 enables fast filling of the mould cavities and very thin residual layers. Curing at low UV doses reduces the imprint cycle times to a minimum. Pattern sizes from sub-30 nm to several microns can be imprinted simultaneously with a high pattern transfer fidelity. Details can be found in M. Vogler et al., Microelectronic Engineering 84 (200/) 984
- Possible market
  - Semiconductor technology, wafer processing
- Stage of development
  - industrial product
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[1] Please beware that only information which is readily available in the public domain should be included as this might affect the owner's right to seek protection (eg patent) the results.

Result #3:
Moiré alignment mechanism for UV-NIL

- Result description
  - An alignment process has been established for UV-NIL, which uses Moiré markers to achieve sub-wavelength alignment accuracy. It has successfully been used in an EVG®620 nanoimprinter in the fabrication of a 3D photonic crystal layer stack, with alignment requirements below 100nm. Details can be found in M. Mühlberger et al., Microelectronic Engineering 84 (2007) 925
- Possible market applications
  - Everywhere where NIL can be applied: Microfluidic Devices, Patterned Media, Micro-/Nano-Optics, 3D-patterning, Microelectronics – R&D
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