Technology portfolio

Prototyping mastering & replication

Version 1 Nov., 12th 2010

Organis.	Technology	page
CNRS	Grating fabrication by lithography & etching	4
IMEC	laser ablation	6
	Polishing	9
	UV lithogrpahy & laser lithography	11
IPHT	Electron beam lithography	13
	Thin Film deposition	15
	UV lithogrpahy	17
	Plasma etching	19
	Optical fibre fabrication	21
ITME	Electron beam lithogrpahy (multi step) for the fabrication of DOEs	23
	Optical fiber fabrication (nonlinear photonic crystal fibers, PCF)	25
KIT	X-ray lithography	27
	Hot embossing	29
	Modular free space photonic microsystems	31
	Nickel electroplating for mold insert fabrication	33
	Waveguide fabrication in polymers by UV modification	35
MPL	Electron beam lithography (system RAITH 150two)	38
	Laser lithography for fabrication of micro optical elements	41
Sintef	Micro injection moulding	43
UEF	Electron beam lithography	45
	Ion etching (RIE and ICP) of dielectrics and metals	47
	Micro Injection moulding	49
	Nanoimprint lithography	51
	Nickel electroplating for mold insert fabrication	53
	Wet etching of Silicon	55
UFC	Glass reflow for microlenses fabrication	57
	Silicon electrostatic comb-drive micro actuator fabrication	59
	Wet etching of silicon moulds for microlens fabrication	61
VTT	Nanoimprint lithography	63
	UV lithography	65
VUB	Proton Writing to fabricate optical elements	67
WUT	Polishing, cutting and grinding of optical elements	69

Technology	**Organis.**	**page**
Electron beam lithography	IPHT	13
Electron beam lithography	UEF	45
Electron beam lithography (system RAITH 150two)	MPL	38
Electron beam lithogrpahy (multi step) for the fabrication of DOEs	ITME	23
Glass reflow for microlenses fabrication	UFC	57
Grating fabrication by lithography & etching	CNRS	4
Hot embossing	KIT	29
Ion etching (RIE and ICP) of dielectrics and metals	UEF	47
laser ablation	IMEC	6
Laser lithography for fabrication of micro optical elements	MPL	41
Micro injection moulding	Sintef	43
Micro Injection moulding	UEF	49
Modular free space photonic microsystems	KIT	31
Nanoimprint lithography	UEF	51
Nanoimprint lithography	VTT	63
Nickel electroplating for mold insert fabrication	KIT	33
Nickel electroplating for mold insert fabrication	UEF	53
Optical fiber fabrication (nonlinear photonic crystal fibers, PCF)	ITME	25
Optical fibre fabrication	IPHT	21
Plasma etching	IPHT	19
Polishing	IMEC	9
Polishing, cutting and grinding of optical elements	WUT	69
Proton Writing to fabricate optical elements	VUB	67
Silicon electrostatic comb-drive micro actuator fabrication	UFC	59
Thin Film deposition	IPHT	15
UV lithography	VTT	65
UV lithogrpahy	IPHT	17
UV lithogrpahy & laser lithography	IMEc	11
Waveguide fabrication in polymers by UV modification	KIT	35
Wet etching of Silicon	UEF	55
Wet etching of silicon moulds for microlens fabrication	UFC	61
X-ray lithography	KIT	27

Partner:	**CNRS / Lab Hubert Curien**	**Prototyping**
	Hubert Curien Laboratory UMR CNRS 5516	**Mastering**
	18, Rue du Prof. B. Lauras, Bât. F, F-42000 Saint-Etienne	
	http://laboratoirehubertcurien.in2p3.fr/	

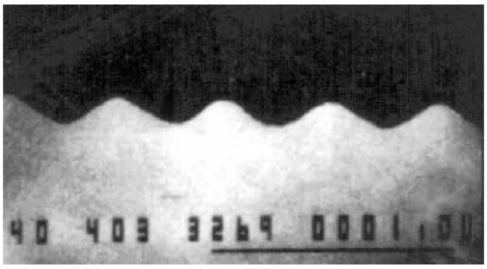
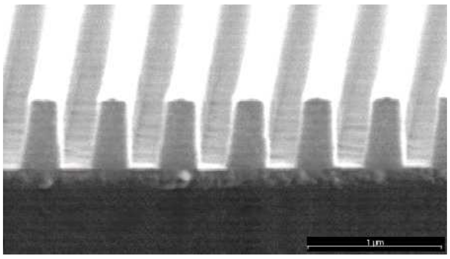
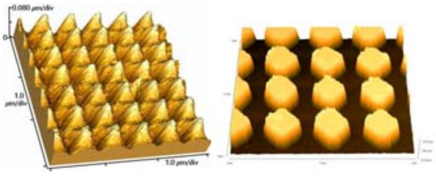
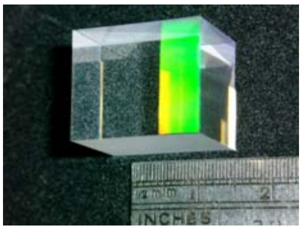
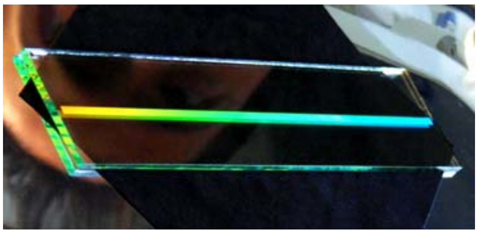
Technology: Prototyping/Mastering	**Grating fabrication by lithography & etching**	

resp. person	Yves JOURLIN	Yves.jourlin@univ-st-etienne.fr	+33 477 91 58 21	+33 477 91 57 81

Technology:
(short description, appr. 100 words)

- **Grating photolithography** : interferogram exposure (Holographic Printing), amplitude mask transfer, phase mask projection, long/wide grating writing by write on the fly, full grating photolithographic process on dissolvable substrates (PMMA))
- Grating printing on highly reflective substrates
- Grating printing on unusual substrate shapes
- Photoresist process on plastic substrates (PMMA, PC, Polystyrol…)

- **High spatial resolution grating etching**: Reactive Ion Beam Etching, Wet chemical etching (SiO2, germanium, amorphous silicon, Si3N4, photoresist)

Typical structures		
	Sinusoidal gratings	Rectangular gratings
		
	Asymmetrical (blazed) gratings	Two-dimension gratings
		
	Grating printing on a cube	Long grating (300 mm long, 650 nm period)

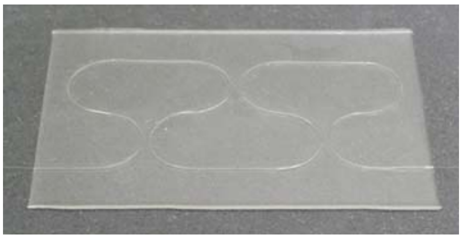
Special features	Limitations/constrains	Design rules / Technology
• 1D&2D Sinusoidal, rectangular, and saw-tooth resist profiles • Rectangular profiles with different duty-cycles • Inverse trapeze resist profiles for lift-off • Variable depth, variable period gratings • Sinusoidal profile gratings in glass surfaces	• Periods between 250 and 50’000 nm • Area up to Φ150 mm	 Holographic bench
Further publications (pdf available through NEMOS knowledge management centre)	1. S.Tonchev, Y.Jourlin, S.Reynaud, M.Guttmann, M.Wissmann, R.Krajewski, M.Joswik, “Photolithography of variable depth grating on a polymer substrate for the mastering of 3D diffractive optical elements”, Proceedings of MOC'08, 14th Microoptics Conference, September 25-27, pp. 160-161, Brussels, Belgium, 2008. 2. “Flying phase mask for the printing of long submicron-period stitchingless gratings”, E. Gamet, Y. Jourlin, S. Pelissier, R. Min, S. Reynaud, C. Veillas, J.-C. Pommier and O. Parriaux. Microelectronic Engineering, Volume 83, Issues 4-9, pages 734-737 (2006).	

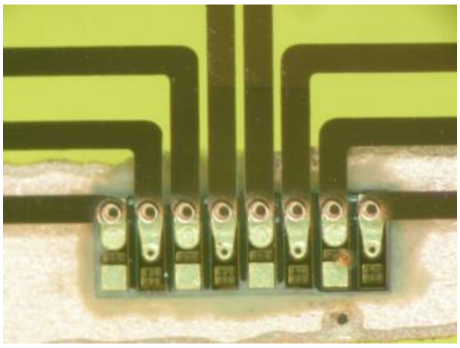
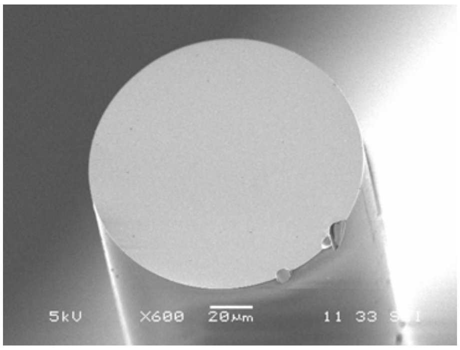
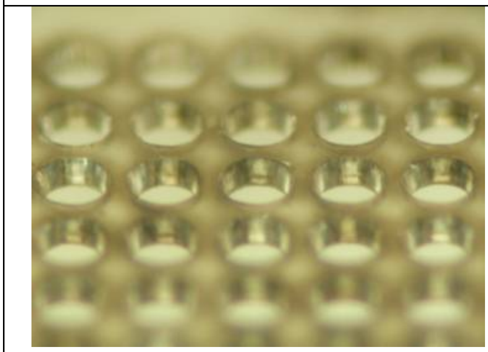
Partner:	**IMEC**	Prototyping
	Centre for Microsystems Technology (CMST)	Mastering
	Technologiepark 914A, B-9052 Zwijnaarde, Belgium	
	http://www.cmst.be	

Technology: (identification name)	Laser ablation	

resp. person	Geert Van Steenberge	geert.vansteenberge@elis.ugent.be	+3292645560	+3292645374

Technology: (short description, appr. 100 words)	Laser ablation is a micromachining technology that is based on the controlled removal of material with intense laser pulses. In general, the energy of the laser beam is absorbed in a thin layer or small volume and the ablation process takes place through rapid fragmentation. Depending on the laser wavelength and laser pulse duration, the nature of the process can have the characteristics of ablative photo-decomposition, or rapid heating and vaporization. Two different ablation set-ups are available: A nanosecond laser system integrating a KrF excimer laser (248nm wavelength), a frequency tripled Nd:YAG laser (355nm wavelength), and a CO_2 laser (10.6µm wavelength). An ultrafast laser system operating in femtosecond and in picosecond regime (pulse durations from 200fs up to 10ps). With these unique systems we are capable of structuring a whole set of materials in different applications, some examples are shown below.

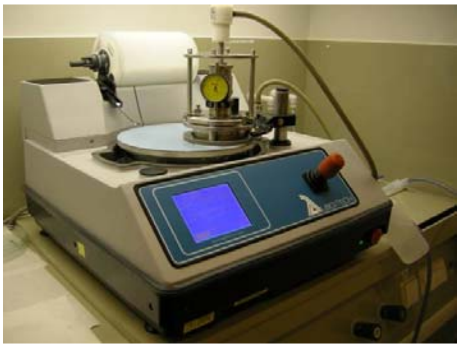
Typical structures		
	Flexible polymer substrate containing low-loss multimode optical waveguides patterned by laser ablation.	Optical fiber sensor embedded in a stretchable sensing skin. The fiber position is determined by a laser ablated groove in the polymer substrate.

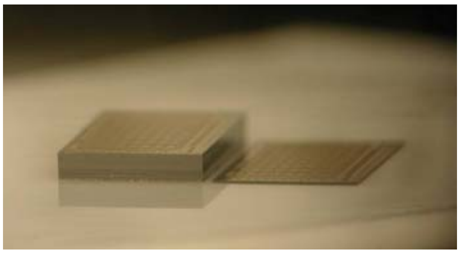
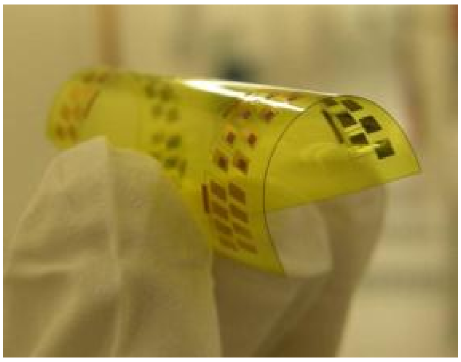
		
	1x4 VCSEL array chip embedded in an optical transparent polymer. The chip is contacted by laser drilled blind vias.	Silica glass fiber terminated by UV laser pulses.
		
	2D array of laser drilled high precision microholes.	Optical transparent and electrical conductive polymer patterned by laser ablation (top view).

Special features	Limitations/constrains	Design rules
• Surface roughness down to 20nm (material dependent) • Minimal structure detail down to 1µm • High aspect ratios • Good layer selectivity • Broad range of materials • Fast processing	• Limited 3D capability	• dxf files

Further publications	
	MT-compatible laser-ablated interconnections for optical printed circuit boards. JOURNAL OF LIGHTWAVE TECHNOLOGY, Volume: 22, Issue: 9, Pages: 2083-2090, SEP 2004 Laser cleaving of glass fibers and glass fiber arrays. JOURNAL OF LIGHTWAVE TECHNOLOGY, Volume: 23, Issue: 2, Pages: 609-614, FEB 2005 Laser ablation of parallel optical interconnect waveguides. IEEE PHOTONICS TECHNOLOGY LETTERS, Volume: 18, Issue: 9-12, Pages: 1106-1108, MAY-JUN 2006

	Laser ablated micromirrors for printed circuit board integrated optical interconnections. IEEE PHOTONICS TECHNOLOGY LETTERS, Volume: 19, Issue: 9-12, Pages: 822-824, MAY-JUN 2007 Highly Reliable Flexible Active Optical Links. IEEE PHOTONICS TECHNOLOGY LETTERS, Volume: 22, Issue: 5, Pages: 287-289, MAR 1 2010 Patterning of Flexible Organic Light Emitting Diode (FOLED) stack using an ultrafast laser. OPTICS EXPRESS, Volume: 18, Issue: 8, Pages: 7575-7583, APR 12 2010	

<table>
<tr><td rowspan="4">Partner:</td><td colspan="3">IMEC</td><td>Prototyping</td></tr>
<tr><td colspan="3"><i>Centre for Microsystems Technology (CMST)</i></td><td>Mastering</td></tr>
<tr><td colspan="3"><i>Technologiepark 914A, B-9052 Zwijnaarde, Belgium</i></td><td></td></tr>
<tr><td colspan="4">http://www.cmst.be</td></tr>
<tr><td>Technology:
(identification name)</td><td colspan="3">Polishing</td><td></td></tr>
<tr><td>resp. person</td><td>Geert Van Steenberge</td><td>geert.vansteenberge@elis.ugent.be</td><td>+3292645560</td><td>+3292645374</td></tr>
<tr><td>Technology:
(short description, appr. 100 words)</td><td colspan="4">Polishing involves the use of a grinding wheel that rotates while in contact with the substrate or component, with the aim to reduce the component thickness or to make the surface optically smooth. The process is assisted by a slurry containing grains or chemical substances which remove material from the component on a respectively mechanical or chemical basis.
In general the thinning and polishing process is split into two consecutive steps. A lapping step using a suspension of 9 µm Al_2O_3 grains resulting in fast processing. A polishing step using a very fine 0.3 µm Al_2O_3 grain resulting in a smooth surface.
The polishing technology is mainly used for thinning silicon and opto-electronic chips, for use in flexible and stretchable applications. In addition optical coupling structures for integration in board-level optical interconnects are developed.</td></tr>
<tr><td rowspan="2">Typical structures</td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td colspan="2">Mechanical lapping and polishing tool used for thinning bare dies, and for providing smooth optical surfaces.</td><td colspan="2">Micro optical mirror plug for 90˚ light bending in PCB integrated optical interconnects. 45˚ mirror by polishing and metal coating.</td></tr>
</table>

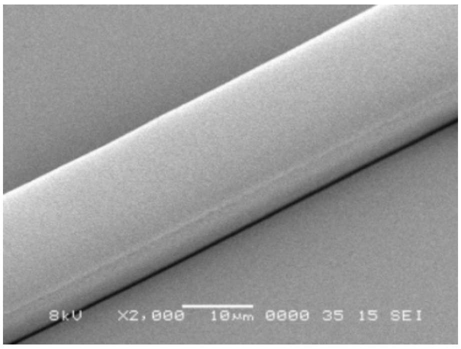
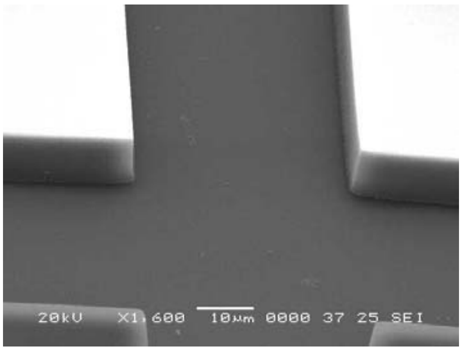
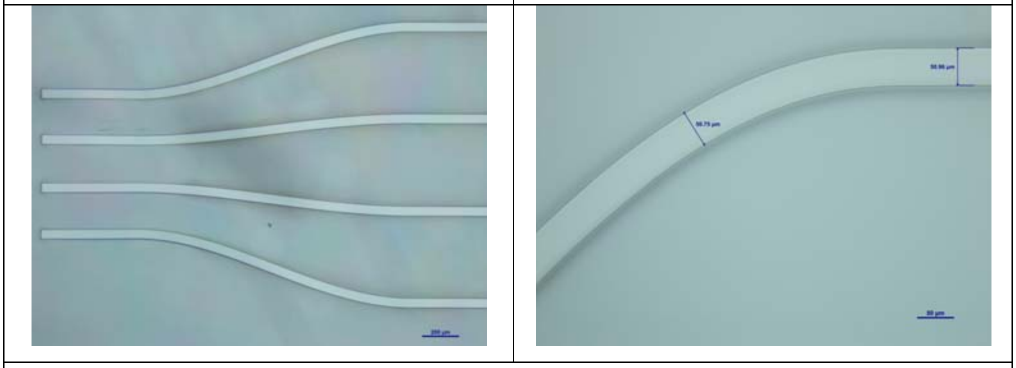
		
	Silicon chip before and after thinning, as achieved with mechanical polishing.	Flexible substrate with embedded laser and detector chips. Dies are thinned prior to embedding.

Special features	Limitations/constrains	Design rules
• Surface roughness down to 5nm • Thickness control down to 1µm • Single chip thinning capabilities • Si and III-V materials. Polymers • Low cost	• Planar process	• Custom
Further publications	Embedded Micromirror Inserts for Optical Printed Circuit Boards. IEEE PHOTONICS TECHNOLOGY LETTERS Volume: 20 Issue: 17-20 Pages: 1727-1729 Published: SEP-OCT 2008 Fabrication Processes for Embedding Thin Chips in Flat Flexible Substrates. IEEE TRANSACTIONS ON ADVANCED PACKAGING, Volume: 32 Issue: 1 Pages: 77-83 Published: FEB 2009 Highly Reliable Flexible Active Optical Links. IEEE PHOTONICS TECHNOLOGY LETTERS, Volume: 22, Issue: 5, Pages: 287-289, MAR 1 2010	

Partner:	**IMEC**	Prototyping
	Centre for Microsystems Technology (CMST)	Mastering
	Technologiepark 914A, B-9052 Zwijnaarde, Belgium	
	http://www.cmst.be	

Technology: (identification name)	Photolithography (UV and laser direct writing)			
resp. person	Geert Van Steenberge	geert.vansteenberge@elis.ugent.be	+3292645560	+3292645374

Technology: (short description, appr. 100 words)	Photolithography is a microfabrication technology that uses light to transfer a geometric pattern to a light-sensitive photo resist on the substrate. The geometric pattern can either be defined by a photo mask, or by laser direct writing. Both approaches are available, using commercially available photo resists. Main applications are polymer optical waveguides, and more general photo resist patterning for subsequent layer etching.

Typical structures		
	Small core polymer optical waveguide defined by mask lithography.	SU-8 polymer structures defined by laser direct writing.
		
	In plane polymer optical waveguide bending for signal routing. Waveguides defined by mask lithography.	

Special features	Limitations/constrains	Design rules
• Non contact exposure	• Planar substrates	• dxf files

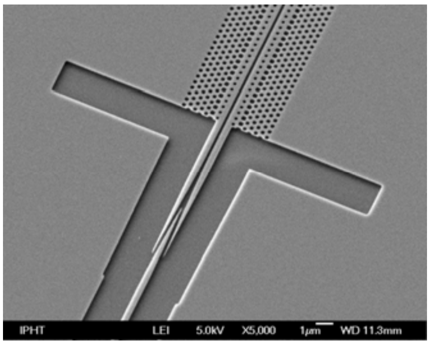
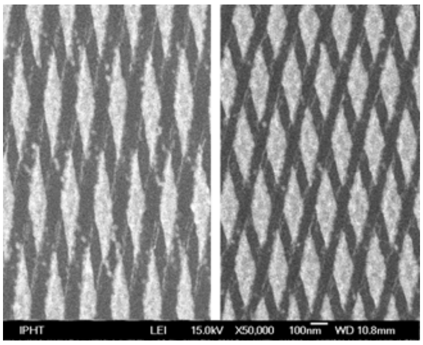
(laser direct writing) • Fast processing (laser direct writing)	• Substrate size 300mm	
Further publications	Highly Reliable Flexible Active Optical Links. IEEE PHOTONICS TECHNOLOGY LETTERS, Volume: 22, Issue: 5, Pages: 287-289, MAR 1 2010	

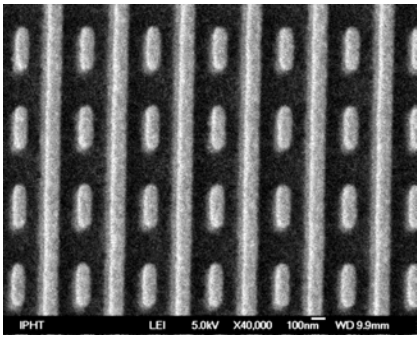
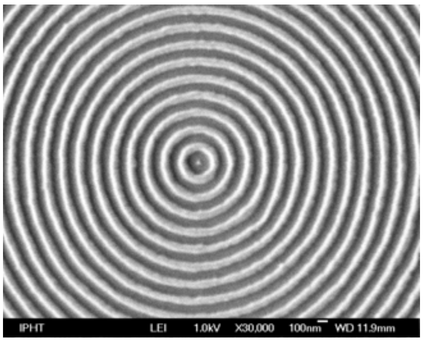
Partner:	**Institute of Photonic Technology**	Prototyping
		Mastering
	Albert-Einstein-Strasse 9, 07745 Jena, Germany	
	http://www.ipht-jena.de	

Technology: (identification name)	Electron beam lithography	

resp. person	Uwe Huebner	uwe.huebner@ipht-jena.de	++49 3641 206126	++49 3641 206199

Technology: (short description, appr. 100 words)	The IPHT can offer a long time experience on the field of electron beam lithography. We use two commercial e-beam writers from the Vistec Electron Beam GmbH Jena (formerly Leica Microsystems Lithography GmbH). The shaped beam writer **SB350 OS** (50 keV) fulfils the 65 nm-node of the semiconductor industry. It can handle substrates up to 300 mm in diameter and performs very accurately placed and **relatively fast** e-beam exposures down to **sub-100 nm structures on large areas.** The Gaussian beam writer **LION LV-1** (20keV) offers two kinds of exposure modes: the conventional “step-and-repeat-exposure-field”-mode and the so called “Continuous Path Control”-mode (CPC-mode). The CPC-mode is a special feature of the LION e-beam writer and means that during an exposure the stage moves with a quasi-fixed e-beam along the pattern geometry. The CPC-mode allows the user to generate very sophisticated curved structures and to write **large-scale stitch-free** patterns like gratings. The produced resist masks can be used in lift-off- and plasma-etching processes.

Typical structures		
	Photonic crystal and planar waveguide, etched in SOI. (**SB350OS**-exposure on a 4” substrate, hole diameter 200nm)	SEM-pictures of rhombus-shaped gold nanostructures for the surface enhanced Raman spectroscopy (SERS). (CPC-mode exposure **with LION-LV1** on a 4” substrate, structures: gold on quartz, pitch 200nm, grating area: 1x1 mm²)

		
	SEM micrograph of a microfabricated Au-MgO-Au metamaterial (**SB350 OS** - exposure**,** linewidth: 130nm, sub-pitch: 250nm, grating area: 2x2mm²).	SEM images of a circular nano-grating (silicon on quartz) (**LION-LV1** -exposure**,** pitch 160nm, exposed in CPC-mode)

Special features	Limitations/constrains	Design rules
Vistec SB350 OS - Variable shaped beam, - Resolution: 65 nm node, - 50 keV, - Wafer size: up to 300 mm, - Shared in use with IAP and IOF Fraunhofer Institute, site: IOF. **Vistec LION LV1**: - Gaussian beam, - resolution: 25 nm, - 2,5 to 20keV, - wafer size: up to 6" substrates, - CPC-mode (continuous path control, **stitching free**). **Mix&Match** by using alignment marks: e-beam – e-beam, e-beam – Mask Aligner Multi-layer patterning	**Chip/wafer sizes:** from 10x10mm² to 6" **Minimum feature size**: 50 nm **Alignment/stitching errors** < 20 nm **Wafer materials:** Si, Si/SiO$_2$, fused silica, SOI **Resist:** Positive: PMMA, ZEP520 Negative: maN2410 --- IMPORTANT ---- Because of the reconstruction of our clean room building, the micro/nanotechnology will be available at the II. quarter of 2011.	• GDSII data format • DXF data format

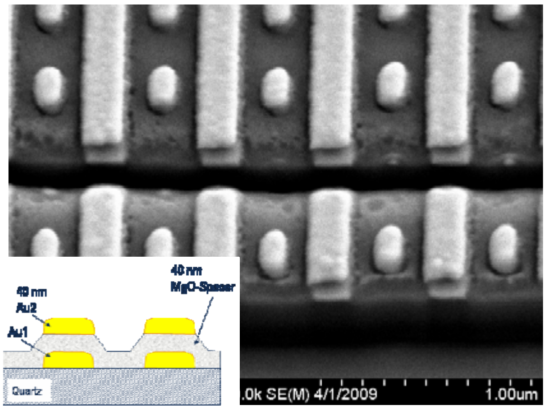
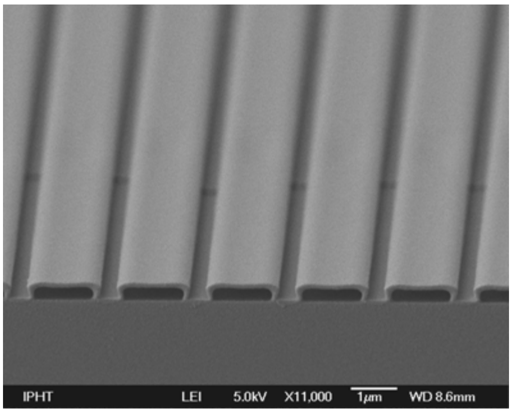
Further publications	
	U. Huebner, R. Boucher, H. Schneidewind, D. Cialla, J. Popp, Microelectronic Engineering, 85 (2008) 1792-1794. D. Cialla, J. Petschulat, U. Hübner, H. Schneidewind, M. Zeisberger, R. Mattheis, T. Pertsch, M. Schmitt, R. Möller, J. Popp, ChemPhysChem, 11 (2010) 1918-1924. J. Petschulat, D. Cialla, N. Janunts, C. Rockstuhl, U. Hübner, R. Möller, H. Schneidewind, R. Mattheis, J. Popp, A. Tünnermann, F. Lederer, T. Pertsch, Optics Express, 18 (2010) 4184-4197.

Partner:	**Institute of Photonic Technology**	Prototyping
		Mastering
	Albert-Einstein-Strasse 9, 07745 Jena, Germany	
	http://www.ipht-jena.de	

Technology: (identification name)	**Deposition techniques**	

resp. person	Uwe Huebner	uwe.huebner@ipht-jena.de	++49 3641 206126	++49 3641 206199

Technology: (short description, appr. 100 words)	The microfabrication of the IPHT is specialised on the deposition of thin films and thin film stacks of various metals, dielectrics and silicon. Evaporation, ion beam sputtering, chemical vapour deposition and also atomic layer deposition are available as deposition techniques. Metallic pattern can be obtained using plasma etching- or lift-off-processes. Evaporated gold layers combined with e-beam lithography are suited for the use in plasmonic devices.

Typical structures		
	FIB-cross-sectional SEM micrograph of a microfabricated Au-MgO-Au metamaterial (linewidth: 130 nm, sub-pitch: 250 nm, size of the grating area: 2 x 2 mm²).	Freestanding “nano-tunnel”, completely covered with ALD-A_2O_3 (wall thickness 40nm)

Special features	Limitations/constrains	Design rules
Evaporation: Metals: Au, Ag, Al, Pt, Ti Dielectrics: MgO **Sputtering** Metals: Au, Nb, Mo, AuPd, NiCr, Ta Semiconductors: Si Dielectrics: SiO_2 **PECVD** SiO_2, Si_3N_4. **Atomic layer deposition** SiO_2, Al_2O_3, TiO_2.	**Chip/wafer sizes:** from 5x10mm² to 6” 8” (ALD) **Substrate materials:** Si, Si+SiO_2, fused silica --- IMPORTANT ---- Because of the reconstruction of our clean room building, the micro/nanotechnology will not be available until the II. quarter of 2011.	

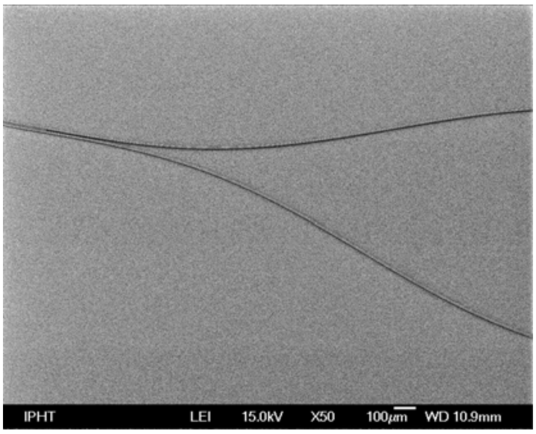
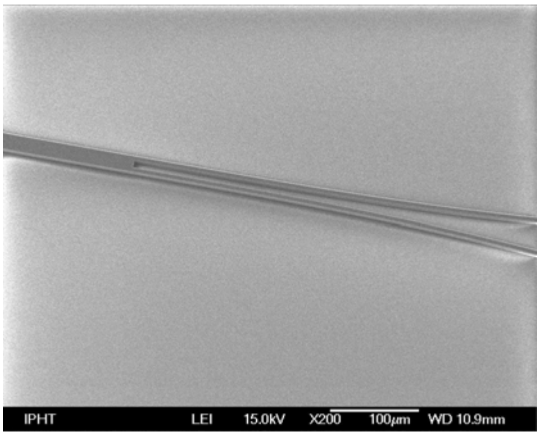
Further publications	[1] Ekaterina Pshenay-Severin, Uwe Hübner, Christoph Menzel, Christian Helgert, Arkadi Chipouline, Carsten Rockstuhl, Andreas Tünnermann, Falk Lederer, and Thomas Pertsch, "Double-element metamaterial with negative index at near-infrared wavelengths" Opt. Lett. 34, 1678-1680 (2009).C. M. Soukoulis, S. Linden, M. Wegener, Science 315, 47-49, 2007. [2] Uwe Huebner, Joerg Petschulat, Ekaterina Pshenay-Severin, Arkadi Chipouline, Thomas Pertsch, Carsten Rockstuhl and Falk Lederer, “Negative index materials: two approaches for nanofabricated metamaterials”, Microelectronic Engineering 86 (2009), pp. 1138-1141.

Partner:	**Institute of Photonic Technology**	Prototyping
		Mastering
	Albert-Einstein-Strasse 9, 07745 Jena, Germany	
	http://www.ipht-jena.de	

Technology: (identification name)	Photolithography	

resp. person	Uwe Huebner	uwe.huebner@ipht-jena.de	++49 3641 206126	++49 3641 206199

Technology: (short description, appr. 100 words)	The IPHT offers its experience in the field of photolithography. Available are an i-line wafer stepper with a 5:1 reduction optic and two 1:1 mask-aligners. The stepper has a resolution of 700 nm and an exposure field of max. 14 x 14 mm². Extended optical devices like planar waveguides (see fig's.) can be exposed using the contact lithography (mask aligner). The minimum feature size of the exposed mask aligner resist structures is around 2 µm. Chromium masks can be fabricated in-house with our e-beam writers or by using an optical pattern generator. The produced resist masks can be used for lift-off- or plasma-etching processes.

Typical structures		
	Planar waveguides with an Y-bend Etched in FHD-oxide on 4" Si-wafer, exposure: Maskaligner	Y-branches of a multimode interference (MMI) coupler Etched in FHD-oxide on 4" Si-wafer, exposure: Maskaligner

Special features	Limitations/constrains	Design rules
Wafer stepper - GCA Series 8500 - i-line - 5:1 optic **Mask-aligner** - EVG 620 - AL6-2 - Backside alignment front-and	**Chip/wafer sizes:** from 5x10mm² to 6" **Field size (stepper):** Max. 14x14mm² **Minimum feature size**: **Stepper:** 700 nm **Mask aligner:** 2 µm **Pattern generator:** 2 µm	**Data formats:** GDS II, CIF, DXF

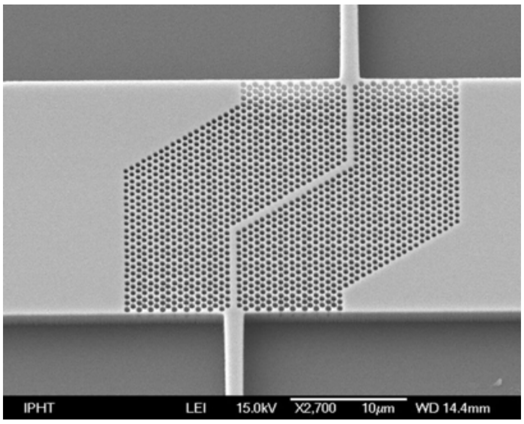
Optical pattern generator - GCA MANN3600 - For mask exposure. **Mix&Match** and **multi-layer patterning** (by using alignment marks): Photolith. – photolith. E-beam. – photolith.	**Alignment/stitching errors** **Stepper:** +/-200nm **Mask aligner:** 2 µm **Pattern generator:** 2 µm **Cr-masks:** Mask aligner: 4”, 5”, 6” Stepper: 5” **Resists:** AZ 5214E, AZ1514H, AZ4562 --- IMPORTANT ---- Because of the reconstruction of our clean room building, the micro/nanotechnology will not be available until the II. quarter of 2011.	
Further publications	U. Huebner, R. Boucher, H. Schneidewind, D. Cialla, J. Popp, Microelectronic Engineering, 85 (2008) 1792-1794. D. Cialla, J. Petschulat, U. Hübner, H. Schneidewind, M. Zeisberger, R. Mattheis, T. Pertsch, M. Schmitt, R. Möller, J. Popp, ChemPhysChem, 11 (2010) 1918-1924. J. Petschulat, D. Cialla, N. Janunts, C. Rockstuhl, U. Hübner, R. Möller, H. Schneidewind, R. Mattheis, J. Popp, A. Tünnermann, F. Lederer, T. Pertsch, Optics Express, 18 (2010) 4184-4197.	

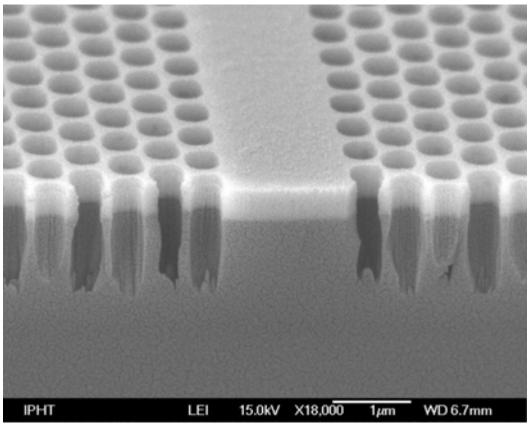
Partner:	**Institute of Photonic Technology**	Prototyping
		Mastering
	Albert-Einstein-Strasse 9, 07745 Jena, Germany	
	http://www.ipht-jena.de	

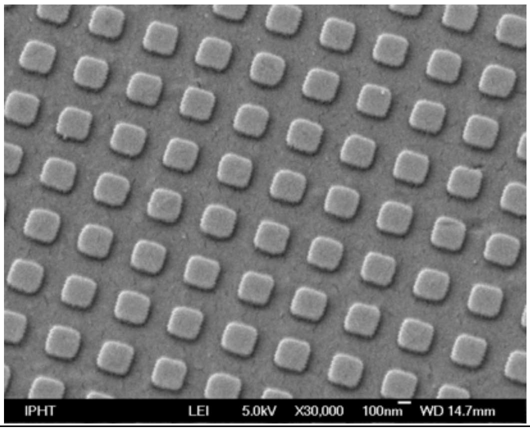
Technology: (identification name)	Dry etch techniques of metallic and dielectric thin films	

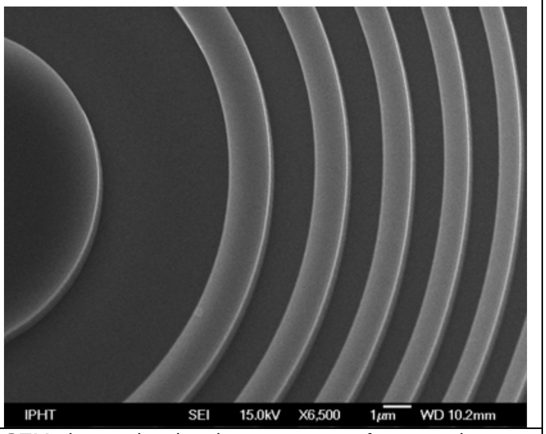
resp. person	Uwe Huebner	uwe.huebner@ipht-jena.de	++49 3641 206126	++49 3641 206199

Technology: (short description, appr. 100 words)	For the fabrication of micro-optical devices like planar waveguides, micro-gratings, photonic crystals or plasmonic structures different dry etch techniques (IBE, RIE, RIBE, ECR-RIE, ICP-RIE) are available. Argon ion beam etching (IBE) is mainly used to pattern thin films of metals (like gold, aluminium, NiCr) and dielectrics like the high-index waveguide-material Ta_2O_3 (see fig.). To pattern Si- and SiO_2-thin films and substrates fluoride based ECR- and ICP-techniques can be applied. The RIE-ICP has been developed for high rate and low damage plasma etch processes, especially in microoptical applications. Etching masks may consists of polymer resist or NiCr - hard masks.

<table>
<tr>
<td>Typical structures</td>
<td>


</td>
<td>


</td>
</tr>
<tr>
<td></td>
<td>SEM picture of a 60° double-bent W1-PC-waveguide etched in a Ta_2O_5 layer.</td>
<td>SEM picture of a cross-section of a W3-PC waveguide with 380 nm diameter holes in a 620nm hexagonal grid, etched more than 1.5µm into 500nm tantalum pentoxide on 2.5µm SiO2 on a silicon substrate. The structure in the centre of the PC is the waveguide.</td>
</tr>
<tr>
<td></td>
<td>


</td>
<td>


</td>
</tr>
<tr>
<td></td>
<td>Dot grating, etched in fused silica (height: 50 nm, pitch 400 nm, grating area: 2x2mm^2)</td>
<td>SEM picture showing the centre part of a zone plate, etched in Si_3N_4 on SiO_2</td>
</tr>
</table>

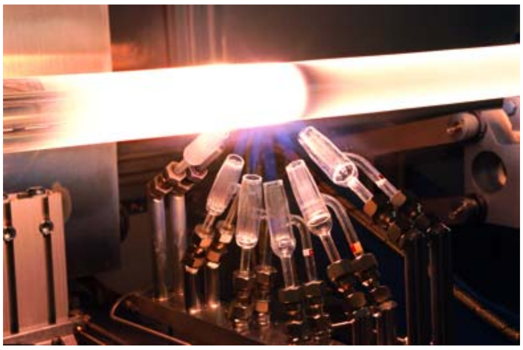
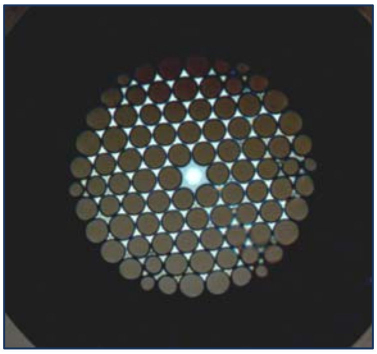
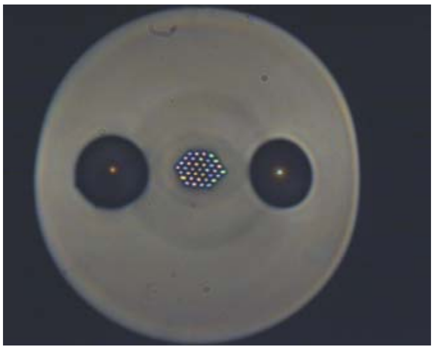
Special features	Limitations/constrains	Design rules
(Reactive) Ion Beam Etching - Physical etching of metals and dielectrica - Substrate holder cooling down to 100 K, - Gases: Ar, O_2 **Reactive Ion Etching (ECR-RIE)** - Substrate holder cooling down to 100 K, - Gases: CF_4, SF_6, CHF_3, O_2, Ar. **RIE-ICP Etching** - Sentech SI-500 F and - SI-500 Si - For SiO_2 and Si Gases: SF_6, CHF_3, CF_4, **RIE-ICP Etching** **-** Sentech SI-500 Cl - For metals like Cr, NiCr - Gases: Cl_2	**Chip/wafer sizes:** from 5x10mm² to 6" **Substrate materials:** Si, Si+SiO_2, fused silica --- IMPORTANT ---- Because of the reconstruction of our clean room building, the micro/nanotechnology will not be available until the II. quarter of 2011.	
Further publications	R. Boucher, U. Hübner, W. Morgenroth, H. Roth, H. -G. Meyer, M. Schmidt and M. Eich "Etching of sub-micron high aspect ratio holes in oxides and polymers" Microelectronic Engineering, Volumes 73-74, June 2004, Pages 330-335. M. Schmidt, G. Boettger, M. Eich, W. Morgenroth, U. Huebner, R. Boucher, H. G. Meyer, D. Konjhodzic, H. Bretinger, and F. Marlow, "Ultralow refractive index substrates–a base for photonic crystal slab waveguides", Appl. Phys. Lett. 85, 16 (2004). M. Schmidt and M. Eich, U. Huebner and R. Boucher: "Electro-optically tunable photonic crystals" Appl. Phys. Lett. 87, 121110 (2005) Uwe Huebner, , R. Boucher, W. Morgenroth, J. Kunert, H. Roth, H.-G. Meyer, T. Glaser and S. Schroeter, "Fabrication of photonic crystals in tantalum pentoxide films", Microelectronic Engineering, Volumes 78-79, March 2005, Pages 422-428. Uwe Huebner, R. Boucher, W. Morgenroth, M. Schmidt, M. Eich, "Fabrication of photonic crystal structures in polymer waveguide material", Microelectronic Engineering Volume 83, Issues 4-9 , April-September 2005, Pages 1138-1141, Micro- and Nano-Engineering MNE 2005	

Partner:	**Institute of Photonic Technology**	Prototyping
	Fiber Optics	Mastering
	Albert-Einstein-Strasse 9, 07745 Jena, Germany	
	http://www.ipht-jena.de/de/forschungsschwerpunkte/fasertechnologie.html	

Technology: (identification name)	Optical Fiber Technology	

resp. person	Jens Kobelke	jens.kobelke@ipht-jena.de	+49-3641-206280	+49-3641-206299

Technology: (short description, appr. 100 words)	Speciality optical fibers, namely Microstructured Optical Fibers (MOF) are prepared using the technological chain: Material development - Preform preparation - Fiber drawing. Materials are high purity silica glasses, HMO (heavy metal oxide) glasses. Preform components are prepared by MCVD, powder sintering technology or melting-casting-methods. The preforms for MOFs were finally manufactured by Stack-and-Draw-technology. The multiple functionality of the 14-m drawing tower allows to prepare fibers on a wide scale of diameters and different coatings.

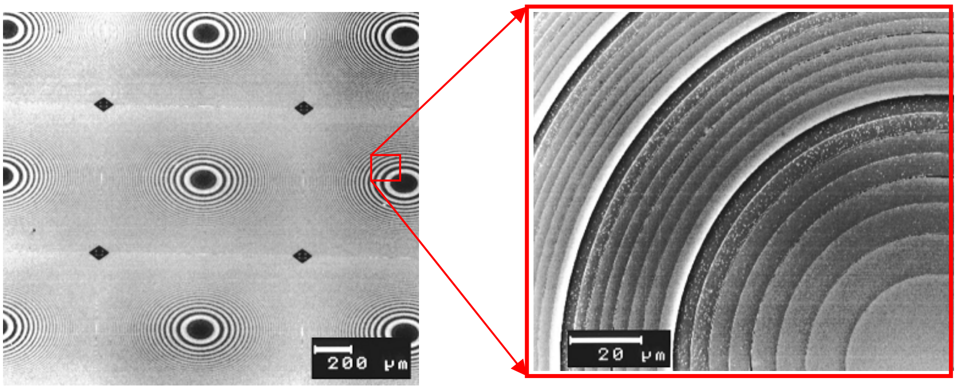
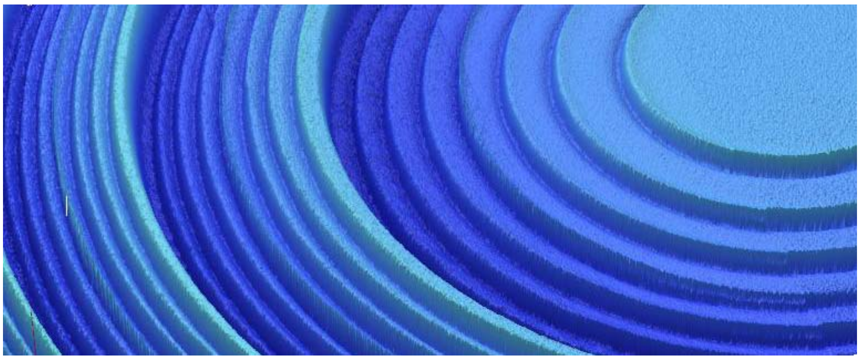
Typical structures		
	Preform preparation by MCVD	Fiber drawing furnace
		
	Microstructured fiber with highly germanium doped core for non linear application	highly birefringent high power laser fiber with filamented Yb doped core for LMA design

Special features	Limitations/constrains	Design rules
• Fibre diameter 60 – 8000 µm • Complex holey structures with structure details < 500 nm • Multiple coating application (high index, low index, temperature resistant)	• Material limitations (high silica glasses, HMO) • Using stack and draw technology limits reproducibility • Limited longitudinal homogeneity	• Hexagonal structure
Further publications (pdf available through NEMOS knowledge management centre)	J. Kobelke, K. Schuster, D. Litzkendorf, A. Schwuchow, J. Kirchhof, V. Tombelaine, H. Bartelt, Ph. Leproux, V. Couderc, A. Labruyere, R. Jamier, “Highly germanium and lanthanum modified silica based glasses in microstructured optical fibers for non-linear applications “, Optical Materials 32 (2010) 1002–1006 Ph. Roy, S. Fevrier, L. Lavoute, D. Gaponov, R. Jamier, C. Lecaplain, G. Martel, A. Hideur, M. E. Likhachev, M. M. Bubnov, E. M. Dianov, M. YU. SalganskiiI, V. F. Khopin, M. YU. Yashkov, A. N. Guryanov, K. Schuster, J. Kobelke, S. Grimm ,”Large Mode Area All-Solid Optical Fiber Lasers with Tailored Microstructured Cladding“, Fiber and Integrated Optics, 27, 440–452, 2008	

Partner:	**INSTITUTE OF ELECTRONIC MATERIALS TECHNOLOGY**	Prototyping Mastering
	Wolczynska 133, 01-919 Warsaw, Poland	
	http://www.itme.edu.pl/PRDOEs.htm	

Technology:	Multi-step electron beam technology for the fabrication of diffractive optical elements	

resp. person	Andrzej Kowalik	akowalik@itme.edu.pl	+48 22 835 30 41	+48 22 864 54 96

Technology:	Multi-step electron beam technology enables the fabrication of a structure with the $L=2^n$ discrete phase levels in n sequential lithographic steps. In each step, the pattern written in a resist layer is transferred after development into the substrate by reactive ion etching to form the phase profile. The method has been successfully applied in the fabrication of different types of diffractive elements, including spherical, cylindrical or elliptical diffractive lenses and their arrays on quartz, GaAs and Si wafers. The diffraction efficiencies of 8-phase-level elements were found to be up to 92%. The lens exhibited diffraction-limited focusing characteristics and an insignificant wave front aberration (rms 0.01λ).
Typical structures	 *fragment of the microlens array* *central region of the quartz f/5 microlens*
	Fig. 1. SEM photographs of 8-level diffractive microlenses.
	
	Fig. 2. 3D optical profilometer image of the 8-phase-level quartz microlens.

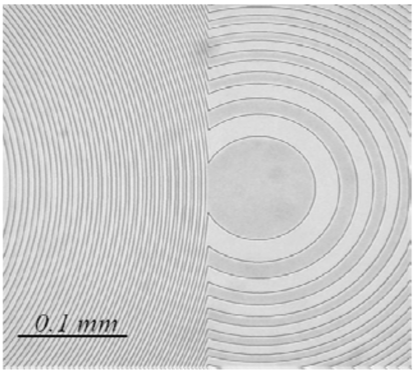


Fig. 3. Outer fragment of the diffractive beam concentrator (elliptical lens array) for linear laser diode arrays.

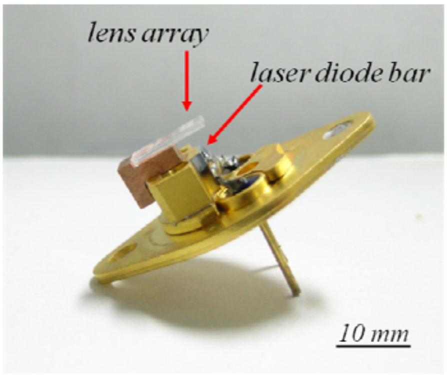


Fig. 4. Laser diode bar in a standard package equipped with diffractive beam concentrator (elliptical lens array).

Special features	Limitations/constrains	Design rules
• large area elements • submicrometer feature size • binary elements generated in PMMA resist (fast and cheap method of prototyping) • binary and multilevel elements on quartz, Si and GaAs wafers	• max. pattern size: 100x100 mm^2 • minimal feature size: binary element - 0.4 µm, multilevel element – 0.6 µm • position resolution - 0.1 µm	Data format • standard elements (e.g. spherical or elliptical lenses) – list of basic parameters • computer generated holograms – AutoCAD drawing or DXF file consisting of polylines, arcs and circles.

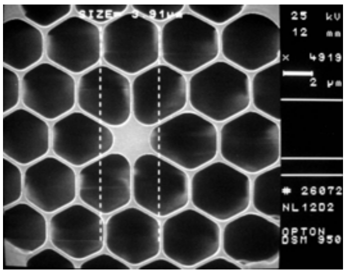
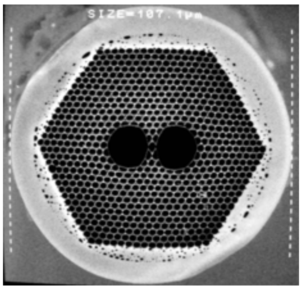
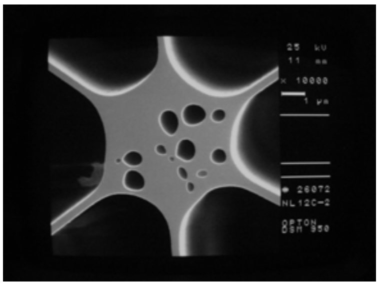
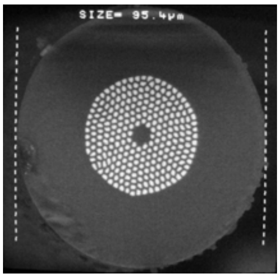
Further publications	
	A. Kowalik, K. Góra, Z. Jaroszewicz, A. Kołodziejczyk: *Multi-step electron beam technology for the fabrication of high performance diffractive optical elements*, Microelectronic Engineering 77 (2005), 347-357 A. Kowalik, K. Góra, G. Adamkiewicz, M. Ziętek, G. Mikuła, A. Kołodziejczyk, and Z. Jaroszewicz: *Efficient Diffractive Collimator for Edge-Emitting Laser Diodes*, Proc. SPIE 6189, (2006), 61871E, A. Kowalik, A. Kołodziejczyk, and Z. Jaroszewicz: *Diffractive beam concentrator for laser diode bars*, Proc. EOS Annual Meeting 2008, Tom4-Micro- and Nanoscale Photonics Systems (2008) A. Kowalik, Z. Jaroszewicz, A. Kołodziejczyk, and T. Osuch: *Apodised linear axicons*, Proc. SPIE 7141, (2008),

Partner:ITME	**INSTITUTE OF ELECTRONIC MATERIALS TECHNOLOGY**	Prototyping X
		Mastering X
	Wolczynska 133, 01-919 Warsaw, Poland	Replication
	http://www.itme.edu.pl , www.supercontinuum.pl	

Technology: (identification name)	Fabrication of nonlinear photonic crystal fibers (PCF)	

resp. person	dr. Ryszard Buczynski	ryszard.buczynski@itme.edu.pl	48 228353041 int.456	Fax of resp. person

Technology: (short description, appr. 100 words)	ITME offers a full food-chain for a development of nonlinear photonic crystal fibers (PCF), form glass synthesis and its characterization, though design up to manufacture and testing.

Typical structures		
	Nonlinear photonic crystal fibers	Dular air core photonic crystal fiber
		
	Air-glass nanostructures in the fibers	All-solid microstructured fibers

Special features	Limitations/constrains	Design rules
• active fibers, metal oxide soft glasses, silica glass, nanostructures in the fiber	• minimum feature size of nanorods is 50 nm	• finite element method, plane wave expansion, SSFM

Further publications (pdf available through NEMOS knowledge management centre)	1. R. Buczynski, H.T. Bookey, D. Pysz, R. Stepien, I. Kujawa, J.E. McCarthy, A.J. Waddie, A.K. Kar, M.R. Taghizadeh, Supercontinuum generation up to 2.5 um in photonic crystal fiber made of lead-bismuth-galate glass, Laser Phys. Lett. 7(9), 666-672 (2010). 2.R. Buczynski, I. Kujawa, D. Pysz, T. Martynkien, F. Berghmans, H. Thienpont and R. Stepien, Highly birefringent soft glass rectangular photonic crystal fibers with elliptical holes, Appl. Phys. B, 99 13-17(2010). 3. R. Buczynski, D. Pysz, T. Martynkien, D. Lorenc, I. Kujawa, T. Nasilowski, F. Berghmans, H. Thienpont, and R. Stepien, Ultra flat supercontinuum generation in silicate dual core microstructured fiber, Laser Phys. Lett. 6(8), 575–581 (2009)

Partner:	**Karlsruhe Institute of Technology (KIT)**	Prototyping
	Institute for Microstructure Technology	Mastering
	Hermann-von-Helmholtz-Platz 1; D-76131 Eggenstein-Leopoldshafen	
	http://www.imt.kit.edu/english/profile.php	
Technology: (identification name)	Deep X-ray lithography	

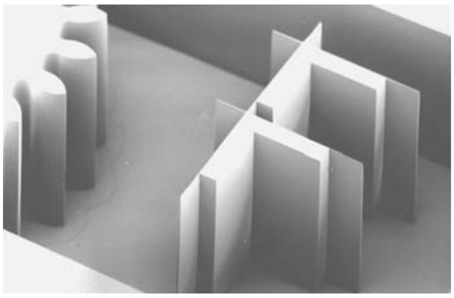
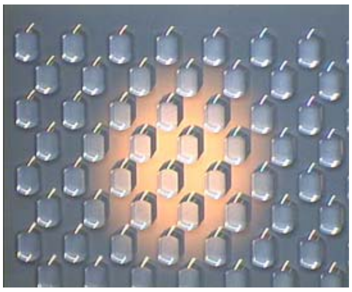
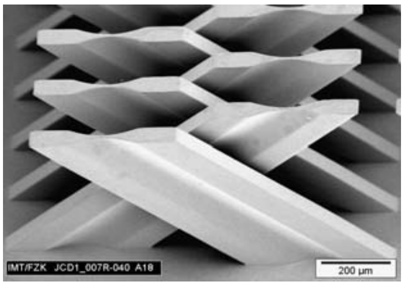
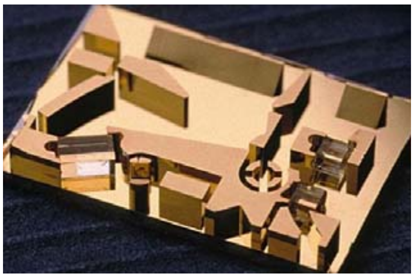
resp. person	Dr. Martin Börner	boerner@kit.edu	+49-7247-824437	+49-7247-824331

Technology:
(short description, appr. 100 words)

Deep X-ray lithography uses synchrotron radiation to pattern thick PMMA layers (thickness: several microns up to several millimetres) in order to achieve high aspect ratio microstructures (aspect ratio up to 50) with precisions in the submicrometer range.

The structures are characterised by very steep sidewalls (slope angle better than 1 mrad) and sidewall roughness in the range of 20 to 30 nm. The technology is used to fabricate mechanical, optical as well as fluidic micro structures. In case of optical applications usually micro-optical benches with cylinder lenses, prisms and fixing structures for other optical components are fabricated.

The structures are either used as prototypes, as lost forms for metal replication or as moulds to fabricate mould inserts.

Typical structures		
		
	500 µm high PMMA structure (width of the small bare: 5 µm)	Cylindrical lenses with optimized curvatures
		
	Crossed X-ray lenses (SU-8)	Micro-optical bench with cylindrical mirrors and fixing strutures

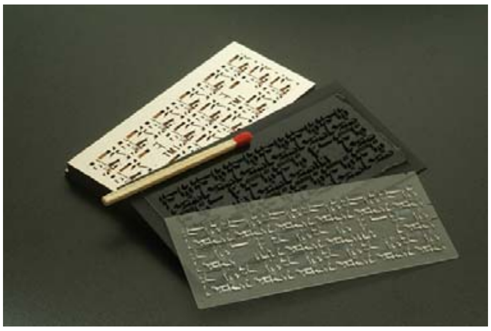
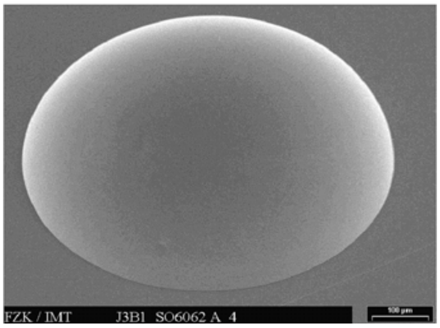
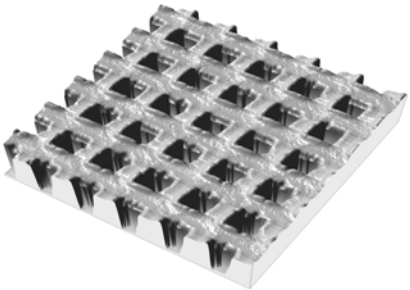
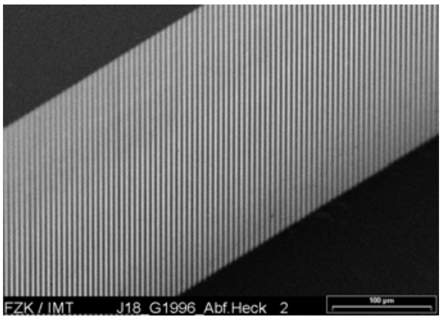
Special features	**Limitations/constrains**	**Design rules**
• Aspect ratios up to 50 and higher (depending on design features) • Structural height up to several millimetres • Structural details less than 1 µm • Slope angle better than 2 mrad • Roughness Ra < 30 nm	• 2.5D shape (transfer of a 2D shape into the depth) • Only PMMA and SU8 (in case of prototyping) • Time consuming process for prototyping due to mask fabrication (6 to 8 weeks)	• Rounding of structural edges (radius > 2 µm), smaller values are possible depending on the structure dimension
Further publications	Mohr, J.; Polymer Optics and Optical MEMS; Advanced Micro & Nanosystems, LIGA and its Applications, Edited by Volker Saile, Ulrike Wallrabe, Osamu Tabata and Jan G. Korvink, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Volume 7 (2009), 205-232, ISBN:978-3-527-31698-4 Schüle, S.; Hengsbach, S.; Hollenbach, U.; Li, J.; Leuthold, J.; Mohr, J.; Active Modular Microsystems Based on Mach-Zehnder Interferometers; Photonics Europe 2010, Proceedings of SPIE Vol.7716, 2010 Simon, M.; Nazmov, V.; Reznikova, E.; Last, A.; Mohr, J.; Jakobs, P.-J.; Saile, V.; Bunk, O.; Kewish, C.; Batchelor, D. Simon, R.; Refractive X-ray Optics made from Polymer Microstructures; Photonics Europe : Micro Optics ; Proc.of the Conf., Bruxelles, B, April 12-16, 2010 Bellingham, Wash. SPIE, Vol. 7716 2010 Paper 77161B	

Partner:	**Karlsruhe Institute of Technology**	🟨
	Institute for Microstructure Technology	🟩
	Hermann-von-Helmholtz-Platz 1; D-76131 Eggenstein-Leopoldshafen	Replication
	http://www.imt.kit.edu/213.php	

Technology: (identification name)	Micro Hot Embossing	

resp. person	Alexander Kolew	kolew@kit.edu	+49 7247 82 2761	+49 7247 82 4331

Technology: (short description, appr. 100 words)	In micro hot embossing, a microstructured tool (mould insert) in an evacuated chamber is pressed with high force into a thermoplastic foil that has been heated above its softening temperature. The mould insert is filled by the plastic material that replicates the microstructures in detail. Then, the setup is cooled down and the mould insert is withdrawn from the plastic. Suitable for all structures with precise details in the order of a few hundreds of nanometres up to several millimetres on a large polymer sheet with low inner stress. Other advantages are the multiple special applications developed from basic hot embossing. Aligned moulding for the replication on prestructured substrates, double-sided replication for the fabrication of additional features on the backside or multilayer replication.

Typical structures		
	Mould insert and replicated micro optical bench 750 µm high (PMMA, PC)	Micro lens replicated from a Si-mould insert 800 µm diameter)
		
	Replicated holes with 500 nm width and 1 µm depth.	Micro optical grating replicated by hot embossing

Special features	Limitations/constrains	Design rules
• Prototyping, material screening, multilayer embossing, high precision	• Materials: Thermoplastic polymers, amorphous metals, ceramics • Slow process	• No undercuts in the mould insert • Aspect ratio below 20 for freestanding structures
Further publications (pdf available through NEMOS knowledge management centre)	M. Heckele, W.K. Schomburg: “Review on micro molding of thermoplastic polymers”, *Journal of Mircomechanics and Microengineering*, vol. 14 (2004) pp. R1-R14. M. Heckele, W. Bacher, K.D. Müller: “Hot embossing - The molding technique for plastic microstructures,” *Microsystem Technologies* 4 (1998) 122-124. M. Worgull: Hot embossing: theory and technology of microreplication, Oxford, William Andrew, 2009, ISBN 978-0-8155-1579-1.	

Partner:	**Karlsruhe Institute of Technology**	Prototyping
	Institut für Mikrostrukturtechnik	
	Hermann-von-Helmholtz-Platz 1; D-76131 Eggenstein-Leopoldshafen	
	http://www.imt.kit.edu	

Technology: (identification name)	Modular free space photonic microsystems based on micro optical benches	

resp. person	Sven Schüle	schuele@kit.edu	+49-7247-829239	+49-7247-824331

Technology:
(short description, appr. 100 words)

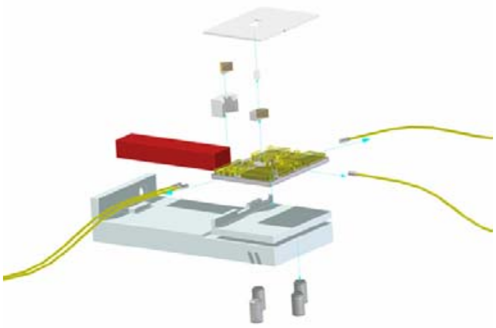
Modular photonic systems are realized on the basis of a concept using LIGA structures as assembling aids, i.e. as microstructured optical benches (MOB) for the integration of hybrid components such as mirrors, prisms, beam splitters, cylindrical lenses, gradient index lenses, or optical fibers. Depending on the desired application, the LIGA structures themselves may include optical features and may serve as cylindrical lenses, aspherical mirrors or plane mirrors. Complex systems are implemented by combining different functional platforms:

- micro-optical bench (MOB) with integrated beam shaping and beam guidance elements,
- electro-optical base plate (EOP) with light sources and detectors,
- actuator platform with movable microstructures,
- interface boards with Bluetooth and USB
- fluid platform with fluid guidance structures.

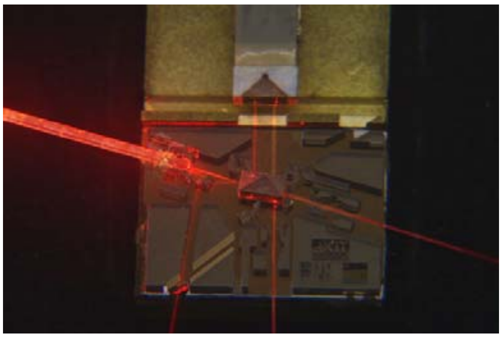
Systems developed during the recent years include, for example, multiport interferometers, laser triangulation sensors, FFT interferometers, bypass switches, attenuators, heterodyne receivers, and fiber plugs.

The components and systems are manufactured applying the LIGA process with mechanical micro-manufacturing and assembly & packaging playing a major complementary role.

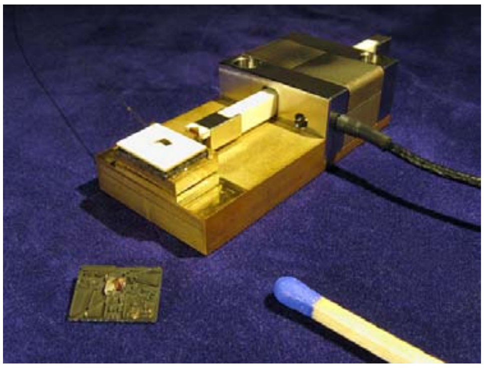
Typical structures



Modular concept of micro-optical sub-systems (example: micro interferometer)



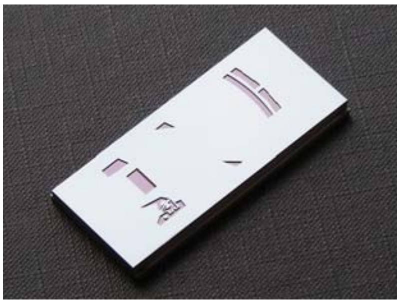
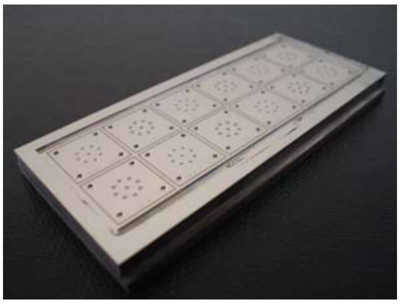
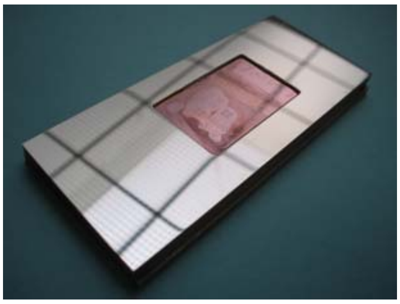
Micro-optical bench (10 mm x 8 mm) of a micro-hybrid interferometer.

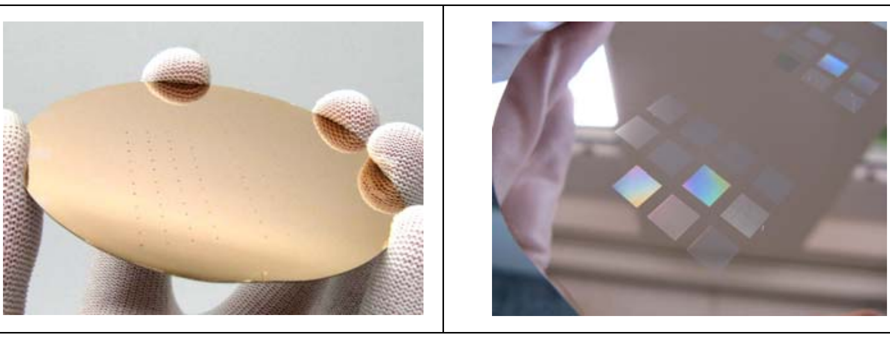
		
	Optical subsystem with a inchworm microactuator module.	Boxed System with electro-optical base plate and interface board.

Special features	**Limitations/constrains**	**Design rules**
• Adaptable to customers wishes • Free space, fiber based or optoelectronical light detection. • Combination with fluid structures possible	• New designs take at least six month • Size of the optical system in the range of e.g. 11 x 8 mm² • Maximum travel range 20 mm	• 2 D optical designs without constraints. • 2 ½ D in- and outcoupling structures possible.
Further publications	Schüle S., Hollenbach U., Li J., Leuthold J., Mohr J., *Set Up of a Modular Micro-Optical System Based on Free Space Optics*, Proc. MOC 2008 Conference, 334-335 (2008). Schüle S., Hollenbach U., Li J., Vorreau P., Efremov A., Schonhardt S., Leuthold J., Mohr J., Active Modular Microsystems Based on Mach-Zehnder Interferometers, Proc. SPIE 7716, (2010). S. Schüle; *Modular adaptive mikrooptische Systeme in Kombination mit Mikroaktoren : ein mikrooptisches System auf der Basis mikrooptischer Bänke.* KIT Scientific Publishing, ISBN-13: 978-3866445291, 2010.	

Partner:	**Karlsruhe Institute of Technology**			
	Institut für Mikrostrukturtechnik			Mastering
	Hermann-von-Helmholtz-Platz 1; D-76131 Eggenstein-Leopoldshafen			
	www.imt.kit.edu			
Technology: (identification name)	Fabrication of micro- or nanostructured mold inserts			
resp. person	Dr. Markus Guttmann	markus.guttmann @kit.edu	+49-7247-823850	+49-7247-824331

Technology: (short description, appr. 100 words)	For the fabrication of micro- or nanostructured mold inserts, usually lithography structures (E-Beam lithography, X-ray lithography, Deep lithography with protons) or mechanical machined structures are used. The structures are fabricated either directly on top of a copper or silicon substrate as well as mounted on the substrate by special methods. This polymer template on an electrically conducting substrate is metallized by PVD technique and subsequently filled electrochemically with a metal suitable for molding, typically Nickel. The deposition of the metal is continued significantly beyond the resist height until a thick metal layer has developed above the resist, forming a continuous and solid metal base-plate for the fragile micro- or nanostructures. This monolithic approach leads to molds of different thickness with excellent height control and, through the rigid base-plate, to molds that can withstand the mechanical loads during the injection molding / hot embossing process.

Typical examples		
	Nickel mold inserts (LIGA fabrication) with microspectrometer layout (left) and gear wheel layout (right)	
		
	Nickel mold insert (combination of deep proton writing, joining technology and electroplating) for a fiber connector plate (left) or for optical prisms (right)	



Shim mold inserts in nickel with optical nanostructures

Special features (LIGA)	**Limitations/constrains**	**Design rules**
• Aspect ratios up to 20 (single standing structures) • Structural depth up to 1000 µm • Structural details less than 1 µm • Slope angle better than 1 mrad • Roughness Ra < 30 nm	• Resist material: PMMA • Mold insert material: nickel • Max. structured area: up to 60 x 20 mm • Mold insert size: 66 x 30 x 5 mm • Time consuming process due to mask fabrication (10 to 12 weeks) – not for prototyping	•

Special features (Shims)	**Limitations/constrains**	**Design rules**
• Aspect ratio up to 3 • Structural depth between 25 nm and 3,5 µm • Structural details wider than 25 nm	• Resist material: PMMA • Mold insert material: nickel • Max. structured area: up to 80 mm in diameter • Mold insert size: 86 mm in diameter or smaller • fabrication time depends on availability of e-beam writer; normally 1 to 2 weeks	•

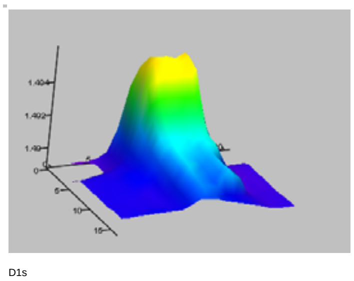
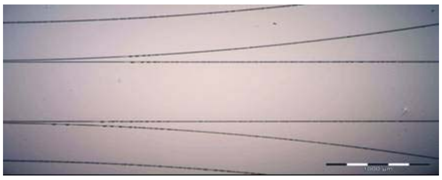
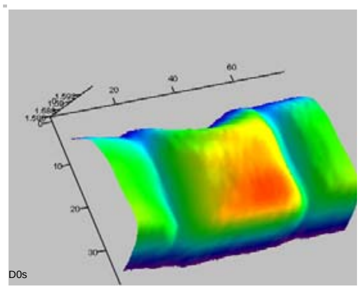
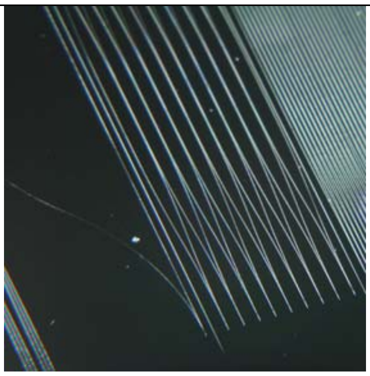
Further publications (pdf available through NEMOS knowledge management centre)	M. Guttmann, J. Schulz, V. Saile; *„Lithographic Fabrication of Mold Inserts"* in „Advanced Micro and Nanosystems", Vol. 3, Microengineering of Metals and Ceramics, edited by H. Baltes, O. Brand, G.K. Fedder, C. Hierold, J.G. Korvink, O. Tabata, Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, (2005) 187-219 J. Van Erps, M. Wissmann, M. Guttmann, M. Hartmann. C. Debaes, J. Mohr, H. Thienpont[1]; *"Hot embossing of microoptical components prototyped by deep proton writing";* IEEE Photonics Technology Letters, 20 (2008) 1539-1541 M. Wissmann, M. Guttmann, M. Hartmann, M. Beiser; *„Alternative technology for fabrication of nano- or microstructured mould inserts used for optical components"*; Proc. SPIE Vol. 7590 (SPIE Photonics West; San Francisco, January 2010) C. Vannahme, S. Klinkhammer, A. Kolew, P.-J. Jakobs, M. Guttmann, S. Dehm, T. Mappes, U. Lemmer; *„Fabrication process for the integration of organic lasers and passive waveguides into PMMA substrate"*; Microelectronics Engineering, 87 (2010) 693-695

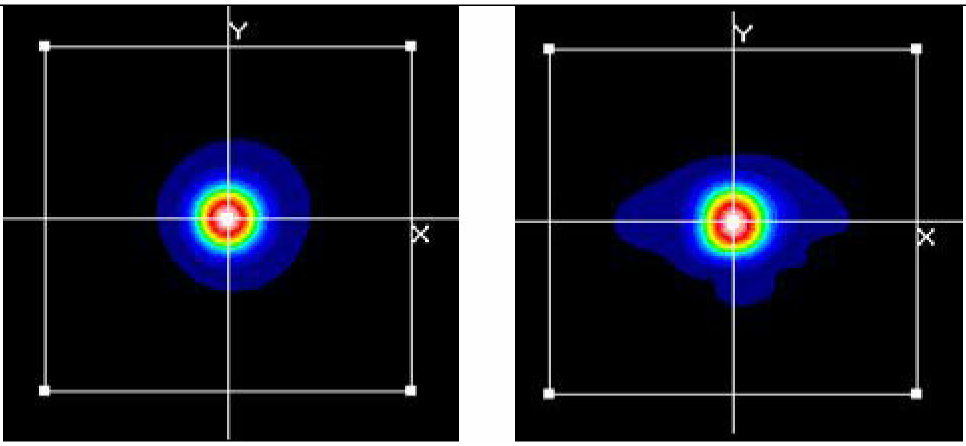
Partner:	**Forschungszentrum Karlsruhe**	Prototyping
	Institut für Mikrostrukturtechnik	
	Postfach 3640, 76021 Karlsruhe	

Technology: (identification name)	Waveguide fabrication in polymers by UV modification	

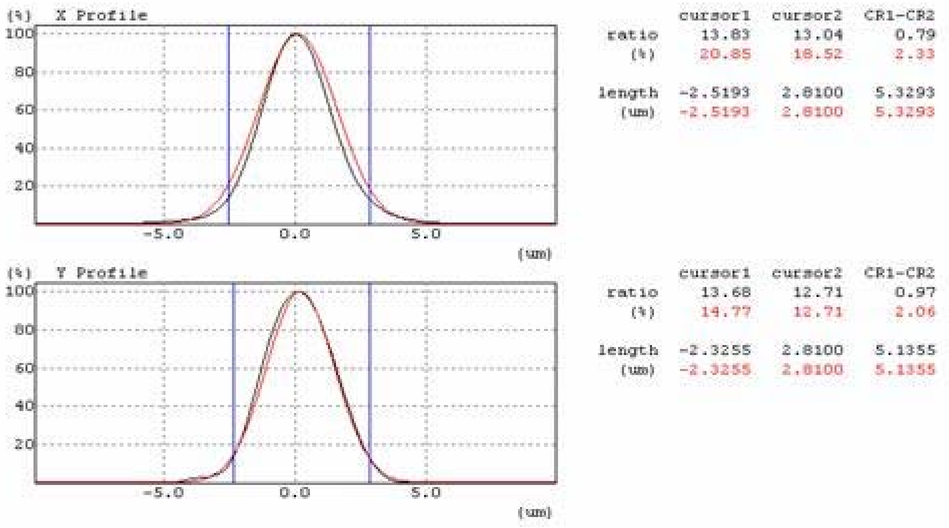
resp. person	Uwe Hollenbach	Uwe.Hollenbach@kit.edu	+49-7247-822767	+49-7247-824331

Technology: (short description, appr. 100 words)	Integrated optical systems are fabricated on the basis of a photosensitive process that allows manufacturing single- or multi-mode optical waveguides in polymers, for example in PMMA plates or in epoxy resist, by means of UV exposure. In a simple quasi-single-material process, optical waveguides embedded in a substrate are obtained after exposure and tempering for cross-linking of the photosensitive epoxy resist. Novel polymer mixtures with improved properties in view of modal field symmetries and refraction index contrasts of structured optical waveguides are developed and tested.

Typical structures		
	3D Refractive index distribution in PMMA after UV exposure	Single mode waveguide in PMMA fabricated by deep UV exposure
		
	3D Refractive index distribution in Epoxy after UV exposure	Single mode waveguide in Epoxy fabricated by i-line UV exposure



Mode intensity distributions of a single-mode fiber (left, for comparison) and an optical waveguide in epoxy (right) @ 808nm after mode field diameter adjustment.



Intensity sections with nearly perfect Gaussian distribution of the near-field intensity of an optical waveguide in epoxy @ 808nm.

Special features	Limitations/constrains	Design rules
Single mode wave-guides in PMMA for VIS range 500 – 700 nm, [1], [2], [3], [4]	Intrinsic loss ~1 dB/cm (structured waveguides, not covered by over cladding) PDL ~0.5 dB	smallest core diameter 2 µm also combined with bio- fluidic plattforms
Single mode wave-guides in Epoxy for NIR range 780 – 1310 nm, [5], [6], [7]	Intrinsic loss ~ 0.2 dB/cm (structured waveguides, covered by overcladding) PDL ~0.5-1 dB	smallest core diameter 2 µm multilayer compatible

Further publications

[1] Patric Henzi, Dominik Rabus, Klaus Bade, Alexander Welle, Juergen Mohr: UV-Induced Modification of Dielectric Properties of Polymers for Photonic applications

[2] P. Henzi, D. G. Rabus, U. Wallrabe, J. Mohr: Fabrication of Photonic Integrated Circuits by DUV-induced Modification of Polymers

[3] Mathias Bruendel, Yasuhisa Ichihashi, Juergen Mohr, Martin Punke, Dominik G. Rabus, Matthias Worgull, Volker Saile, “Photonic Integrated Circuits fabricated by Deep UV and Hot Embossing”, Proc. of ………….. Invited paperTuB2.6 ieeexplore.ieee.org/iel5/4288288/.../04288354.pdf

[4] Dominik G. Rabus, Mathias Bruendel, Yasuhisa Ichihashi, Alexander Welle, R. Adam Seger, Michael Isaacson, “ A Bio–Fluidic–Photonic Platform Based on Deep UV Modification of Polymers”, IEEE Journal of Selected Topics In Quantum

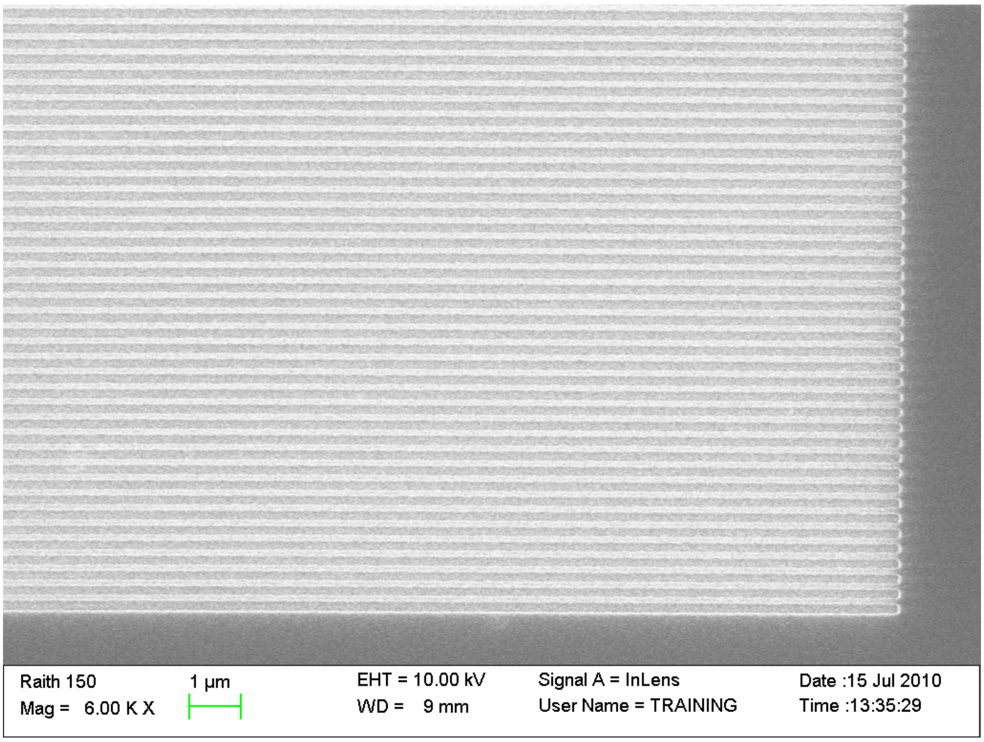
	Electronics, Vol. 13, No. 2, March/April 2007 [5] U. Hollenbach, H.-J. Boehm, J. Mohr, D. Ross, D. Samiec, “UV Light Induced Single Mode Waveguides in Polymer for Visible Range Application”, Proc. Of European Conf. on Integrated Optics (ECIO), Paper THD3, Copenhagen, Denmark, April 25-27, 2007. [6] G. Golojuch, U. Hollenbach, T. Mappes, J. Mohr, A. Urbanczyk, W. Urbanczyk, “Investigation of birefringence in PMMA channel waveguides inscribed with DUV radiation”. Measurement Science and Technology, Vol. 19, pp. 025304/1-6, 2008. [7] H. Sieber, H.-J. Boehm, J. Mohr, U. Hollenbach, J. Leuthold, N. Lindenmann, „Polymer Light Waveguides for Nanophotonics; Manufactoring Process and Refractive Index Profile Analysis“, Proc. Of European Conf. on Integrated Optics (ECIO), Poster presentation WeP35, Cambridge, April 07-09, 2010.	

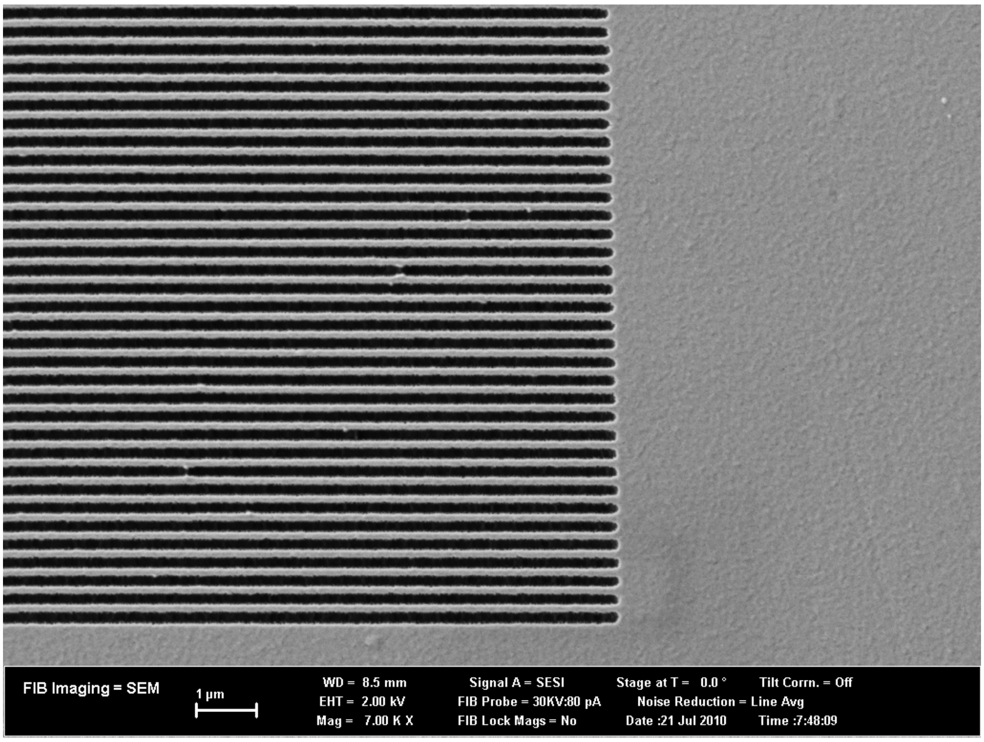
Partner:	**Max Planck Institute for the Science of Light (MPL)**	Prototyping
	Division 1: Prof. Dr. Gerd Leuchs	Mastering
	Staudtstr. 7/B2, 91058 Erlangen, Germany ***and** Günther-Scharowsky-Str. 1, Bau 24,* *91058 Erlangen, Germany*	
	http://mpl.mpg.de/mpf/php/abteilung1/index.php?lang=en	

Technology: (identification name)	E-beam writing of optical elements (system RAITH 150two)	

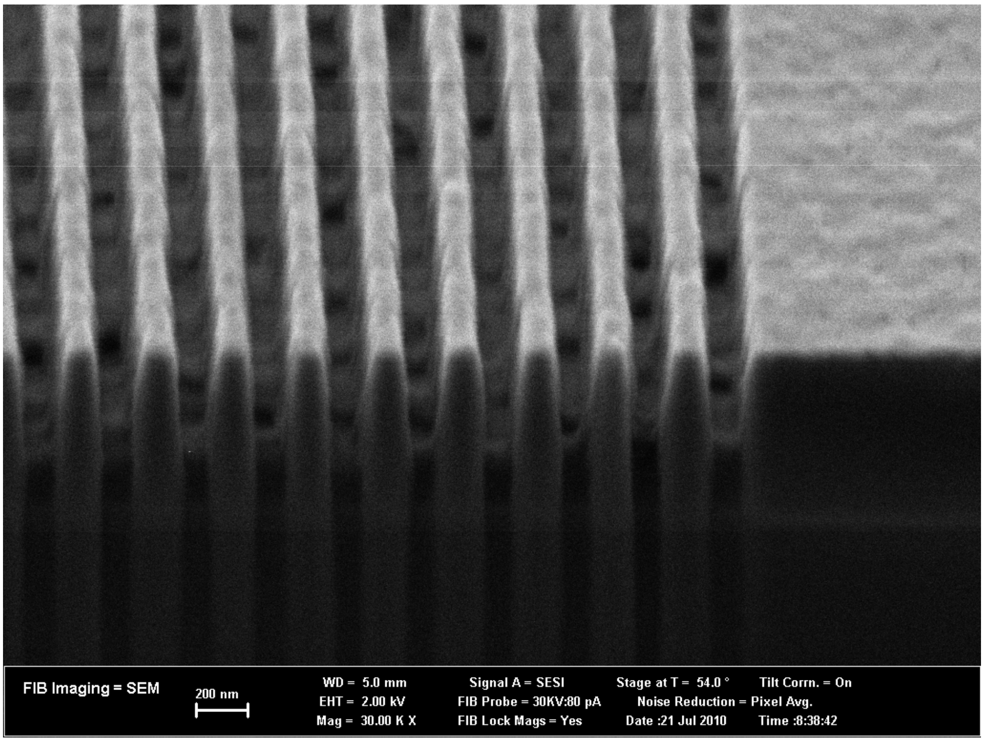
resp. person	Prof. Dr. Norbert Lindlein	norbert.lindlein@physik.uni-erlangen.de	++49-9131-8528395	++49-9131-13508

Technology: (short description, appr. 100 words)	Structures down to 10 nm line width can be written by e-beam into resist and subsequently etched (by reactive ion etching or wet chemical etching) into the layer beneath (metal or glass substrate). A gray scale illumination is possible to achieve three-dimensional structures in resist. For large one-dimensional structures a so called “fixed beam moving stage” mode exists, where the stage is moved while the beam deflection corrects only small deviations of the stage path electromagnetically. This allows to write e.g. long linear or curved trajectories without having the typical stitching errors of e-beam writing systems. Although the writing area is quite large (150 mm x 150 mm), the writing speed is quite limited so that only small fields can be written on the whole area (about 1 mm^2 filled area in 4 hours for a simple grating, for more complex structures the writing time can increase significantly). A mix and match operation with the laser lithography system Heidelberg Instruments DWL 425 is possible, so that coarse and large structures can be written there.

<table>
<tr>
<td>Typical structures</td>
<td>




</td>
</tr>
</table>

	
	SEM pictures of sub-wavelength grating (period 300 nm) acting as artificial quarter wave plate fabricated in SiN_x. Top row: resist structure before etching, central row: etched structure, bottom row: cross section of the etched grating structure.

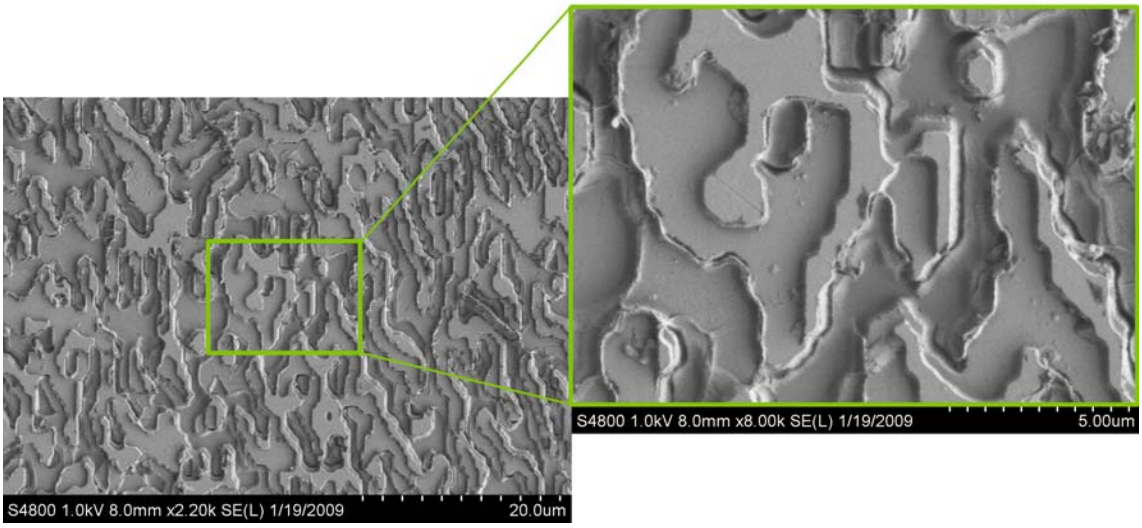
Special features	Limitations/constrains	Design rules
• Minimum feature size: 10 nm • Maximum writing area: 150 mm x 150 mm	• Stitching accuracy (3σ) < 80 nm • Overlay accuracy (3σ) <80 nm • Fixed beam moving stage accuracy < 10 nm • Writing speed: depends strongly on the concrete structure; for simple grating it is about 0.25 mm^2/h	• File formats: GDS II, Bitmaps
Further publications (pdf available through NEMOS knowledge management centre)	No publications available up to now.	

Partner:	**Max Planck Institute for the Science of Light (MPL)**	Prototyping
	Division 1: Prof. Dr. Gerd Leuchs	Mastering
	Staudtstr. 7/B2, 91058 Erlangen, Germany ***and** Günther-Scharowsky-Str. 1, Bau 24,* *91058 Erlangen, Germany*	
	http://mpl.mpg.de/mpf/php/abteilung1/index.php?lang=en	

Technology: (identification name)	Laser lithography for fabrication of micro optical elements	

resp. person	Prof. Dr. Norbert Lindlein	norbert.lindlein@physik.uni-erlangen.de	++49-9131-8528395	++49-9131-13508

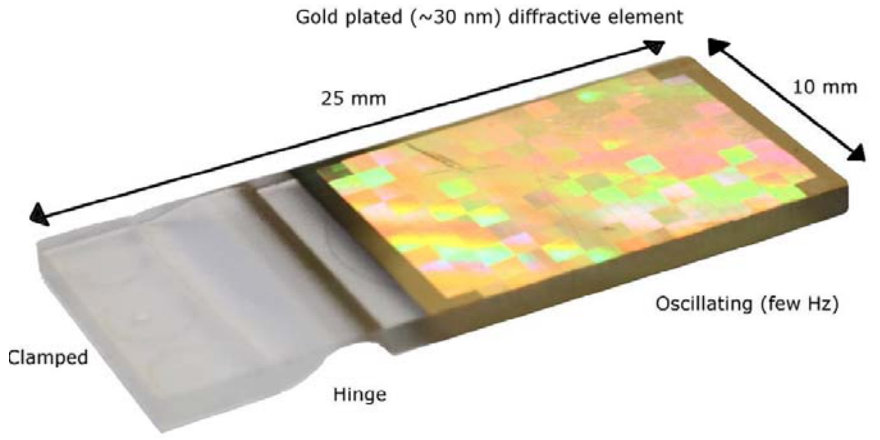
Technology: (short description, appr. 100 words)	Structures down to 0.5 µm line width can be written by a laser into photo resist and subsequently etched (by reactive ion etching or wet chemical etching) into the layer beneath (metal or glass substrate). A gray scale illumination with 128 intensity levels is possible to achieve three-dimensional structures in photo resist. The writing head (lens) can be changed so that the numerical aperture of the lens and hence the lateral resolution and depth of focus change also. Additionally, the writing speed then changes and structures with smaller lateral resolution can be written faster. A mix and match operation with the e-beam writing machine RAITH 150two is possible for writing locally small structures.
Typical structures	
	Diffractive optical element for testing a spherical surface, i.e. diffractive optical lens, fabricated in fused silica. Left: binary element, right: blazed element.

	 Local part of a diffractive beam shaping element with four height levels fabricated in fused silica (SEM picture).	
Special features	Limitations/constrains	Design rules
- Minimum feature size: 0.5-0.6 µm - Maximum writing area: 400 mm x 400 mm - Writing speed: 12 mm^2/min (0.5-0.6 µm minimum feature size) 265 mm^2/min (1.6 µm minimum feature size)	- Edge roughness < 80 nm - Overlay accuracy < 80 nm - Interferometric position control: 10 nm	- File formats: GDS II, CIF, DXF, Bitmap
Further publications (pdf available through NEMOS knowledge management centre)	*No specific publications available up to now.*	

Partner:	**SINTEF**	
	SINTEF Materials and Chemistry	
	PO Box 124 Blindern, NO-0314 OSLO, Norway	Replication
	http://www.sintef.no/mpc	

Technology: (identification name)	Injection moulding (thermoplastic polymer materials)	

resp. person	Erik Andreassen	erik.andreassen@sintef.no	+47-9828-2492	

Technology: (short description, appr. 100 words)	Components with relatively high precision and small micro features can be mass produced at low cost by injection moulding. A mould insert (master) can made by any adequate technique, e.g. electron beam lithography followed by Nickel electroplating, or direct mechanical micromachining of brass. A number of thermoplastic polymer materials can be injection moulded. Examples: COC, COP, PC, PMMA and PSU. There are also elastomer materials with some transparency. The materials can also be modified, e.g. in order to reduce the thermal expansion (in this case the transparency is usually lost). SINTEF can mould small series (10-100 parts), as well as larger series. Different polymer materials can be tested.
Typical structures	 Fig 2 Oscillating diffractive optical element in CO_2 sensor (OptoSense, Norway)

Special features	Limitations/constrains	Design rules
• Variotherm process for structures with high aspect ratio • Injection-compression moulding for thin-walled large-area parts (this process is used for the 0.6 mm thick layers in DVDs) • SINTEF has two injection moulding machines and several mould bases (for mounting inserts). • SINTEF's smallest injection moulding machine can be used for special materials that are only available in small amounts (e.g. < 50 g), or materials that are modified as part of the project. This machine is used in combination with a special mixer (extruder) unit.	• It is an advantage if the master fits one of the existing mould bases. • SINTEF's equipment is not suitable for micro parts • Aspect ratios above 1 are challenging, and the replication depends on the properties of the master (surface roughness, surface chemistry, draft angle) and the polymer material. If the aspect ratio is low, the features can be very small.	• Avoid undercuts in master • A draft angle is usually needed in order to eject the finished part without defects • The part is usually ejected by ejector pins, which leave small marks on the surface
Further publications	T. R. Tofteberg, H. Amedro, F. Grytten, E. Andreassen, *Effects of injection molding holding pressure on the replication of surface microfeatures*, International Polymer Processing, 25, 236 (2010) T. R. Tofteberg, E. Andreassen, *Multiscale simulation of injection molding of parts with low aspect ratio microfeatures*, International Polymer Processing, 25, 63 (2010) T. Tofteberg, H. Amedro, E. Andreassen, *Injection molding of a diffractive optical element*, Polymer Engineering and Science, 48, 2134-2142 (2008)	

Partner:	**University of Eastern Finland**	Prototyping
	Department of Physics and Mathematics	Mastering
	Yliopistokatu 7, FI-80100 Joensuu, Finland	
	http://www.uef.fi/fysmat	

Technology: (identification name)	Electron beam lithography	

resp. person	Pertti Pääkkönen	Pertti.paakkonen@uef.fi	+358 13 251 3238	+358 13 251 3290

Technology: (short description, appr. 100 words)	The electron beam lithography (EBL) uses electrons to pattern resist layers. In our Vistec EBPG5000+ES EBL system the energy of electrons can be chosen in the range 50-100 keV. Depending on the type of used resist and conditions of the exposure different kind of profiles can be obtained: positive or negative, binary or multilevel (Figs. 1 – 3). The type of resist is chosen depending on application and on possible further processing steps (lift-off, reactive ion etching, wet etching e.t.a., Figs. 4 - 6).

Typical structures

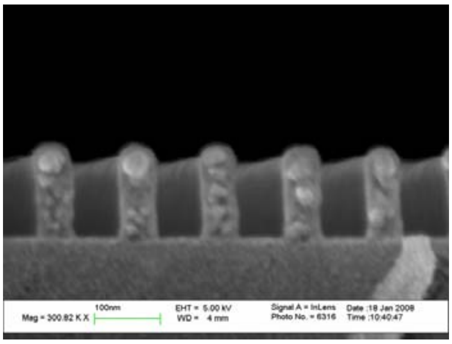


Fig 1. Side-view of binary a profile on a 140 nm positive resist after EBL. Line width 60 nm.

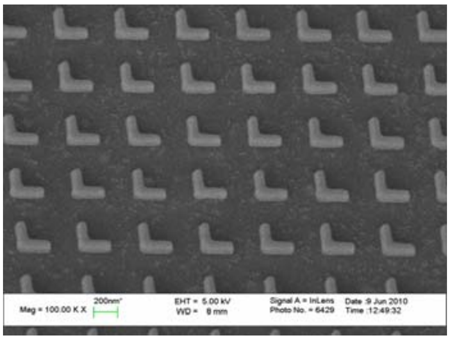


Fig 2. Nanopatterns on a high resolution negative EBL resist. Line width 80 nm.

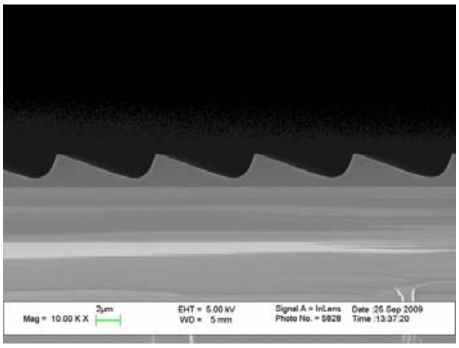


Fig 3. Side-view of multilevel profile in low contrast resist after EBL. Period of the grating 8 µm.

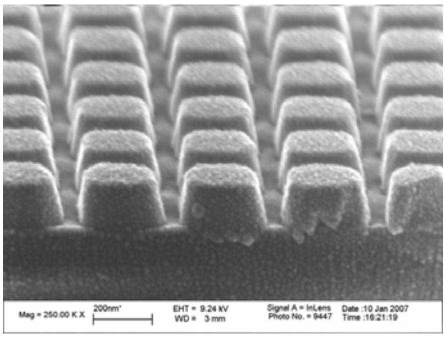
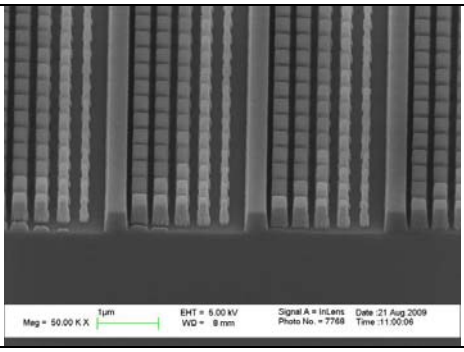
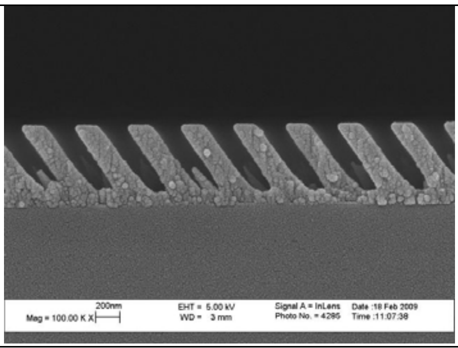


Fig. 4. Pillars etched into quartz using lift-off technique. Pillar diameter 250 nm, height 150 nm.

		
	Fig. 5. Polarization insensitive blazed Si3N4 grating on SiO2. Profile depth 570 nm.	Fig. 6. Slanted TiO2 grating on SiO2. Line width 200 nm, profile height 630 nm.

Special features	Limitations/constrains	Design rules
• Gaussian electron beam vector scan system • Multiple exposure is possible using alignment marks. Positioning accuracy is ~30 nm.	• For submicron structures exposure time strongly depends on number of features (lines/rectangles).	• Customer designed patterns shall be delivered as GDSII, Vistec GPF, CIF, Bitmap, or AutoCAD DXF files with certain limitations.
Further publications (pdf available through NEMOS knowledge management centre)	P. Laakkonen, J. Lautanen, V. Kettunen, J. Turunen, and M. Schirmer, “Multilevel diffractive elements in SiO2 by electron beam lithography and proportional etching with analogue negative resist,” Journal of Modern Optics 46, 1295-1307 (1999). A. Hakola, S. C. Butcher, T.Kajava, H. Elfström, J. Simonen, P. Pääkkönen, and J. Turunen, “Bessel-Gauss output beam from a diode pumped Nd:YAG Laser,'” Opt. Commun. 238, 335-340 (2004). S. Yu, Popov, A. T. Friberg, M. Honkanen, J. Lautanen, B. Schnabel, “Apodized annular-aperture diffractive axicons fabricated by continous path-control electron beam lithography”, Opt. Commun. 154, 359-367 (1998). Heikki J. Hyvärinen, Petri Karvinen, and Jari Turunen, "Polarization insensitive resonance-domain blazed binary gratings," Opt. Express 18, 13444-13450 (2010).	

Partner:	**University of Eastern Finland**	Prototyping
	Department of Physics and Mathematics	Mastering
	Yliopistokatu 7, FI-80100 Joensuu, Finland	
	http://www.uef.fi/fysmat	

Technology: (identification name)	RIE and ICP ion etching of dielectrics and metals	

resp. person	Victor Prokofiev	victor.prokofiev@uef.fi	+358 13 251 3211	+358 13 251 3290

Technology: (short description, appr. 100 words)	Reactive ion etching (RIE) is a sophisticated method to transfer the pattern from the resist or metal mask into the underlying layer or substrate. We are mainly specialized in RIE of SiO2 substrates since it is most common material used for production diffractive optical elements. Different types of profiles can be achieved by using different types of the etching mask: binary (Figs.1-2), multilevel (Fig. 3) or continuous. Also hybrid type profiles can be obtained, such as depth-modulated binary gratings shown in Fig. 4. Chromium dry etch process in chlorine/oxygen plasma was developed and optimized on the Oxford Instruments Plasma Technology PlasmaLab System 100 (ICP 380) machine. The similar process for aluminum etching is under development.

Typical structures

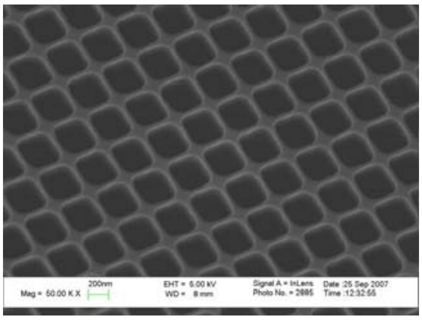


Fig 1. Two dimensional grid etched into Silicon. Line width 90 nm, profile depth 190 nm.

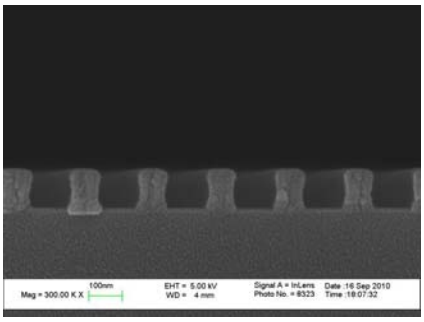


Fig 2. Chromium lines etched with EBL resist mask in a Cl2/O2 process. Line width 90 nm, line height 128 nm.

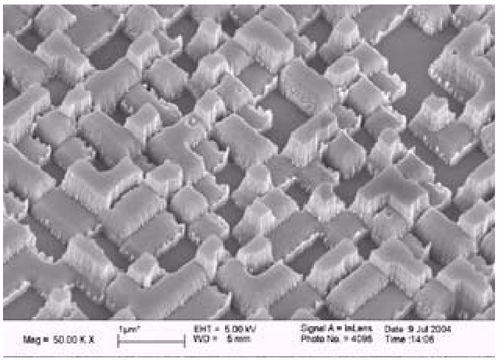


Fig 3. Four-level pixelized structure in SiO2. Pixel
size 450 nm.

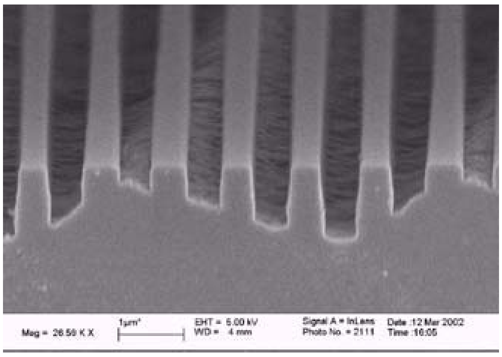


Fig. 4. Depth modulated binary grating. Linewidth 1 µm.

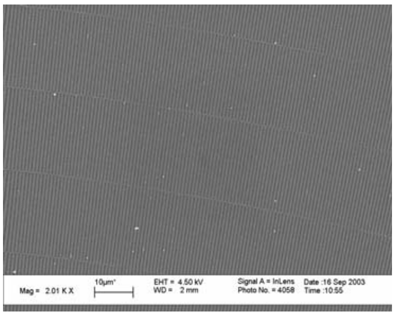
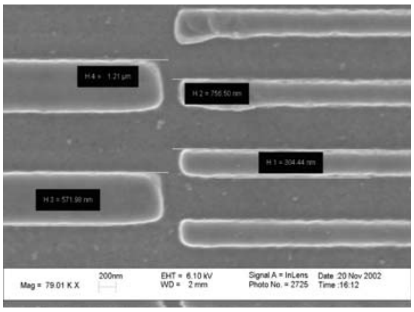
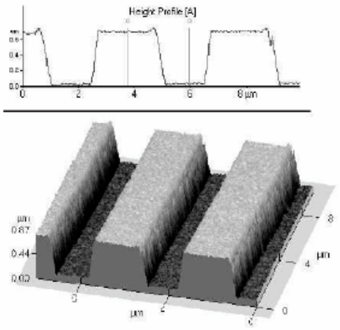
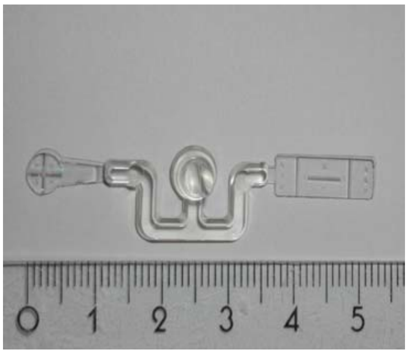
Special features	Limitations/constrains	Design rules
• Typical etching rate of SiO2 ~40 nm/min (much faster using ICP) • Both isotropic and anisotropic etching can be achieved by varying the etching parameters.	• The resolution is basically limited by the etching mask. • Etching depth is limited by the thickness and selectivity to the mask to the substrate. Usually, it does not exceed 2-3 µm in case of SiO2.	
Further publications (pdf available through NEMOS knowledge management centre)	Janne Simonen: *Applied diffractive optics with electron beam lithography*. University of Joensuu. Dissertations 37, 2003. Konstantins Jefimovs*: Fabrication of surface relief diffractive optical elements and their applications.* University of Joensuu, Dissertations 40, 2003.	

Partner:	**University of Eastern Finland**	
	Department of Physics and Mathematics	
	Yliopistokatu 7, FI-80100 Joensuu, Finland	Replication
	http://www.uef.fi/fysmat	

Technology: (identification name)	Micro injection moulding	

resp. person	Pertti Pääkkönen	pertti.paakkonen@uef.fi	+358 13 251 3238	+358 13 251 3290

Technology: (short description, appr. 100 words)	Micro-injection moulding disparity from traditional injection moulding is that current method has designed for the small products and details (shot volume less than 1 cm^2). The micro structures are fabricated to the surface of the small products and micro parts. Micro structures are copied from insert located in to the injection mould. The insert material can be SiO_2, Si or Nickel.

Typical structures		
	Fig 1. Binary injection moulded grating. Grating period 750 nm and height 380 nm.	Fig 2. Binary injection moulded gratings. Line width 200 nm and height ~200 nm.
		
	Fig 3. Binary injection moulded grating. Grating period 4 µm and height 700 nm.	Fig 4. Micro-injection moulded part with surface relief test structures.

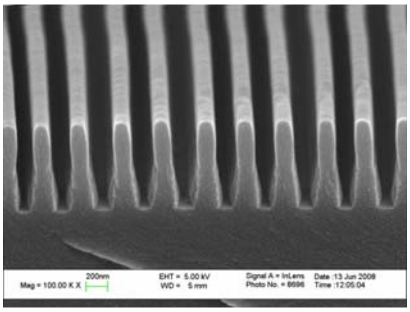
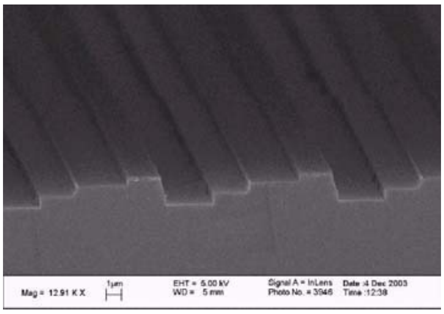
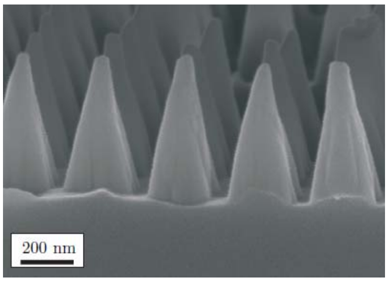
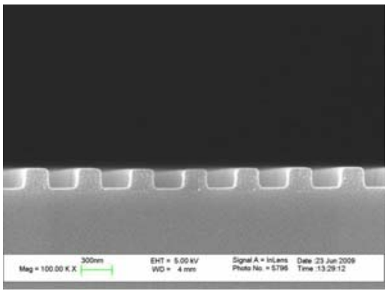
Special features	Limitations/constrains	Design rules
• Surface relief microstructure integrated to small plastic parts. • Mass production.	• Product volume less than 1 cm^3. • Surface relief feature size >500 nm. • Maximum aspect ratio of the obtained structures decreases with feature size (~1:1 for 500 nm lines ~2:1 for 1 µm lines).	
Further publications (pdf available through NEMOS knowledge management centre)	J. Pirskanen, J. Immonen, V. Kalima, J. Pietarinen, S. Siitonen, M. Kuittinen, K. Mönkkönen, T. Pakkanen, M. Suvanto, E.J. Pääkkönen, “Replication of sub-micrometre features using microsystems technology” Juha Pietarinen, Samuli Siitonen, Noora Tossavainen, Janne Laukkanen, Markku Kuittinen, “Fabrication of Ni-shims using UVmoulding as an intermediate step”, Microelectronic Engineering 83, 492–498 (2006).	

Partner:	**University of Eastern Finland**	
	Department of Physics and Mathematics	
	Yliopistokatu 7, FI-80100 Joensuu, Finland	Replication
	http://www.uef.fi/fysmat	

Technology: (identification name)	Nanoimprint lithography	

resp. person	Pertti Pääkkönen	pertti.paakkonen@uef.fi	+358 13 251 3238	+358 13 251 3290

Technology: (short description, appr. 100 words)	Nanoimprint lithography (NIL) enables surface relief patterns on a master to be copied into plastics (hot embossing), UV curable resins (UV moulding), or into nanoimprint resists. The resist mask can be used in proportional reactive ion etching to further transfer the pattern into underlying substrate material. This also enables profile deepening compared to the master (Fig. 3).

Typical structures		
	Fig 1. Binary UV moulded grating. Line width 128 nm, profile depth 805 nm.	Fig 2. Four level UV moulded grating. Profile height ~2 µm.
		
	Fig. 3. Nanopyramids etched on SiO2 as a hydrophobic AR surface. Pyramid base 370 nm, height 550 nm.	Fig. 4. Submicron grating in nanoimprint resist prior reactive ion etch step. Line width 210 nm, profile depth 170 nm.

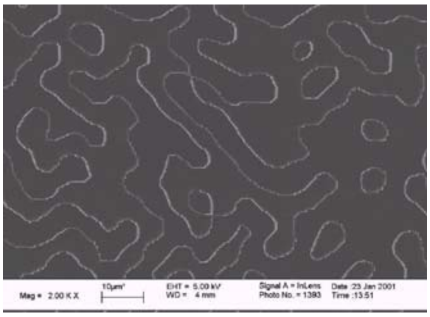
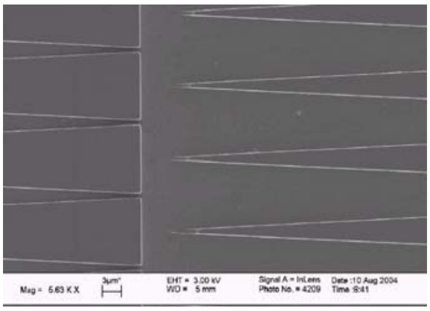
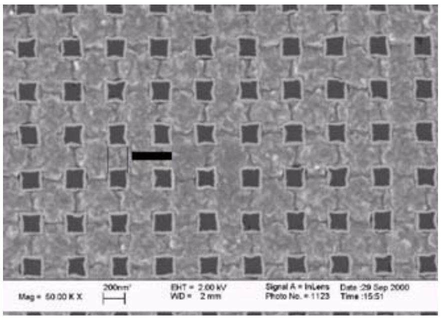
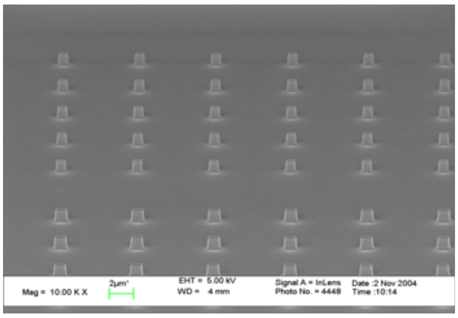
Special features	Limitations/constrains	Design rules
• Feature size > 100 nm. • Maximum aspect ratio of the obtained structures decreases with feature size (~2:1 for 200 nm lines, ~3:1 for 400 nm lines).	• Requires high quality of master surface and positive slope in structures side walls. • For UV-NIL the master element or replication substrate must be transparent.	
Further publications (pdf available through NEMOS knowledge management centre)	J. Pietarinen, S. Siitonen, P.Laakkonen, E. Herrala and J. Lehtomaa,``UV-molding of high aspect ratio diffractive gratings for spectrograph applications," Technical Digests of 2004 ICO Frontier (Tokyo, Japan, 2004) p.481-482. Juha Pietarinen, Samuli Siitonen, Noora Tossavainen, Janne Laukkanen, Markku Kuittinen, “Fabrication of Ni-shims using UVmoulding as an intermediate step”, Microelectronic Engineering 83, 492–498 (2006). B. Päivänranta, T. Saastamoinen, and M. Kuittinen, "Wide-angle broadband antireflective surface," Nanotechnology 20, 375310 (2009).	

Partner:	**University of Eastern Finland**	
	Department of Physics and Mathematics	
	Yliopistokatu 7, FI-80100 Joensuu, Finland	Replication
	http://www.uef.fi/fysmat	

Technology: (identification name)	Nickel electroplating for mold insert fabrication	

resp. person	Pertti Pääkkönen	pertti.paakkonen@uef.fi	+358 13 251 3238	+358 13 251 3290

Technology: (short description, appr. 100 words)	Nickel electroplating is usually used to grow surface relief copy (Ni-shim) from the master substrate. The obtained Ni-shim (1stgeneration shim) can be used as a master to grow Ni-shim with inverse profile (2nd-generation shim). A 3rd-generation shim is grown from the 2nd-generation shim e.t.a. This process allows us to produce sufficient amount of Ni stamps with either positive or negative surface profile and use them further in replication process (Nanoimprint lithography, UV-moulding, hot-embossing, injection moulding) to produce plastic copies. Alternatively, electroplating can be used in overplating process to grow metal only in the openings in a resist. In this case, the thickness of the grown metal usually does not exceed the thickness of the resist mask (Fig 3).

Typical structures		
	Fig 1. A nickel shim for a binary beamsplitter reproduction.	Fig 2. A nickel shimm with sharp edges.
		
	Fig 3. Nickel mesh structure obtained by overplating technique. Square size ~200 nm.	Fig 4. A Nickel shimm with submicron pin structure.

Special features	Limitations/constrains	Design rules
• Sufficient conductivity of substrate is required. Metal layers are deposited to unconductive substrate.	• Nickel shimm thickness 50 µm – 500 µm.	
Further publications (pdf available through NEMOS knowledge management centre)	K. Mönkkönen, J. Lautanen, V. Kettunen, V.-P. Leppänen, T.T. Pakkanen, and T. Jääskeläinen, “Antireflecting element replicated by hot embossing technique in COC plastics”, J. of Materials Chemistry, 10, 2634-2636 (2000). Juha Pietarinen, Samuli Siitonen, Noora Tossavainen, Janne Laukkanen, Markku Kuittinen, “Fabrication of Ni-shims using UV-molding as an intermediate step”, Microelectronic Engineering 83, 492–498 (2006).	

Partner:	**UFC**	Prototyping
	FEMTO-ST, Université de Franche-Comté	Mastering
	16 route de Gray, 25030 Besançon cedex, France	~~Replication~~
	http://www.femto-st.fr	

Technology: (identification name)	Etching of silicon moulds for microlenses fabrication	

resp. person	Christophe Gorecki	christophe.gorecki@univ-fcomte.fr	+33 381 66 66 07	+33 381 66 64 23

Technology: (short description, appr. 100 words)	This technology uses silicon to fabricate spherical moulds of microlenses. The moulds are fabricated by wet etching of silicon: - Isotropic etching: Deep moulds and small diameters - Anisotropic etching: Big diameters and small depths By these means we can fabricate microlenses with circular footprints as well as other less conventional footprints, such as cylindrical moulds, triangular, hexagonal or elliptical, among others.

Typical structures

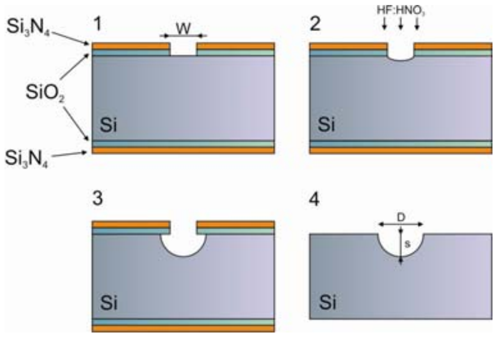


Fig.1. Schematic view of the isotropic etching of silicon to produce moulds with shapes nearly hemispherical

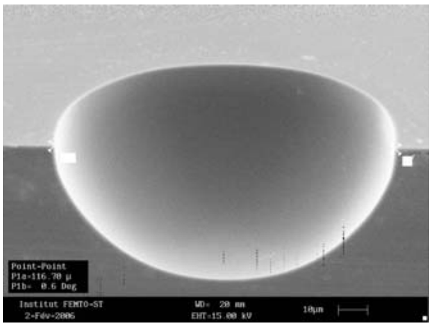


Fig. 2. Cross-section of a spherical mould

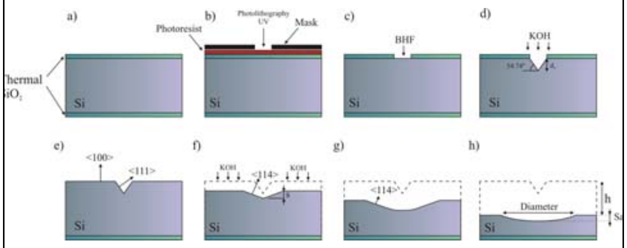


Fig.3. Schematic view of the double-step anisotropic etching of silicon to produce moulds with spherical profiles

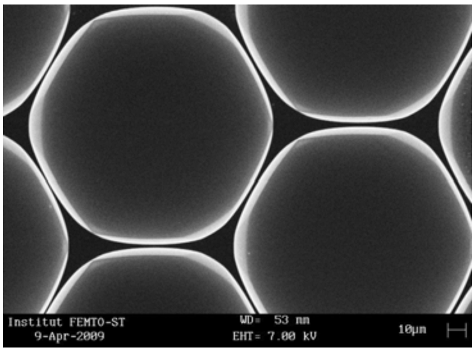


Fig. 4. Example of a matrix of hexagonal moulds

Special features	Limitations/constrains	Design rules
- Compatible with MEMS - Low roughness of the surfaces	- Isotropic etching: o Diameters<500 µm o Depth<160 µm	- On request

• High fulfil factors: Over 92% and 100% in special cases.	• Anisotropic etching: o Diameters>100 μm o Depth<60 μm	
Further publications (pdf available through NEMOS knowledge management centre)	J. Albero, L. Nieradko, C. Gorecki, H. Ottevaere, V. Gomez, H. Thienpont, J. Pietarinen, B. Päivänranta, and N. Passilly, "Fabrication of spherical microlenses by a combination of isotropic wet etching of silicon and molding techniques," Opt. Express **17**, 6283-6292 (2009). J. Albero, C. Gorecki, L. Nieradko, B. Päivänranta, V. Gomez, H. Thienpont and N. Passilly, "Matrixes of unconventional micro-optical components molded with etched silicon," J. of the European Optical Society – Rapid Publications, Vol 5, 10001 (2010).	

Partner:	**UFC**	Prototyping
	FEMTO-ST, Université de Franche-Comté	Mastering
	16 route de Gray, 25030 Besançon cedex, France	~~Replication~~
	http://www.femto-st.fr	

Technology: (identification name)	Glass reflow for microlenses fabrication	

resp. person	Christophe Gorecki	christophe.gorecki@univ-fcomte.fr	+33 381 66 66 07	+33 381 66 64 23

Technology: (short description, appr. 100 words)	This technology uses glass bonded in vacuum atmosphere to silicon moulds in order to fabricate spherical glass microlenses integrated onto silicon membranes. With this technology we can obtain microlenses in a wide range of sizes and optical properties. By these means we can fabricate microlenses as single elements or in matrix disposition. The shapes include circular footprints as well as other less conventional footprints, such as cylindrical microlenses, triangular, hexagonal or elliptical, among others.

Typical structures

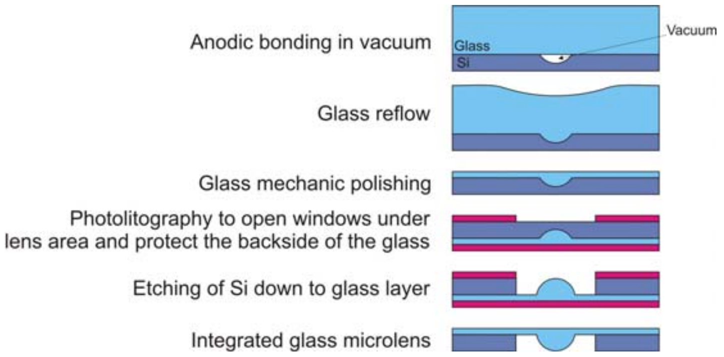


Fig.1. Schematic view of the glass reflow process

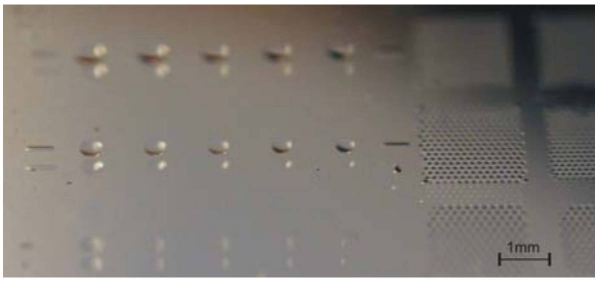


Fig. 2. Glass microlenses: single items and in matrix disposition

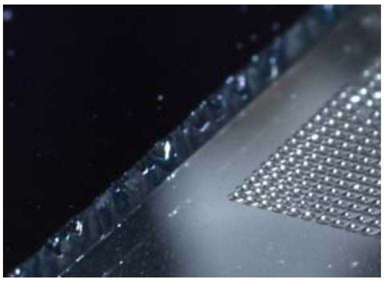


Fig. 3. Glass microlenses matrix onto a silicon frame

Special features	Limitations/constrains	Design rules
• Compatible with MEMS • Mechanical and thermal advantages of glass • High fulfil factors: Over 92% and 100% in special	• From isotropic etching: o NA>0.1 o Diameters<500 µm • From Anisotropic etching:	• On request

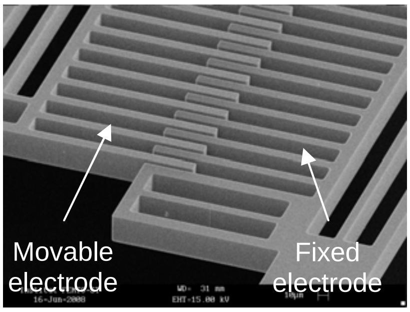
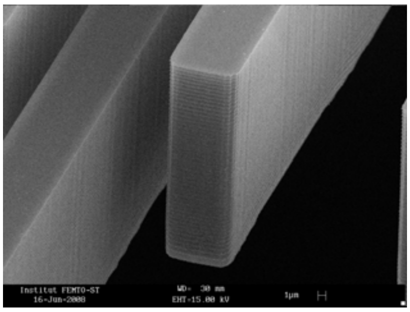
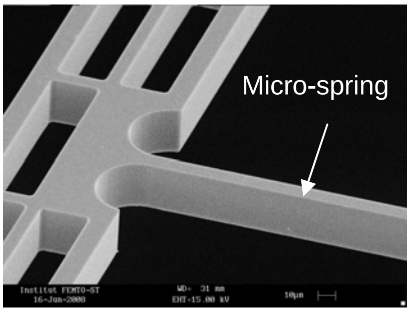
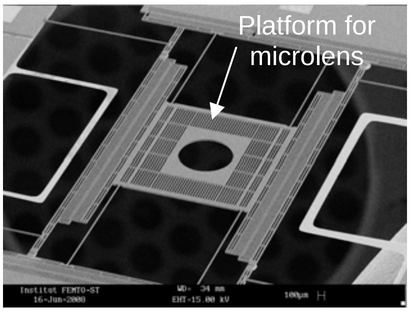
cases.	o NA<0.05 o Diameters>100 μm	
Further publications knowledge management centre)	J. Albero, L. Nieradko, C. Gorecki, H. Ottevaere, V. Gomez, and J. Pietarinen, “Si moulds for glass and polymer microlenses replication”, Proc. SPIE 6992, 69920A (2008), DOI:10.1117/12.783093.	

Partner:	**CNRS**	Prototyping
	FEMTO-ST Institute	
	16, Route de Gray, 25030 Besancon, France	
	http://www.femto-st.fr	

Technology: (identification name)	Silicon electrostatic comb-drive micro-actuators for MOEMS	

resp. person	Sylwester Bargiel	sylwester.bargiel@femto-st.fr	+33 381 666 302	+33 381 666 423

Technology: (short description, appr. 100 words)	Electrostatic comb-drive micro-actuators are well suited for in-plane displacement of micro-optical components in MOEMS due to high precision, fast response, and relative large travel range at low power consumption. Fabrication process of comb-drives is compatible with IC technology and involves dry deep reactive ion etching (DRIE) of high aspect ratio trenches into a device layer of silicon-on-insulator (SOI) wafers. Set of micro-actuators may be combined with a system of suspension springs to realize one- or two-directional movement of refractive or diffractive optical parts.

<table>
<tr>
<td rowspan="4">Typical structures</td>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Structure of comb-drive actuators etched by DRIE into 30-μm-thick device layer of SOI wafer (finger width 9.5 μm, gap 5.5μm)</td>
<td>Enlarged view of individual finger of comb-drive actuator (width 9.5 μm)</td>
</tr>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Silicon micro-spring etched by DRIE (height 30μm, width 9.5μm)</td>
<td>Electrostatic X-Y micro-stage with four comb-drive micro-actuators, fabricated on SOI (static displacements: X-axis ±27μm, Y-axis ±35μm at 100V</td>
</tr>
</table>

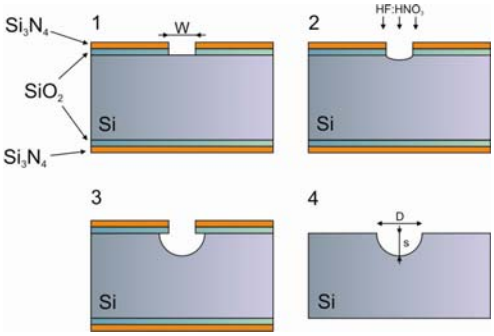
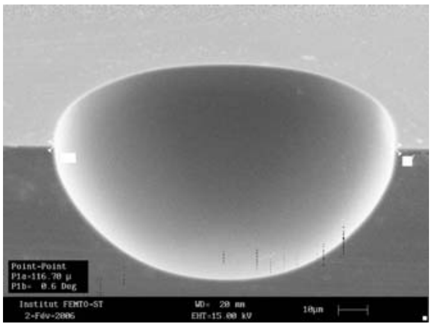
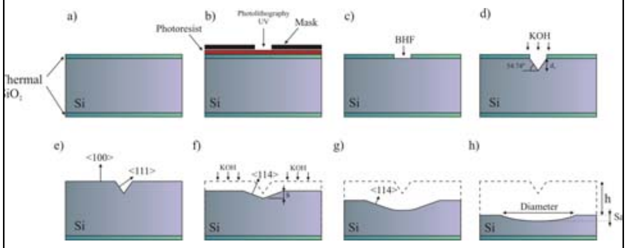
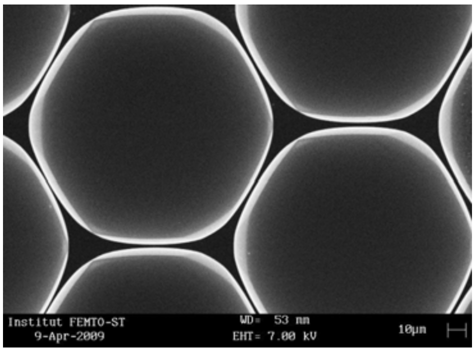
Special features	Limitations/constrains	Design rules
• Aspect ratios <20 • Thickness of SOI device layer <100μm • Structural details >2μm • Side-walls slope 90° ±1°	• Alcatel A601E machine with mechanical clamping only • Bosch process (SF_6/C_2F_6 chemistry for etching/passivation) • Single wafer up to 4 inches • Masks: thermal SiO_2, photoresist, thin-film metal layers (Cr, Al, Ni)	• Mask opening = width opening minus 1.5μm
Further publications (pdf available through NEMOS knowledge management centre)	K. Laszczyk, S. Bargiel et al, A two directional electrostatic comb-drive X-Y micro-stage for MOEMS applications, Sensors and Actuators A 2010	

Partner:	**UFC**	Prototyping
	FEMTO-ST, Université de Franche-Comté	Mastering
	16 route de Gray, 25030 Besançon cedex, France	~~Replication~~
	http://www.femto-st.fr	

Technology: (identification name)	Etching of silicon moulds for microlenses fabrication	

resp. person	Christophe Gorecki	christophe.gorecki@univ-fcomte.fr	+33 381 66 66 07	+33 381 66 64 23

Technology: (short description, appr. 100 words)	This technology uses silicon to fabricate spherical moulds of microlenses. The moulds are fabricated by wet etching of silicon: - Isotropic etching: Deep moulds and small diameters - Anisotropic etching: Big diameters and small depths By these means we can fabricate microlenses with circular footprints as well as other less conventional footprints, such as cylindrical moulds, triangular, hexagonal or elliptical, among others.

<table>
<tr><td rowspan="4">Typical structures</td><td>
</td><td>
</td></tr>
<tr><td>Fig.1. Schematic view of the isotropic etching of silicon to produce moulds with shapes nearly hemispherical</td><td>Fig. 2. Cross-section of a spherical mould</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Fig.3. Schematic view of the double-step anisotropic etching of silicon to produce moulds with spherical profiles</td><td>Fig. 4. Example of a matrix of hexagonal moulds</td></tr>
</table>

Special features	Limitations/constrains	Design rules
- Compatible with MEMS - Low roughness of the surfaces	- Isotropic etching: o Diameters<500 µm o Depth<160 µm	- On request

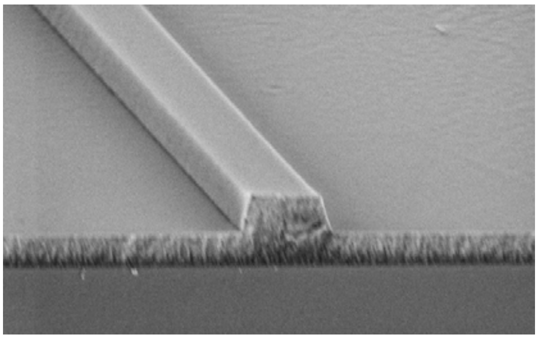
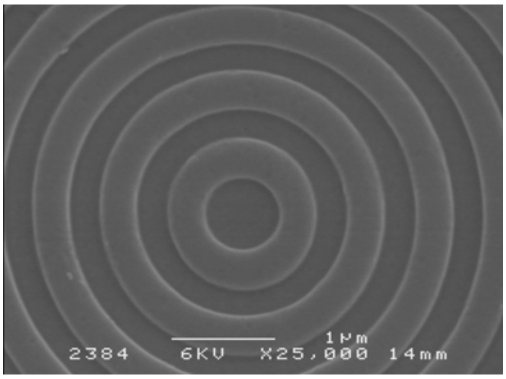
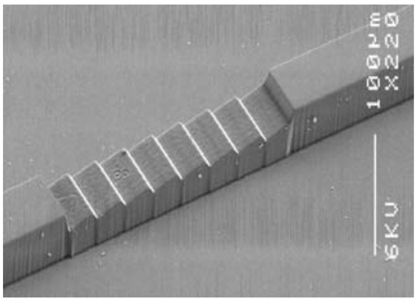
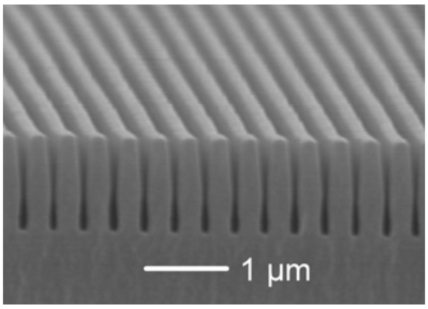
• High fulfil factors: Over 92% and 100% in special cases.	• Anisotropic etching: o Diameters>100 μm o Depth<60 μm	
Further publications (pdf available through NEMOS knowledge management centre)	J. Albero, L. Nieradko, C. Gorecki, H. Ottevaere, V. Gomez, H. Thienpont, J. Pietarinen, B. Päivänranta, and N. Passilly, “Fabrication of spherical microlenses by a combination of isotropic wet etching of silicon and molding techniques,” Opt. Express **17**, 6283-6292 (2009). J. Albero, C. Gorecki, L. Nieradko, B. Päivänranta, V. Gomez, H. Thienpont and N. Passilly, “Matrixes of unconventional micro-optical components molded with etched silicon,” J. of the European Optical Society – Rapid Publications, Vol 5, 10001 (2010).	

Partner:	**VTT TECHNICAL RESEARCH CENTER OF FINLAND**	
	Kaitoväylä 1, FIN-90571 Oulu, Finland	Mastering
	http://www.vtt.fi	Replication

Technology: (identification name)	Wafer-scale UV nano- and microimprinting	

resp. person	Jarkko Tuominen	Jarkko.Tuominen@vtt.fi	+35820 722 2053	+358 20 722 2320

Technology: (short description, appr. 100 words)	VTT provides process equipment to pattern nano- and microstructures in wafer-scale for optical applications through the use of UV nano- and microimprinting. Processing is mainly substrate independent; VTT has demonstrated fabricating structures on e.g. PCB, semiconductor, glass, ceramic and plastic. Intermediate masters can be fabricated also by VTT to provide longer lifetime of original moulds. VTT has expertise on imprinting mould fabrication using positive tone resists. VTT can also provide combined imprinting and shadow-mask lithography process for simultaneous nano-, micro- and macroscale structures fabrication. Processing with commercial UV cured materials is preferred, but experimental materials can also be used.

Typical structures		
	Fig 1. UV- imprinted single-mode optical waveguide.	Fig. 2. SEM-picture of ring grating structure replicated using UV imprinting.
		
	Fig. 3. Lithographically patterned multi-mode waveguide with imprinted microprisms.	Fig. 4. UV-imprinted submicron period and high-aspect ratio grating structure.

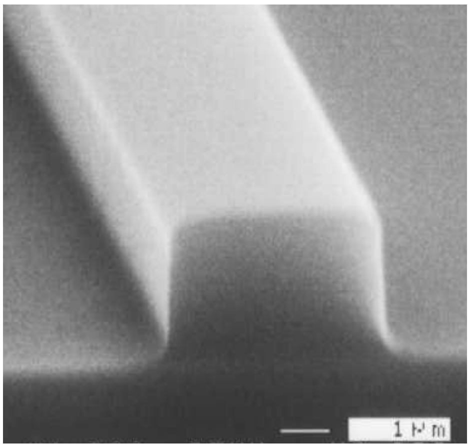
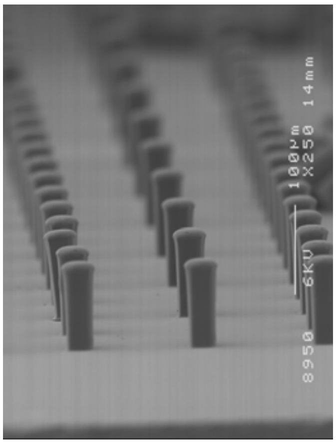
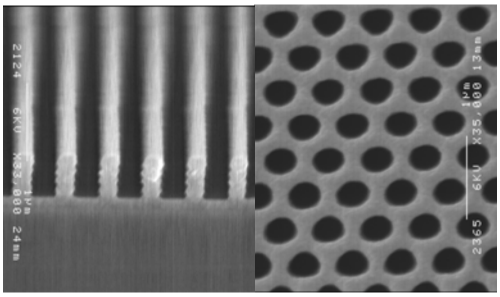
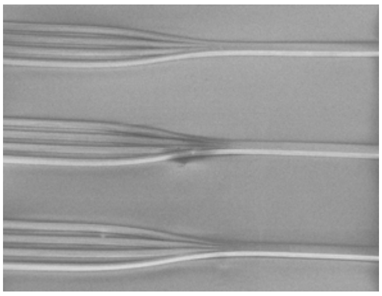
Special features	Limitations/constrains	Design rules
• alignment gap 1-300µm • From microscale to submicron structures down to 100 nm replication	• Max. wafer size 100mm • Max. exposure diameter 100 mm • Mask size up to 7” x 7” • alignment mechanical resolution 0.1µm	
Further publications (pdf available through NEMOS knowledge management centre)	Wang, M.; Hiltunen, Jussi; Uusitalo, Sanna; Puustinen, J.; Lappalainen, J.; Karioja, Pentti; Myllylä, R., *Fabrication of optical inverted-rib waveguides using UV-imprinting*, Microelectronic Engineering - article in press (2010) Hiltunen, Jussi; Hiltunen, Marianne; Karioja, Pentti; Puustinen, Jarkko; Lappalainen, Jyrki. *Fabrication of optical waveguides by imprinting: usage of positive tone resist as a mould for UV-curable polymer*, Optics Express. Vol. 17 (2009) No: 25, 22813 - 22822 Tuominen, Jarkko; Hiltunen, Jussi; Wojdyla, A.; Karppinen, Mikko; Suutala, A.; Jantunen, H.; Bouffaron, R.; Escoubas, L., *Direct patterning of micro-optical structures by combined nanoimprinting and lithography*, Micro-Optics 2008. Strasbourg, France, 7 April 2008 Proceedings of SPIE - The International Society for Optical Engineering. Vol. 6992 (2008) No: Article number 69920B	

Partner:	**VTT TECHNICAL RESEARCH CENTER OF FINLAND**	Prototyping
	Kaitoväylä 1, FIN-90571 Oulu, Finland	
	http://www.vtt.fi	

Technology: (identification name)	UV lithographic patterning for optical applications	

resp. person	Jarkko Tuominen	Jarkko.Tuominen@vtt.fi	+35820 722 2053	+358 20 722 2320

Technology: (short description, appr. 100 words)	VTT provides process equipment to pattern fine structures lithographically for optical applications. Submicron structures can be processed by the use of a near field holography (NFH) unit, which is part of the lithography/mask align system. Processing is mainly substrate independent; VTT has demonstrated fabricating structures on e.g. PCB, semiconductor, glass, ceramic and plastic. In addition to processing with commercial photoresists, testing of experimental materials can be carried out.

Typical structures		
	Fig. 1. Lithographically patterned optical waveguide	Fig. 2. SEM-picture of pillars manufactured using shadow mask lithography
		
	Fig. 3. SEM-pictures of gratings having different symmetries manufactured with NFH	Fig. 4. Multimode power splitters on FR4 substrate.

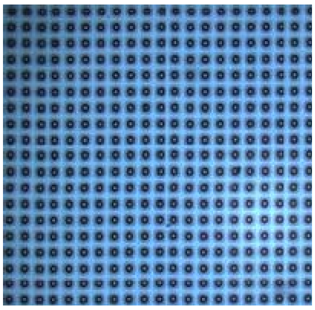
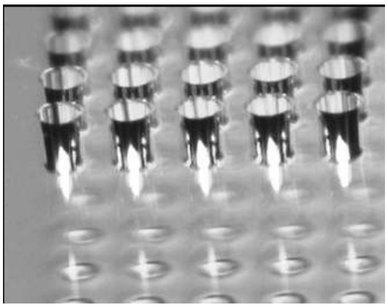
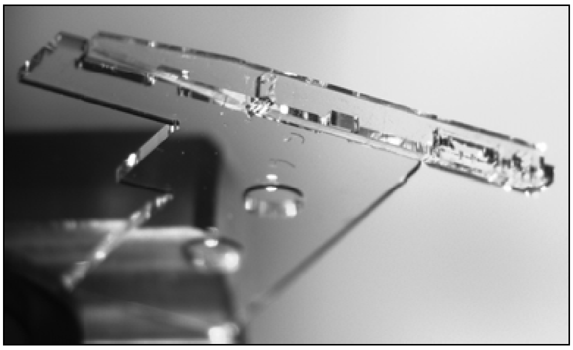
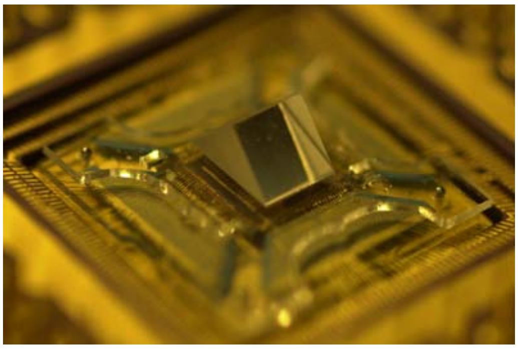
Special features	Limitations/constrains	Design rules
• exposure gap 1-100µm • alignment gap 1-300µm • exposure resolution 1-7µm depending on exposure gap • submicron gratings with NFH option	• Max. wafer size 100mm • Max. exposure diameter 100 mm • mask size up to 7” x 7” • alignment mechanical resolution 0.1µm	
Further publications (pdf available through NEMOS knowledge management centre)	Debaes, C.; Van Erps, J.; Karppinen, Mikko; Hiltunen, Jussi; Suyal, H.; Last, A.; Lee, M. G.; Karioja, Pentti; Taghizadeh, M.; Mohr, J.; Thienpont, H.; Glebov, A. L.*Fabrication method to create high-aspect ratio pillars for photonic coupling of board level interconnects*, Micro-Optics 2008. Strasbourg, France, 4 April 2008, Proceedings of SPIE - The International Society for Optical Engineering. Vol. 6992 (2008) No: Article number 69920T	

Partner:	**Vrije Universiteit Brussel**	Prototyping
	Department of Applied Physics and Photonics	Mastering
	Pleinlaan 2, B-1050 Brussels, Belgium	
	https://www.b-phot.org	

Technology: (identification name)	Deep Proton Writing to fabricate optical elements	

resp. person	Christof Debaes Jurgen Van Erps Michael Vervaeke	Cdebaes@b-phot.org jverps@b-phot.org mvervaek@b-phot.org	+32 2 629 10 18 +32 2 477 48 71 +32 2 477 48 69	+32 2 629 34 50

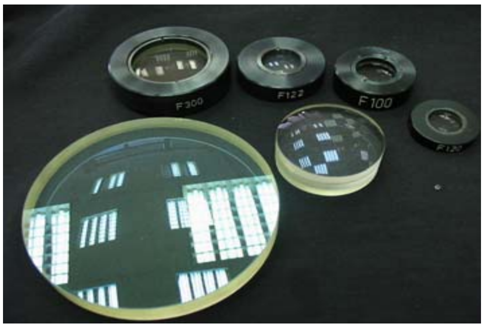
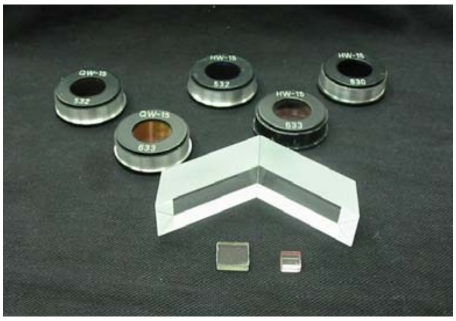
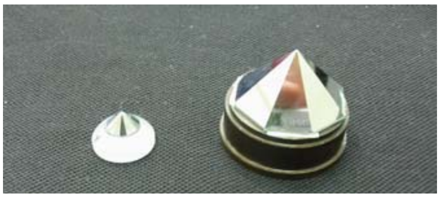
Technology:	Deep Proton Writing (DPW) is a rapid prototyping technology for the fabrication of 2D1/2 plastic micro-optical and micro-mechanical components. In general the processing steps consist of a local proton beam irradiation of a PMMA layer in well defined regions, followed by either a development of the irradiated zones with a selective solvent or by a volume expansion of the bombarded zones caused by a selective diffusion of an organic monomer vapour. The idea behind DPW originates from the physics department of the Erlangen-Nürnberg university where its proof-of principle was demonstrated. Since 1996 the department of Applied Physics and Photonics at the VUB upgraded DPW for the fabrication of micro-optical structures with functionalities in free-space parallel optical data-links and fiber-based interconnects and is continuously improving its performances and extending its range of practical applications.

Typical structures		
	2D spherical micro-lens array with sags of 10.5µm ± 0.25µm and diameters of 120µm	2D lens-based fiber connector
		
	A stitch detector for high-volume platesetters	Assembled free-space parallel

	with integrated cylindrical micro-lenses	interconnection module
Special features	Limitations/constrains	Design rules
• Reflective surfaces (Rq=20nm, Rt=100nm on 50x50 μm^2) • Mechanical fiber alignment elements with conically shaped inner surfaces • Conicity of 3.14 µm over 500 µm depth • Possibility to apply the process on different height levels • Possibility to perform angled irradiations • Possibility to use pre-processed samples	• All possibilities of replication are not fully explored • Flatness optical surfaces is limited to 10mrad • Maximum processing zone 2.54 x 2.54 mm^2 (centered)	Proton Beam sizes (minimal feature size): • circular: 20µm, 25µm,30µm, 50µm, 100µm, 120µm, 122µm, 125µm, 140µm, 200µm, 400µm • square: 20µm,50µm,125µm, 140µm, 200µm, 210µm, 300µm, 500µm, 1mm • hexagonal:80µm, 125µm, 250µm
Further publications	[1] C. Debaes , J. Van Erps , M. Vervaeke, B. Volckaerts, H. Ottevaere, V. Gomez, P. Vynck, L. Desmet, R. Krajewski, Y. Ishii, A. Hermanne, H. Thienpont, ”Deep Proton Writing: a rapid prototyping polymer microfabrication tool for micro-optical modules”, New Journal of Physics, Focus on nanotechnology, Vol 8, Art. No. 270, Nov 2006 [2] J. Van Erps, N. Hendrickx, C. Debaes, P. Van Daele, H. Thienpont “Discrete out-of-plane coupling components for Printed Circuit Board-level optical interconnections,” IEEE Photonics Technology Letters, Vol 19, pp. 1753-1755, nov 2007 [3] J. Van Erps, M. Wissman, M. Guttmann, M. Hartmann, J. Mohr, C. Debaes, H.Thienpont “Hot Embossing of Microoptical Components Prototyped by Deep Proton Writing”,IEEE Photonics Technology Letters, Vol 20, Issue 17, pp. 1539-1541, Oct 2008	

<table>
<tr><td rowspan="4">Partner:</td><td colspan="3">Warsaw University of Technology</td><td colspan="2">Prototyping</td></tr>
<tr><td colspan="3"><i>Institute of Micromechanics and Photonics</i></td><td colspan="2">Mastering</td></tr>
<tr><td colspan="3"><i>8 Sw.A.Boboli 8 02-525 Warsaw Poland</i></td><td colspan="2"></td></tr>
<tr><td colspan="5">http://zto.mchtr.pw.edu.pl</td></tr>
<tr><td>Technology:
(identification name)</td><td colspan="4">Cutting, grinding and polishing of optical elements</td><td></td></tr>
<tr><td>resp. person</td><td>Michał Józwik</td><td>jozwik@mchtr.pw.edu.pl</td><td>+48 22 234 86 35</td><td colspan="2">+48 22 234 86 01</td></tr>
<tr><td>Technology:
(short description, appr. 100 words)</td><td colspan="5">Cutting, grinding and polishing of various optical materials working in wide range of wavelengths (0,19 – 28µm).

Fabrication of various optical elements:

- Lenses: both spherical and cylindrical simple convex and concave lenses achromatic doublets, objectives
- Flat and spherical mirrors and windows, non-conventional substrates, plate beam splitters, plate standards
- Prism elements: cubes, polarizing beamsplitters, retarders (quarter and half waveplates both zero and multiple orders), achromatic retarders (Fresnel rhombs), Dove, Wollaston, Pellin Broc and Rochon prisms, dispersing prisms, Savart plates
- Non-conventional optical elements: Billet lenses, atypical objectives, microscope components, pyramids, cuvettes</td></tr>
<tr><td rowspan="4">Typical structures</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td colspan="3">Wide range of spherical lenses</td><td colspan="2">Retarders for various wavelengths</td></tr>
<tr><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td colspan="3">Spherical element with a drilled hole</td><td colspan="2">8 and 16 edges reflecting pyramides</td></tr>
</table>

Special features	Limitations/constrains	Design rules
Processed materials: optical and filter glass, quartz, sapphire, CaF_2, MgF_2, NaCl, KBr, ZnSe, Silicon , Germanium , diverse crystal materials, etc. Features adapted to individual order with respect to technology limit	• limitations of standard glass technology • optical component dimensions limited to 300mm • non-toxic material can be processed • flatness up to λ/50 • lenses diameters not smaller than 3 mm • minimal focal length 2mm • parallelism > 2 arc sec	• min edge chamfer 0.2 mm • provided technical documentation need to be discussed with our optical workshop