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Nanoimprinted surface relief Bragg gratings for sensor applications

M. Förthner [1,4*], M. Girschikofsky [2], M. Rumler [1,4], M. Rommel [3], R. Hellmann [2], L. Frey [1,3,4]

[1] Chair of Electron Devices, University Erlangen-Nuremberg, Erlangen, 91058, Germany
[2] Applied laser and photonics group, University of Applied Sciences Aschaffenburg, Aschaffenburg, 63743, Germany
[3] Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, 91058, Germany
[4] Erlangen Graduate School in Advanced Optical Technologies (SAOT), Erlangen, 91058, Germany

Introduction

Optical devices, especially Bragg gratings, are advantageous for many applications [1, 2].

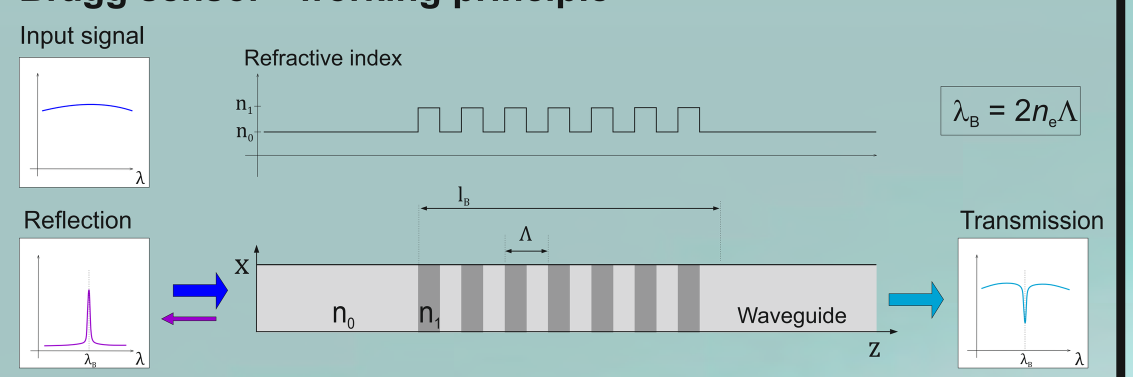
Reducing process time and costs can widen the field of use.

Miniaturization and device integration are suitable options, while requiring high resolution features and new processing routes.

We present a process option to manufacture Bragg grating sensors in one step on a full wafer level (up to 200 mm).

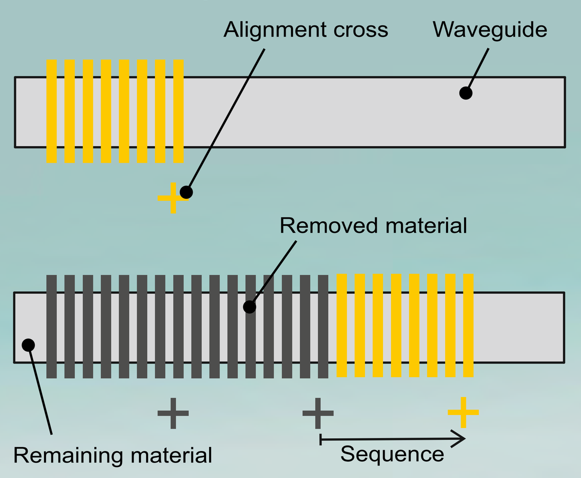
- Substrate conformal imprint lithography (SCIL) is used to replicate combined micro- and nanostructures [3].
- OrmoComp®, a hybrid polymer with enhanced thermal, chemical and mechanical stability, is used as functional material.

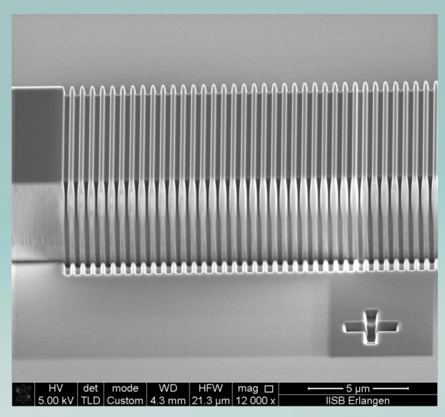
Bragg sensor - working principle



Sensor fabrication

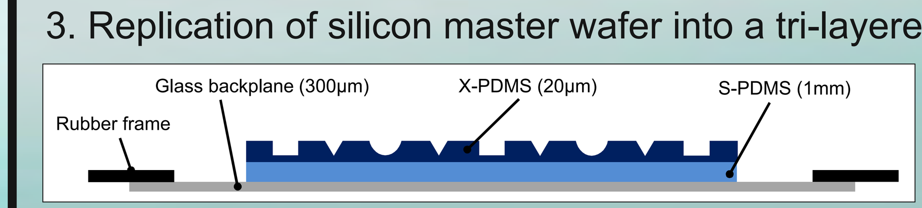
1. Silicon master wafer structured by standard photolithography and reactive ion etching (RIE)
2. Local inscription of surface relief Bragg gratings by focused ion beam (FIB) milling.





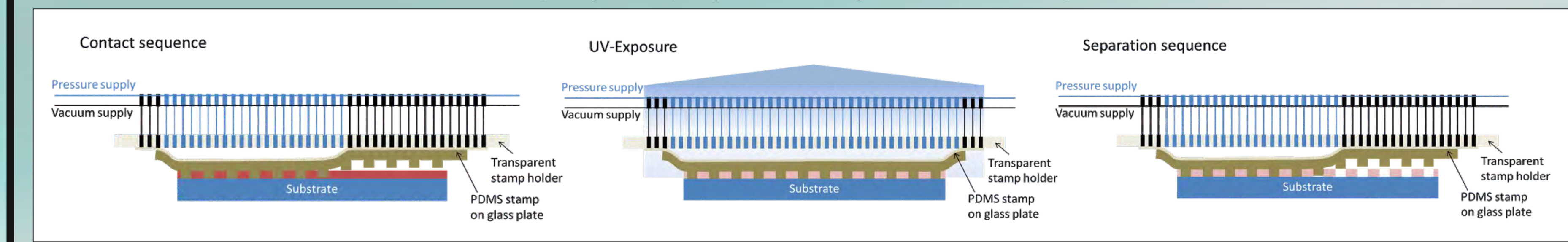
Scheme of automated FIB-milling process (left) to fabricate surface Bragg gratings with 1mm overall length. A single sequence (yellow) is about 17µm in length and takes 4 minutes of writing time (in case of the standard gratings defined with 530nm period and 250nm grating depth). SEM-image of a silicon waveguide with inscripted surface gratings (right).

3. Replication of silicon master wafer into a tri-layered SCIL stamp.



Cross sectional scheme of a typical UV-SCIL stamp [3]. X-PDMS (~50MPa) as the structure containing layer facilitates high resolution, while S-PDMS (~2MPa) as the buffer layer compensates particles and defects on the imprinted substrate.

4. Structure transfer into OrmoComp® hybrid polymer using the UV-SCIL process.

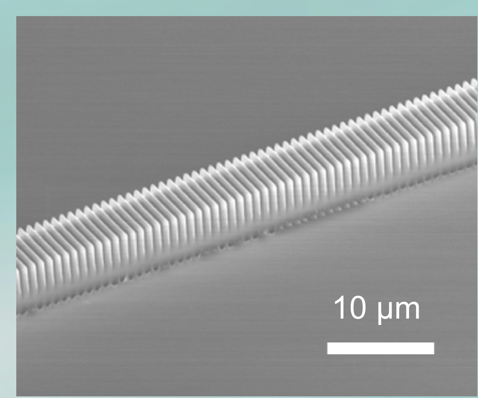


Steps of the UV-SCIL process:

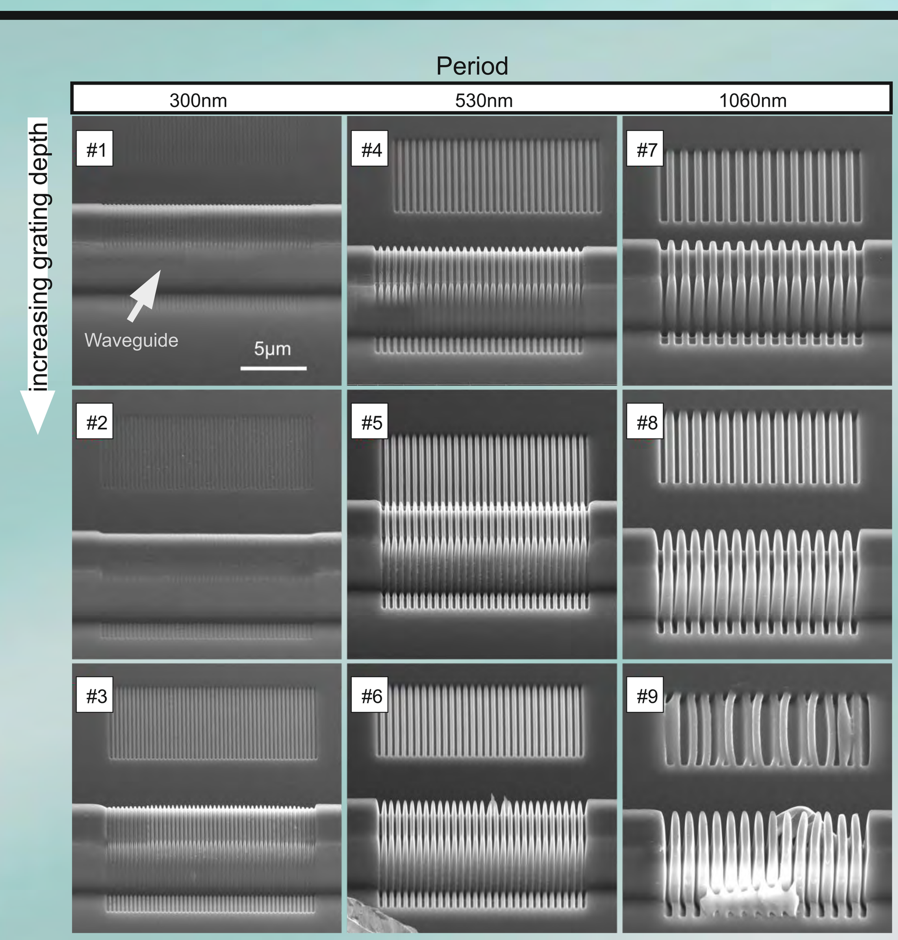
Left: *The stamp, fixed to the stamp holder by multiple vacuum channels, is stepwise released and contacted with the coated substrate below.* ***Middle:*** *After the contact sequence, the resist is cured by UV exposure.* ***Right:*** *The stamp is stepwise pulled of the substrate by evacuating single vacuum channels.*

Imprint results

Image of a 100mm silicon wafer containing waveguide strucutres with surface Bragg gratings imprinted into OrmoComp®.



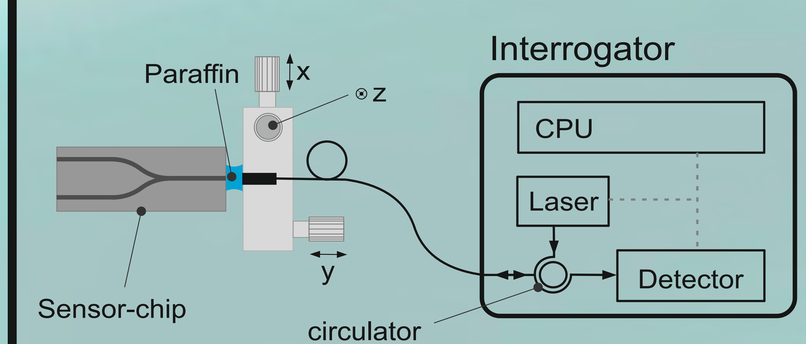
SEM-image of a surface Bragg grating imprinted into OrmoComp®. The sample was tilted by 52°.



SEM images of test structures with varying period and grating depth imprinted into OrmoComp®. The maximum grating depth was 2µm in case of structure #9, which corresponds to an aspect ratio of 4. In case of high aspect ratios, collapsing grating structures and partial demolition of the stamp were visible. Each grating was written once on the waveguide and once beside of it. The samples were tilted by 52°.

Sensor application

1. Measurement setup



Scheme of the measurement setup. An interrogator system was used (sm125-500 by Micron Optics) to control the functionality of the gratings which operates in the telecom wavelength range from 1510nm-1590nm (resolution 1pm; sampling rate 2Hz).The light is guided to the chip via a single mode glass fiber.

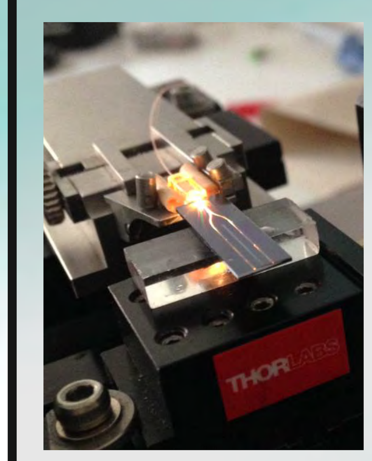
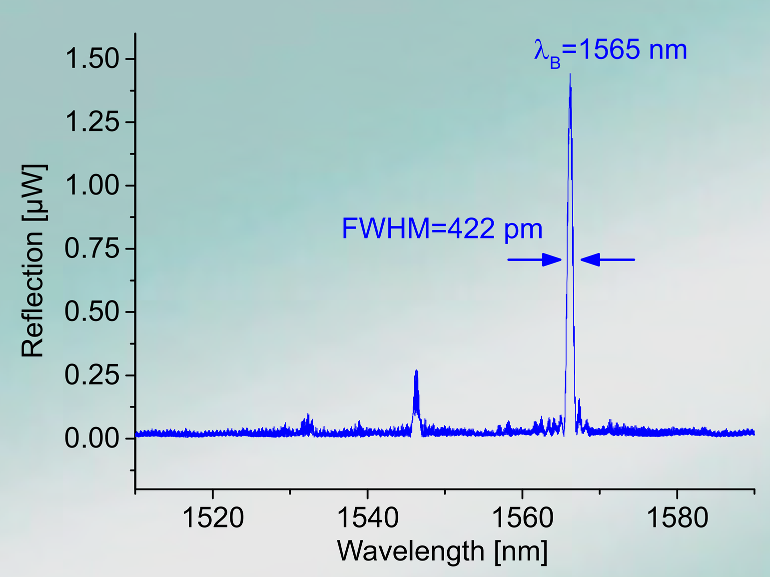


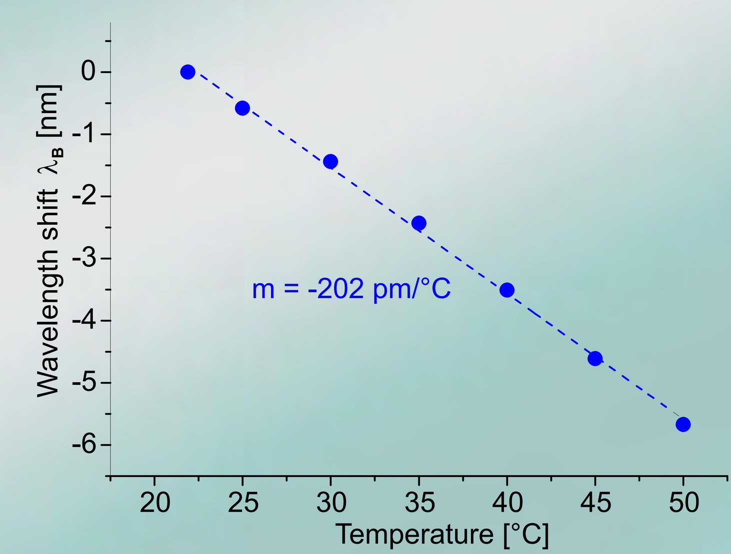
Image of the measurement setup with a sensor chip fixed to the micro stage and coupled to a single mode fibre. For visualization purposes a laser emitting in the visible range was applied for this image.

2. Reflection spectrum



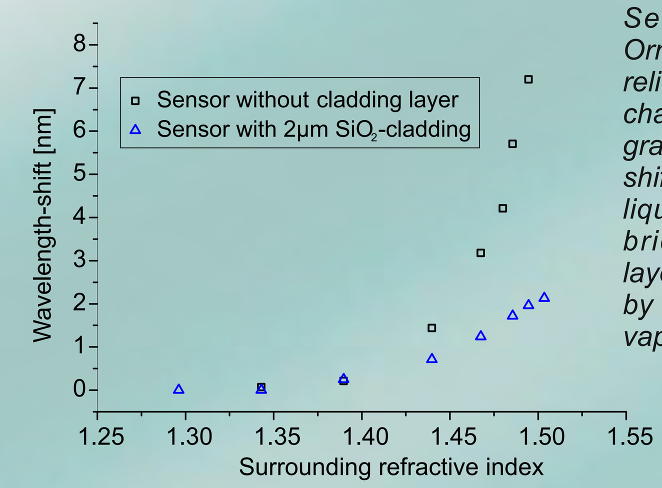
Spectrum of a Bragg grating with an overall length of 2mm, a grating period of 530nm and a grating depth of 250nm. The results feature a clear Bragg reflection of the fundamental mode at 1565nm. The signal's full width half maximum (FWHM) amounts to 422pm.

3. Temperature sensitivity

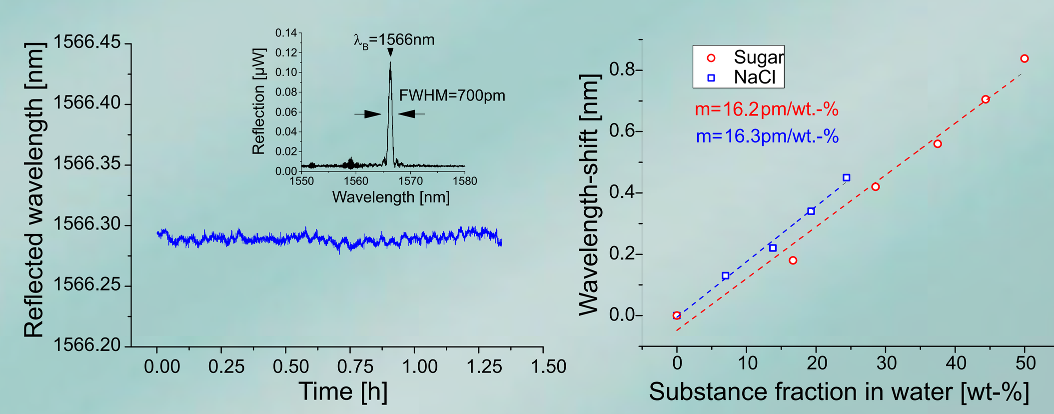


Temperature sensitivity of an imprinted OrmoComp® surface relief Bragg grating. An increasing temperature leads to a redshift of the signal, due to the negative thermo-optical coefficient of OrmoComp®. The sample was positioned on a hotplate and heated in steps of 5°C, while the Bragg wavelength was monitored by the software.

3. Refractive index sensitivity



Sensitivity of an imprinted OrmoComp® (n=1.507) surface relief Bragg grating towards a changing surounding index. The graph shows the relative peak shift for different index matching liquids. One sensor was fabricated with an additional layer on top of the waveguide by plasma enhanced chemical vapor deposition (PECVD).



Sensor characteristics in water: the sensor provided a stable signal in water (left) during 90 minutes measurement time. The inset shows the according reflection spectrum. The sensitivity towards aqueous solutions with salt and sugar led to a rising Bragg wavelength with increasing concentrations (right).

Summary

- Surface relief Bragg gratings were successfully fabricated using a hybrid polymer (OrmoComp®) and UV-SCIL.
- Combined micro- and nanostructured sensors were realized in one imprint step on a full wafer level.
- Optical measurements showed a clear Bragg reflection and a high temperature sensitivity of -202pm/°C.
- The sensitivity towards a changing surounding refractive index could be shown for oily liquids and aqueous solutions.

Acknowledgements:

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[1] Hill et al., J. Lightwave Technol. 15 (1997) [2] Sparrow et al., J. Sensors 9 (2009) [3] M. Verschuuren, PhD Thesis (2012)

University of Erlangen-Nuremberg
Chair of Electron Devices
Cauerstraße 6
91058 Erlangen, Germany

Mail: michael.foerthner@leb.eei.uni-erlangen.de
Internet: **http://www.leb.eei.uni-erlangen.de**