Exploring the boundaries of large-area nanoimprinting for mass production of AR waveguides

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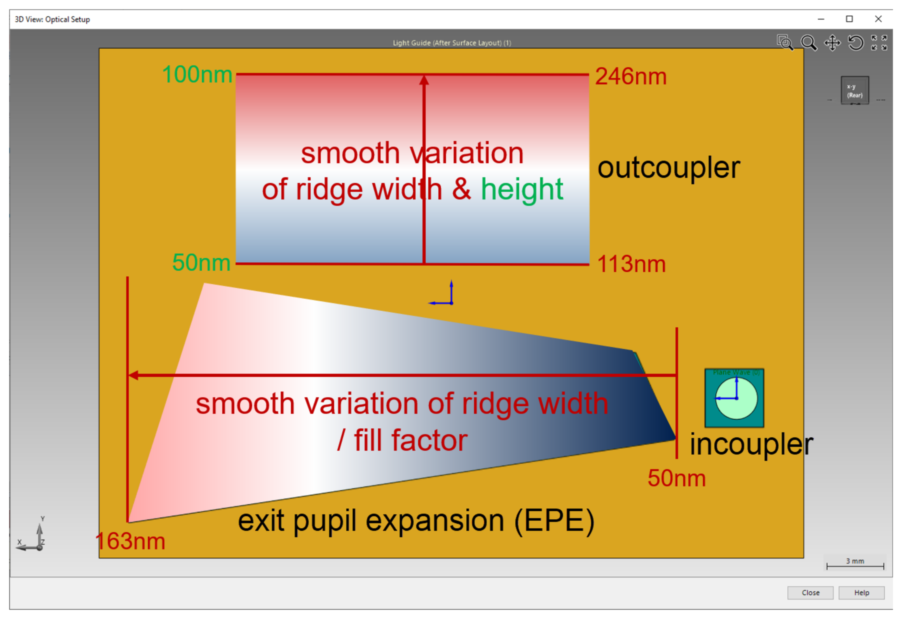
KEY BUILDING BLOCKS

Leveraging large-area nanoimprinting technology and equipment is crucial for achieving cost-effective mass production of Surface Relief Grating (SRG) waveguides. This work demonstrates the key building blocks in advancing this technology, including the successful demonstration of:

- Slanted gratings replication;
- Low RLT possibility using large-area NIL;
- Lighter & flatter glass-based nanoimprinting.

Design



Top view of designed waveguide with 3 SRGs: incoupler, EPE and outcoupler. Modulation direction of grating parameters indicated by red arrows with optimized values shown next to respective region.

In the design process a fully rigorous model of the waveguide was employed. For the optimization, the grating parameters were varied continuously in horizontal (EPE) and vertical (outcoupler) direction. Later, the modulation was discretized according to the demands of the fabrication.

Specifications of waveguide:

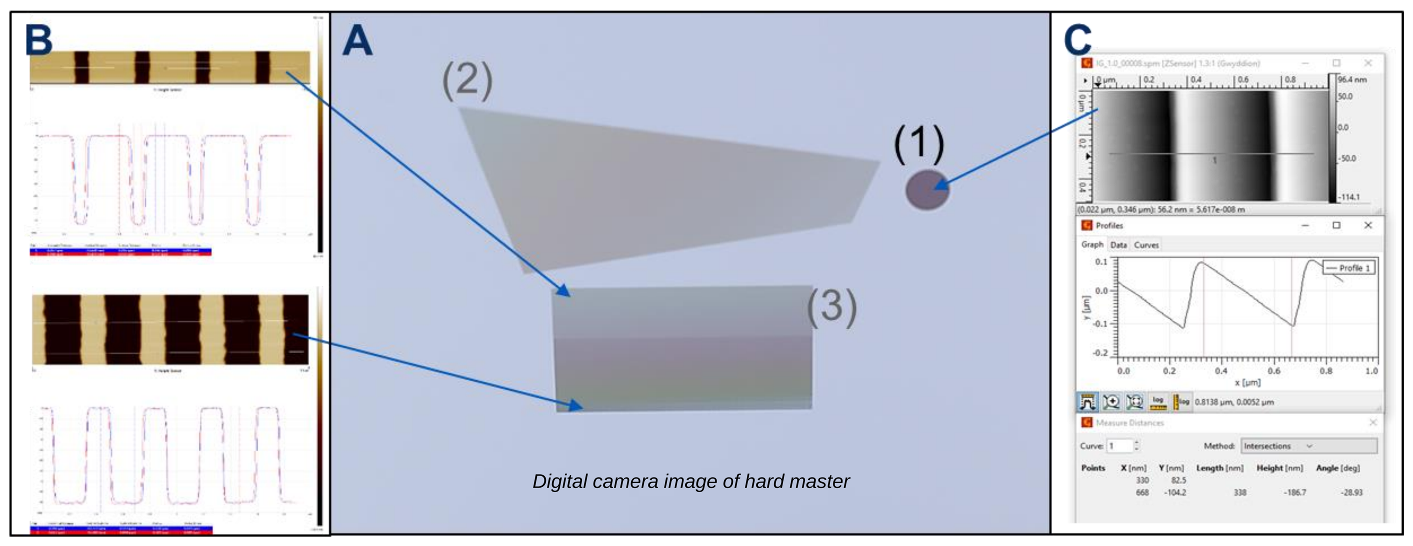
- 532 nm wavelength;
- 1D-1D pupil expansion;
- FOV: 32° × 18°;
- Eyebox: 15 mm × 8 mm;
- 1D-periodic gratings;
- Refractive index: 1.9.

Mastering

Two types of masters were used:

- Full eye-piece SRG waveguide master (designed by LightTrans)
- Test master with 4 slanted gratins each with different orientations

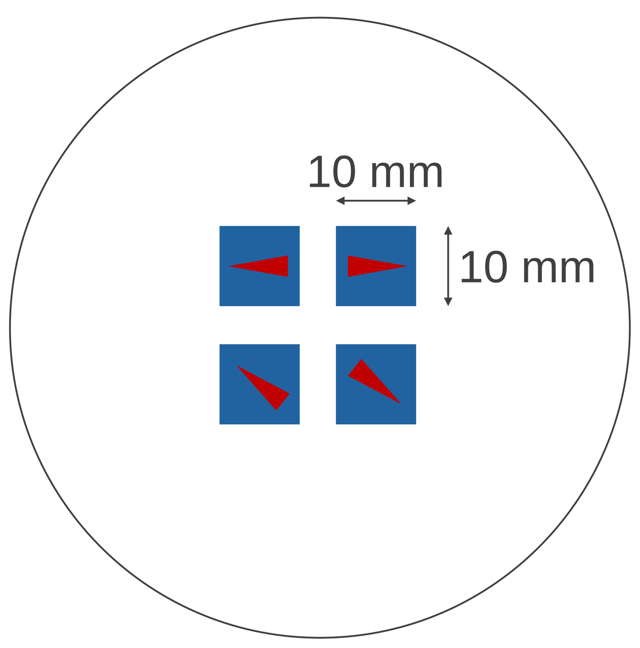
SRG Waveguide Master

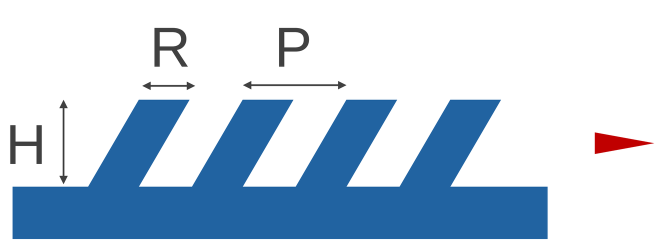


Specifications: (1) Blazed input grating, (2) Shallow binary expansion grating, (3) Discrete multi-depth binary output grating

(A) Digital camera image of hard master, (B) Representative AFM scans of shallow and deep section of binary output grating (note fill factor as well as depth is different), (C) Representative AFM scan of blazed input grating

Slated Grating Master





Specifications:

- Height (H): 300 nm
- Pitch (P): 310 nm
- Ridge (R): 155 nm
- Slant angle: 30°
- Orientations: 4 (red arrows)

Sketch of slanted grating hard master; Four 1 cm² grating areas with different slant directions (indicated by red arrows). Including cross sectional sketch of each of the four gratings showing the grating parameters.

Glass

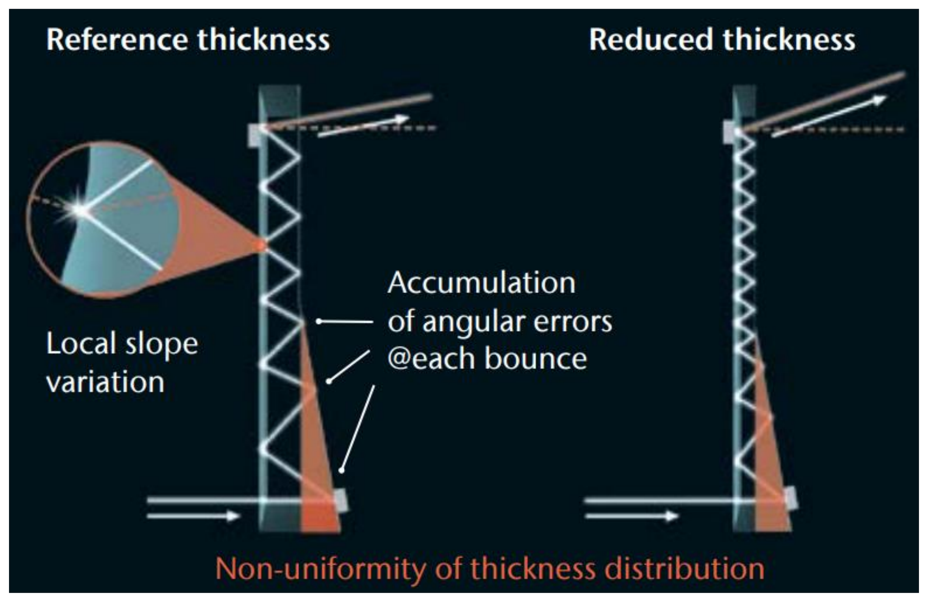
SCHOTT RealView® Portfolio

The backbone of AR waveguides is specialty grade high-index optical glass. Recent development has extended the RealView glass portfolio to a broad refractive index range beyond 2.0 and formats up to 300mm round and square, which allows for mass production of high-quality small form factor devices.

SCHOTT RealView® Ultra

A new grade of ultra-flat wafers helps to minimize fluctuation of image quality of diffractive waveguides and enables thinner and lighter devices maintaining stunning image quality.

- Beam path deflections account for the loss of image quality
- Local slope and wedge directly correlate to image quality and values were cut in half for ultra-flat wafers

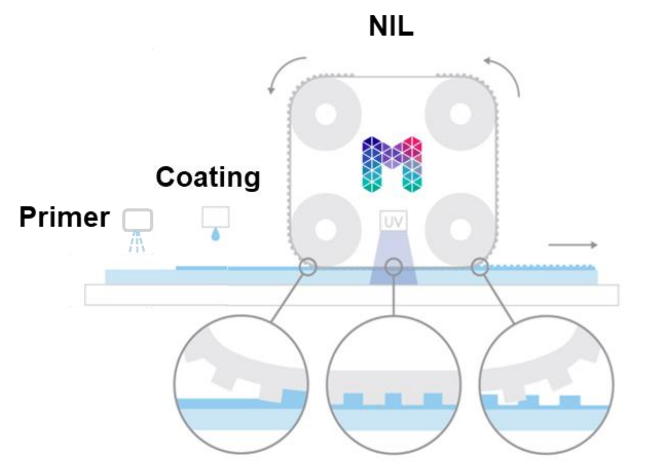


Waveguide beam paths encounter aberrations when thickness varies, causing local slope and wedge non-uniformity. Thinner waveguides intensify this effect with more bounces.

The Ultra grade is now available for the whole RealView portfolio and is the key for weight reduction of AR devices. Thinner wafers can be used as relatively higher number of bounces is balanced out.

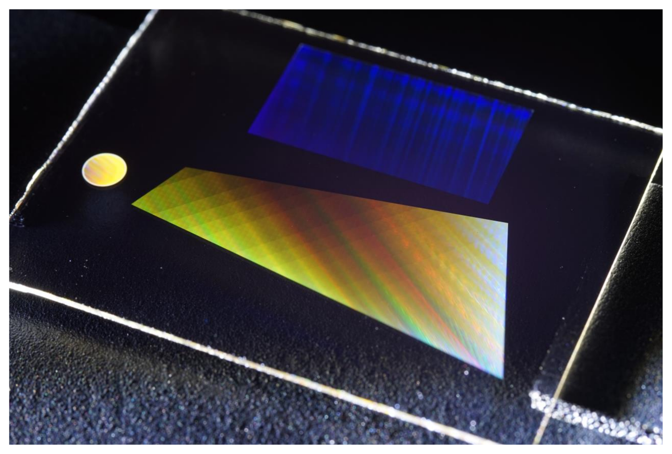
Large-Area Nanoimprinting

Roll-to-Plate (R2P) Nanoimprint Technology



R2P Nanoimprint Technology comprised of Primer, Coater, and NIL modules

Surface Relief Grating (SRG) imprint



Singulated SRG waveguide produced with Large-Area Nanoimprinting

- Imprint using High Dimensionally Stable (HDS) stamps ensuring dimensional stability.
- Imprint resin and substrate Refractive Index (RI) can range from 1.4 to 2.0.
- Solvent-based resins were used to obtain thin residual layer thickness (< 100 nm).
- Replication on round wafers also possible by using a wafer-carrier.

Nº	Texture type	Resin RI	Solvent-based resin	Glass RI	Ultra-flat Glass	Stamp type
1	SRG Waveguide	1.8	Yes	1.8	No	HDS
2	SRG Waveguide	1.9	Yes	1.9	No	HDS
3	SRG Waveguide	2.0	Yes	2.0	No	HDS
4	SRG Waveguide	1.9	Yes	1.9	No	IDS
5	Slanted gratings	1.4	No	1.5	No	HDS
6	Slanted gratings	1.4	No	1.5	No	HDS
7	SRG Waveguide	1.9	No	1.9	Yes	HDS
8	SRG Waveguide	1.9	No	1.9	No	HDS
9	SRG Waveguide	2.0	No	1.9	No	IDS

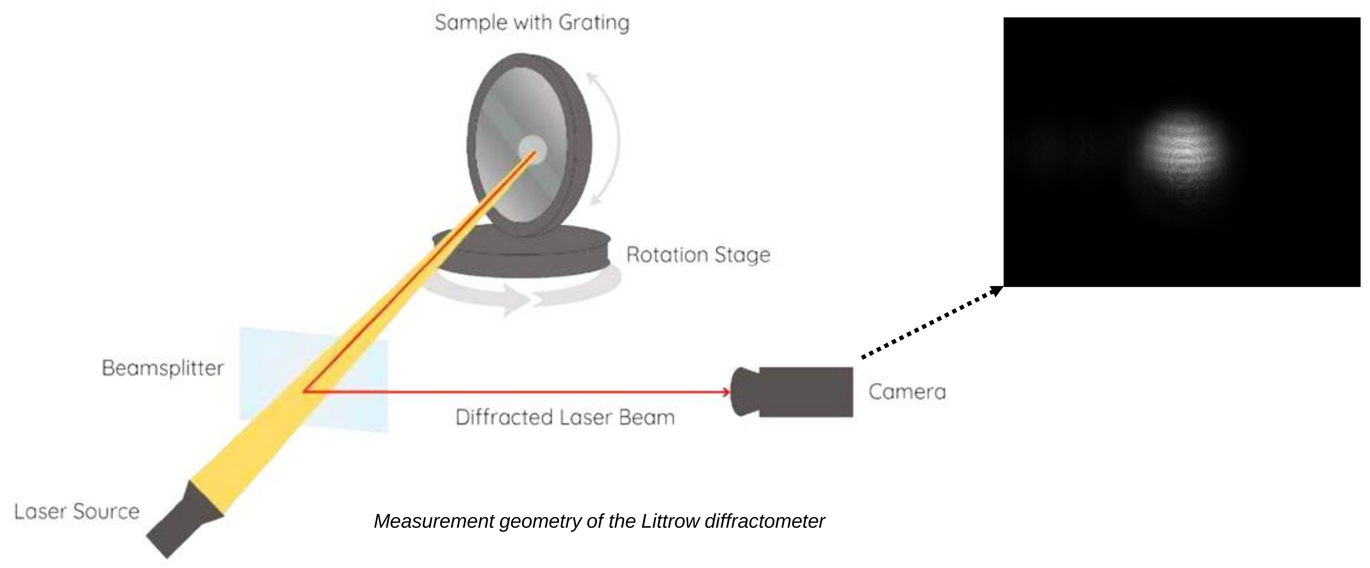
Table 1: List of produced and measured samples.

Metrology

Littrow diffractometer

Based on finding the Littrow angle, where light diffracts back to the laser from the grating

- Laser wavelength 405.007 nm, beam spot size: Ø ~1.0 mm
- Grating period measurement: resolution <0.5 pm, accuracy ±70 pm
- Grating relative orientation measurement: resolution < 0.5 arcsec, accuracy ±50 arcsec



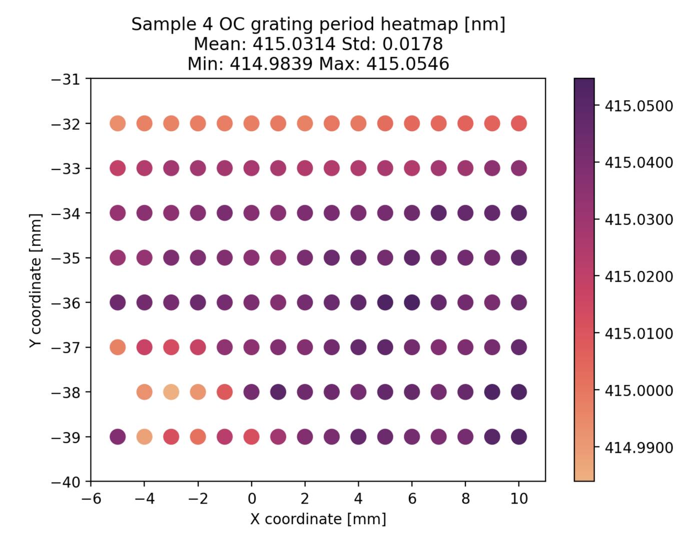
Measurement geometry of the Littrow diffractometer

Results, samples 1-4

Input coupler(IC) scanned with 0.5 mm step, output coupler (OC) and exit pupil expander (EPE) with a 1.0 mm step.

ID	Average period (nm)	Period std (pm)	Average relative angle (deg)	Angle std (arcsec)
Sample 1				
IC	414.93	32.15	44.9967	9.90
OC	415.02	34.79	134.9962	3.65
EPE	293.43	8.98	0.0017	5.59
Sample 2				
IC	414.92	34.03	44.9984	6.14
OC	414.98	13.39	134.9973	2.84
EPE	293.42	3.70	0.0018	2.90
Sample 3				
IC	414.91	27.66	44.9960	6.00
OC	414.99	31.44	134.9959	3.74
EPE	293.41	5.13	0.0009	2.45
Sample 4				
IC	414.85	34.02	44.9864	8.23
OC	415.03	17.78	134.9874	2.77
EPE	293.41	3.91	0.0004	2.73

Summary results for Samples 1-4

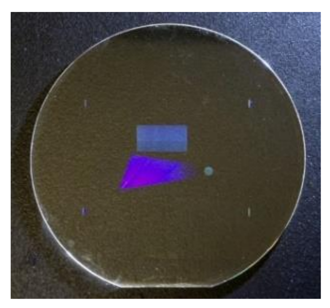


Grating period uniformity for Sample 4 outcoupler grating

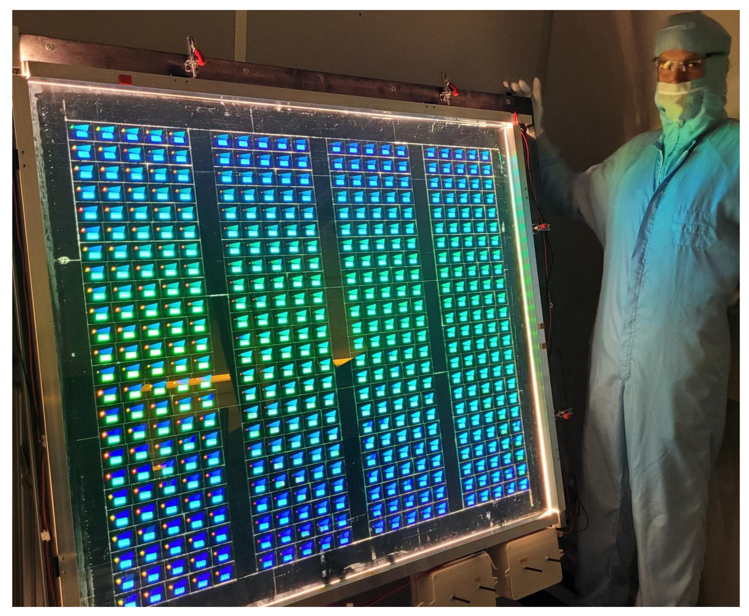
Results, sample 5

Grating period uniformity (std) 20 pm, grating relative angle uniformity (std) below 7 arcsec. Average period accurate to within 20 pm.

From a single eyepiece to many



Single eyepiece Master



R2P Imprint – 480 waveguides on 16 substrates per run

- Masters can be tedious & complex to originate, only a limited number of eyepieces can be produced in wafer format.
- Upscaling of masters is needed to increase throughput.
- Large-area nanoimprinting can substantially increase production throughput and maintain high replication quality for binary, blazed, and slanted gratings.

References:
1. M. Jotz et al., "The path towards mass manufacturing of optical waveguide combiners via large-area nanoimprinting," Proc. SPIE, 11931 1193109
2. S. Steiner et al., "Enabling the Metaverse through mass manufacturing of industry-standard optical waveguide combiners," Proc. SPIE, 12449 1244906

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