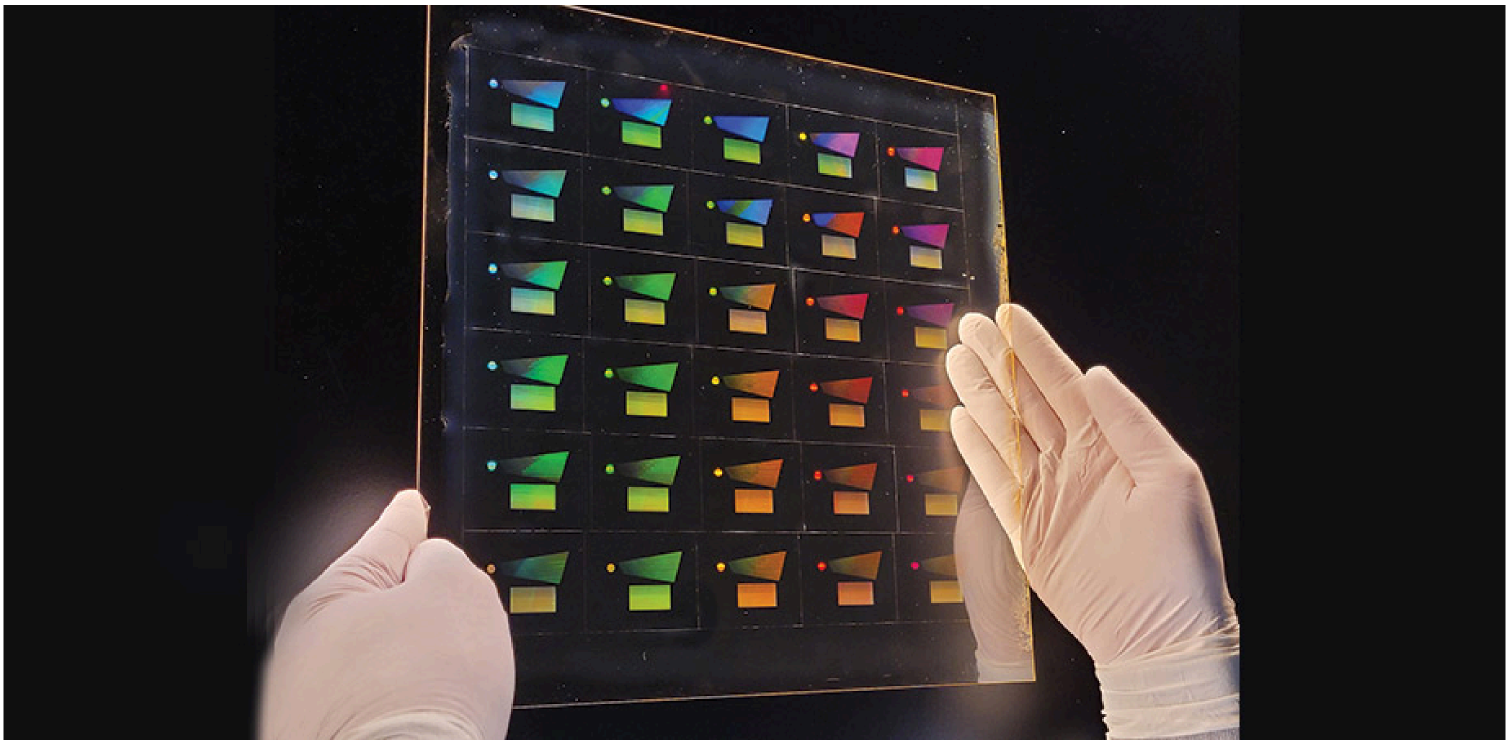
A leap forward in AR smart glass optics manufacturing

01 January 2024 By Jan Matthijs ter Meulen and colleagues Technology



Replication of the 30-up sub-master on 9 single wafers producing 270 waveguides in one imprint pass. Photo credit: Morphotonics

The metaverse, a virtual world integrated with our reality, fascinates tech experts and enthusiasts. Despite some doubts, the widespread adoption of smart glass as the next frontier for communication and computing platforms seems inevitable.

High-performance, scalable, yet cost-effective optics can play a pivotal role as one of the key smart glass building blocks. Large-area nanoimprint lithography (NIL), a method for reproducing nanoscale patterns on substrates beyond wafers, holds the promise of producing surface relief grating (SRG) waveguides in high volume. Our work on this technology, detailed in the *Journal of Optical Microsystems,* demonstrates how NIL can improve manufacturing throughput and waveguide quality. However, challenges remain in waveguide design, scalability, and reproducibility.

We have used a comprehensive approach with key partners spanning design, mastering, materials, imprinting, and metrology to prove that large-area NIL improves waveguide manufacturing efficiency and quality. Our approach consistently replicates the intended design, delivering high-quality results on large, high-refractive-index (1.9 RI), square (300 × 300 mm) glass substrates with high-refractive index resins (1.9 RI). Our goal is to establish this innovative approach as a path toward high-volume, cost-effective manufacturing of SRG waveguides.

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Waveguide optics design starts with a well-established layout, a 1D-1D pupil expansion, which simplifies the manufacturing process. Advantages of this approach come with trade-offs, for example, maximum field of view (FoV) limitations. To ensure sufficient optical performance, a parametric optimization process performed using LightTrans International's VirtualLab Fusion software, considered grating parameters like blaze angle, height, and ridge width for incoupler, and EPE and outcoupler. The goal was balanced uniformity and efficiency for five modes from different FoV quadrants.

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For highest-quality SRGs, the SRG waveguide master is meticulously crafted in silicon using electron beam lithography (EBL) and dry etching. The design features a binary pupil expander, output gratings, and a blazed input grating.

The use of EBL for all SRGs ensures precise grating periods and lateral dimensions, and perfect relative position and rotation between the individual gratings. Silicon dry etching maintains structural fidelity and etch-depth precision. After pattern transfer, the master is cleaned, and a first-generation submaster is created via Ormostamp replication on glass for subsequent waveguide production.

To achieve optimal SRG waveguides, a holistic approach from design to final waveguides is essential. The SRG waveguide design complies with silicon master fabrication and replication processes. NIL Technology offers more intricate SRGs, including slanted and advanced binary gratings, all combinable on the master with flexible relative placement and rotation options.

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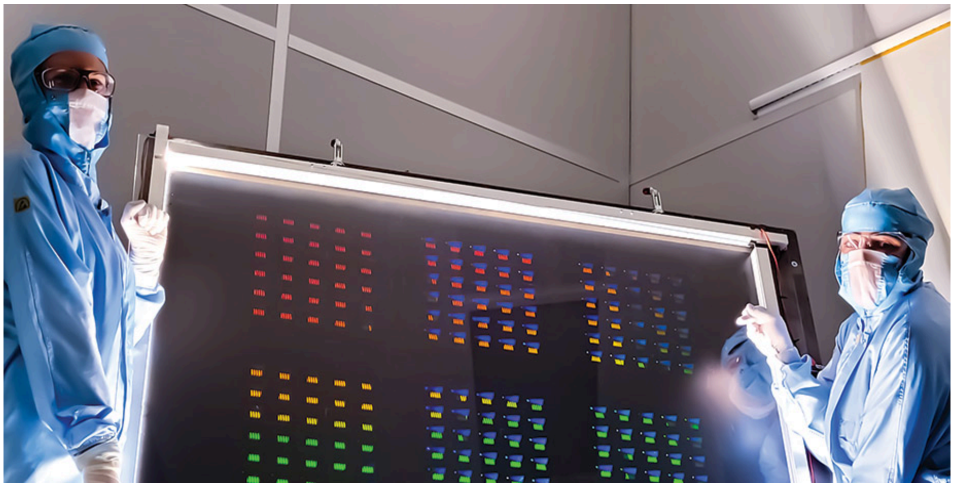
For mass manufacturing, accurate waveguide optics replication from the master to a substrate is crucial. Morphotonics' Roll-to-Plate (R2P) nanoimprint lithography (NIL) technology plays a pivotal role. With its scalability to larger substrate sizes, it can maintain replication fidelity and dimensional stability. Multiple waveguides can be imprinted in one go, making mass-volume production feasible. Moreover, the flexibility and reusability of the stamp contribute to highly reproducible and cost-effective manufacturing.

Morphotonics uses a proprietary process to create an array of waveguiding eyepieces, beginning with the enlargement of a submaster.

The R2P NIL modules enable the production of 270 (and later, 480) eyepieces per-Gen-5-sized (1100 × 1300 mm) imprint run. Morphotonics' flexible stamps maintain consistent imprint quality, and HDS stamps ensure dimensional stability. High-refractive index resins (supplied by Pixelligent

Technologies) are used for maximum FOV and low waveguide losses. Uniform imprints with minimal layer-thickness variations are essential for optimal performance.

The results we presented are a collaborative effort with limited optimization time. Ongoing refinements are being made to thoroughly optimize the process.



Replication of the 30-up sub-master on 9 single wafers producing 270 waveguides in one imprint pass. Photo credit: Morphotonics

Glass is integral to SRG waveguides made through nanoimprint lithography. SCHOTT RealView® 100–300 mm-diameter wafers, 0.3- to 1-mm thick, are extensively used in NIL manufacturing. They come in various refractive indices, typically from 1.7 to 2.0, with index-matching resins. For high-volume manufacturing needs, SCHOTT created larger square and rectangular wafers from high-index glass that meet strict AR specifications.

Glass properties significantly affect AR device performance. Material properties, like refractive index and transmission, limit FoV and battery life. Reducing thickness affects image quality due to increased ray bounces in the waveguide. High flatness, expressed as total thickness variation (TTV), is crucial, aiming for TTV below 1 μm. Local thickness variation (LTV) must also be below 1 μm for superior image quality. Surface roughness should stay under 1 nm to minimize scattering.

For larger panels, the technical-glass route, using overflow fusion or downdraw, gives direct access to thin sheets. However, viscosity and crystallization behavior of high-index glass still present major challenges. Alternatively, the optical-glass route offers a variety of high-index glass, which are cut and polished into wafers. The maximum format of the glass strips determines maximum-possible wafer size.

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Two essential methods, Littrow diffractometer and image-quality measurements, assess replicated waveguide quality.

The first directly evaluates homogeneity and reproducibility of the grating fabrication process, ensuring grating period and relative orientation measurements with picometer and arcsecond accuracy. Our setup involves a stable 405-nm laser beam positioned on the sample surface with a machine vision camera. High-accuracy rotary stages control sample yaw and roll. An XY-stage enables measurements across the entire grating area, but it can be time consuming.

Our study assessed nine different samples, including three homogeneity- and six reproducibility- test waveguides. Littrow measurements confirmed excellent uniformity across grating periods and orientations with waveguide track-pitch variation of less than 10 pm inside the outcoupler and expander, in 100 consecutive imprints.

Image quality measurements evaluated waveguide homogeneity and reproducibility. Using a specialized WG-IQ tester with a uniform OptoProjector light engine and OptoEye 2.0 lens, we projected test patterns through the waveguides and analyzed checkerboard contrast and luminescence uniformity. Both contrast and uniformity showed consistent reproducibility over nine different waveguides, indicating high homogeneity and reproducibility.

Finally, we employed modulation transfer function (MTF) measurements— an assessment of a system's ability to reproduce fine spatial details—to quantify imaging resolution crucial for AR devices. Our system, customized for AR waveguides, featured pupil matching and precise equipment alignment. Results revealed good MTF agreement for most samples, with a slight decrease for only two of them, and those came after 100 imprints.

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Mass production of AR waveguide optics is crucial for widespread adoption of smart glass and realization of the metaverse. While the industry continues to evolve, the tools, techniques, and collaborative spirit needed are in place already. The commitment to large-area manufacturing, intricate design, high-end mastering, advanced materials, and rigorous quality control is a testament to mass production potential. This exemplary work by a consortium of pioneers encourages industry to fulfill the promise of smart glass and the boundless opportunities of the metaverse. The future of AR is bright, and it's time to step into the next dimension.

Jan Matthijs ter Meulen, *CEO and co-founder of Morphotonics, was a co-author along with colleagues from LightTrans International, SCHOTT, NIL Technology, and OptoFidelity.*

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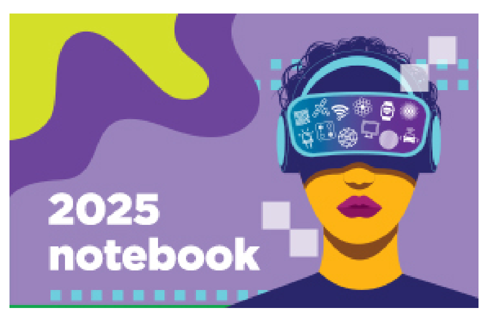

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