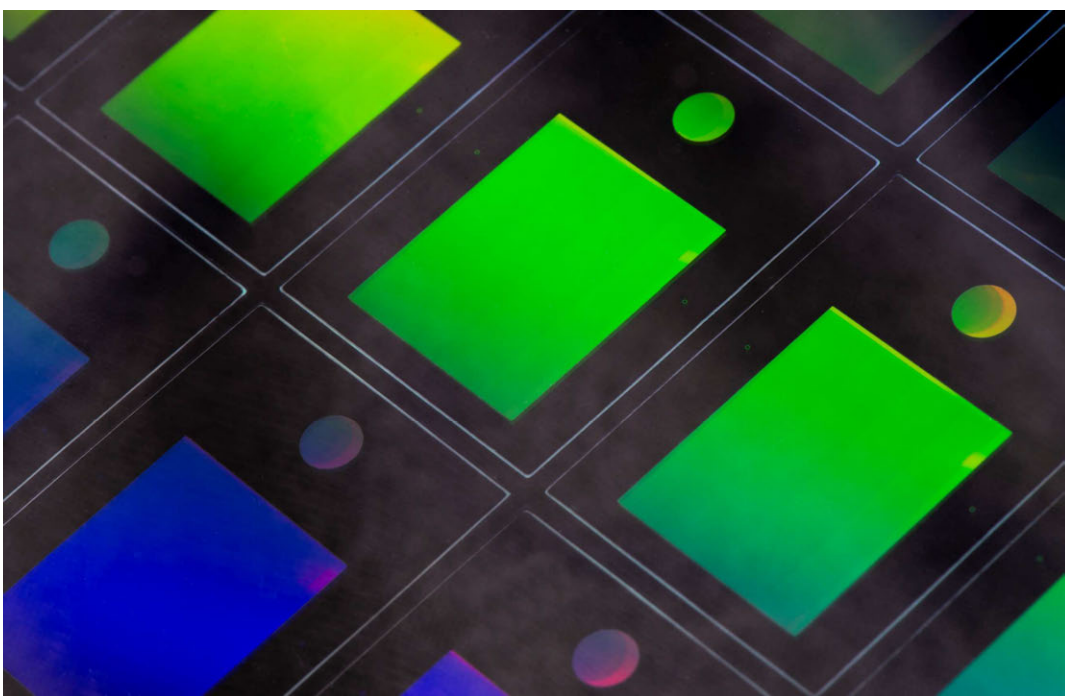
UV-NIL Technologies

SmartNIL® Imprint Process with LuxNIL® High Refractive Index Resins for Augmented Reality Optical Devices



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Introduction

Augmented, Virtual and Mixed realities (AR/VR/MR) enable smart solutions in real time across a wide spectrum of industries from entertainment to communication to healthcare. AR/VR/MR devices bend and combine light to create virtual images that project onto the physical world. To provide the widest viewing angle and maximize the field of view (FOV), materials with refractive indices greater than 1.7 at 589 nm are employed. High refractive index glasses are available, and nanometer scale structures can be imprinted on these glasses economically by photo nanoimprint lithography (UV-NIL or P-NIL); in this technique, a UV-curable resin is coated on the substrate, a working stamp with nanometer scale images is pressed onto the resin, the resin is cured photochemically, and the working stamp is removed.

Key points

- UV-nanoimprint lithography
- High refractive index resins
- High precision imprints
- Sub-nm height gains

Wafer-level UV-NIL with high refractive index resins is a critical deliverable for semiconductor equipment and materials companies addressing the needs of AR/VR/MR device manufacturers. To become the de facto process for AR devices, the resins must overcome a number of challenges including insufficient resin filling of the working stamp, difficulty in release of the wafer from the polymer working stamp, and poor imprint quality in the nano-structures. As leaders in manufacturing equipment and materials, EV Group (EVG) and Addison Clear Wave Coatings (ACW) joined forces in developing a ready to use, high volume wafer-level UV-NIL process with EVG's SmartNIL® technology and ACW's LuxNIL® high refractive index resins.

ACW's LuxNIL® High Refractive Index (RI) Resins

To achieve the requirements of AR/VR/MR devices and to enable mass production capability using SmartNIL® processes, the LuxNIL® high RI resins must meet several performance objectives. The viscosity of the resins must be low enough such that uniform ultra-thin coatings of 0.1 to 4 microns can be produced by spin coating. After removal of solvent, the resins must maintain enough fluidity such that they fill the binary or the slanted nano-structures of the polymer working stamp by capillary action. The resins must be capable of imprinting with accurate capture of the nanometer scale structures. Finally and importantly, the resins must be chemically inert so that they do not etch nor deposit residues on the polymer working stamp thus changing the dimensions of the nano-structures produced in multiple uses of the working stamp.

After processing, the cured films must be strong enough to maintain the structures when the working stamp is removed from the cured resin layer, and the cured films must meet industrial level testing requirements without significant deterioration of optical properties including refractive index, haze, optical clarity, and transmission. For optical applications of AR/VR/MR, the refractive indices of the cured films must be >1.7 and, for many applications, >1.8 at 589 nm.

The bulk properties and environmental stabilities of three ACW LuxNIL® high RI resins studied in this work are reported in the Table. Thin films coated on glass were exposed to reliability performance testing of 85 °C and 85% relative humidity for extended periods. The Table reports properties measured before and after the stress tests. The films maintained high transmission and clarity with low haze, and the refractive indices and film thicknesses were effectively unchanged.

Table. *Properties of LuxNIL® films before and after 85 °C and 85% relative humidity exposure.*[a]

Film	Property[b]	Before Stress	After Stress
LuxNIL® P276	Refractive Index at 633 nm	1.843	1.817
	Thickness (nm)	669	670
	Haze / Clarity / Transmission[c] (%)	0.20 / 100 / 100	0.21 / 100 / 100
LuxNIL® P285	Refractive Index at 633 nm	1.918	1.918
	Thickness (nm)	698	692
	Haze / Clarity / Transmission[c] (%)	0.15 / 100 / 100	0.18 / 100 / 100
LuxNIL® P289	Refractive Index at 633 nm	1.961	1.966
	Thickness (nm)	705	693
	Haze / Clarity / Transmission[c] (%)	0.27 / 100 / 100	0.30 / 100 / 100

[a]Resin was coated on glass, heated at 100 °C for 1 minute to remove solvent, cured with 365 nm UV light, conditioned at 150 °C for 4 hours, and then stressed at 85 °C and 85% RH. [b]The RI and thickness were measured on samples stressed for 360 hours; haze, clarity, and transmission were measured on 1 micron samples stressed for 1,000 hours. [c]Transmission values are corrected for reflections.

Nano-Imprint Structures with EVG's SmartNIL® Process

To demonstrate nano-imprint manufacturing feasibility with EVG's SmartNIL® process, ACW's LuxNIL® P276, P285 and P289 resins were studied with a PFAS-free polymer working stamp with a focus on the following properties:

A. Accuracy of nanoimprint structures with binary and slanted structures
B. Working stamp height change following multiple imprints
C. Resolution capabilities of the resins

The samples were replicated on the EVG HerculesNIL® system, a fully integrated high volume manufacturing equipment that is dedicated for nano imprinting lithography and wafer-level optics. All imprints were on glass wafers with AR/VR-like structures with dimensions of 200 nm and a pitch of 400 nm using EVG NIL UV/AS5 working stamps which are PFAS-free. The final characterizations were conducted by SEM and AFM for exact determinations.

Accuracy of nanoimprint structures

An important requirement of AR/VR/MR market is the production of imprinted structures with an exact replication of the shape of the original master template. In general, such fidelity is a function of the fluidic properties of the material after the solvent removal bake step, the compatibility of the resin with the chosen working stamp material, and the proper process settings. In the present study, the LuxNIL® resins were investigated in terms of their pattern replication on the PFAS-free working stamp. Figure 1 shows AFM measurements of the SmartNIL® process with the LuxNIL® resins. The results demonstrate perfect replication with superior pattern fidelity for all three materials.

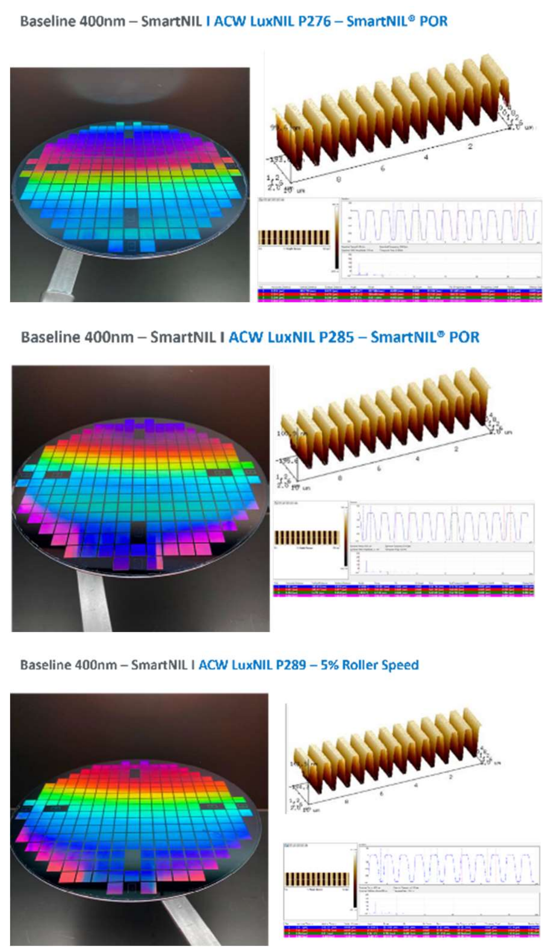

Figure 1. *AFM results of binary with 400 nm depth nano-imprint structures of LuxNIL® P276, P285, and P289 with SmartNIL® processes.*

Height gain from multiple imprints

A single perfect replication is not sufficient performance for a bulk manufacturing process. The EVG SmartNIL® process is a highly cost-effective technology when multiple replications from the same polymer working stamp give useful imprinted surfaces. Thus, each of the three LuxNIL® resins was applied in 25 imprints on a single working stamp, and heights of structures on the imprints were measured. Figure 2 shows the results. The observed average height gains were 0.64 nm/imprint (P276 and P289) and 0.80 nm/imprint (P285). These uncommonly small height gains, which are groundbreaking results for materials with refractive indices as high as 1.96 at 633 nm, reflect the good compatibility of the resins with the polymer working stamp.

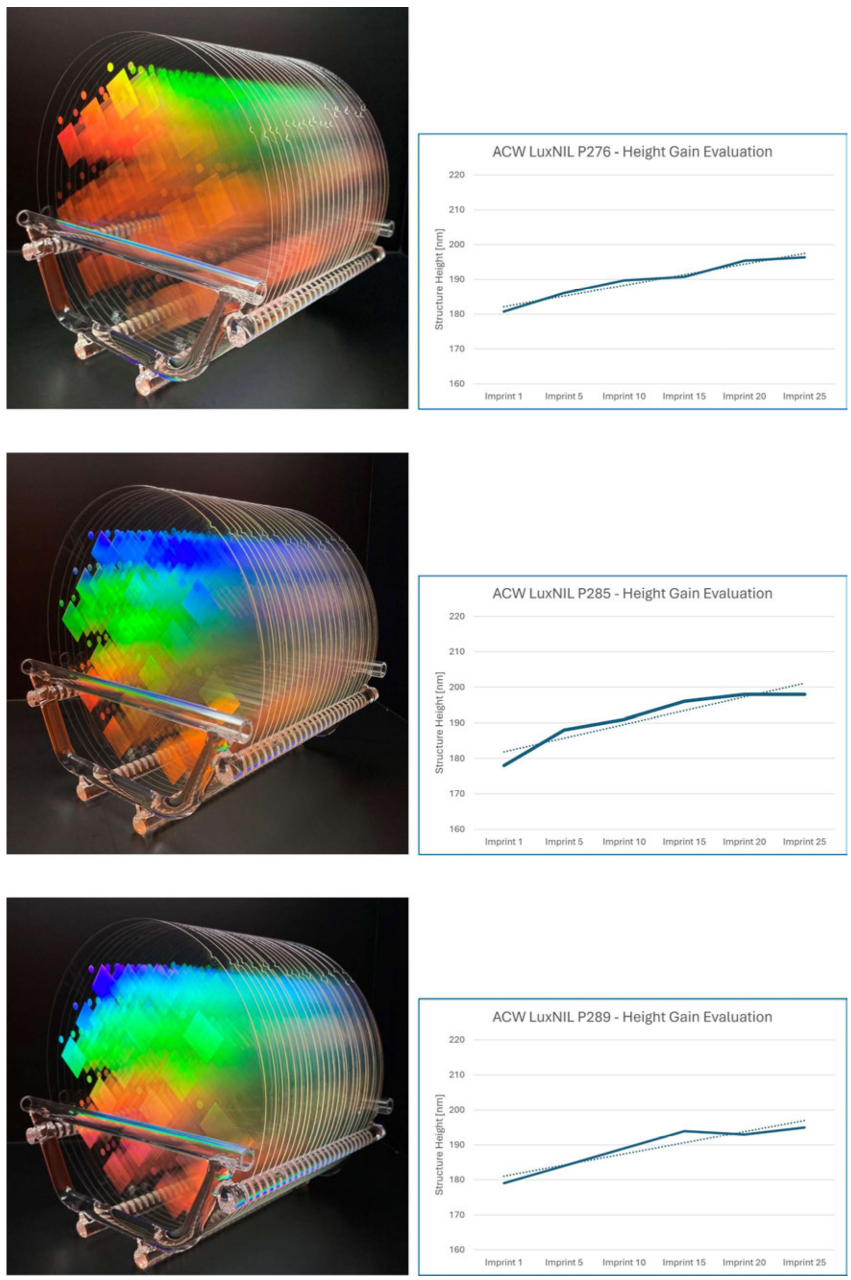

Figure 2. *Height gain over 25 imprints for ACW LuxNIL® P276, P285 and P289.*

Resolution capabilities of the resins

High resolution capability of the resins is necessary for the replication of sharp edges. This property was investigated using a dedicated resolution master. The smallest features on this master are 50 nm, and there are complex meander structures on the template which are more challenging than simple line and space structures since they contain 90° curves. The AFM results of the resolution tests, illustrated in Figures 3-5, demonstrate that each of the LuxNIL® resins achieved an exceptional resolution of 50 nm.

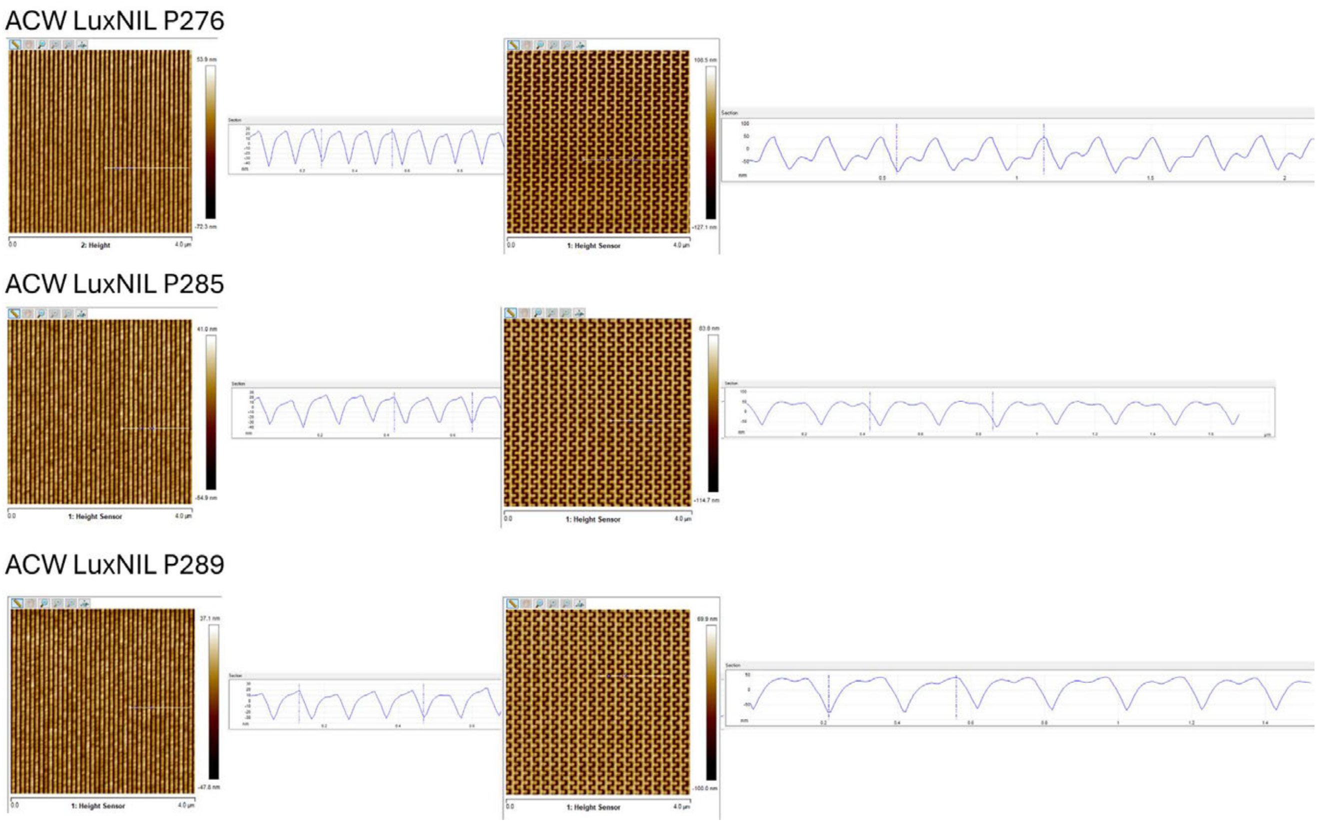

Figure 3-5. *Resolution tests.*

In summary

EVG's SmartNIL® process with ACW's LuxNIL® resins produces high resolution structures with high refractive indices in multiple replications on inexpensive working stamps. These are necessary properties and performance standards for economical bulk manufacturing of optical components that can be incorporated into AR/VR/MR devices.

EV Group SmartNIL® Process Summary

The process flow consists of two steps: First, manufacturing multiple low-cost polymer working stamps (WS) from a previously manufactured master and then utilizing them for the actual imprints during the second step. This intermediate approach avoids wearing out the original master template and improves the overall production economics, as the achievable number of imprints is increased tremendously. The NIL process is depicted in detail in Figure 6. To ensure defect-free WS fabrication, the master is coated with an anti-sticking layer applied by spin coating. The WS material is then dispensed directly on the master, also by a spin coating process. Next, the transparent SmartNIL® backplane is attached to the coated master. The WS polymer is cured with UV light from an LED, and the WS is demolded from the master. Upon completing this process, the actual SmartNIL® imprinting process begins, where a dedicated material is applied onto the substrate by the same method as used for the WS fabrication, e.g., spin coating. After removal of the solvent in a short "bake" step, the WS and the substrate with the dispensed material are brought into contact. Similar to the WS fabrication, this step is followed by UV curing and demolding, allowing multiple imprints to be made with the final structures.

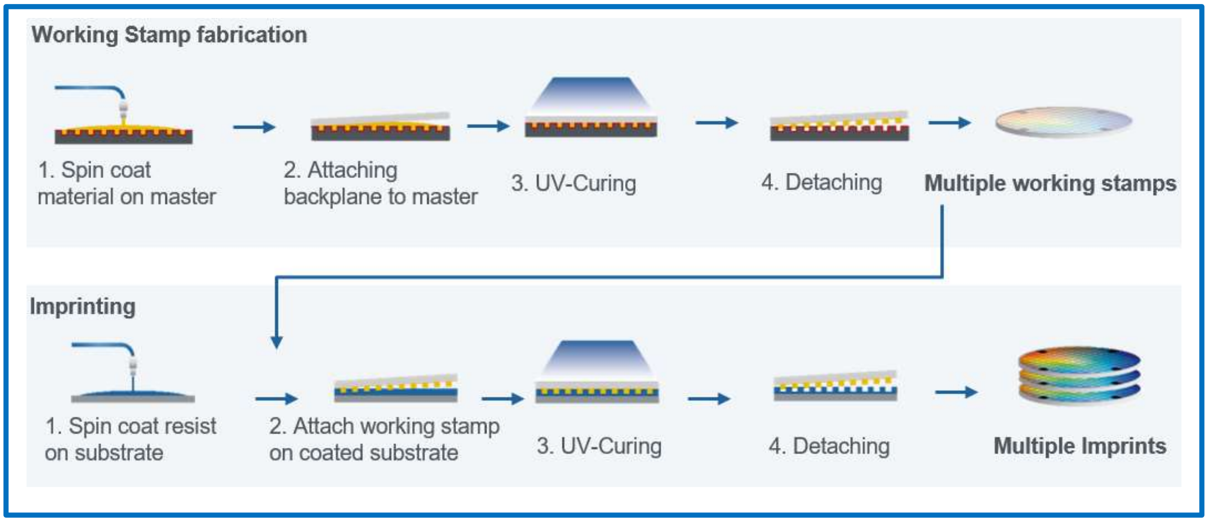

Figure 6. *The EV Group SmartNIL® Process.*

High Refractive Index LuxNIL® Resins

Addison Clear Wave Coating's LuxNIL® resins provide films with refractive indices in the range of 1.70 to 1.97 at 589 nm that are suitable for high volume wafer-level photo nanoimprint lithography manufacturing. In addition to the essential high refractive indices, these resins were developed with an eye towards chemical inertness and compatibility with contemporary equipment, processes and working stamps as demonstrated by the studies conducted here. As immersive experiences in AR/VR/MR mature and markets grow, additional requirements for high RI materials undoubtedly will surface; ACW is poised to continue vigorous research and development activities to ensure delivery to device manufacturers of the most technologically advanced imprint resins.

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