White Paper

Reliability, Repeatability and Uniformity: NTT-AT High Refractive Index Resins with EVG SmartNIL® Technology

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Introduction

Augmented reality (AR) is a technology that combines virtual reality with the physical world, thus transcending the physical boundaries of the real world to deliver more attractive user experiences.
As this technology becomes more accessible to consumers, optical devices for AR are becoming increasingly compact and sophisticated, as exemplified by optical waveguide-based AR lenses. The focus has now shifted to the technologies utilized for the fabrication of microstructures, including diffraction gratings, holograms, and metamaterials, which manipulate the phase and polarization of light.
Nanoimprint technology facilitates the repeated replication of high-precision nanostructures. In particular, when utilizing UV-curable resin as the transfer material, the replication process can be conducted in simple steps across the surface of large-area wafers at ambient temperature and atmospheric pressure. This is advantageous in terms of expeditious turnaround times, rendering it highly suitable for mass production. Furthermore, when employed in combination with inkjet technology, it provides benefits such as the capacity to generate structures exhibiting various pattern widths and heights on a single substrate, with a uniform residual layer thickness.

Material properties and reliability

NTT-AT offers a range of UV-curable high refractive index resins, which are ideally suited to the fabrication of microstructures in AR applications. The range of

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refractive indices of the product line, from 1.6 to 1.9+, offers a significant degree of flexibility in the design of optimal optical systems for a range of applications. The NH700 series, which comprises solvent-dispersed and PFAS-free high refractive index resins, demonstrates excellent photostability and pattern fidelity. In addition to the adjustment of refractive index and film thickness, customization for use in inkjet printing is also available.

NH700 series	Refractive index	1.8, 1.9
	Film thickness	200nm~1μm (Typ. 300nm)

N762 is a newly developed resin with a refractive index of 1.8. The essential characteristics of this resin are outlined below.

Table 1. The essential characteristics of NH762

Solvent type	PGMEA
Coating method	Spin coating
Curing method	UV
Refractive index	1.8
Transparency*	>90%
Haze	<0.1%

**This value includes reflection loss*

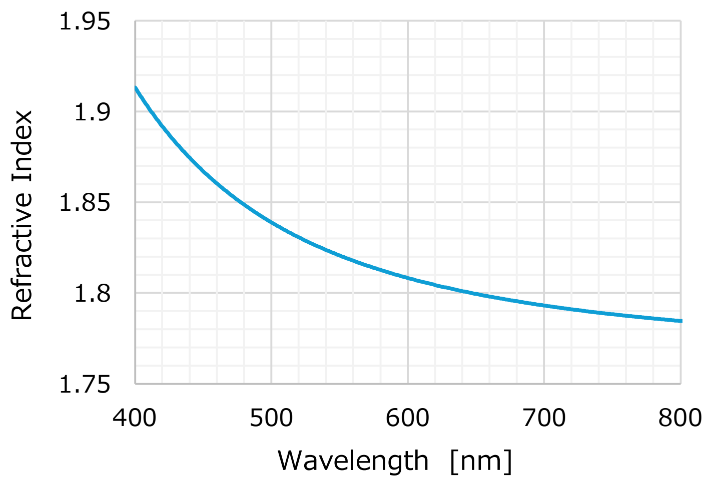

Figure 1. Wavelength dispersion of the refractive index of NH762

The following scanning electron microscope (SEM) cross-sectional images illustrate examples of nanoimprint pattern transfer of the NH762. The pattern is of a binary line-and-space structure with a line width of 350 nm and an aspect ratio of 1, which demonstrates excellent pattern fidelity with a thin residual layer thickness.

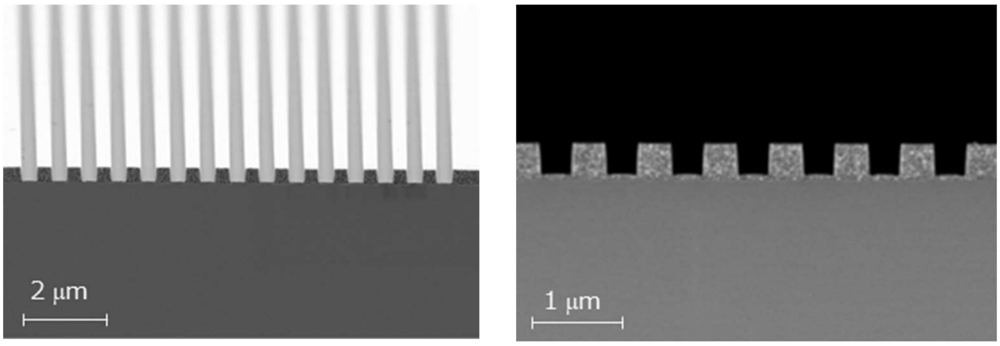

Figure 2. SEM images of nanoimprinted binary pattern of NH762

Reliability tests were conducted on the nanoimprinted samples of NH762 to evaluate the photostability and the durability of high temperatures and humidity. Minimal alterations in pattern geometry were observed by SEM both prior to and following the tests, confirming the excellent resistance.

Table 2. The reliability test results of NH762

	Change of properties	
Photostability Test condition: UV-cut, 1W@420nm, BPT=50℃, 100 hours	Pattern width	-2.0%
	Pattern depth	-3.0%
Damp heat Test condition: 60℃, 90%RH, 100 hours	Pattern width	+1.0%
	Pattern depth	- 0.5%

Imprinting process

To utilize this resin for large-scale manufacturing, it is essential to be able to produce multiple replicas from a single working stamp, exhibiting excellent pattern fidelity and being free of defects. From this standpoint, the consecutive replication test of NH762 has been demonstrated by using EVG SmartNIL® system.
Wafer-level nanoimprint lithography (NIL) was carried out using EVG's SmartNIL® technology, employing a two-step stamp replication strategy. In the first step, a low-cost polymer working stamp (WS) is fabricated from a previously manufactured master. The working stamp is subsequently used for the imprinting of functional structures in the second step. This intermediate stamp approach effectively protects the original master from wear and substantially enhances manufacturing economics by enabling a significantly higher total number of imprint cycles. In addition, a defective working stamp can be replaced rapidly and at minimal cost, providing a key advantage for high-volume production environments.
The fabrication of the working stamp begins with the application of an anti-sticking layer to the master via spin coating. A UV-curable polymer material is then deposited onto the master using spin coating, followed by the attachment of a

SmartNIL® backplane. The polymer is cured by UV LED exposure and subsequently demolded. In the second step, a dedicated imprint material is applied to the target substrate by spin coating or inkjet coating. The working stamp is brought into contact with the coated substrate, followed by UV curing and demolding. Reuse of the EVG® NIL UV/AS5 over multiple imprint cycles significantly improves process throughput and efficiency.

Repeatability and pattern fidelity results

The results of the atomic force microscopy (AFM) evaluation of the relationship between the number of transfers and changes in pattern height for an L/S ratio of 400 nm are shown below. A height changes of 9 nm (+2.2%) was observed after 25 transfers, confirming that the material exhibits excellent dimensional stability and release properties from the EVG® NIL UV/AS5 working stamp material.

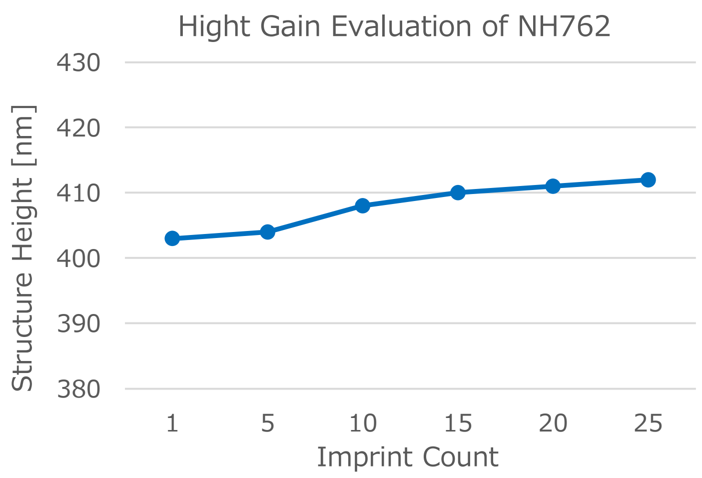

Figure 3. The height gain evaluation result of the consecutive 25-replication test of NH762

To evaluate the material combination of NH762 and EVG® NIL UV/AS5 working stamp materials also on complex 2.5D structures, such as slanted gratings with an angle of 45°, or meta optical elements with smallest critical dimension of 65nm at an aspect ratio of 1:4, were successfully imprinted. For both cases, the pattern fidelity shows smooth and uniform structures over the entire SEM image, without any missing structures or deformation after the imprinting process.

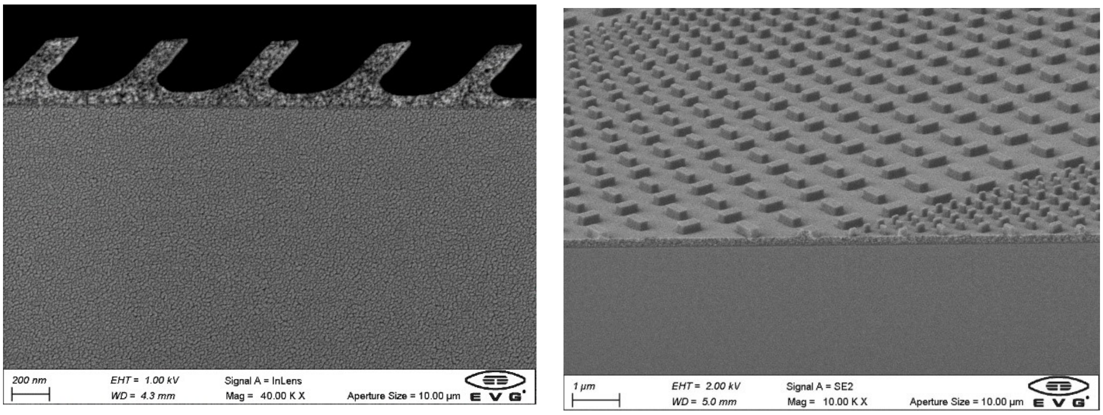

Figure 4. SEM Images of 45° Slanted gratings (a) and meta optical elements with critical dimensions down to 65nm (b)
Master provided by Tekscend

Conclusion

The combination of NIL and reliable, robust high index imprinting materials offers a practical and cost-effective way to high performance, scalable AR waveguides. The latest results on NTT's NH762 show excellent optical performance, long term reliability, and pattern fidelity. Especially in combination with EVG's SmartNIL® process and the EVG® NIL UV/AS5 working stamp material, the material demonstrates stable and effective high-volume manufacturing. Together, advanced NIL processes and optimized resin materials form a robust foundation for next-generation AR optical systems, accelerating the commercialization of compact, high-quality AR devices.

■ About NTT ADVANCED TECHNOLOGY CORPORATION (NTT-AT)

Since its establishment in 1976, NTT ADVANCED TECHNOLOGY CORPORATION (NTT-AT) has served as a technology-driven company within the NTT Group, leveraging advanced technologies developed by NTT laboratories as well as leading-edge technologies from around the world. By integrating these technologies, NTT-AT continuously delivers value to customers by addressing a wide range of technical and business challenges. NTT-AT operates its business through four core domains: Applications, Materials & Nanotechnology, Social Platforms, and Total Solutions.

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■ About EV Group (EVG)

EV Group (EVG) provides innovative process solutions and expertise that serve leading-edge and future semiconductor designs and chip integration schemes. The company's vision of being the first in exploring new techniques and supporting next-generation applications of micro- and nanofabrication technologies enables customers to successfully commercialize new product ideas. EVG's high-volume-manufacturing-ready products, which include wafer bonding, lithography, thin-wafer processing and metrology equipment, enable advances in semiconductor front-end scaling, 3D integration and advanced packaging, as well as in other electronics and photonics applications.

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