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Developing a Platform for Creating Waveguide Combiners for AR Headsets and Metasurface-based Optics

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ABSTRACT

Augmented and Virtual Reality (AR and VR) will enable new and ubiquitous platforms for communicating, learning, and computing. These new display platforms rely on essential waveguide combiners for transporting, expanding, and faithfully rendering the image generated by the light engine onto the glasses. Using its more than 50 years of experience in creating and structuring thin films for semiconductor technology, Applied Materials is now developing waveguide combiners on glass. Metasurface-based optics will revolutionize the world of optics, creating many opportunities for developing new, nanostructured optical devices with a much thinner form factor not previously possible with classical optics. In this paper, we will describe the new materials and the techniques needed to create these nanostructured optical devices.

1 Introduction

Optics is playing an increasingly important role in modern life, and advances in nanostructure-based flat optical devices hold great promise for revolutionary new opportunities in the display space. Augmented and Virtual Reality (ARVR) are expected to enable the next ubiquitous computing and communication platform.[1] Augmented Reality, especially, is a transformational new category of display that allows for the overlay of timely, location-based, or other useful information on the user's natural view of the surrounding world. This will create new opportunities in teaching and learning, enterprise applications, entertainment, and beyond. Optical metasurfaces also leverage engineered nanostructures to offer the possibility of extreme wavefront control, enabling further miniaturization of imaging and display optical systems and exciting new applications not achievable with conventional optics. [2,3]

Applied Materials is a materials engineering company, with expertise in manipulating materials at an atomic level on an industrial scale. This expertise, and our tools for nanoscale engineering, are key to unlocking the potential of Augmented and Virtual Reality and of optical systems based on metasurfaces. Our products, research, and development span the electronics, energy storage, displays, and optics necessary to make ARVR devices and flat optics truly ubiquitous.

Within Applied Materials, the Office of the Chief Technology Officer (CTO) identifies high-value problems that can be addressed with Applied's materials engineering and tool manufacturing expertise, outside of our semiconductor and traditional display-related established businesses. We then develop needed technical building blocks to address the problems, retire technical risks, and accelerate time to market for our solutions.

2 Methods and Discussion

The mission of the Engineered Optics™ group in the Office of the CTO at Applied Materials is to enable the next revolution in optics. We envision a world where thinner, light-weight optical systems enable precise wavefront engineering to make possible novel optical devices. In pursuit of this goal, we have developed a platform for the precision fabrication of a variety of nanostructured optical devices on 300mm diameter glass wafers, as well as metrology, optical performance characterization, and back-end assembly of these devices. We are leveraging this platform for the production of waveguide combiners for AR/VR applications and optical metasurfaces for multi-functional wavefront control in the near infrared, and are also working towards additional applications.

2.1 Fabrication of Waveguide Combiners

Waveguide combiners are a key component in lightweight augmented reality headset or glasses systems, and one of the most difficult to fabricate to the high precision required for simultaneous high optical image quality of the AR content and clear vision of the real world. [1] The combiner in an AR system takes the image formed by the light engine and guides it, through a process of many bounces of total internal reflection, to an exit pupil or exit pupil expander region that then projects the image onto the user's eye. [1] While possible combiner architectures including freespace reflective combiners and freespace birdbath combiners exist, only waveguide-based combiners are thin, lightweight display optics that can be implemented in the glasses-type hardware that is the goal of many companies in the AR space.

There are a variety of different waveguide combiner technologies, all offering their own tradeoffs, including holographic, reflective, and surface relief grating waveguide combiners. To achieve the highest AR display performance in terms of key performance indicators of field of view, efficiency, uniformity, sharpness, contrast, and color uniformity, plus fabricability, we find that surface relief grating-based waveguide combiners offer the greatest advantages. Surface relief grating waveguide combiners can be fabricated in a top-down manner on flat glass substrates, leveraging decades of semiconductor fabrication research and development. However, they have drawbacks, including challenging design for full-color displays given the inherently dispersive nature of diffractive structures, and difficult modeling of the optical effects from the nanoscale surface relief gratings to the macroscale device performance. Their performance also depends strongly on the use of high-refractive index, low-loss optical materials.

As we have established, the design and fabrication of surface relief grating-based waveguide combiners with appropriate image quality, form factor, lifetime, and reliability at an appropriate cost for large-scale commercialization of augmented reality glasses is a significant materials engineering challenge on many levels. The Engineered Optics platform now has in place a fully integrated front-end process flow that we use to make customized surface relief grating-based waveguide combiner devices for our customers. All our tools are customized to enable handling of transparent substrates of a variety of refractive indices and thicknesses. We can produce binary and slanted nanostructures using UV or nanoimprint lithography and etch in high-quality, low-loss optical materials including silicon nitride, titanium dioxide, silicon dioxide, and other materials of interest. We are able to process single- or double-sided devices with high alignment fidelity, and to create desired gradient features with global and local-area processing techniques. Six waveguide combiner devices fabricated on a transparent, high-RI substrate are shown in Figure 1.

The Engineered Optics platform offers full end-to-end capabilities: after front-end fabrication on 300mm substrates, we fully optically characterize device performance at the wafer level, then complete back-end singulation, edge blackening, stacking assembly, and final testing to produce completed and known good flat optical sheets for our customers. These completed waveguide combiner devices can then be integrated with light engines and appropriate electronics, power sources, and housings to create a final augmented reality glasses or headset device.

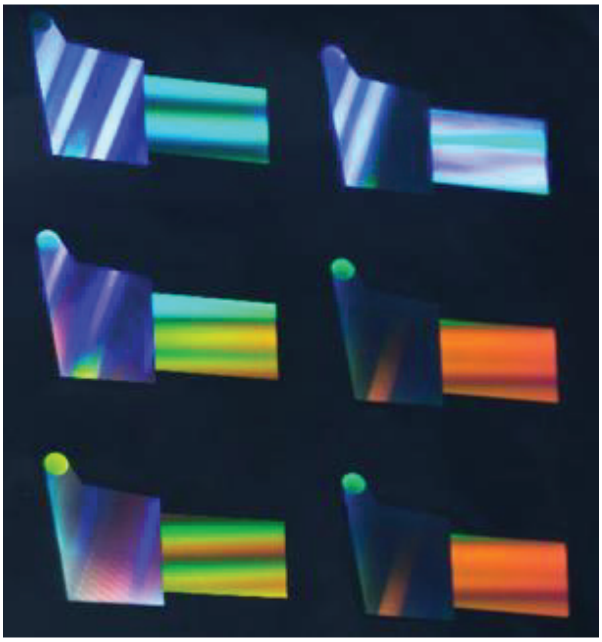

Fig. 1 Waveguide Combiner devices designed by Dispelix and fabricated by Applied Materials, shared with permission by Dispelix

2.2 Fabrication of Optical Metasurfaces

Modern nanofabrication techniques developed for semiconductor fabrication are making it possible to fabricate the carefully engineered sub-wavelength nanostructures that comprise optical metasurface devices operating in the near-infrared (IR) and visible wavelength regimes. [2,3] The total wavefront control enabled by metasurfaces' phase engineering of light on the nanoscale allows for the creation of single-sheet multifunctional optical devices that would require a large stack of traditional refractive lenses to create, and even creates new opportunities for applications that cannot be achieved with traditional optics. [2,3]

As with waveguide combiner fabrication, the Engineered Optics platform, with 300mm tools optimized for the handling of transparent substrates, has been developed to enable direct fabrication of these revolutionary flat optical devices, without any sort of transfer from silicon substrates. We can fabricate the extremely high aspect-ratio structures required for full 2π phase control in a variety of extremely low-loss, high-refractive index optical materials.

We have worked with a variety of customers who have designed amorphous silicon-based multifunctional metasurfaces for near-IR wavelengths, fabricating thousands of millimeter-scale devices on 300mm glass substrates. One such wafer is shown in Figure 2.

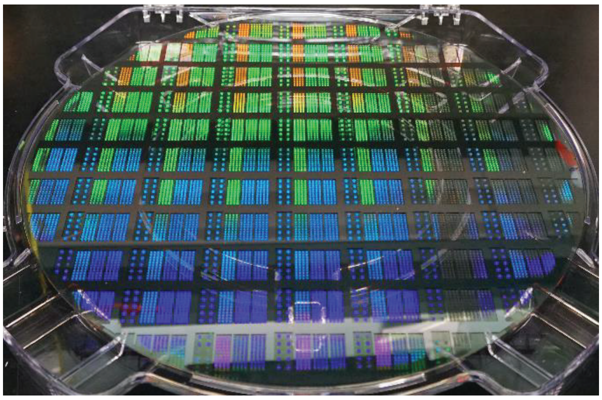

Fig. 2 Near-IR multifunctional metasurfaces devices designed by Metalenz and fabricated by Applied Materials on a 300mm diameter glass substrate

As with our waveguide combiner fabrication, we offer additional front-end and back-end services for metasurfaces, including anti-reflection coatings, dicing, and singulation.

2.3 Additional Applications

In addition to waveguide combiners and metasurfaces, the Engineered Optics group works on other novel optical applications where our expertise in fabrication of nanostructures on transparent and traditional semiconductor substrates is applicable, including photonic integrated circuits, optical computing, optical data communication, and beyond; please contact us if you would like to collaborate.

3 Conclusions

At Applied Materials, our innovations make possible a better future. The Engineered Optics group within the Office of the CTO is leveraging our expertise in materials engineering on the nanoscale to enable next-generation thin, lightweight nanostructured flat optical devices. Our unique position as a tool manufacturing company enables us to overcome many of the challenges in working with optical materials and substrates in place of the semiconductor materials historically processed with the required nanoscale precision. The Engineered Optics platform is producing waveguide combiner devices for augmented reality glasses and headsets, optical metasurfaces for near-infrared multifunctional wavefront control, and other novel optical devices.

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