ENABLING NEW APPLICATIONS WITH FLAT OPTICS

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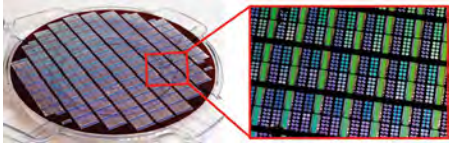

Picture of a 300 mm transparent wafer composed of Near Infra-Red Metalenses. Each metalens has a millimeter diameter pupil size, which allows thousands of devices per wafer.

Over the past decade, flat optics, also known as flat metasurfaces, have been a new hot topic in the photonics community. The application opportunities seem nearly limitless. In this article, we will discuss the exciting potential of flat optics for the photonics industry and market. We will also discuss some of the requirements and challenges.

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With increased interest in applications for augmented reality (AR) and virtual reality (VR), the design and fabrication of smaller, thinner, and highly efficient optics, is becoming more and more challenging. We believe that flat optics have a key role to play in the photonics industry.

In 2019, flat optics were mentioned as one of the top 10 emerging technologies by the World Economic Forum [1]. Over the past few years, we have witnessed increasing interest in metasurfaces, and a larger ecosystem being built.

For those who are not familiar with the topic, a new class of optical components has recently emerged in the photonics industry. Interchangeably known as metasurfaces, meta-optics or flat optics, this new type of component can locally engineer the wavefront of light by using periodically arranged nanostructures, also referred to as “moxels” (stands for meta-optical element), at a subwavelength scale. The principle of using subwavelength structures to manipulate electromagnetic waves has existed since 1948 and was first introduced by Winston E. Kock [2]. In the 1990s, the same principle was introduced by Prof. Lalanne [3] in the visible spectrum. It was only in 2011 that the topic re-emerged and was made popular by Prof. Capasso, who saw the full potential of flat optics [4].

One could argue about this technology’s full potential [5], but as is often mentioned by the scientific community, flat optics do not aim to replace classical refractive optic components. By locally controlling the phase response, amplitude and/or polarization, flat optics pave the way to new optical functionalities and applications such as edge detection or photonic computing [6-7], which are complicated to realize with classical bulky refractive optics.

MARKET ADOPTION

Flat optics are not only attractive [8] because they are able to reduce the size of optical systems and bring new functionalities, but also because they are compatible with semiconductor industry manufacturing processes, potentially making them a suitable candidate for high-volume manufacturing, which would reduce the cost of production compared to classical refractive optics. Moreover, it has been demonstrated that flat optics can be directly integrated on existing devices, such as vertical cavity surface-emitting lasers (VCSEL) made with traditional silicon foundry processes. This approach allows the VCSEL emitted beam to be directly shaped, without the need to integrate wafer-level optics on the top of the VCSEL, which could be a challenge in terms of alignment [10]. Last year, Harvard spinoff company Metalenz designed, and made possible the introduction to the market, of a new time-of-flight (ToF) module composed of flat optics. Slowly but surely, flat optics are showing the promise of becoming more mainstream and a reality.

Flat optics are now well-suited for narrow-band and single wavelength application, like 3D sensing based on IR active illumination. The market for 3D

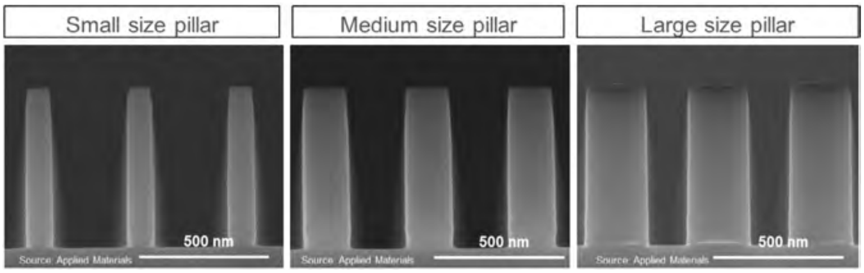

Figure 1. To fully achieve its functionality, the dielectric nanostructures composing the metasurfaces should have a perfect form factor, which could be close to 5 to 1 in certain cases. On a large range of diameters, we are able to get a sidewall angle comprised between 88 and 90 degrees across the design rule critical diameter.

sensing devices is forecasted to be close to 7.5B$ for mobile and 3B$ for automotive applications in 2027 with a total of 16B$ for all market segments [11]. If we consider only the sensing application, flat optics are one of the best candidates to solve key technical challenges that wafer-level optics have faced for many years, the benefits of which include reducing the form factor or reducing cost due to low-yield alignment processes and integration.

There are now gaps in where the technology could be leveraged, and this requires all the actors in the industry to jointly bring the technology to market by demonstrating useful product applications.

CHALLENGES

As mentioned, flat optics are compatible with classical semiconductor foundry manufacturing processes. However, most semiconductor factories use a CMOS-related manufacturing process utilizing electronics materials and Manhattan geometry structures on silicon substrates.

Flat optics are different; they need non-Manhattan geometry structures, made of optical grade materials, and on transparent substrates. This can introduce several challenges.

For example, how do you process transparent substrates? Silicon factories may need to implement additional steps, like wafer bonding between silicon and transparent substrates. We have conducted R&D work to solve this problem and has demonstrated the ability to process transparent substrates directly without the need to bond to a silicon substrate.

Flat optics need high refractive index materials with very low optical absorption. Materials are key to optical performance.

Another key technical challenge is to pattern the nanostructures precisely on target. We solved this with a special Optical Proximity Correction (OPC) model. The OPC model is a critical

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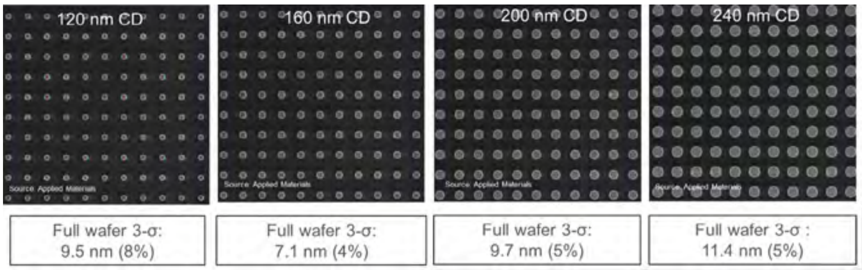
Figure 2. The same principle as the sidewall applies to the diameter of the structure. In that special example, the metalens is composed of high refractive index nanopillars. The uniformity of the diameter over the entire device should be as close as possible to the design dimension, hence the importance of the OPC model.



step in lithography-related processes. This technique is commonly used in the semiconductor industry to increase the final pattern fidelity with the original design. Indeed, OPC models are well-known, but the feature size, aspect ratio and the density of nanostructures are more challenging in the case of flat optics.

The form factor and the shape of the nanostructures are strongly linked to their resonance properties, which could play a significant role on the overall performance and the desired optical functionality of the flat optics. For that reason, it is crucial to obtain nanostructures precisely following the initial design. As we show on Figure 1 and 2, we have a full control of the geometrical parameters of the nano-antenna. The sidewall of the structure is perfectly shaped with an angle in the range of 88 to 90 degrees overall. The diameter required for the design and the height planarity over the entire wafer are fully controlled. The critical diameter pillar uniformity is also well-controlled over the different diameter range, as we underline on Figure 2, with a full wafer 3-σ less than 8%.

Finally, to avoid any performance variation and increase its reliability, the metasurface needs to be encapsulated. As we present in Figure 3, we have developed an encapsulation method to increase the stability and reliability of devices, without the need for additional post-process planarization steps.

Based on Applied's strong knowledge of designing and manufacturing semiconductor equipment to modify materials at atomic levels, the Photonics Platform is leveraging years of research and development to innovate on the next disruption in photonics components. We have made significant progress in technology development, including materials, tooling, and processes to enable direct on transparent substrate flat optics components and diffractive waveguide combiners.

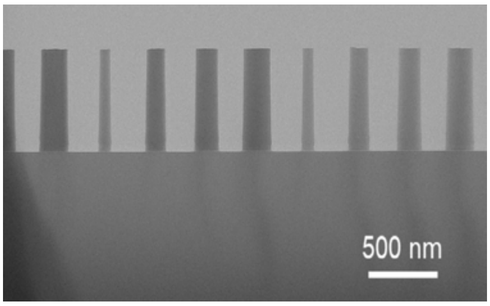


Figure 3. Flat optics should be also reliable and work in all environments. Therefore, several methods of encapsulation were developed to fully protect the nanopillars. Here, we show an example of encapsulation for a near infrared metalens, made of a low refractive index material.

CONCLUSION

Flat optics is an emerging technology with, we believe, a strong potential in different market segments. As we already mentioned, the first 3D sensing product composed of flat optics entered the market recently. This is the first in a long list of sensing and imaging sensors required by new emerging markets such as AR and VR. Flat optics has an important role to play in reducing form factors and enhanced new functionalities. As the technology continues to evolve, it's showing itself to be ideal for numerous cases that are expensive or impossible to solve using classical refractive optics, especially for smart sensing use cases like optical detection, polarization control or waveguides for AR.

Flat optics do not aim to replace refractive optics, rather this disruptive technology could answer some key technical challenges that refractive optics have not been able to solve for many years. The research and development necessary to achieve new functionalities and manufacturing with a compelling price-point is still a long road. This road has inevitable challenges, one is to have better resolution and new shape antennas. Another is to have higher RI materials, which requires further advancements in material science. ●

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