# Metasurface Beam Deflector Array on a 12-inch Glass Wafer

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**Abstract:** We have demonstrated a large-area metasurface beam deflector array patterned directly on a 12-inch glass wafer using immersion lithography. The captured random points at 940 nm wavelength show a good match with the design.
**OCIS codes:** (220.0220) Optical design and fabrication; (110.5220) Photolithography; (310.6628) Subwavelength structures, nanostructures.

## 1. Introduction

In recent years, metasurface has become one of the fastest expanding areas in nano-photonics. It is made from sub-wavelength scale meta-element, which is able to precisely control the phase shift of the optical wave. By designing the spatial distribution of these meta-elements, the wavefront can be shaped to achieve various optical functionalities, such as focusing [1], polarization control [2], optical vortex generation [3], etc. In order to produce these optical devices in large scale with high reliability and low cost, the fabrication process compatible with the current complementary metal-oxide-semiconductor (CMOS) technology is a suitable option [4] due to the fact that it is a mature technology currently used in the microelectronics industry, and it has also been used to demonstrate various optical components on silicon photonics platform [5–9]. Recently, such technology has been applied to fabricate metasurface based optical devices on either silicon or glass wafer substrate [10–15]. The significance of the metasurface demonstrated on glass wafer from CMOS fabrication platform is contributed by the capability of mass-producing the flat optics devices in transmission mode at both visible and near-infrared wavelength regime. While in our recent work demonstrated on glass wafer [15], the meta-elements are processed on silicon wafer substrate followed by a transfer process and the device is designed based on Huygens metasurface with limitation on the index contrast between the metasurface layer and the bonding glue. Patterning the metasurface based devices directly on the glass wafer is expected to reduce the fabrication cost and increase the index contrast.

In this work, we report a large-area pixelated beam deflector array with metasurface layer patterned directly on the glass wafer. A fabrication process has been developed in the Institute of Microelectronics (IME) to overcome the non-detectable issue of the glass wafer due to its transparency in the CMOS-compatible fabrication line. The beam deflector array is designed to work at 940 nm with a pixel of 21×21, and nanopillars are used as phase shifter. The captured image of random points generated by the beam deflector array shows a good match with the design. It has potential applications in 3D sensing and Light Detection and Ranging (LiDAR).

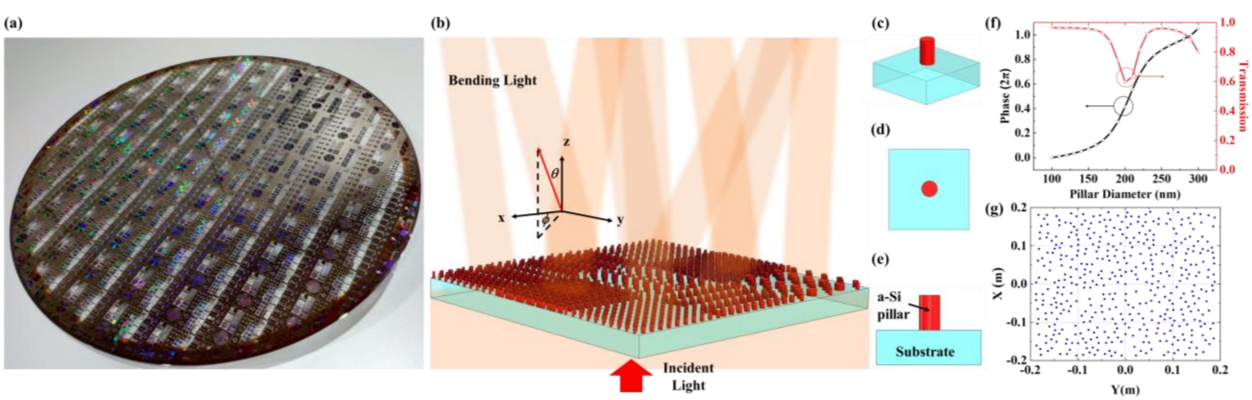


Fig. 1 (a) 12-inch glass wafer with metasurface based devices directly patterned on it. (b) Schematic of large-area beam deflector array on glass wafer (not to scale). (c-e) Perspective view, top view and side view of the nanopillar phase shifter. (f) The phase and transmission profile of nanopillars with various diameters. (g) Designed random points on a screen.

## 2. Device Design, Fabrication and Characterization

The photo image of directly patterned 12-inch glass wafer and the schematic of the beam deflector array are illustrated in Fig. 1(a) and (b) respectively. The device consists of 21×21 deflectors. Each deflector has a size of 120×120 µm. The perspective, top and side view of the nanopillar phase shifter are shown in Fig. 1(c), (d) and (e) respectively. These pillars are with the height of 400 nm on this wafer and the edge-to-edge distance of 200 nm. By varying the pillar diameter from 100 nm up to 280 nm, a 2π phase shift can be achieved, as presented in Fig. 1(f). The bending angle of each deflector is generated and determined by both polar angle θ and the azimuth angle ϕ. The bending in polar angle is achieved by the spatial phase shift gradient, as governed by the generalized Snell's law [16]. The bending in azimuth angle is achieved by changing the orientation of the phase shift gradient. The designed random points on a screen is provided in Fig. 1(g).

The photo mask for immersion lithography is shown in Fig. 2(a)-(c). The orientation of the nanopillars and the boundary between different pixels can be observed. In Fig. 2(c), the area highlighted within the black dotted line is one unit cell laid out with an orientation of ϕ which gives the azimuth angle. The fabrication process of the beam deflector is briefly summarized in Fig. 2(e). Starting from the 12-inch glass wafer (step I), an opaque layer is deposited at the bottom (step II) to make the glass wafer non-transparent and hence detectable by the fabrication tools. The amorphous silicon (a-Si) metasurface layer is then deposited at the top (step II). After that, another opaque layer is deposited at the top followed by the photoresist (PR) patterning using immersion lithography (step III). The top layer and the a-Si layer are etched together. Lastly, the bottom and the top opaque layers are removed to form the patterned metasurface layer on glass wafer (step IV). Upon the completion of the fabrication, the wafer is diced into small dies with dimensions of 26×33 mm, as shown in Fig. 2(d) with the device highlighted in red dotted line. The scanning electron microscopy (SEM) image of the nanopillars on central die is shown in Fig. 2(f) and (g).

The experimental setup to characterize the fabricated device is shown in Fig. 3(a). A fiber based supercontinuum source cascaded with an acoustic-optic tunable filter is used as a tunable laser source. The laser beam diameter is expanded through two lenses with different focal lengths, before the collimated laser beam is injected onto the metasurface. A paper screen is placed at the back to collect the projected beam spots, which are captured by the infrared (IR) camera placed beside the metasurface device. The image from the IR camera is presented in Fig. 3(b), with 2-D random spots clearly observed. Fig. 3(c) illustrates the overlap between the designed 2-D random points from Fig. 1(g) and the projected spot image from Fig. 3(b), showing a good match.

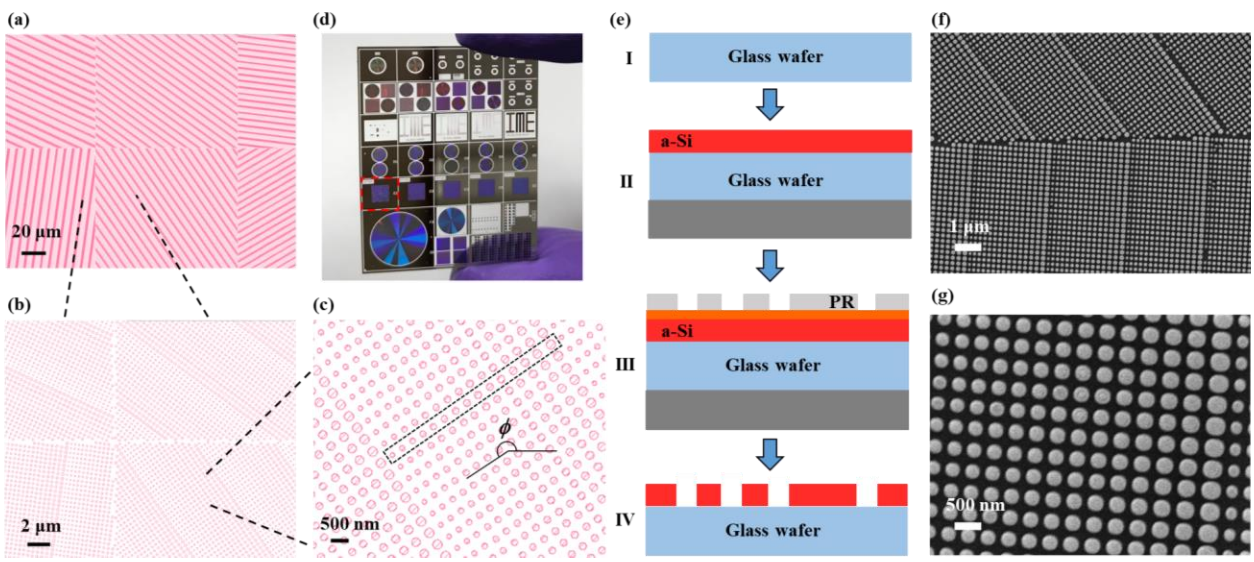


Fig. 2 (a-c) Pattern mask for 193-nm immersion photolithography, showing pixels of beam deflector with different orientation. (d) The photo of the central die with the pixelated deflector array device highlighted in red-dotted line. (e) Glass wafer fabrication process to achieve the direct patterning of the metasurface layer on glass wafer. (f) (g) SEM images of the patterned a-Si nanopillar, showing the boundary between different beam deflector pixels.

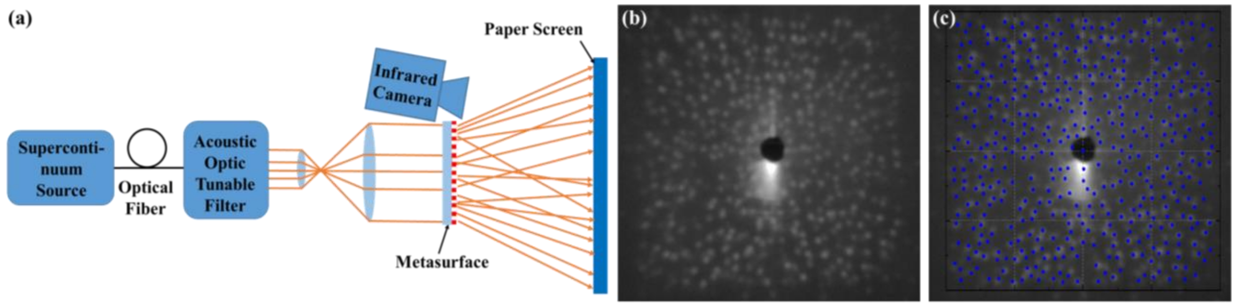


Fig. 3 (a) Schematic of the characterization setup. (b) The random point image projected on paper screen captured by the IR camera. (c) The overlap between the captured image from experiment and the design from calculation, showing good match.

## 3. Conclusion

In summary, a large-area metasurface based beam deflector is demonstrated, with the metasurface layer directly etched on 12-inch glass wafer for the first time. The glass wafer handling issues in the CMOS fabrication facilities have been resolved by depositing additional non-transparent layers on the glass wafer. The beam deflector array is designed with 21×21 pixels, and the random spot array image captured by IR camera is presented as the preliminary experimental results. Further works include optimizing the fabrication process, improving the critical dimension drift of nanopillars on the wafer for obtaining high efficiency of the beam deflector, and characterizing the wafer-level device performance.

The authors acknowledge the RIE2020 Advanced Manufacturing and Engineering (AME) Domain's Core Funds: SERC Strategic Funds (A1818g0028).

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