1D Line-scan Metalens Integrated with MEMS Actuator for Depth Sensing Applications

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Abstract: A 1D line-scan metalens integrated MEMS actuator with a field-of-view 80° × 60° has been demonstrated as proof-of-concept. This metalens integrated MEMS actuator shows promise as a compact optical module for depth sensing applications.

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1. Introduction

Optical metasurfaces are quasi-periodic arrays of subwavelength nanostructures, named meta-atoms, that enables arbitrary control of phase, amplitude and polarization of electromagnetic waves. Using such metasurfaces, the spatial phase profile of an incoming wavefront can be controlled in a sub-diffractive manner to fulfill different optical functionalities. A metalens is used to form the lens functionality, replacing complex and bulky conventional lens that relies on freeform geometric lens curvatures, on a flat form factor with thicknesses down to wavelength-scale and reduced weight. Due to these advantages, metalens shows promise in developing high-speed micro-opto-electromechanical systems (MOEMS) -based optical modules when integrated with microelectromechanical systems (MEMS) technology [1–4]. In this work, we designed and fabricated a compact 1D line-scan optical module using metalens integrated with a MEMS actuator. The compact module enables the incorporation of metalenses into mobile devices, robots and drones for depth sensing applications.

2. 1D Line-scan Metalens

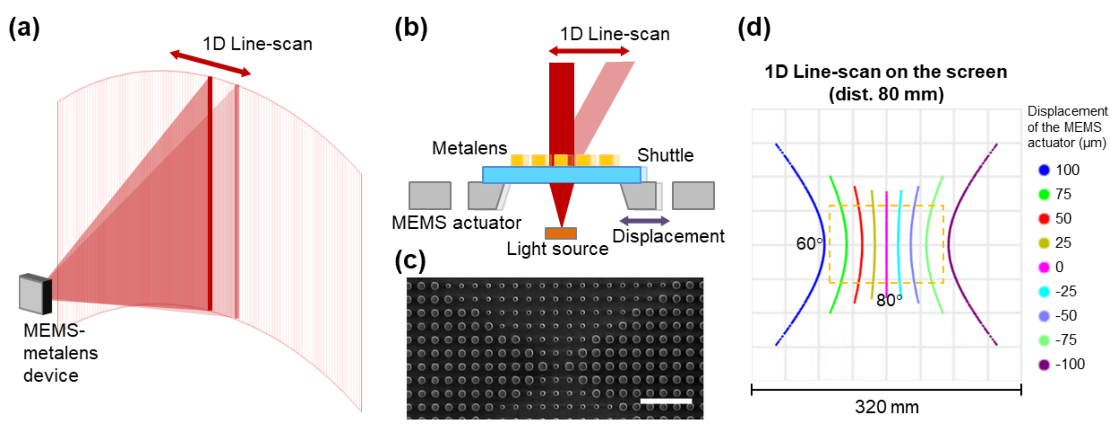

Fig. 1 (a) Schematic of 1D line-scan LiDAR. (b) Cross-sectional schematic of the compact 1D line-scan optical module with the metalens integrated with MEMS actuator. (c) SEM image of a section of the metalens, illustrating the quasi-periodic array of meta-atom for spatial phase control (inset, scale bar: 2 µm). (d) Simulation results of the line beam projected on a screen, at a distance of 80 mm away, as a function of the MEMS shuttle displacement.

Light Detection and Ranging (LiDAR) is a depth sensing technology that relies on the emission of light beam across the scene or field of view (FOV) and the subsequent detection of the reflected light beam with timing information to calculate the distances between objects and the sensor. Several methods can be used to illuminate the scene, either by scanning (1D line-scan or 2D raster point-by-point scan) or so-called flash illumination. The raster scan is compute power-intensive as it relies on point-by-point acquisition to form the scene whereas flash illumination requires the use of high counts of receivers in a 2D array format to capture the entire target scene. In comparison, the 1D line-scan method strikes a balance between the other two, using a vertical beam of light that scans from one end to the other to complete the scene as shown in Fig. 1(a). Fig. 1(b) shows an illustration of the proposed compact 1D line-scan MEMS-metalens optical module that comprises of a MEMS actuator and a membrane that mounts the metalens onto a shuttle. The horizontal displacement of the shuttle (and hence the metalens) is controlled by the MEMS actuators with a designed maximum displacement of ± 100 µm. The shuttle has an optical window to allow light from a light source to pass through the metalens. The metalens is designed to form vertical line patterned beams at various outgoing angles given the relative incident position of the laser light on the metalens (as controlled by the displacement of the shuttle by the MEMS actuator). The metalens is formed by an array of a-Si nanopillars with various diameters patterned with 12-inch 193 nm ArF deep UV (DUV) immersion lithography [5], arranged to create the spatial phase profile, of which the top-view SEM image is shown in Fig. 1(c). Fig. 1(d) is the simulation results of the line beam projected on a screen as the function of the displacement of the shuttle. The designed FOV is 80° × 60° (denoted by the orange color dashed line rectangle in Fig. 1(d)) whereby the shuttle displacement is near the maximum of ± 100 µm.

3. Results and Discussions

Fig. 2(a) schematic shows the experimental setup used to capture the image of the line beam projected on a screen at a distance of 80 mm away from the integrated MEMS-metalens. A point source generated from a focused laser light with a wavelength of 940 nm is used as the light source. The circular beam from the point source is translated into 1D line beams and steered by the MEMS-metalens with its image projected on a screen and captured by an IR camera. Fig. 2(b) illustrates a series of images of the projected 1D line beams at MEMS-metalens shuttle displacements of 0, 20, 40, 60, 80, and 100 µm respectively. The rectangular box denoted by the orange dashed lines indicates the 80° × 60° FOV. Scanning of 1D line-scan is clearly observed and the displacement of the line beam shows good agreement with the simulation shown in Fig. 1(d). The observed round spot is due to conversion efficiency in line spot generation and can be reduced as the efficiency of the metalens increases.

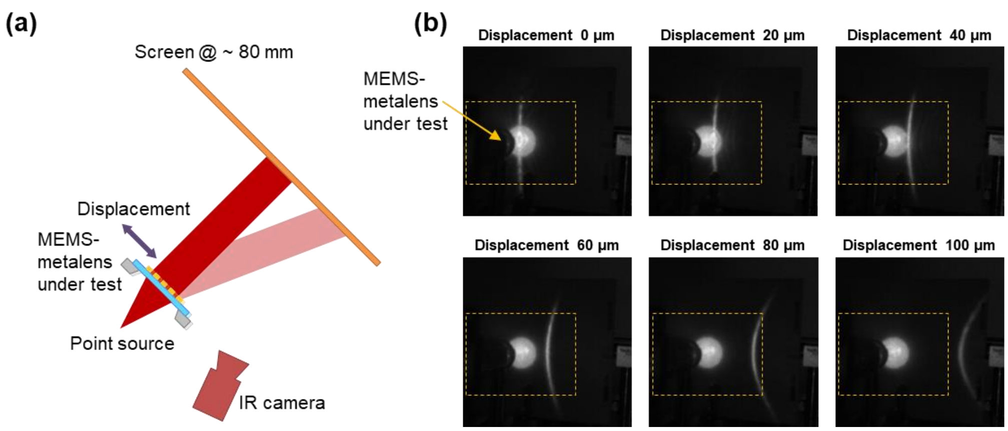

Fig. 2 (a) Schematic of the experimental setup to capture the image of the line beam projected on a screen. (b) A series of images of the scanning line beam at displacements of 0, 20, 40, 60, 80 and 100 µm projected on the screen as captured by an IR camera.

4. Conclusion

In summary, a metalens integrated on MEMS actuator designed for 1D line-scan has been demonstrated as proof-of-concept. The metalens integrated MEMS actuator was fabricated via wafer-level 12-inch 193 nm ArF deep UV (DUV) immersion lithography and MEMS process line. Results show a field-of-view of 80° × 60° with continuous 1D line-scan while the MEMS actuator oscillates with a displacement of ± 100 µm, which is in good agreement with the simulation. This work paves the way of development of metalens integrated MEMS optical module for imaging and sensing applications.

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5. References

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