Optical Metasurface Fabricated Using 3-D Nanoimprint Lithography

Jiacheng Ye, Yunxaing Wang, Zhexiang Tang, Zerui Liu, Hongming Zhang, Wei Wu*

Ming Hsieh Department of Electrical Engineering, University of Southern California,

Los Angeles, California, 90089, USA

*Email wu.w@usc.edu

Nowadays, the development of optical sensing, quantum information, and particle-controlling technologies boasts the demand for compact optical metasurface devices. These devices are required to have the characteristics of ultra-uniform light distribution and higher power utilization efficiency. Previously, the widespread metasurface structures were designed to be single-layer structures, which leads to the issue of carrying limited phase information. To further improve the performance of the metasurface device, nanoimprint lithography technology is advocated to fabricate the multilayer optical metasurface structure. Compared to traditional lithography technology, which could only transfer a single-layer of information in one process, nanoimprint lithography could carry out 3-D information as a one-time event.

In recent years, the metasurface-based multichannel beam splitter has become prevalent in the field of 3D imaging flash LiDAR (Light Detection and Ranging) systems. By replacing the wide-angle laser pulse illumination light with a multilayer beam splitter to form the laser dots array, as shown in Fig 1, we could alleviate some conventional problems, like low detector array efficiency, uneven energy distribution, and low light source utilization. These improvements could elevate the driving safety level with the realization of long-distance, high-precision detection.

The metasurface beam splitter is realized by the principle of phase modulation in spatial. The light intensity of each diffraction beam could be coded by the amplitude of the spatial Fourier component. In the fabrication aspect, the phase shifting could be controlled by the etching depth and refractive index of the substrate material. Although the multilayer structure shows a better approximation of phase shift, this structure suffers from a misalignment issue among each layer. To solve this problem, we applied an alignment array with different preset deviations to compensate for the alignment error. By this method, we could control the alignment error within 0.3μm. This alignment precision enables us to design a multilayer metasurface structure with higher precision phase matching, which provides the device with ultra-uniform light distribution and higher SNR (Signal-to-Noise Ratio).

In our design, we use a four-level thickness structure to demonstrate the spatial phase distribution of the one-to-eight beam splitter. The nanoimprint mother mold is prepared by 3 times photolithography and deep reaction ion etching process, which is shown in Fig 2. And we use the nanoimprint technology to duplicate the multilayer structure. That avoids the redundant photolithograph and etching work and further reduces the cost. To demonstrate the performance of the multilayer one-to-eight beam splitter, we use the measurement setup in Fig 3. We used a collimated laser beam to illuminate the sample with normal incidence. And use the Nanoscan camera to collect the intensity information of each diffraction order. We found out that the multilayer structure has a higher energy utilization ratio and more uniform light intensity distribution. This structure also shows the robustness to the alignment error.

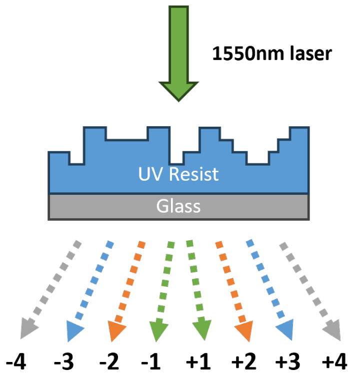


Figure 1 Schematic of multilayer beam splitter

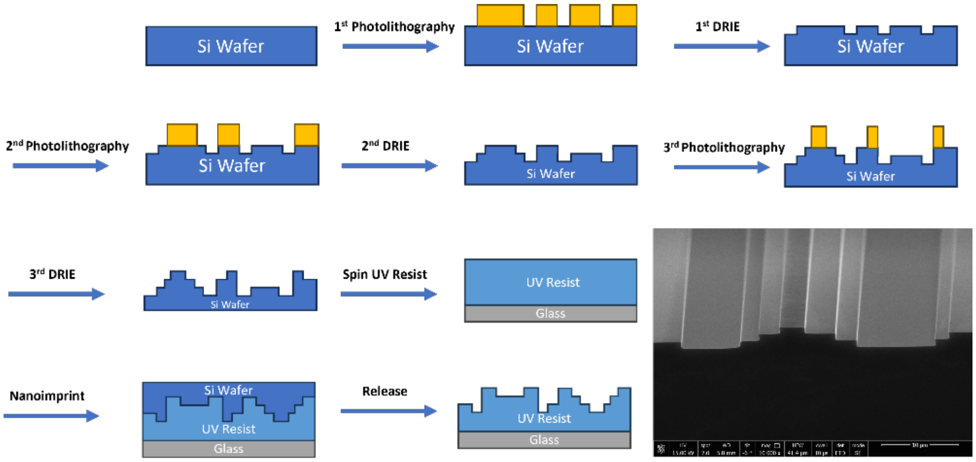
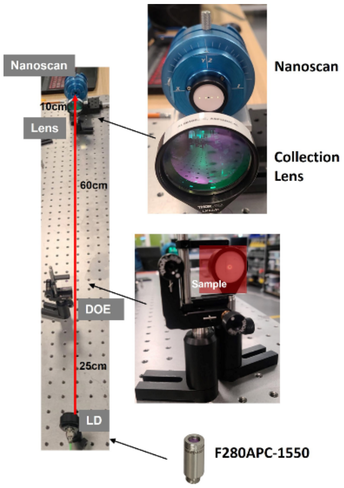


Figure 2 Fabrication process and SEM image of the beam splitter



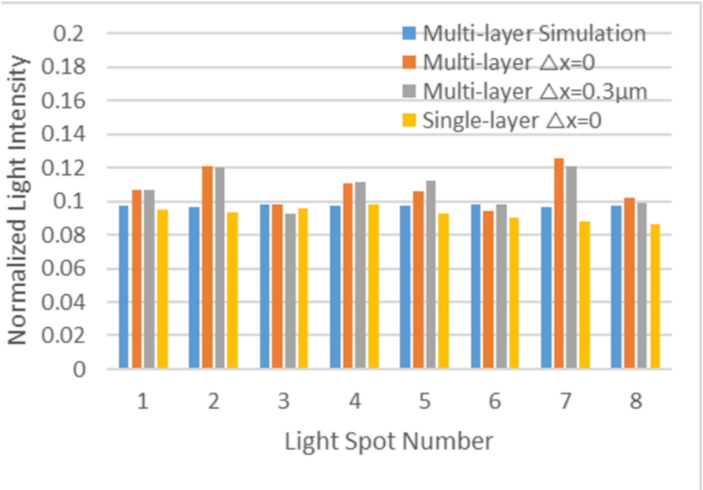


Figure 3   Measurement setup and data