Inverse design of angle-sensing metasurface by particle swarm optimization

Yunxiang Wang, Yuanrui Li, Hao Yang, Wei Wu
Ming Hsieh Department of Electrical Engineering, University of Southern California, Los Angeles, California 90089, United States
yunxianw@usc.edu

The conventional CMOS photodetectors detect only the intensity of light, and all the directional information is lost. While the intensity information alone is enough for traditional applications, this limitation becomes apparent in advanced imaging tasks. For example, the incident angle of light is essential for a light field camera to refocus an image after it is taken. Combing micro-lens or apertures with photodetecting pixels are two typical ways to measure the incident angle. However, the minimum size is limited by the large volume of micro-lens, resulting in a difficulty to integrating it into commercial imaging system. And the apertures can block part of the incident light, leading to a significant decay of brightness. Here, we use a carefully designed angle-sensing metasurface and commercial photodetectors to measure incident angle. The metasurface with small volume and low-loss property is a good candidate to solve current problems.

The metasurface employed here should support several resonance modes, which can interact constructively or destructively as the incident angle changes to produce a monotonous transmission curve. Such metasurface is hard for intuitive design due to the structure is relative complicated. With the extensive growth of computing performance, many optimization algorithms have shown their capability of designing metasurfaces. Particle swarm optimization (PSO) is one of these methods that has been widely used in inverse metasurfaces designs, from integrated optical components to flat optical devices. We employed the particle swarm optimization algorithm to optimize the configurations of the metasurface.

Here, the metasurface is optimized for 850 nm incident wavelength and its material is hafnium dioxide (H_fO_2). As shown in Figure. 1, the optimization region is separated into M × N pixels with same area. If the pixel's state is chosen to be "1", this pixel belongs to H_fO_2 region; on the contrary, if the pixel's state is "0", this pixel belongs to air. The algorithm optimizes each pixel's state from an initial random configuration to reach an optimization configuration with monotonous transmission curve. The transmission in each incident angle is calculated by RCWA. During the optimization process, the employed fitness function has a crucial impact on the result. The value of fitness function in this case need to reflect the monotonic relationship between incident angle and the total transmission. Correlation coefficient (CC) is a numerical measure (from -1 to 1) of correlation between two variables. The CC can be expressed as

$$\mathrm{CC} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

where n is sample size, x_i and y_i are the individual sample points and $\overline{x}$ and $\overline{y}$ are the sample means. The algorithm's task is searching the global maximum value of this function. Figure.2 shows our current optimization result. As the incident angle changes from -40° to 40°, the transmission of the metasurface increase from 0.4 to 0.8.

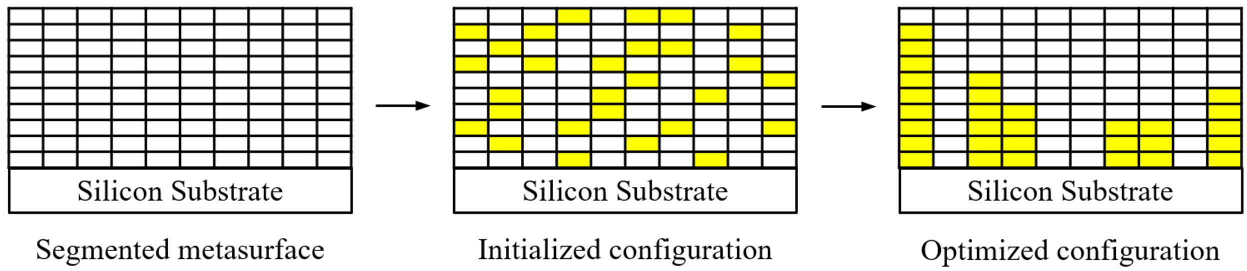

Figure 1. The scheme of particle swarm optimization for angle-sensing metasurface

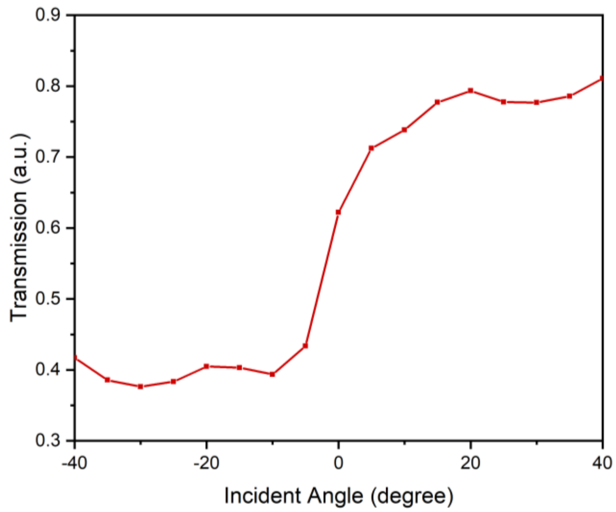

Figure 2. The optimized transmission of the metasurface as a function of the incident angle