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# Dielectric metasurface based advanced image processing

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## ABSTRACT

We numerically and experimentally demonstrate an optical image processing technique in the form of edge detection of an object by exploring the angular selectivity of dielectric metasurfaces. By taking the advantages of resonant dielectric metasurfaces with spatial dispersion property, we efficiently filter-out the lower k-vector components of an image and only allow the higher k-vectors resulting in displaying the silhouettes of an object. We have considered dielectric amorphous silicon (a-Si) nanodisk with hexagonal structure interface which provides nearly zero transmission for lower k-vectors and near-unity transmission for higher k-vectors at the operating wavelength of 1550 nm. The proposed metasurface has been fabricated using electron beam lithography followed by a lift-off process. Our results suggest a new way to realize the effective edge detection with dielectric metasurfaces and open new opportunities for ultra-compact optical image processing devices, having various applications in microscopy.

**Keywords:** Dielectric metasurfaces, optical image processing, edge detection, angular dispersion, nanophotonics.

## 1. INTRODUCTION

Metasurfaces offer unique opportunities for optical signal processing [1] and the design of neuromorphic optical networks for image-processing [2]. Among different image-processing operations, edge detection is one of the essential algorithms with practical applications in microscopy or autonomous systems. The edge detection removes the plain parts of an image, to keep only the edges where the intensity changes abruptly. By utilizing the spatial dispersion of metasurfaces, filter functionality can be achieved of the metadevices where lower k-vectors will fully block and will allow only higher k-vectors passing through the metasurfaces, as a result only silhouettes of the object will appear. The optical edge detection technique will able to significantly reduce the volume of data in the computational image processing, which will enhance device performance vividly. Recently, metasurface based edge detection techniques have been investigated [3, 4]. However, all the reported works have been carried out theoretically or in one spatial dimension. In this work, we experimentally demonstrated that a single ultra-thin (hundreds of nanometers) silicon metasurface can be used in edge detection without any additional optical components and post computational processing.

## 2. METASURFACE DESIGN AND EXPERIMENTAL RESULTS

The schematic of the dielectric metasurface based edge detection technique is shown in Fig. 1a, where certain k-vectors components are filtered while passing through the spatially designed metasurface, therefore displaying only the edges of the target image. For such spatial filtering to be effective, one needs a metasurface with a sharp resonance feature, which shifts quickly with the angle of incidence. To design such a metasurface, we first carry numerical investigation using CST Microwave studio with unit cell boundary conditions. We use a dielectric metasurface composed of silicon nanodisks with the diameter of 724 nm, the height of 200 nm and periodicity of 974 nm, and considered the experimental refractive index during the computational investigation. The nanodisks parameters were optimized aiming to achieve well-pronounced electric and magnetic responses with a large spectral gap between them and near-zero transmission at the resonant wavelengths. We considered an embedding medium with a refractive index of 1.55 which helps to avoid the Fabry-Perot resonances and allows to investigate the transmission spectra of metasurfaces with hexagonal unit cell architecture. In Fig. 1b, it is visible that the proposed metasurface exhibits Mie-type resonances in the infrared spectral range. The inset figures show the magnetic and electric mode profiles at the resonant wavelengths of 1550 nm and 1757 nm, respectively.

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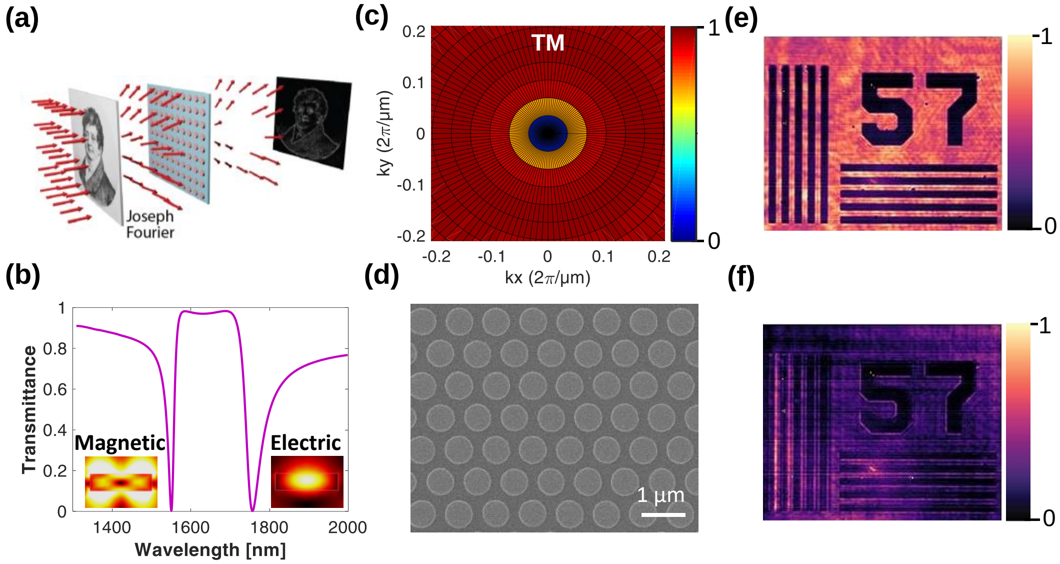


Figure 1. (a) Principle of edge detection with a dielectric metasurfaces. (b) Simulated transmittance spectra of silicon nanodisks metasurfaces. The insets show the magnetic and electric mode profiles at the corresponding resonant wavelength of 1550 nm and 1757 nm, respectively. (c) Angular dispersion of transmittance at the magnetic response state. (d) Scanning electron microscopy (SEM) image of the fabricated metasurface. (e) Experimental target image for edge detection. (f) Experimental shot of *k*-space filtered image after metasurface insertion.

We investigate the angular dispersion at the wavelength of the electric and magnetic resonances. It shows that magnetic response can significantly narrow down the smaller k-vectors components with the near-zero transmission. As a result, we consider the magnetic resonance state for further investigation. The hexagonal arrangement helps to block the smaller k-vectors precisely. Figure 1c indicates that transmission goes to zero for smaller k-vectors while it is near-unity for the larger k-vectors. To fabricate the sample, first 196 nm a-Si layer has been deposited on a glass substrate using the plasma-enhanced chemical vapour deposition (PECVD) process. Subsequently, the proposed metasurfaces have been fabricated using electron beam lithography with a total area of $500\times500$ $\mu m^2$. Figure. 1e shows the SEM image which was illuminated with a tunable laser at 1550 nm and imaged onto the IR camera. To detect the edge of the targeted image, we placed the fabricated metasurface sample behind it at an arbitrary distance and later adjusted the distance, which is limited by the aperture of the metasurface. Fig. 1f shows the vertical and horizontal edges of the target image, which clearly indicates the edge detection operation with the proposed silicon metasurface.

## 3. CONCLUSION

We experimentally demonstrated that by engineering the spatial dispersion of the dielectric metasurfaces, it is possible to filter the required k-vectors which provides the efficient edge detection of an object. Such miniaturize and relatively simple edge detection technique based on silicon metasurfaces will pave the way for optical imaging applications including microscopy and navigation for autonomous systems.

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