# Plasmonic Metasurfaces for Directional Light Emission and Photodetection

**Roberto Paiella**

*Department of Electrical and Computer Engineering and Photonics Center,*
*Boston University, 8 St. Mary's St., Boston, MA 02215, USA*
*Email address: rpaiella@bu.edu*

**Abstract:** We report the development of near-infrared plasmonic metasurfaces integrated with optoelectronic active materials for the demonstration of geometrically tunable collimated light emission and angle-sensitive photodetection. 

## 1. Introduction

Plasmonic and dielectric metasurfaces have been widely investigated in recent years as a means to tailor the wavefronts of externally incident light for passive device applications [1]. At the same time, their integration within active optoelectronic devices such as light emitters and photodetectors is far less established. In this work, we report the design and development of metasurfaces that can promote directional photoluminescence and angle-sensitive photodetection from a nearby active material. These results are significant for the continued miniaturization and large-scale integration of optoelectronic devices, where functionalities that are commonly performed by external optical elements such as lenses are instead integrated directly with the device active material.

## 2. Directional light emission

The use of gradient metasurfaces for beamed light emission [2, 3] is illustrated in Fig. 1. The experimental samples used in this work consist of a continuous distribution of colloidal CdTe/ZnS quantum dots (QDs) deposited on a one-dimensional array of rectangular plasmonic nanoparticles (NPs) supported by a metal film [Fig. 1(a)]. The NP widths are selected so that, under external illumination, the array introduces a linear phase shift upon reflection. In this configuration, the dominant radiation mechanism involves the near-field excitation of surface plasmon polaritons (SPPs) at the metal film, and their diffractive scattering by the metasurface into well-collimated beams along geometrically tunable directions (determined by the slope of the phase gradient).

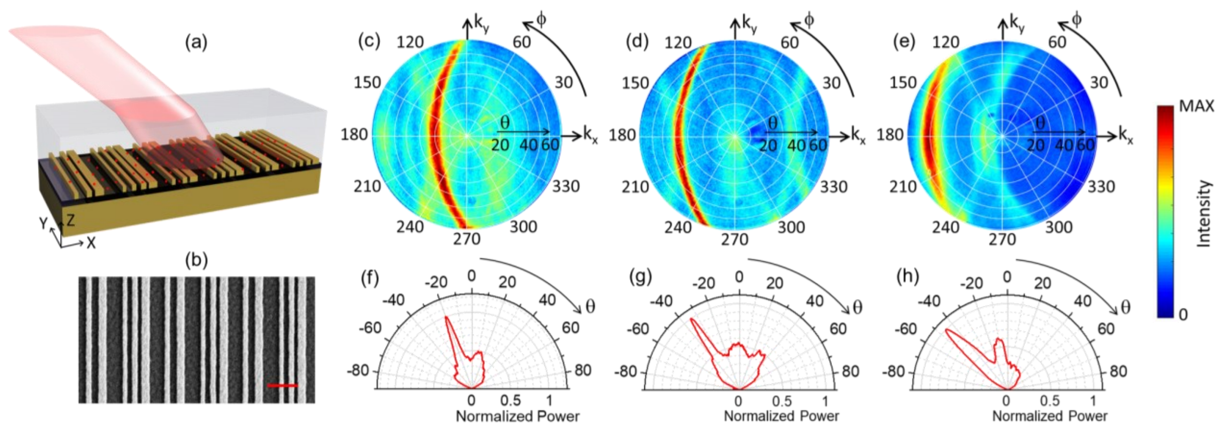


Fig. 1. Plasmonic metasurfaces for beamed light emission. (a) Schematic illustration of the device structure, including its directional radiation output. (b) Top-view SEM image of a metasurface designed for peak emission at $\theta_0 = -20°$. The scale bar is 500 nm. (c)-(h) Measurement results for three representative metasurfaces of different periods. (c)-(e) *x*-polarized far-field radiation patterns of a planar distribution of QDs in the near field of a metasurface with $\theta_0$ near –20° (c), –30° (d), –40° (e). (f)-(h) Line cuts of the color maps of (c)-(e) along their horizontal axis, rescaled by a cos$\theta$ normalization factor.

Several devices based on this idea were developed, each providing beamed light emission along a different target direction. A top-view scanning electron microscopy (SEM) image of a representative metasurface is shown in Fig. 1(b). Figures 1(c)-(e) show the far-field radiation patterns (at $\lambda$ = 800 nm) measured with a Fourier microscopy setup from samples of target peak emission angles $\theta_0$ = –20°, –30°, and –40°. The expected directional light emission is clearly observed in these maps, with the corresponding line cuts along the horizontal axis [Figs. 1(f)-(h)] featuring a narrow beam with divergence angle (HWHM) as small as 5° in panel (g).

## 2. Directional photodetection

Similar devices were also developed for the demonstration of angle-sensitive photodetection [4]. In these samples, the device active material is again coated with a metal film stacked with an array of rectangular metallic NPs. The metal film is sufficiently thick (~ 100 nm) to block any externally incident light from propagating directly into the underlying active layer. As a result, photodetection can only take place through an indirect process [Fig. 2(a)] where light incident at the desired detection angle $+\theta_p$ is first diffracted by the NPs (in the periodic "grating coupler" section of the array) into SPPs on the top surface of the metal film. A small number of suitably positioned subwavelength slits in the metal film are then used to scatter these SPPs into radiation propagating predominantly into the absorbing active layer, and as a result a photocurrent signal is produced. Light incident along any other direction is instead either immediately reflected by the metal film, or diffracted into SPPs propagating towards the "grating reflector" section of the NP array, which comprises a phase-gradient metasurface designed to scatter the incoming SPPs back into the air above.

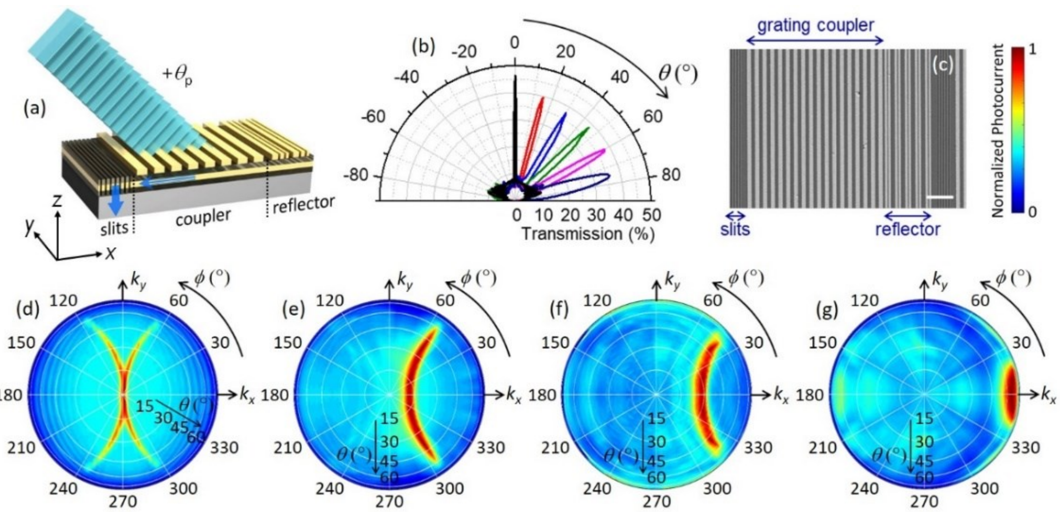


Fig. 2. Plasmonic metasurfaces for angle-sensitive photodetection. (a) Schematic illustration of the device geometry and operation principle. (b) Calculated optical transmission coefficient at $\lambda_0$ = 1550 nm through six different metasurfaces for *p* polarized light versus angle of incidence $\theta$ on the *x-z* plane. (c) Optical image of a representative experimental sample. The scale bar is 4 μm. (d)-(g) Measured angular dependence of the photocurrent of four different samples based on the design set of (b). The devices are illuminated with laser light at 1550 nm and each map is summed over two orthogonal polarizations.

Several metasurfaces producing directional photodetection peaked at different angles were designed via FDTD simulations for operation at 1550-nm wavelength [Fig. 2(b)], and then fabricated on the illumination window of standard Ge photoconductors [Fig. 2(c)]. The color maps of Figs. 2(d)-(g) show the photocurrent signals measured with four different devices as a function of polar θ and azimuthal ϕ illumination angles. In each map, the incident directions of high photocurrent form a rather narrow region within the full hemisphere, in good agreement with numerical simulations. In ref. 4, these measured device characteristics were used to demonstrate a novel compound-eye camera architecture capable of providing an ultrawide field of view of over 150° in a planar lensless format.

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## 3. References


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