Electrically Switchable Metasurface for Beam Steering Using PEDOT Polymers

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Abstract: We present an electrically switchable metasurface for beam steering where we use the conducting polymer PEDOT as an active material. We show intensity-tunable beam diffraction with angles up to 10°, employing an externally applied voltage.

Emerging display technologies such as dynamic holo-graphy or augmented and virtual reality require ever-increasing pixel densities and thus new smart optical methods with the ability to manipulate optical wavefronts, beam paths, polarization, or similar actively on ultra-small length-scales. For the realization, the research field of plasmonics has gained significant interest over the last years as plasmonic nanoparticles allow to focus, manipulate, or steer light on the nanometer scale at subwavelength dimensions. The combination of optically active and externally switchable materials with plasmonics into hybrid nanosystems has increased their applicability even further and opened the door towards active plasmonically-driven light manipulation [1]. We present an optically active system to perform switchable beam steering realized via a novel hybrid metasurface. It consists of a unique combination of gold plasmonic nanoantennas and the electrically switchable and conducting polymer poly(3,4-ethylene-dioxythiophene) (PEDOT) [2,3].

Fig. 1. (a) Schematic picture of the active plasmonic metasurface for beam steering. Gold nanoantennas on an ITO covered glass substrate, coated with electropolymerized PEDOT, which acts as the reversibly switchable layer (refractive index shift) during cyclic voltammetry. ITO is used for electrical contact. (b) Schematic picture of the electrochemical cell where the PEDOT is actively switched via cyclic voltammetry.

The main idea of our hybrid metasurface is sketched in Fig. 1a. The metasurface consists of gold nanoantenna arrays with progressively rotated elements along one axis and is placed on an Indium-Tin-Oxide (ITO) covered substrate for electrical contact. To make our hybrid metasurface electrically switchable in the visible spectral range, we cover the metasurface with a 150–200 nm thick PEDOT layer. This PEDOT layer undergoes a significant refractive index change in the visible spectral range when the applied voltage is varied by cyclic voltammetry and thus results, in combination with the metasurface, in electrochemically activated switchable beam steering. As schematically depicted in Fig. 1b, the sample is placed inside a custom-made electrochemical cell to perform cyclic voltammetry on the active PEDOT layer with a three-electrode setup.

The optical performance of our switchable hybrid metasurface is shown in Fig. 2. The beam profiles and intensities of the 0th order main and 1st order diffracted beam in k-space are illustrated in Fig. 2a and b for the oxidized (+0.5 V) and reduced state (-1 V) of PEDOT, respectively. The illumination wavelength is λ = 750 nm. The intensity ratio I1/I0 of our hybrid metasurface during cyclic voltammetry is plotted in Fig. 2c. We find that the hybrid metasurface quickly reacts to voltage changes. In the oxidized state after t = 24 s, the ratio has a sharp
maximum whereas in the reduced state after $t = 104$ s we find a flat plateau around the minimum. The observed temporal behavior of the intensity ratio clearly shows that we can actively control the intensity of both beams.

![Diagram](image)

**Fig. 2.** (a) and (b) Intensity on CCD camera in k-space (lower image panels) and integrated intensity profiles (upper panels) for reduced and oxidized state, respectively, displaying 0th order beam and 1st order diffracted beam. (c) Contrast (intensity ratio $I_1/I_0$ of the first and zeroth order beams) during cyclic voltammetry (tuning of applied voltage). The areas of the respective beam sizes for the intensity calculation are shown with white frames in (a) and (b). (d) Intensity on CCD camera during one cycle.

Consequently, we are able to vary the diffraction-efficiency of the hybrid metasurface via the applied voltage. Selected k-space images of this beam steering process are depicted in Fig. 2d. We observe the switching behavior of the metasurface cycling between a higher intensity in the diffracted beam and a higher intensity in the main beam. By increasing the scan rate of the cyclic voltammetry, we are able to reach switching frequencies around 1 Hz while the extension to display frequencies is only limited by the measurement components and not intrinsically by the optical and electrical properties of our hybrid metasurface.

Our approach finds implications in the design, fabrication, and realization of optically active nanophotonic systems that are electrically switchable. Our results will help to develop future optical technologies such as virtual and augmented reality as well as dynamic holography.

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