Technology Offer

Electrochemically-Controlled Metasurfaces for High-Contrast, Fast-Switching Optical Applications

Ref.-No.: 1201-6070-BC

Abstract

This invention introduces an advanced optical component based on electrochemically-controlled metasurfaces. These metasurfaces, designed for high-contrast switching at visible frequencies, combine ultrathin, planar structures with precise light manipulation capabilities. The core innovation leverages a repeating array of unit cells containing two different scattering structures. These structures contain materials of varying refractive indices, which are tunable through an external control signal. Using conducting polymers for one scattering structure, such as polyaniline (PANI), the metasurfaces achieve fast, reversible, and efficient optical response. This breakthrough enables compact, adaptive optical devices for modern photonic applications.

Background

Traditional optical systems rely on static elements, such as lenses and prisms, which are limited in adaptability and miniaturization. With increasing demands for dynamic, lightweight, and energy-efficient solutions, metasurfaces have emerged as a transformative technology. Despite their promise, most active metasurfaces exhibit limited performance at visible frequencies. By introducing electrochemically-controlled designs, this invention overcomes challenges in switching speed, optical contrast, optical reconfigurability and operational efficiency. The integration of dynamic materials like PANI enhances the responsiveness and scalability of these optical elements, paving the way for real-world photonic applications.

Technology

The technology features an advanced metasurfaces composed of goldnanorods precisely arranged on an ITO-coated quarts substrate. These nanorods are organized in altering rows, with one set statically coated in a dielectric polymer such as polymethyl methacrylate (PMMA) and the other dynamically tunable through a coating of a second substance such as PANI (Fig. 1). PANI's refractive index can be electrochemically adjusted, enabling active control of light transmission, reflection, and phase shifting. This design facilitates high-intensity contrast ratios (up to 860:1) and fast switching speeds (approx. 35 – 48 milliseconds) (Fig. 2B). Additionally, the metasurfaces demonstrate exceptional reversibility over multiple switching cycles, making them highly durable and efficient for optical modulation tasks (Fig. 2C).

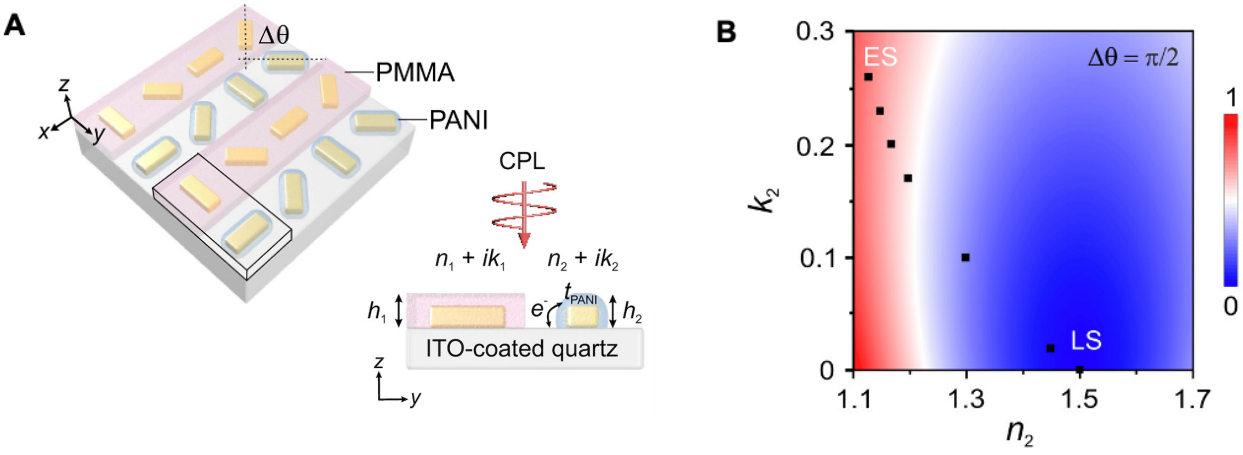

Figure 1: (A) Schematic of the electrochemically controlled metasurface. (B) Heatmap showing the intensity modulation as a function of PANI's refractive index. The transition between the low-absorption (Leucoemeraldine) and high-absorption (Emeraldine) states demonstrates precise light control, a key advantage of this technology (Kaissner et al., 2021).

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Advantages

- **High-contrast light modulation:** PMMA/ PANI system achieves intensity contrast ratios exceeding 860:1 (Fig. 2A).
- **Fast switching:** Speeds of approx. 40 milliseconds were shown exemplary (Fig. 2B).
- **Compact and lightweight:** Ultrathin metasurface design suitable for space-constrained applications.
- **Reversible and durable:** Maintains performance over extensive switching cycles (Fig. 2C).
- **Cost-effective and scalable:** Utilizes affordable, easily synthesized materials like PANI.

Potential applications

- Dynamic lenses and zoom optics: Enabling electrically controlled adjustments of focal length and focus.
- Extended Frequency Ranges: Adaption of metasurface technology for various spectral regions, from visible to infrared light.
- Dynamic holography for imaging and communication systems.
- High-speed optical sensors for medical and industrial use.
- Photonic displays with tunable resolution and brightness.
- Light-based data communication networks.

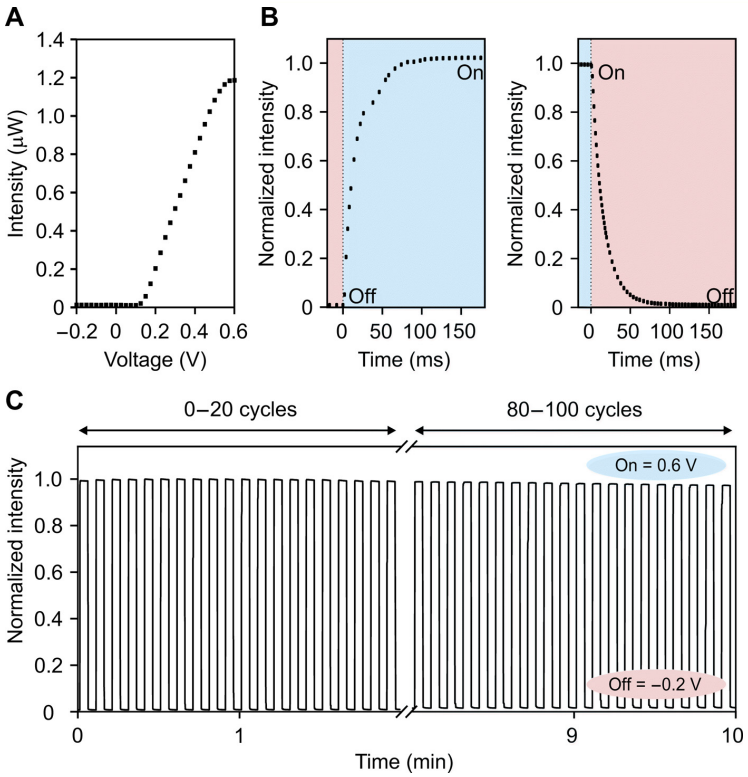

Figure 2: This figure highlights the key advantages of electrochemically-controlled metasurfaces. Panel (A) demonstrates the high-contrast light modulation, with intensity increasing sharply as the applied voltage rises from -0.2 V to 0.6 V. Panel (B) showcases the fast-switching dynamics, with the "Off→On" transition completed in approximately 48 milliseconds and the "On→Off" transition in 35 milliseconds. Finally, Panel (C) illustrates the durability of the metasurface, maintaining stable performance over 100 switching cycles without significant degradation. These features underline the metasurface's suitability for applications requiring rapid, reliable, and precise optical control (Kaissner et al., 2021).

Patent Information

PCT application (WO2022128410A1; 26.11.2021)

Publications

Li et al., „Electrically-controlled dynamic optical component comprising a metasurface," US Patent 20240053510, 26. November 2021.
Kaissner, Robin, et al. "Electrochemically controlled metasurfaces with high-contrast switching at visible frequencies." *Science Advances* 7.19 (2021): eabd9450.

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