Zinc Oxide Metasurfaces Design To Increase Spatial Resolution In Retinal Prostheses Device

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Abstract

Recent retina implants have been shown to form monochromatic vision with prosthetic visual acuity of 20/438, dependent on the individual pixel size of 100 microns [1]. It is still far from meaningful image formation. Overall, the key challenge in retinal stimulation is the unresolved inability to independently activate retinal neurons across a large area of the visual field. These devices, usually based on metal electrodes or silicon semiconductors, are energy-intensive, and inorganic electrode coatings may not be suitable from a clinical perspective. Organic photovoltaic (OPV) devices in a bulk heterojunction (BHJ) architecture show significant potential for overcoming the limitations of silicon photovoltaic systems in wireless applications. However, their functionality is constrained by the necessary potential for safe capacitive stimulation.

We propose and introduce an innovative approach by incorporating an intrinsic metasurface into an OPV device with an architecture of indium-doped tin oxide (ITO)/zinc oxide (ZnO)/ polymer: non-fullerene BHJ. The ZnO thin film can be utilized as a metasurface to generate spatially selective electric field distributions, resulting in high visual acuity without the need for physical separation.

To demonstrate the functionality of the proposed ZnO metasurface design, we utilized COMSOL Multiphysics software. We created a planar patterned structure on a surface with an approximate area of 5 µm × 5 µm, featuring square-shaped nano pixels, each measuring 325 nm × 325 nm with a periodic spacing of 650 nm (Figure 1a). We chose a unit electrode of 5 µm × 5 µm based on calculations for normal visual acuity of 20/20 in previous works [1]. Figure 1b shows a 3D model of the device prepared using a built-in module in COMSOL. We defined different surfaces in the model, including a 150 nm-thick ITO surface and a 150 nm-thick ZnO nanopixel. We included the physics of electromagnetic waves in the frequency domain to study the ZnO metasurface. The preliminary design was expected to give an output electric field distribution with the performance tuned to the red-light frequency of the incident light. The electric field strongly depends on electrode geometry and is strongly enhanced with the electrode size [2]. It becomes more uniform at a distance larger than the radius of the electrode, which is essential for reliable neural stimulation. The previously established relation between the electric field and electrode size was used for the evaluation. [1]

Figure 1c shows the output electric field distribution on the ZnO surface. The simulated local electric field strength at the surface (~10^6 V/m) is comparable to the theoretical calculation for the desired electric field required to depolarize the cells. It reveals a significant opportunity to utilize metasurfaces for the selective stimulation of retinal cells. Moreover, the reduced size of a unit electrode allows for the possibility of approaching practical visual acuity.

Reference

1. Palanker, D., et al., Design of a high-resolution optoelectronic retinal prosthesis. J Neural Eng, 2005. 2(1): p. S105-20.
2. Mierisch, A.M., S.R. Taylor, and V. Celli, Understanding the Degradation of Organic Coatings Through Local Electrochemical Impedance Methods: II. Modeling and Experimental Results of Normal Field Variations above Disk Electrodes. Journal of The Electrochemical Society, 2003. 150(7): p. B309.

Figures used in the abstract

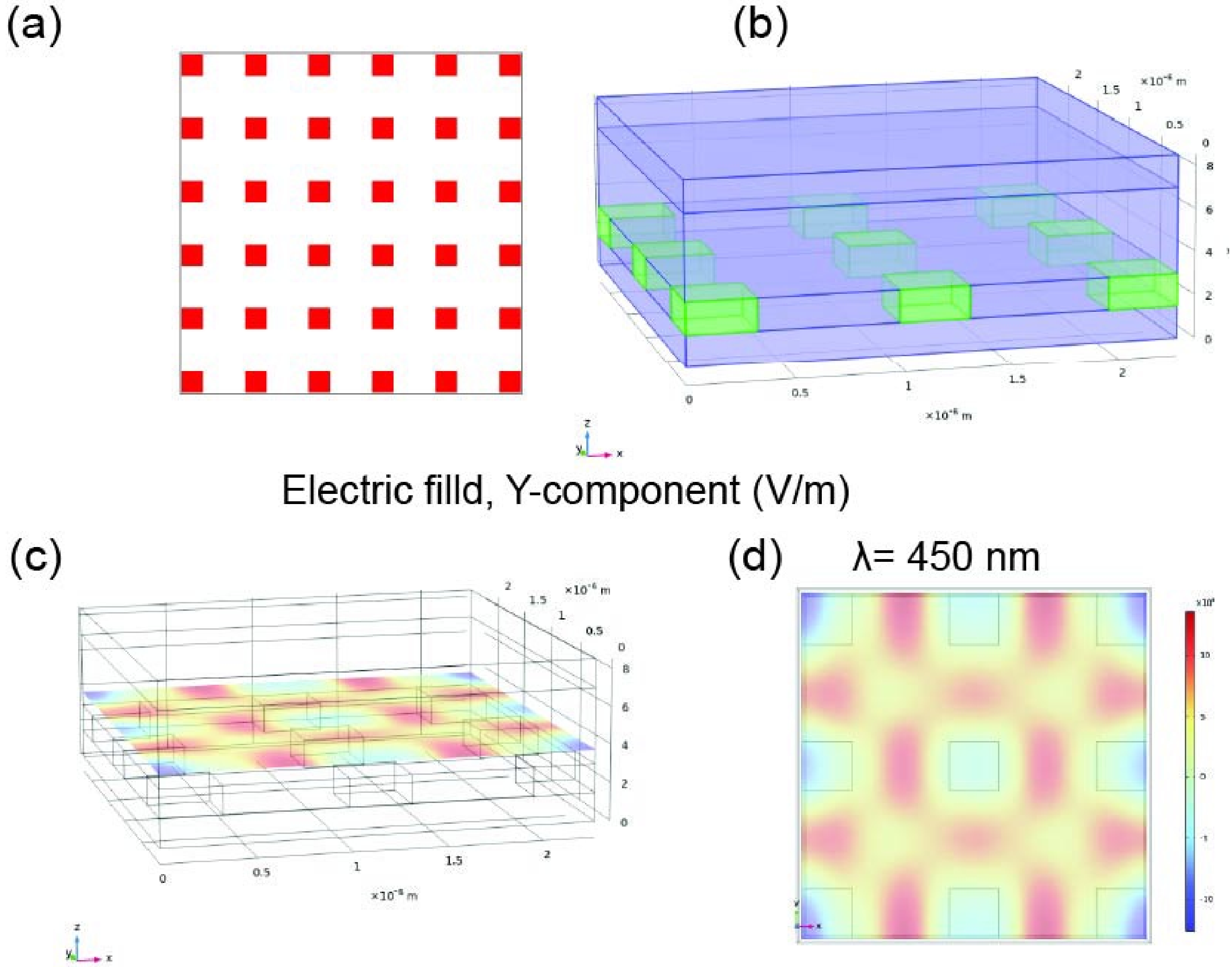

Figure 1 : Figure 1(a) 2D metasurface design (b) a 3-D model (c) Depth profile showing the electric field distribution (d) Patterned electric field distribution.