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Geometrical optimization for silver nanowire mesh as a flexible transparent conductive electrode

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We report the effect of the geometric parameters on transparency and conductivity in a metallic nanowire mesh as a transparent electrode. Today, indium tin oxide and fluorine-doped tin oxide are used as the transparent electrode for displays and solar cells. Still, there is a definite need for their replacement due to drawbacks such as brittleness, scarcity, and adverse environmental effects. Metallic nanowire mesh is likely the best replacement option, but the main issue is how to find the optimal structure and how to get the best performance. Since the interaction of light with nanowire mesh is complicated, there is no straightforward rule with a simple analytical solution. We developed a kit based on wave optics for calculating the optical transmission of metallic nanowire mesh, which, unlike previous works, includes the interaction of light with the nanowire mesh, such as localized surface plasmon resonance (LSPR), surface plasmon polariton (SPP), and Rayleigh anomaly (RA). So, it is possible to accurately predict the effect of these phenomena and the transmission of mesh. Using the mentioned kit, we will be able to investigate the different geometrical structures of meshes to achieve optimal geometry. This kit is based on the classical Maxwell theory and empirical data and uses finite-difference time-domain for solving equations and experiential results for validation. Comparing the results by a redefined figure of merit shows that LSPR has the most significant reduction on transparency, whereas increasing the thickness (t) to width (w) ratio of the nanowire in the metallic mesh can reduce the LSPR effect and/or shifts it to the invisible region. The wire pitch (p) has no tangible impact on LSPR, but p can be chosen higher than 700 or lower than 350 nm to remove the extinction effects of the first-order RA. If p was larger than 150 nm, SPP could appear in the visible region of the spectrum. In small p, lower modes of SPP with higher intensities occur; therefore, there is an optimum value for p around 300 nm. The reduction of t and w reduces the intensity of SPP and causes it to red shift. By comparing the 900 different structures, the highest figure of merit is obtained in a p of 300 nm with a minimum w (10 nm) and maximum t (100 nm).

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1. INTRODUCTION

A transparent conductive electrode is a necessary element in optoelectronic devices such as displays, solar cells, and touch-screens. The opaqueness of the conductive materials and the low conductivity of the transparent ones have arisen as a challenge. Indium tin oxide (ITO) is a semiconductor material ($\rho \approx 7 \times 10^{-4}$ Ω.cm) used to resolve the problem. However, it is faced with several shortcomings like brittleness, high cost, lack of flexibility, adverse environmental effects, high-temperature production, and ionic diffusion into the organic displays [1–3]. Nanotechnology creates hope to overcome all shortcomings and the challenge between conductivity and transparency while manufacturing an electrode with high flexibility.

Flexible transparent electrodes provide an opportunity to make roll-folding displays, flexible solar cells, electronic papers, wearable devices, skin displays, and soft lighting. Researchers have introduced different materials, including oxide semiconductors [4–6], conductive polymers [7–9], and nanostructure layers for making such electrodes. Nanostructured transparent electrodes consist of graphene layers [10–17], carbon nanotubes