IOCC 2026 Conference
The 5th International Online Conference on Crystals
15–17 June 2026 | Online
INSTITUTE OF PHYSICS
National academy of Sciences of Ukraine
MDPI

Plasmonic Poynting vector vortices for uniform coupling to photocatalytic coatings

Ivan Yakovkin, Nataliia Petrova
Institute of Physics NAS of Ukraine

INTRODUCTION

Plasmon-assisted photocatalysis often suffers from spatial nonuniformity in electromagnetic energy distribution, leaving significant portions of adjacent catalytic coatings weakly activated. A more effective approach involves modes that confine energy uniformly along the entire metal–catalyst interface. In the present research, we propose using Poynting vector vortices (PVVs) for photocatalytic activation. These vortices arise from surface plasmon polariton-like waves that circulate along the nanorod boundaries, analogous to whispering-gallery modes [1,2], and distribute electromagnetic energy uniformly around the rod perimeter. Unlike asymmetric excitations that localize fields on the illuminated side, these modes create a homogeneous electromagnetic environment along the full interface, which is particularly beneficial for activating conformal photocatalytic coatings.

METHODS

We investigate these PVV modes in periodic arrays of Au and Ag nanorods coated with a photocatalytic film and supported on a dielectric SiO_2 substrate. Using full-field finite-element simulations, we characterize the emergence of these PVV modes and evaluate the optical power dissipated within the surrounding catalytic layer.

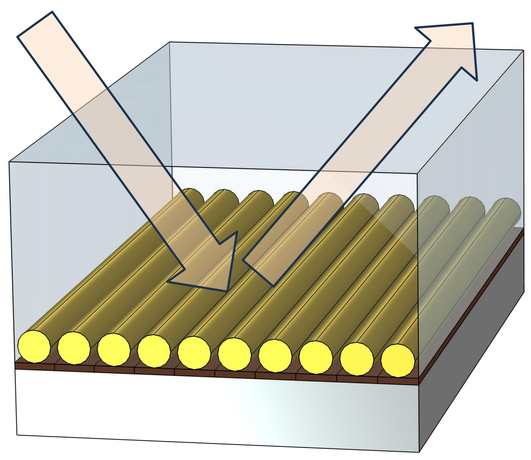

Fig. 1. Metastructure under study

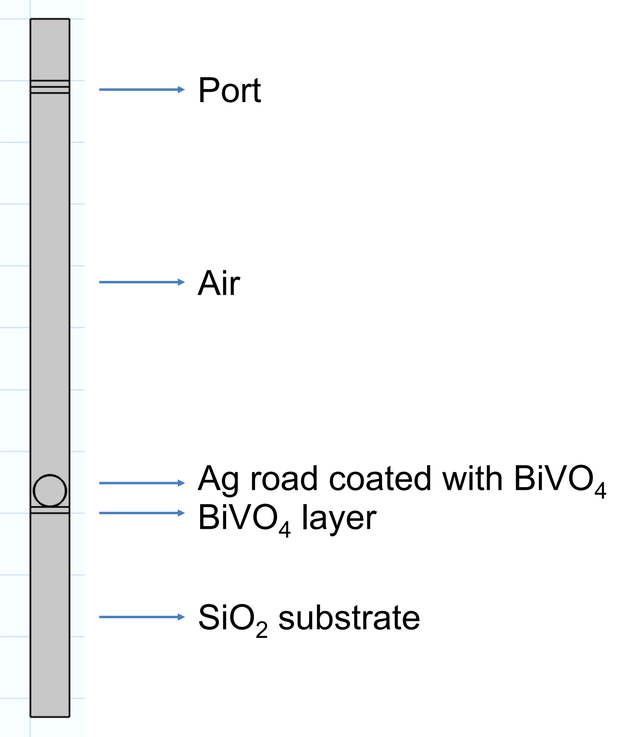

Fig. 2. Unit cell

RESULTS

The simulations reveal the formation of circulating electromagnetic energy flows localized near the nanorod boundary, characteristic of PVV modes. These vortex-like energy circulation patterns originate from surface plasmon polariton-type excitations propagating along the curved metal–dielectric interface, resembling whispering-gallery electromagnetic modes. Instead of concentrating electromagnetic enhancement only at the illuminated side of the nanorod, the PVV regime redistributes optical energy along a substantial fraction of the metal–catalyst interface.

The calculated field topology demonstrates that the electromagnetic waves circulate around the Ag nanorod perimeter before being dissipated into the surrounding $BiVO_4$ shell. Such behavior leads to a significantly more homogeneous electromagnetic field enhancement inside the photocatalytic coating compared to conventional localized plasmonic hot-spot excitation regimes.

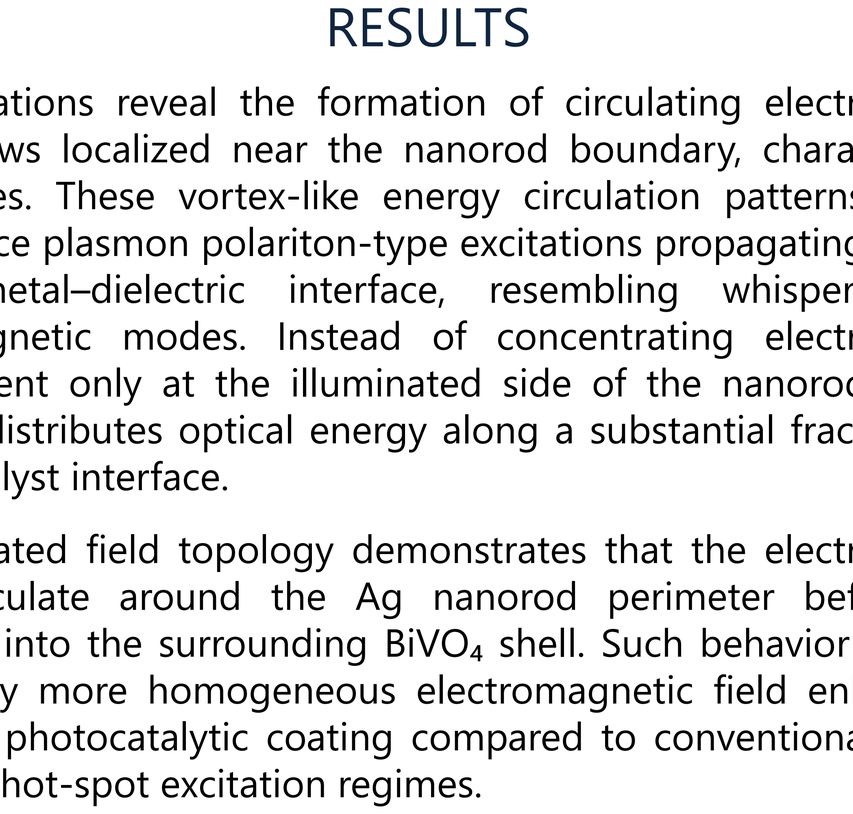

Fig. 3. Distribution of the local magnetic field. The mode is localized on the surface of the Ag nanorods and rotates counter-clockwise.

The oblique incidence angle of 10° breaks the symmetry of the excitation conditions and promotes directional energy circulation within the vortex structure. As a result, the system exhibits locally chiral electromagnetic behavior despite the geometrically symmetric nanorod configuration.

CONCLUSIONS

These results indicate that PVV-mediated plasmonic excitation may provide an efficient mechanism for improving the uniformity of photocatalytic activation in hybrid plasmonic-photocatalytic nanostructures. The observed vortex electromagnetic topology additionally introduces local optical handedness and directional energy transport, opening perspectives for the development of advanced plasmonic metasurfaces, controllable photocatalytic platforms, and chirality-sensitive nanophotonic systems.

Such chiral field distributions may be relevant for catalytic processes sensitive to electromagnetic handedness, including emerging approaches to enantioselective photochemistry [3]. These findings highlight the potential of PVV modes for achieving more uniform and controllable photocatalytic activation across extended metal–catalyst interfaces.

REFERENCES

[1] Cole, R. M., et al. "Easily coupled whispering gallery plasmons in dielectric nanospheres embedded in gold films." Physical review letters 97.13 (2006): 137401.
[2] Chen, Yongpeng, et al. "Recent progress on optoplasmonic whispering-gallery-mode microcavities." Advanced Optical Materials 9.12 (2021): 2100143.
[3] Goerlitzer, Eric Sidney Aaron, et al. "Molecular-induced chirality transfer to plasmonic lattice modes." ACS photonics 10.6 (2023): 1821-1831.