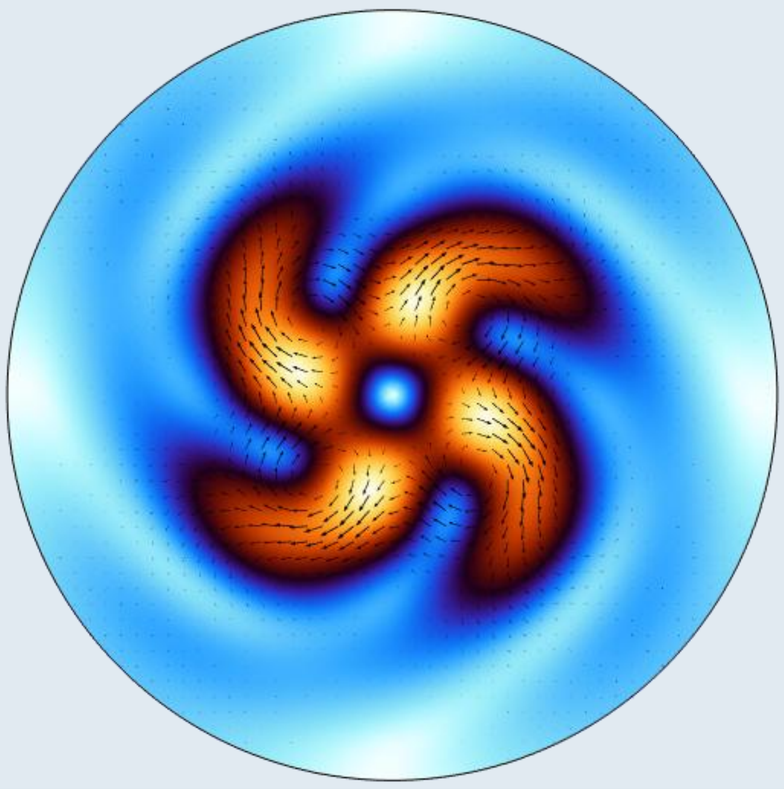


Numerical Simulation of Bidirectional Rotation of Metallic Nanorods Driven by Energy-Flow Reversal

A 3D electromagnetic model reveals switches the sign of the optical torque induced by energy-flow reversal across the focal plane.

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Introduction & Goals

Light-induced rotation is an important approach for dynamic manipulation of micro- and nanostructures. However, conventional optical rotation mainly relies on spin or orbital angular momentum, and switching the rotation direction often requires additional control of the optical field, increasing system complexity.

This work investigates the mechanism of bidirectional rotation of metallic nanorods driven by energy-flow reversal across the focal plane, and to reveal how the local energy-flow distribution and optical torque determine the rotation direction using a 3D COMSOL electromagnetic model.

Methodology

A 3D frequency-domain electromagnetic model is developed in COMSOL Multiphysics to analyze the energy flow and optical torque. A 532-nm azimuthally polarized structured field is used to generate an intensity chirality-invariant field (CIF).

$$E_{in} = A_0\left[e^{i(l\emptyset+\beta r^m)} + e^{-i(l\emptyset+\beta r^m)}\right]\hat{e}_{\emptyset}$$

The optical force is obtained from the Maxwell stress tensor, and the torque on the nanorod is evaluated as

$$T = \sum_{i,j}\left[F_x(x_{i,j}, y_{i,j})(y_{i,j} - y_{0,0}) + F_y(x_{i,j}, y_{i,j})(x_{i,j} - x_{0,0})\right]$$

Positive and negative torques correspond to clockwise and anticlockwise rotation, respectively.

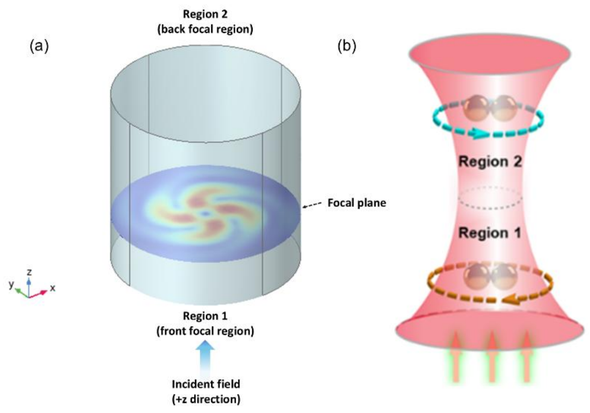


FIGURE 1. (a) 3D computational domain and transverse electric-field magnitude distribution at the focal plane. The transparent cylinder represents the simulation domain, and the colored slice shows the electric-field magnitude | E |. (b) Conceptual diagram of the switchable rotation of a gold dimer in the front and back focal regions.

Results

COMSOL simulations reveal a robust reversal of the annular energy flow across the focal plane. Silver nanorods experience positive optical torque in the front plane and negative torque in the back plane, corresponding to clockwise and anticlockwise rotation, respectively. Although the torque magnitude varies with the orientation angle α and lateral offset ΔL, its sign remains unchanged within each region, supporting robust and switchable bidirectional rotation.

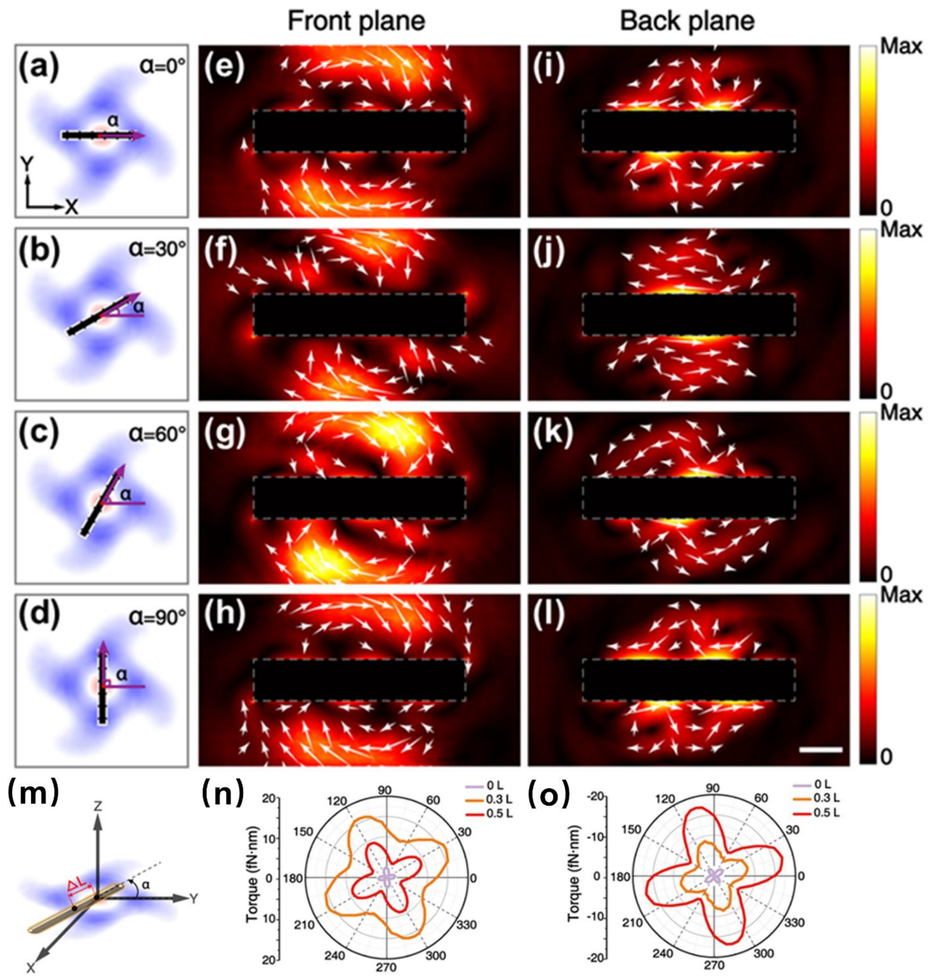


FIGURE 2. (a)–(d) Silver nanorods with different orientation angles αin the CIF. (e)–(l) Energy-flow distributions in the front and back focal planes; arrows indicate the local flow directions. (m) Nanorod geometry with lateral offset ΔL. (n)–(o) Optical torque versus $\alpha$for $\Delta L = 0, 0.3L$, and $0.5L$in the front and back planes, respectively. Scale bar: 0.3 μm.

REFERENCES

1. Y. Chen et al., “Switchable rotation of metal nanostructures in an intensity chirality-invariant focus field,” Opt. Lett. 48, 6328–6331 (2023).

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