Spinoptics: Spin-Based Plasmonics in Nanostructures

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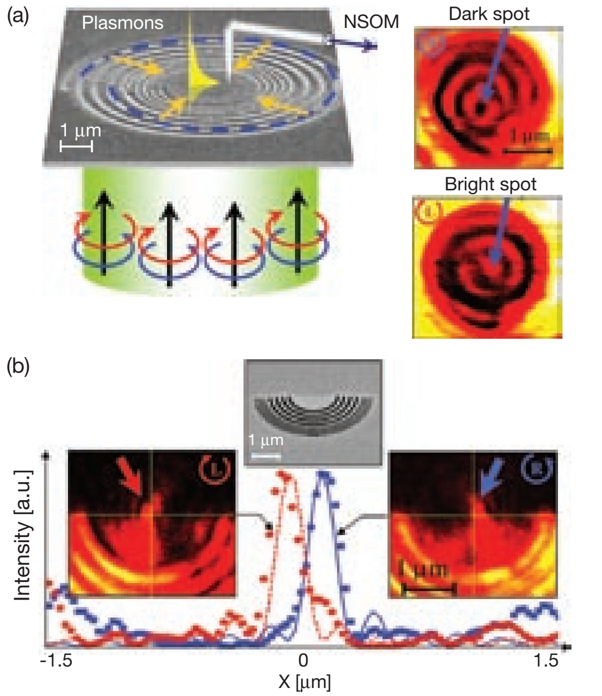
The interaction between light and metallic subwavelength structures results in various anomalous effects, such as extraordinary optical transmission[1] and beaming.[2] These effects have been elegantly explained by a mechanism that involves the coupling of light to collective surface-confined electronic oscillations known as surface plasmon-polaritons (SPPs). Extensive research has been carried out in the field of electromagnetic surface waves, which has rich technological potential.

Apparently, the handedness of the light's polarization (spin of photons) may provide an additional degree of freedom in nanoscale photonics. Here, we demonstrate the spin-dependent behavior of SPPs, which results from a geometric Berry phase that we found experimentally while exploring the interaction of light with metallic anisotropic and inhomogeneous nanoscale structures.[3,4]

The proposed anisotropic inhomogeneous plasmonic structure was produced on top of a thin metal film evaporated onto a glass plate. The element consisted of a spiral Bragg grating with a central defect surrounded by a coupling grating, as shown in part (a) of the figure. The structure was illuminated by circularly polarized light (R=right-handed, L=left handed). The intensity in the plasmonic cavity was measured by a near-field scanning optical microscope (NSOM). The measured intensity distribution exhibits a strong dependence on the incident spin.

An annular ring structure with a dark spot in the center for R illumination and with a bright spot for L illumination indicates coupling to different spiral plasmonic modes (plasmonic vortices). The origin of the spin-dependent change in the near-field intensity distributions is in the geometric phase of the excited plasmonic mode. In the most general case, when a wave carrying an arbitrary intrinsic angular momentum (spin) changes its direction of propagation and polarization state, the geometric phase is given by a simple expression stemming from the Coriolis effect,[3] which appears due to rotation of the reference frame represented by the local direction of the grating grooves.



(a) The scanning electron microscope (SEM) image of the spiral nanostructure and the scheme of the optical setup. Intensity distribution in the cavity measured by an NSOM for **R** and **L** illumination. The blue dashed line represents the spiral phasefront obtained in the cavity. (b) Spin-dependent plasmonic lens based on a plasmonic spin Hall effect. The intensity distributions measured by an NSOM for **R** and **L** illumination and the corresponding transverse cross-sections in the focal plane of the lens (measured: **R**=blue squares, **L**=red circles; calculated: **R**=solid blue line, **L**=dashed red line). The SEM picture of the element is depicted in the inset.

Accordingly, a spiral geometric phase with spin-dependent helicity arises in a circular grating.[4] In the spiral structure, such as that shown in (a), an additional dynamic phase arises as a result of a space-variant path difference. The overall phase in the spiral cavity is the sum of the geometric and dynamic phases, which is manifested by different spiral modes that are obtained in the cavity for different polarizations.

One of the possible technological implementations of the plasmonic geometric phase could be a spin-dependent plasmonic focusing lens. The proposed structure is presented in (b). We illuminated this structure from the bottom with R- and L-polarized planewaves and collected the near-field intensity distribution by the NSOM. We observed a spin-dependent transverse shift of focus by comparing the spots.

This shift can be regarded as a manifestation of the optical spin-Hall effect, which arise in our system due to a spiral geometric phase. The observed effects inspire one to investigate other spin-based plasmonic effects and to propose a new generation of optical elements for nano-photonic applications. ◭

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References

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