Whirling Plasmons: Angular Momentum Selection Rule

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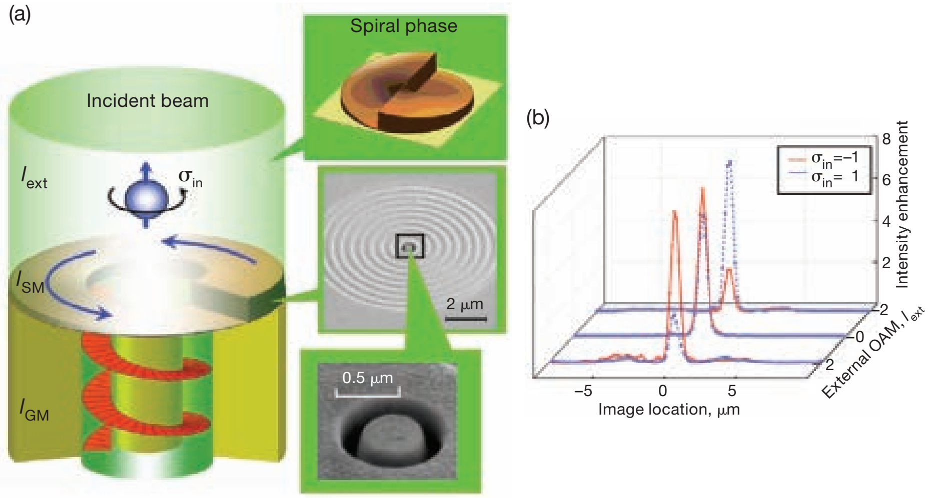
Plasmonic systems have been shown to be resonantly excited when the linear momentum selection rule is fulfilled.[1] However, conservation of total angular momentum (AM) in a closed physical system results in additional selection rules. The AM of an optical beam comprises the intrinsic component—the spin, associated with the handedness of the circular polarization—and the extrinsic component—orbital AM (OAM), associated with a spiral phase front.[2]

Here, we demonstrate a plasmonic nanostructure that exhibits a crucial role of an AM selection rule in a light-surface plasmon scattering process. In our experiment, the intrinsic AM of the incident radiation was coupled to the extrinsic momentum of the surface plasmons via spin-orbit interaction, which was manifested by a geometric Berry phase.[3] Due to this effect, we achieved a symmetry breaking that resulted in a spin-dependent enhanced transmission through coaxial nanoapertures, even in rotationally symmetric structures.[4]

In an optical paraxial beam with a spiral phase distribution ($\phi = -l\varphi$, where φ is the azimuthal angle in polar coordinates, and the integer number l is the topological charge), the total AM per photon, in units of $\hbar$ (normalized AM), was shown to be $j=(\sigma+l)$, where $\sigma=1$ is the right-handed circular polarization and $\sigma=-1$ is the left-handed circular polarization.[2]

In accordance with fundamental physical principles, resonant excitation of the nanoaperture eigenmode requires that the exciting wave match the excited mode, both with its linear and angular momentum. This matching imposes restrictions, or selection rules, on the excitation process.



(a) Mechanism of the nanoaperture’s excitation controlled by AM selection rules. Incident beam bears the intrinsic AM of σ_{in} and the extrinsic AM of l_{ext}. Excited surface mode acquires the OAM of l_{SM} as a result of spin-orbit interaction. Guided mode with l_{GM} is excited only if selection rule is satisfied. (Inset) Scanning electron microscope image of the structure. (b) Intensity distribution cross-sections for different l_{ext}. Blue dashed lines correspond to $\sigma_{in}=1$ and red solid lines to $\sigma_{in}=-1$. Intensity was normalized by the transmission measured via coaxial aperture without the surrounding corrugation. (Horizontal dimension was scaled according to the optical magnification.)

The coaxial nanoaperture was milled by a focused ion beam into a 200-nm-thick gold film evaporated onto a glass wafer. The inner and the outer radii of the ring slit were 250 and 350 nm, respectively. The aperture was designed to be a single mode system—in other words, to possess a single allowed excitation with OAM of $l_{GM}=\pm1$. The aperture was surrounded by an annular coupling grating with a period of 500 nm. This element was illuminated by a green laser light (532 nm) whose phase was modulated by a spatial light modulator to achieve a spiral phase corresponding to an OAM of $l_{ext}=0, \pm2$. The incident spin ($\sigma_{in}=\pm1$) induced a spiral phase of the excited surface plasmons via spin-orbit interaction, and, therefore, was converted to the OAM.[5]

The surface mode then acquired OAM of $l_{SM}= \sigma_{in}+ l_{ext}$. The best overlapping of the surface mode and guided modes was obtained when $l_{SM}= l_{GM}$, i.e. for $l_{SM}=\pm1$; therefore, the transmitted intensity was strongly dependent upon the incident spin. The transmission ratio of the two spin states was shown to be approximately three.

In summary, we presented the effect of spin symmetry breaking via spin-orbit interaction, which occurs in rotationally symmetric (achiral) structure. The results may lead to more complex spin-based nanophotonic applications. ◭

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