Optoinduced magnetization in a metal from the spin and orbital angular momenta of light

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Abstract: We provide a spin and orbital angular momentum representation of the inverse Faraday effect in a metal. We analytically show the role of the spin and orbital angular momenta of light (SAM and OAM, respectively), as well as the spin-orbit interaction (SOI), in the generation of an optoinduced magnetization. We also show that resonances in plasmonic nanoantennas enhance and confine the IFE on the nanoscale, thereby leading to static magnetic fields directly applicable in a vast application domain including all-optical magnetization switching and spin-wave excitation.

Light is known to possess polarization and spatial degrees of freedom, manifested by its linear momentum as well as spin and orbital angular momenta[1]. Remarkably, the SAM of light can be transferred to electrons in matter, a phenomenon which refers to as the IFE [2, 3]. The IFE has attracted much attention for its ability to generate light-induced magnetization, thereby opening the prospect of an ultrafast magnetic data storage and a non-contact excitation of spin-waves. On the basis of a hydrodynamic model of the conduction electron gas [4, 5], we provide a spin and orbital angular momentum representation of the IFE in a metal [6]. The OAM and SOI of light provide additional degrees of freedom in the control of the IFE usually solely attributed to the SAM. We also investigate a resonant IFE within individual nanoantennas [7, 8]. Upon illumination, individual subwavelength gold coaxes and cylinders are shown to develop a strong optomagnetic field on the nanoscale that is controllable by the helicity of the light. In pulse optical regime, this magnetic field is found to reach 0.3 T upon excitation at a light intensity below damage threshold.

Our model shows that both the SAM and OAM contributions to the IFE in the metal bulk rely on an optical drag effect [9]: the underlying optoinduced current densities are proportional to the Poynting energy flow (optical momentum) inside the metal. In the case of an axisymmetric optical system, we find a direct proportionality between the optoinduced drift current at metal surfaces and the radial component of the SAM of light. In the paraxial approximation, the contribution of the SAM vanishes, and the IFE is driven solely by the OAM of light, which is consistent with the interpretation of the spin and orbital angular momenta of purely transverse light fields [10, 11]. We also show that the SOI of light [12] plays a significant role in the IFE. Finally, we numerically quantify the relative contributions of the SAM and OAM to the IFE in a thin gold film illuminated with four different focused beams carrying SAM and/or OAM (see table 1). We find that the SAM of light is the main source of drift current density regardless of the helicity of the incident light. However, the compensation effects between SAM-driven surface and bulk currents of opposite handedness reduce the contribution of the SAM to the observable optoinduced magnetization. Except for circular polarization, the OAM of light is found to be the main contributor to the IFE. We also numerically confirm the importance of the SOI of light in the IFE, which manifests both via SAM-to-OAM and OAM-to-SAM conversions at the focus. The OAM of light thus opens new degrees of freedom in the control of the IFE in metals, thus potentially impacting various research fields, including all-optical magnetization switching and spin-wave excitation.

	l=0,s=1	l=1,s=0	l=1,s=1	l=-1,s=1
SAM	78%	0.2%	36%	49%
OAM	22%	99.8%	64%	51%

Table 1: The table shows relative contribution of OAM and SAM of light into the IFE for four different combinations of the l and s parameters defining the incoming beam entering the microscope objective.

We also investigate the generation of an optomagnetic field in plasmonic nanoantennas upon illumination with a circularly polarized light (Fig. 1). We predict an optomagnetic field reaching 0.3 T at laser fluence below nanostructure damage threshold. We also show that the substrate introduces an important asymmetry of the optomagnetic response of plasmonic nanoantennas fabricated via a top-down technological approach. For a 50-nm thick gold coaxial nanoantenna (Fig. 1b), the

optomagnetism is mainly localized within the substrate, which appears to be advantageous for many applications involving magnetic material within the substrate. Optomagnetism in resonant plasmonic nanoantennas may impact a broad field of applications and techniques including spintronics, magnonics and data storage via the development of on-chip nanoscale plasmonic-magnetic architectures. Optomagnetism may also provide new degrees of freedom in nano-object tweezing based on the combination of optomagnetic and pure optical forces.

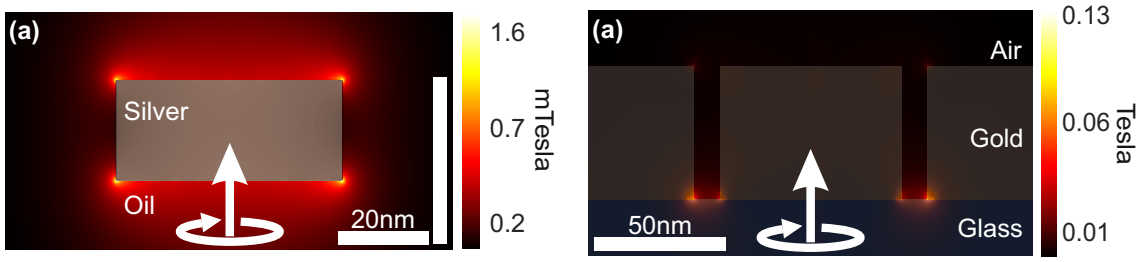

Figure 1: Optically-induced static magnetic field generated by (a) a gold nanocylinder (diameter: 50 nm, thickness: 12 nm) in oil (n=1.45), and (b), a coaxial nanoaperture in a 50-nm thick gold film on a glass substrate (n=1.5). The inner and outer diameters of the coax are of 50 nm and 70 nm, respectively. The wavelength is equal to 800 nm for each configuration.

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