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STRUCTURED LIGHT

Optomechanical tomography

Owing to the extreme sensitivity of a microscopic cantilever to optical forces, it is possible to uncover the fine structure of optical momenta and associated mechanical effects in evanescent fields.

Etienne Brasselet

The understanding that light carries momentum along its direction of propagation dates back to Kepler's astronomical observations of comet tails facing away from the Sun as the mechanical consequence of radiation pressure. Still, the collinearity between the direction that light propagates in and the force it exerts on matter is not a given. An example is the case of a photon impinging on a perfect mirror. The ensuing optical force is always directed perpendicular to the surface of the mirror. In other words, the optical force has in general both longitudinal and transverse contributions with respect to the propagation direction of the incident light. A more intriguing situation occurs when the optical momentum is no longer directed along the propagation direction of light. For instance, this may happen in evanescent waves. These are formed by so-called total internal reflection off an interface between two distinct dielectric transparent media when light propagates from a dense to a rare refractive medium. As their name suggests, evanescent waves have an intensity that vanishes exponentially with the distance from the interface while they propagate along the interface in a direction parallel to the incidence plane.

Two years ago a theoretical study pointed out that the mechanical signature of the polarization-dependent transverse component of the momentum carried by such a wave could be experimentally accessible[1]. The small magnitude of the predicted transverse forces, weaker than usual longitudinal radiation forces, could be argued to be of limited practical interest. However, the detection of such minute forces would represent an important step in the understanding of optical momenta and electromagnetic forces. Indeed, the transverse momentum appears as the manifestation of the so-called spin momentum, a quantity that does not contribute to the energy transport. First introduced by Belinfante in 1940 to solve fundamental issues in vector field theory[2], the observation of spin momentum has remained elusive (if not controversial) so far. Writing in *Nature Physics*, Massimo Antognozzi and colleagues report the direct optomechanical observation of these unusual tiny forces[3].

To detect small forces, Antognozzi *et al.* used a technique that allowed them to retrieve the lateral displacements of an extremely sensitive microscopic cantilever whose tip is placed close enough to the interface where the evanescent field is created that it does not suffer from the inherent optical intensity decay. In this way they can detect forces of the order of a few tens of femtonewtons. Then the mere rotation of a quarter-wave plate — which continuously modulates the polarization of the incident laser beam, hence structuring the evanescent wave in a controllable manner — enables the optomechanical tomography of the structured light field.

Although the experiment might seem simple in principle, Antognozzi *et al.* faced serious practical difficulties. The most important one was probably due to the fact that the cantilever is not an ideal rectangular cuboid. This limits the selective detection of the sought-after transverse forces. This experimental limitation becomes a useful feature once it is realized that the polarization dependence of the predicted longitudinal and transverse momenta, and hence the corresponding optomechanical effects, are characterized by odd and even symmetries with respect to the optical axis orientation of the quarter-wave plate. The experimental polarization-resolved reconstruction of both the longitudinal and transverse optical force components is therefore made easy.

Antognozzi *et al.* were able to clearly identify the mechanical manifestation of Belinfante spin momentum, in addition to another physically intriguing contribution that is proportional to the imaginary part of the complex Poynting vector, which is associated with the "alternating flow of the stored energy"[4]. Importantly, the unveiled transverse optomechanical effects vanish in the single-dipole limit and require at least electromagnetic dipole–dipole coupling, hence emphasizing the intrinsic higher-order nature of the (weak) phenomenon.

This work illustrates a basic feature of optical forces, which depend neither on the properties of the light field alone nor on those of the material system. Namely, a detailed description of the optomechanical effects requires the knowledge of the specific light–matter interaction at play. Recent advances in highly sensitive optical force measurement techniques[5] can boost the investigation of the unconventional properties of light in greater detail. Interestingly, although evanescent waves are only one aspect of structured light fields, they are likely to serve as a basis for investigating further optomechanical phenomena, for instance extension of the present work to optical angular momenta and associated electromagnetic torques[1]. More generally, the interaction of structured light with structured matter is a wonderful playground for exploring new facets of light–matter interactions. To this end, soft matter that may combine rich optical properties such as anisotropy and chirality, spatial inhomogeneities and extreme sensitivity to light fields constitutes an interesting candidate. ❐

Etienne Brasselet is at the University of Bordeaux and CNRS, LOMA, UMR 5798, F-33400 Talence, France. e-mail: etienne.brasselet@u-bordeaux.fr

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