# Optical Spin-transfer Torque Calculated in Relation with Optical Chirality

IIS, the Univ. of Tokyo[1], JST PRESTO[2],

°An'an Wu[1], Yoshito Tanaka[1,2], Ryoma Fukuhara[1], Tsutomu Shimura[1]

E-mail: waa1991@iis.u-tokyo.ac.jp

Light-matter interaction can induce optical torque acting on the matter due to the transfer of angular momenta carried by the light, including the spin angular momentum (SAM) and the orbital angular momentum (OAM). The Maxwell stress tensor (MST) method is extensively used in calculating the optical torque based on the transfer of total angular momentum of SAM and OAM. In other words, this method is unable to separate the optical torques produced by the SAM and the OAM. Here, we introduce an important quantity, that is optical chirality (OC), and reveal its relation to the SAM. Based on the relation, we propose a method to calculate the optical torque produced by the SAM separately from that by the OAM.

The OC in a medium with permittivity $\varepsilon$ and permeability $\mu$ can be expressed as [1]

$$C = \frac{\varepsilon}{2}\mathbf{E}\cdot\nabla\times\mathbf{E} + \frac{1}{2\mu}\mathbf{B}\cdot\nabla\times\mathbf{B}, \qquad (1)$$

where $\mathbf{E}$ and $\mathbf{B}$ are the time-dependent electric and magnetic field. We derived the flux density of the SAM, $-\mathbf{T}_s$, in relation with the OC as

$$\mathbf{T}_S = \frac{\varepsilon c^2}{2\omega^2}\{[\mathbf{E}\otimes(\nabla\times\mathbf{E}) + (\nabla\times\mathbf{E})\otimes\mathbf{E}] + c^2[\mathbf{B}\otimes(\nabla\times\mathbf{B}) + (\nabla\times\mathbf{B})\otimes\mathbf{B}]\} - \frac{c^2}{\omega^2}C\mathbf{I}, \qquad (2)$$

where $\omega$ is the angular frequency. $c$ is the speed of light in the medium. Thus, we can get the time-averaged optical torque produced by only the SAM, that is optical spin-transfer torque,

$$\boldsymbol{\tau}_S = \oint_S \overline{\mathbf{T}}_S\cdot\mathbf{n}dS, \qquad (3)$$

where $\overline{\mathbf{T}}_S$ is the time-averaged $\mathbf{T}_S$.

In Figure 1, $\tau_{M\_i}$ and $\tau_{S\_i}$ ($i$=$x$, $y$, $z$) represent the different components of the torques calculated by the MST method and Eq. (3), respectively. (i) $l$=1, $s$=1. Both the SAM and OAM are $\hbar$ per photon. Therefore, $\tau_S$ by the SAM and $\tau_M$−$\tau_S$ by the OAM should be equal to each other. (ii) $l$=1, $s$=−1. The total optical torque $\tau_M$ is vanished due to the different signs of the SAM and OAM. However, $\tau_S$ by the SAM should be remaining. (iii) $l$=1, *y-pol.*. While $\tau_M$ is non-zero due to the OAM transfer, $\tau_S$ by the SAM should be 0. Thus, we conclude that Eq. (3) is effective for calculating the torque by the SAM separately from that by the OAM.

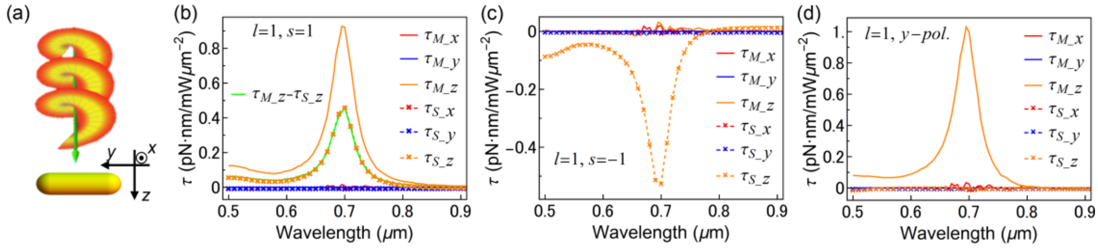


Figure 1. (a) Geometric model of a nanorod (length: 400 nm, diameter: 60 nm) laying along the $y$-axis illuminated by LG beam to propagate along the $z$-axis. Optical torque calculated by the MST method and Eq. (3) with different modes of the LG beam: $l$=1, $s$=1 (b), $l$=1, $s$=−1 (c), and $l$=1, *y-pol.* (d).

[1] L. V. Poulikakos *et. al.*, ACS Photonics 3, 1619 (2016).