# A Light-driven Micro-motor Based on Angular Momentum Transfer through Subwavelength Grating Waveplates

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Angular momentum in a circularly polarized beam was first suggested by Poynting in 1909[1] and later detected experimentally in 1936.[2, 3] With recent development of optical tweezers, transfer of photons' spin and orbital angular momentum has been used to manipulate microscopic objects and enable light-driven motors. One key part in such a light-driven motor is the actuating element that converts the optical torque carried by photons into mechanical rotation. Different schemes have been used for this conversion. For example, natural birefringence in a doubly refracting plate or particle[4] can alter the polarization state of an incident beam so that the change in the beam's angular momentum is converted into mechanical rotation. However, this method is limited by selection of special materials. Absorption of an angular-momentum-carrying beam can also make this conversion, although it may inevitably heat surrounding medium. Directional scattering of an incident beam was also demonstrated in a plasmonic motor but complex design and fabrication limit its applications.[5]

In this work, we propose to use a lithographically fabricated grating structure as an angular momentum converting element in a light-driven micro-motor. TE and TM light in the incident beam passing through a subwavelength grating structure experience different refractive indices.[6] Such a subwavelength grating structure effectively acts as an artificial waveplate, with its key parameters tunable via adjustment of process-related parameters of the structure, such as the material, grating duty cycle, grating height, etc. Moreover, such a subwavelength grating structure is compatible with normal micro/nanofabrication and can be fabricated on different substrates. All these advantages lead to greater design freedom and wider applications of a light-driven micro-motor.

The working principle of such a motor is shown in Fig. 1a and 1b. The incident beam is purely right polarized but reflected and transmitted beams are partly left polarized. Change of polarization causes a torque to rotate the disk. As an example, a design of a silicon subwavelength grating with a grating period of 200 nm and a 1:1 duty cycle is simulated by rigorous coupled wave analysis in order to maximize the torque exerted on the disk. The plate with the grating is suspended in air for simplicity and illuminated by an incident beam of 1550 nm wavelength. Fig. 1c and 1d plot the transmittance and phase delay for TE and TM light respectively at different grating depths. The phase changes of TE wave and TM wave are proportional to the grating thickness so that the grating could be considered as a medium with effective refraction indices of 2.609 and 1.470 for TE and TM, respectively. Our analytical calculation using effective medium theory also obtains similar results. Such an artificial form birefringence is significantly larger than typical natural birefringence and allows for much thinner subwavelength grating structures to be used to achieve effective torque generation. In Fig. 1e, we plot the angular momentum transferred from each incident photon with respect to the grating depth (see the left vertical axis). We also calculated the rotation rate of such a grating disk placed in a viscous liquid environment, as seen by the right axis in Fig. 1e. Here we assume the 1550 nm incident beam has a power of 100 mW, the radius of the disk is 10 μm, and the viscous liquid is water with a viscosity of $9.325 \times 10^{-4}$ Pa s .

In summary, we propose a light-driven micro-motor by using subwavelength gratings to convert angular momentum from incident light into mechanic torque on a rotor. Fabrication and characterization is ongoing to demonstrate such a device. Applications in micro/nanofluidic study and bio-medical devices can be explored using this device.


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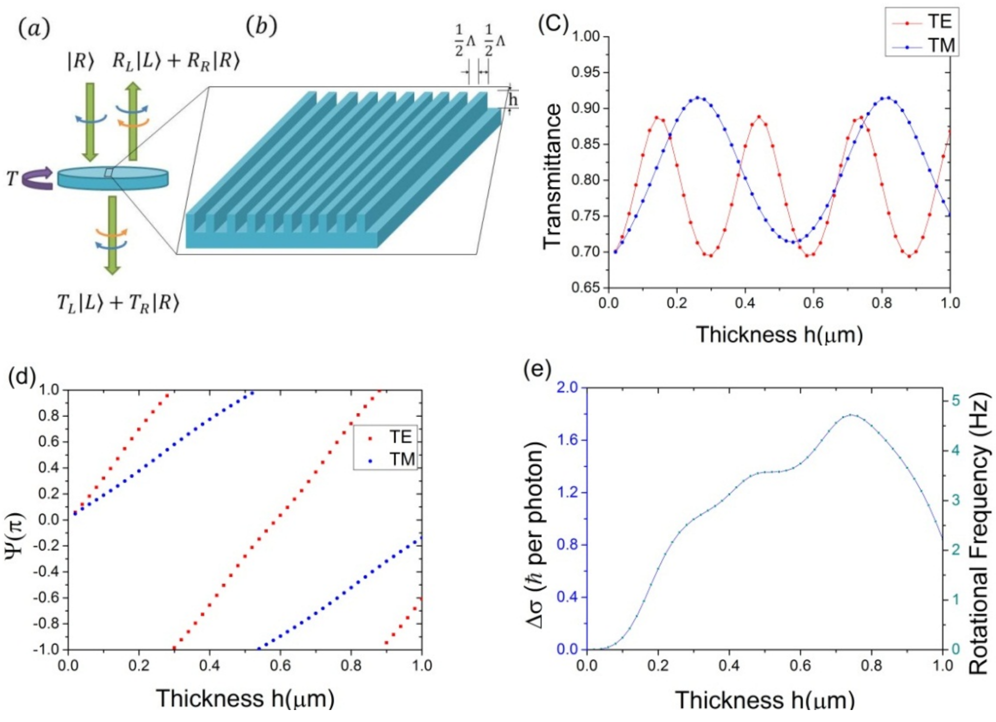


*Fig.1 Schematic and simulation of a light-driven motor based on form birefringence.* (a) and (b), Silicon plate carrying 200-nm-pitch 1:1 gratings converts circularly polarized incident light into partially left polarized reflected and transmitted light, with the change of angular momentum in the beam converted into mechanical rotation; (c),Transmittance and (d) phase delay of TE and TM light at 1550 nm wavelength with respect to the grating depth; (e) Change of angular momentum Δσ and corresponding rotational frequency of the rotating motor when placed in water.