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BIREFRINGENT QUARTZ MICRO-CYLINDERS FOR ANGULAR OPTICAL TWEEZERS

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ABSTRACT

There is a growing demand in developing and optimizing a fast and inexpensive way to produce a large number of microscopic quartz cylinders designated for nanoscale mechanical measurements in angular optical tweezers. Here we present a simple method based on laser interference lithography which meets these requirements and provides quartz micro-particles that are successfully used in our optical setup to apply and measure optical torque.

KEYWORDS: laser interference lithography, RIE, quartz micro-particles, optical tweezers, angular trapping

Angular optical tweezers (OT) are capable of rotating birefringent particles in a controlled manner in addition to manipulating in three dimensions, and have a potential of becoming a powerful tool for nanoscale position and torque measurements [1], e.g. in the studies of molecular motors and gyratory properties of molecules. One of the methods to achieve angular control in OT is based on the transfer of spin angular momentum from the photons to the trapped particle. Photons carry positive or negative angular momentum, which corresponds to the left- and right-circular polarization components respectively. The polarization state of the trapping beam is modified after its propagation through a birefringent particle [2]. This results in an altered total spin angular momentum of the laser beam, and is reflected as the torque transferred to the birefringent particle in the optical trap (Figure 1a).

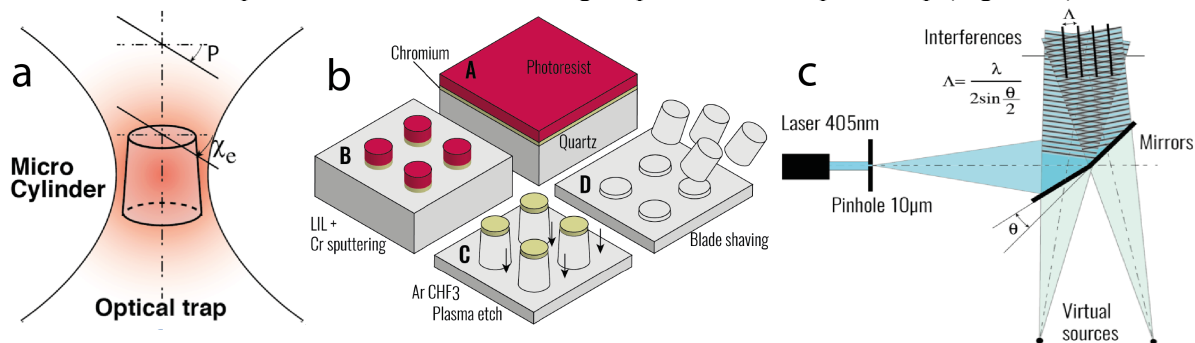


Figure 1: (a) Schematic of a cylindric birefringent particle trapped in angular optical tweezers, (b) microfabrication process and (c) principle of the Laser Interference Lithography.

Typically, angular OT requires a large number of quartz micro-cylinders. While previous works in the field have been using complex and costly electron beam lithography to achieve the patterning of submicron dots [3], we suggest the Laser Interference lithography (LIL) to produce millions of such micro-cylinders on a 20x20 mm² crystalline quartz substrate. LIL is a maskless lithography technique (Figure 1c) based on the direct transfer of light interference patterns (lines and dots) onto a photosensitive material. Therefore, this technique benefits from the ease and speed of a direct illumination. We are able to produce arrays of lines or dots with a pitch ranging from 400 nm up to 2000 nm.

The microfabrication process is depicted in Figure 1b. A 30 nm thick layer of chromium is sputtered onto 20x20 mm² single crystal quartz substrates. Samples with an AZ701 photoresist are then exposed in the LIL setup tuned for a 1µm interference period. Exposure is made in two steps of 130 s each with a rotation of the sample to 90° in the interference plane in order to produce an array of dots. The Cr hard mask layer is dry etched using Reactive Ion Etching with an argon plasma (100 W, 50 sccm Ar, 10 mtorr) and the quartz is etched with a mixture of CHF₃ and O₂ gazes. The height of the microfabricated cylinders ranges from 900 nm up to 1.6 µm with typical diameters of 400 nm on the

top and 600 nm on the bottom (Figure 2e). After the wet etching of the residual Cr the cylinders are detached from the substrate by gently sweeping the surface of the substrate with a scalpel blade.

The optical setup is described in detail in [3, 4]. In brief, the trap is formed by an infrared laser focused by a high numerical aperture objective (NA = 1.2) in a chamber containing the cylinders dispersed in water. In our experiments the orientation of the linear polarization of the laser is controlled by an electro-optical modulator (EOM). By driving the EOM with a sawtooth voltage signal from 0 to few kHz we obtain a typical curve of mean torque transferred to the trapped particle [3].

Due to this transferred optical torque, the extraordinary axis of the trapped cylinder orients parallel to the linear polarization of the laser (Figure 2a). For low polarization rotation frequencies ω , the extraordinary axis of the cylinder follows in phase the polarization rotation (Figure 2b). In this regime, the mean torque transferred to the particle is linearly proportional to ω . The cylinder ceases to follow in phase the rotation of the laser polarization when ω reaches the critical value. In this case, the particle axis does not rotate along with the polarization due to thermal noise. Such stochastic escape events are reflected by the appearance of spikes in the torque signal (Figure 2c,d). After the critical point, the mean torque decreases with the increasing ω . The described dynamical behaviour of the cylinder in the angular optical tweezers confirms that optical torque in the range of pN nm can successfully be applied and measured.

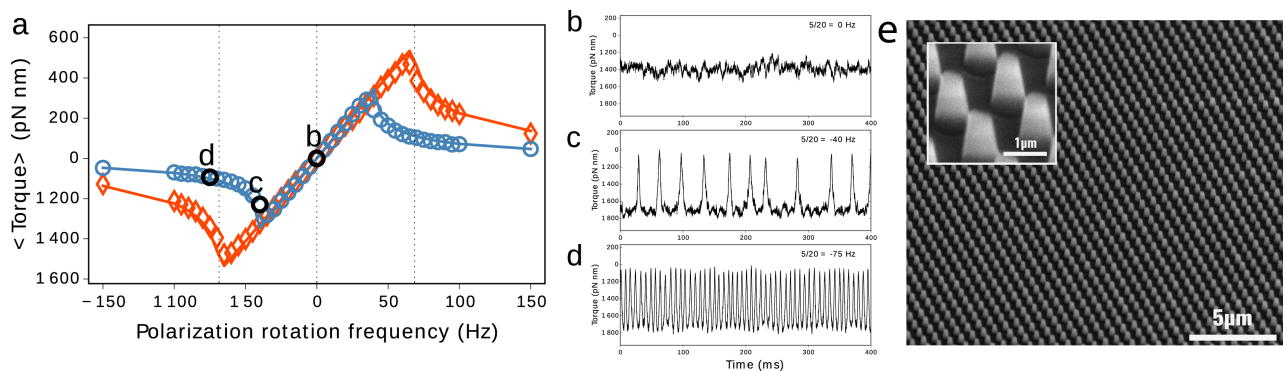


Figure 2. (a) Measurement of the mean torque vs. polarization rotation frequency for two different optical powers and (b,c,d) instantaneous torque traces recorded at the values of ω indicated in (a). (e) SEM picture of a 800 nm pitch array of 1.6 μm tall quartz micro-cylinders, detailed view in the inset

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