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Optically controlled orientation of lithium niobate micro crystal particle

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Abstract: In this work, the experimental system for optically controlled capturing and orientating is designed. Using the system, we demonstrate optically capturing of lithium niobate micro crystal particle. Moreover, the captured particle becomes aligned with the direction of linear polarization. Finally, we present optically controlled orientation theory of lithium niobate crystal particle. The work illustrates that the alignment of lithium niobate micro crystal particles can be optically orientation by the linear polarization' s direction of laser light. These results can be further used in micro sensors, photonics, MEMS, light-induced micro motor, and micro manipulation fields.

Key words: lithium niobate, crystal particle, optically controlled orientation
PACS: 42.70.Mp, 81.07.Bc

铌酸锂微晶的光控制取向行为研究

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摘要:基于光镊机理与倒置显微成像方法成功实现了铌酸锂微晶颗粒的光学捕获控制和光致取向的直接观测. 由于铌酸锂微晶具有光学各向异性性质,所以在线偏振飞秒激光的操控下,所捕获的铌酸锂微晶颗粒能够依据激光偏振方向成功实现光控制取向. 分析了铌酸锂微晶颗粒的激光控制取向机理,说明了铌酸锂微晶颗粒的取向可以利用激光的线性偏振方向进行光致取向旋转,有望应用于微纳光子学、MEMS、光控微型马达和微操作等科学研究领域.

关 键 词:中红外铌酸锂;微晶颗粒;光致取向

中图分类号:TN249; O436.3 **文献标识码**:A

Introduction

Optically controlled orientation of micro particle[1-9], whose application mainly related photonics, micro electro mechanical system (MEMS), micro sensors, and light-induced micro motor, is one of the most significant phenomena in micro-manipulation field. It is widely studied in both theories and experiments. Achieving optically controlled orientation of various advanced optoelectronic materials and explain the corresponding mechanism are quite important works. Friese *et al*. studied circularly polarized light induced orientation of $CaCO_3$ particle and explained its theoretical mechanism[2]. Using linearly polarized near-infrared laser light beam, the optical alignment and rotation of individual plasmonic nanostructures (silver nano rods and gold nano particles) were demonstrated. This phenomenon was caused by the high polarizability of long-axis dipole[4]. Based on optical tweezers technology, researchers studied the rotational dynamics of solid chiral and birefringent micro particles controlled by the laser light with elliptical polarization[9]. Lithium niobate (LN) materials[10-13], which have efficient nonlinear optical properties, have played an important role in various applications, such as laser materials, optical storage, light localization, display technology, sensors, optically controlled modulator, optical waveguide, photonic crystals and so on. Achieving opti-

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cally controlled orientation of LN can extend the materials which can be used in optical micro sensors and micro-manipulation. Moreover, X. Zhang et. al. has studied optically controllable weak localization of photons in a suspension of LN particles[14-16]. This phenomenon was attributed to the reorientation of particles in the optical field. However, optically controlled orientation of Lithium niobate crystal particle has not been observed directly by now.

In this work, the optically controlled orientation of LN micro crystal particle was observed directly for the first time using optical tweezers. The optically controlled orientation system was constructed experimentally. Based on this system, we demonstrated optical capturing of LN micro crystal particle, and the captured particle became aligned with the direction of linear polarization. Then, the optically controlled orientation theory of LN micro crystal particle was discussed. These results illustrated that the alignment of LN micro crystal particles can be optically orientated by the linearly polarized direction of laser light.

1 Experimental setups

Figure 1 shows the experimental setups of optically controlled system of LN micro crystal particle. The manipulation light beam was generated by a femtosecond laser at 800 nm central wavelength with linear polarization (pulse duration: 120 fs, repetition rate: 1 KHz, laser energy: 0.3 mJ). This femtosecond laser was a mode-locked Ti: Sapphire laser system (Spectra Physics, USA) that includes the MaiTai seed source, the pump source Empower 30 and the Spitfire regenerative amplifier. The light beam emitted by the laser was collimated by the lens 1 (L1) and lens 2 (L2). Using Glan-Taylor prism and half wave plate, the linearly polarized direction of light beam could be adjusted continuously, and the degree of linear polarization was larger than 10000:1. Then the laser light beam was reflected by the reflection mirror and beam splitter, and was focused on the sample by a microscope objective lens (NA = 1.45). The sample was fixed on the cover glass of a 3D translation stage. The illumination light which passed through the sample was collected by the objective lens and was imaged to the charge-coupled device (CCD) through lens 3 (L3). A computer was connected to the 3D translation stage and CCD for sample movement and real-time monitoring.

2 Sample

The sample in our experiments was congruent LN micro crystal particles in water suspension. LN single crystal is a quite versatile birefringent photonic material. In our work, a LN single crystal was grown by the Czochralski method. We prepared LN micro crystal particles using a planetary ball mill, and then the LN particles were filtrated through a membrane filter. The suspension which consisted of LN micro particles and deionized water was the sample under studying here. The diameter of the LN particle which was optically controlled was about 1.8 μm measured by microscopy system as shown in Fig. 2 and Fig. 3. To observe optically capturing and orientating obviously, some LN macro crystal particles, which played a role as marking objects in the experiments, were put in the suspension.

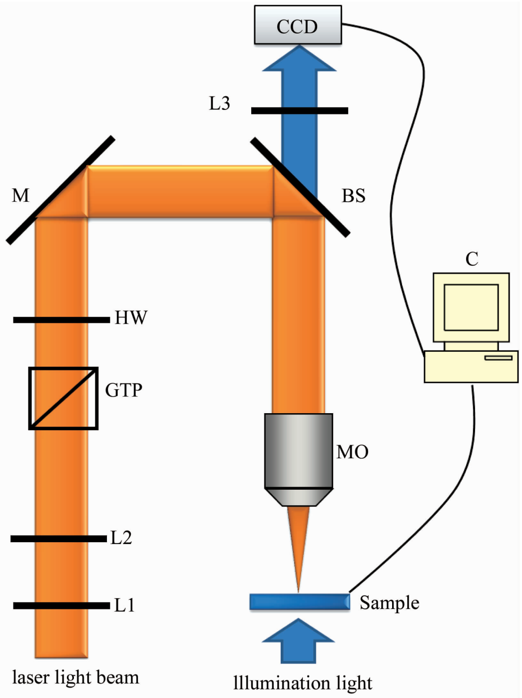


Fig. 1　The experimental setups of optically controlled system of LN micro crystal particle. L1, lens 1; L2, lens 2; L3, lens 3; M, mirror; HW, half wave plate; GTP, Glan-Taylor prism; BS, beam splitter; MO, microscope objective; CCD, charge-coupled device; C, computer

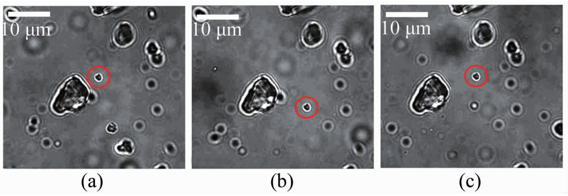
图 1　铌酸锂微晶光致取向实验系统图. L1,透镜 1;L2,透镜 2;L3,透镜 3;M,反射镜;HW,二分之一波片;GTP,格兰泰勒棱镜;BS,分光棱镜;MO 显微物镜;CCD,相机;C,电脑

3 Experimental results

We achieved the stable optical trapping of LN micro crystal particle using linearly polarized laser light, as shown in Fig. 2.

In our experiments, the position of the focused spot of the laser light was fixed and the sample on the 3D translation stage was moved by computer controlling. When the LN micro crystal particle approached the focused spot of laser light, it was pulled to the center of focused spot rapidly. Then, if the sample on the stage was moved, the trapped LN micro crystal particle would not move with the sample. It proved that the LN micro crystal particle was stably captured by laser light. With the removing of laser irradiation, the trapped LN micro crystal particle quickly returned to its original free motion state.

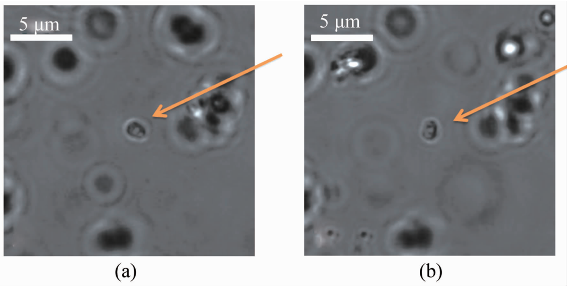
In order to orientate the LN micro crystal particle, the linearly polarized direction of the laser light was adjusted by Glan-Taylor prism and half wave plate. In our work, a LN micro crystal particle which was trapped in linearly polarized laser light field was aligned in a particular orientation. If the direction of the laser light polarization was changed using a half-wave plate, the alignment of LN micro crystal particle would follow the orientation of the direction of laser light polarization exactly. As shown in Fig. 3, when the direction of the laser light polarization was rotated 90°, the orientation of the LN micro crystal particle was changed consistently. This illustrated the alignment of LN particles were optically controlled by the linear polarization's direction of laser light successfully. In our experiments, the lithium niobate microcrystalline with large size can not be captured. Only the lithium niobate microcrystalline whose size was smaller than 5μm can be controlled successfully.



(a) (b) (c)

Fig. 2 The optical trapping of LN micro crystal particle: the laser beams can capture LN micro crystal particles and change its position in the sample

图 2 铌酸锂微晶的激光捕获图像:激光能够捕获并移动铌酸锂微晶的位置



(a) (b)

Fig. 3 The photographs of a captured LN micro crystal particle, showing the alignment with the direction of laser light polarization. When the direction of the laser light polarization was rotated 90°, the orientation of the LN micro crystal particle was also rotated 90°

图 3 捕获的铌酸锂微晶的照片,其取向由激光的偏振方向控制,当激光的偏振方向旋转 90°时,铌酸锂微晶的取向也随之旋转 90°

4 Discussions

Because LN is anisotropic optical material, when a LN micro crystal particle is irradiated by linearly polarized laser light filed, the induced electric polarization of the micro particle is

$$\vec{P} = \varepsilon_0(\varepsilon_\perp - 1)\vec{E} + \varepsilon_0\Delta\varepsilon(\hat{n}\cdot\vec{E})\hat{n} \quad , \qquad (1)$$

in which $\vec{E}$ is the electric field of the laser light beam, $\hat{n}$ is the unit vector of the optical axis of the micro crystal particle, ε_0 is the dielectric constant of vacuum and $\Delta\varepsilon = \varepsilon_{/\!/} - \varepsilon_\perp$ is the dielectric anisotropy of the micro crystal particle for the laser light beam. Therefore, the torque can be described as:

$$\Gamma^{\mathrm{opt}} = <\vec{P}\times\vec{E}> = \varepsilon_0\Delta\varepsilon(\hat{n}\times\vec{E})(\hat{n}\cdot\vec{E}_0) \quad , \qquad (2)$$

where E_0 is the amplitude of the light. Moreover, the free energy[17] supplied by laser light electric field can be described as:

$$-\int\vec{D}\cdot\mathrm{d}\vec{E} = -\varepsilon_0[\varepsilon_\perp\vec{E}^2 + \Delta\varepsilon(\hat{n}\cdot\vec{E})^2]/2 \quad . (3)$$

According to the minimum energy principle, the optical axis of LN micro crystal particle illuminated by linearly polarized laser light would be parallel to the light electric field $n /\!/ E$ for $\Delta\varepsilon > 0$, while $n \perp E$ for $\Delta\varepsilon < 0$. Because LN crystal is a negative uniaxial crystal ($\Delta\varepsilon < 0$), the optical axis of LN micro crystal particle is inclined perpendicular to the polarized direction of laser light. This implies that LN micro crystal particle can be orientated by linearly polarized laser light. The main factors affecting the controlling and orientation of microcrystalline in this system were the energy and polarization state of femtosecond laser. The optically controlling of lithium niobate microcrystalline depended on the laser energy. If the light energy was less than 0.1 mJ, this phenomenon can not be demonstrated. Moreover, to achieve stable orientation controlling of the microcrystalline, linearly polarized light should be used. When circular polarized light was used, the microcrystalline was not be orientated stably and was rotated with constant frequency and angular speed.

5 Conclusions

In conclusion, based on the discussion of optically controlled orientation theory of LN micro crystal particle, the optically trapping and orientating system was constructed experimentally. The LN micro crystal particle which was captured by the laser light field was orientated with the linearly polarized direction of the laser light. These results proved that LN micro crystal particle is orientated successfully in the linearly polarized laser light field. Our work also can be further used in fields of micro sensors, photonics, MEMS, light-induced micro motor, and micro manipulation.

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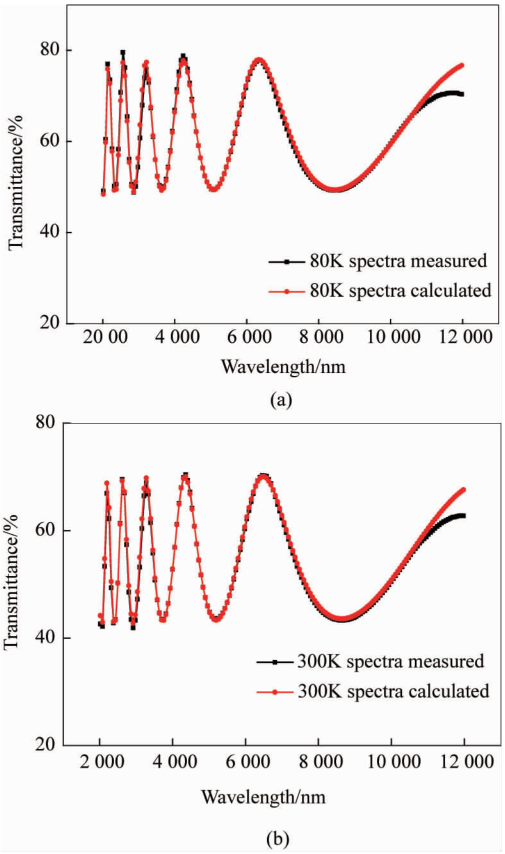

Fig. 5 The contrast of the designed spectra by the formula and the measured spectra at (a) 80 K (b) 300 K

图 5 (a)80 K 和(b)300 K 温度下实测光谱与公式得到的理论值的对比图

cial for the manufacturing of optical devices with high temperature stability.

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