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The study on optical lattice formed by four-beam interference

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ABSTRACT

In parallelized microscopy, the optical lattices can be generated by multi-beam interference and realize parallelization imaging to improve the imaging speed. The optical lattices which depend on the system parameters such as the objective focal length, the distance between interference light sources and the aperture angle α, can affect the imaging quality. We built a simple optical system with the full conjugation between two Wollaston prisms and focal plane to obtain the optical lattices, and discuss the relations between the optical lattice and the system parameters. In the experiment, the interference fringes period of the optical lattice is 27.9 μm for the focusing lens with focal length 150 mm, but it is 46.5 μm for the focusing lens with focal length 300 mm.

1. Introduction

Now high-resolution microscopy has been the important instrument of biological research. There are two kinds of high-resolution optical microscopy. One is wide-field imaging high-resolution microscopy, such as STORM [1], nonlinear SIM [2] and SIM [3]. The STORM and nonlinear SIM can achieve high-resolution but at the expense of imaging speed since they require a large number of raw images per time frame. SIM has a faster imaging speed, but it can only improve the resolution by a factor of two of the diffraction limit. The other is point by point scanning imaging high-resolution microscopy, such as STED [4]. It can realize the high resolution without a large number of frames, but the point by point scanning method limit the imaging speed. But the biological researches, especially in the live cell imaging, require faster imaging speed.

To solve this problem, many technologies [5–7] are proposed to improve the imaging speed. In these technologies, the best one is the parallelization of point by point scanning imaging microscopy, such as the parallelization of STED and RESOLFT, which can both achieve high-resolution and fast imaging speed. The parallelizing STED microscopy in which the Wollaston prisms are used to get four pairs of scanning excitation and doughnut-STED beams has firstly been reported and increases the imaging speed by four times [7]. Another approach used to realize the parallelization is the structured illumination pattern that can generate optical lattices by interference. The massive parallelization of RESOLFT with 2D structured illumination generated by diffraction grating has firstly been reported and improves the imaging speed obviously [8]. The structured illumination has been obtained by Wollaston prisms and half wave plates to improve the imaging speed of STED [9]. The 2000-fold parallelized dual-color STED has been realized with the polarizing beam splitter and half wave plates [10]. Now the approaches to generate the 2D structured illumination for four beams interference are by diffraction grating, by spatial light modulator and half wave plate, and by Wollaston prism and half wave plate, and so on. The configuration using Wollaston prisms and half wave plates is low-cost and simple. In the reported parallelized STED microscopy with two Wollaston prisms,

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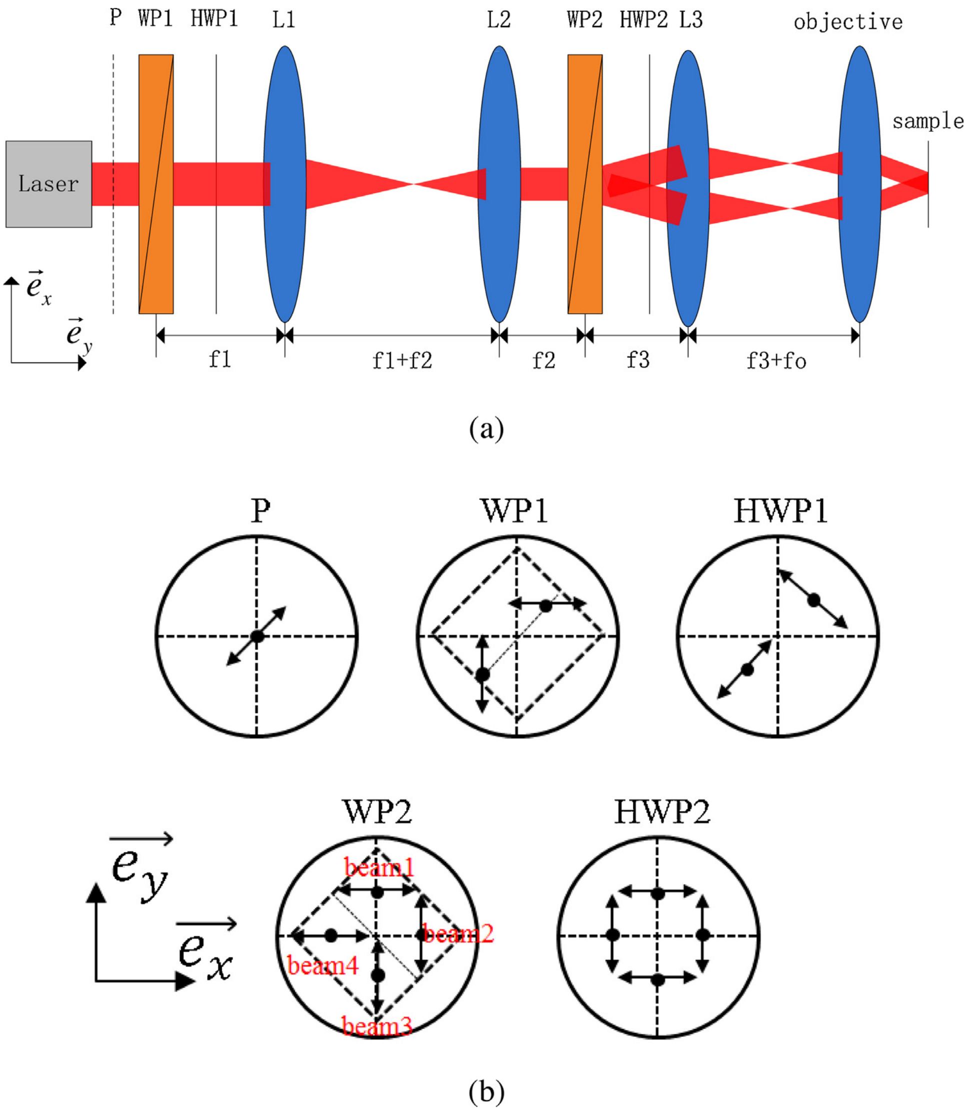

Fig. 1. The four beams generation. (a) The optical Schematic. The two Wollaston prisms and the sample plane are conjugated. P is a polarizer; WP1 and WP2 are Wollaston prisms. HWP1 and HWP2 are half wave plates. (b) The beam's projections on different planes and their polarizations.

the Wollaston prisms are not conjugated with the focal plane of the objective so as to reduce the range of the interference field. So it is important to research what affect the interference field of the optical lattices. In 2008, Stay and Gaylord [11] have derived the general interference expression for N linearly polarized waves and examined three-beam interference. However the influence factors of four-beam interference field of optical lattices is not studied. So in this paper a configuration in which the Wollaston prisms and focal plane are conjugated is proposed to get the interference filed of optical lattices, and the influence factors of four-beam interference field of optical lattices are discussed.

In this article, we deduce the intensity distribution expression for the interference pattern of four-beam on the basis of the expression for the interference pattern of multi-beam. Then a simple optical system in which two Wollaston prisms and focal plane are fully conjugated is set up to generate the four-beam interference pattern of optical lattices. On the basis of the intensity distribution expression, the influences of system parameters on the period and range of the interference pattern of optical lattices are discussed. Finally the interference pattern of optical lattices is obtained in the experiment system, and the experiment results confirm the conclusions about optical lattices.

2. Theory

Fig. 1(a) is the optical schematic in the XZ plane, which can generate the interference pattern for four linearly polarized beams. In the schematic, the Wollaston prisms and half wave plates are used to get four linearly polarized beams. Two Wollaston prisms WP1 and WP2 are placed at the focal plane of the lenses L1 and L2, respectively. So the two Wollaston