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Diffraction and shaping analysis of excimer laser through an ultrasonic grating

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ABSTRACT

A novel numerical simulation method for the shaping of an excimer laser beam by an acoustic grating is proposed. Partially coherent theory and extended Huygens–Fresnel principle are used to analyze the light intensity diffraction pattern. Fast Fourier transform function FFT in the Matlab is used to calculate the numerical integral, which makes the integral operation simple and efficient. It is shown by a numerical simulation that the output intensity distribution is closely related to the coherence width, Raman–Nath comprehensive parameter, diffraction distance and ultrasonic wave frequency. The simulation results show that a flat top beam can be obtained by controlling these parameters. On the other hand, the results are used as an effective analytic tool for the determination of the design parameters of acousto-optic modulator.

1. Introduction

Excimer lasers are widely used for lithography because of their high conversion efficiency, high average power and high pulse energies at UV wavelengths [1]. However, the intensity distribution of output beam produced by most excimer lasers which is a partially coherent Gaussian beam is not uniform [2]. They cannot meet the requirements for the lithography applications such as the manufactures of FPD and HD-PCB [3]. Over the years, some techniques to improve the homogeneity of excimer laser beams have been proposed [4–11]. In particular, diffraction optical elements stand out by their merits of flexibility, high diffraction efficiency and good performances [12,13]. Compared with microlens arrays, the acousto-optic modulator has a lower-cost production. The numerical simulation method using Collins integral and ABCD matrix formalism to shape a Gaussian beam into a flat top beam has been reported [11]. According to different ultrasonic wave frequencies and different acousto-optic interaction lengths, there are two basic regimes of acousto-optic interaction: Bragg and Raman–Nath diffraction [14,15]. The parameter $Q = 2\pi\lambda L/\lambda_s^2 n_0$ is used to predict the two types of diffraction [16].

In this paper, we propose a simple numerical simulation method by building up a new theoretical model for the shaping of an excimer laser beam. Due to the partial coherence of excimer laser, it can be studied using Gaussian Schell-model. The output intensity profile in free space at different propagation distances is analyzed by utilizing the extended Huygens–Fresnel principle. All calculations are done in the near-field. When calculating the integral, the Fourier transform is used to take the place of integral, which can avoid the complicated operation in the analytical calculation. We show the influence of different parameters on the uniformity of intensity distribution. Our work is focused on obtaining a flat top beam by controlling the parameters, which has a wide application value and guiding significance for the beam-shaping experiments.

2. Theoretical model

As an ultrasonic wave propagates in an acousto-optic medium, the acousto-optic medium in the ultrasonic field will be compressed. Variations of density cause the refractive index to vary periodically, which forms an ultrasonic grating. The laser beam will be diffracted and suffers a phase modulation when passing through the acousto-optic interaction medium. Here, we consider only the Raman–Nath diffraction regimes. Based on the Raman–Nath multiple-order diffraction, each position where the laser beam is diffracted will produce a group of discrete diffraction light. Then, the different diffraction orders of each group will overlap and there are no interference effects. As a result, a good approximation of a flat top distribution is obtained. The complex amplitude transmittance of the medium is written as

$$t(x) = T(x)\exp(-jk\,\nabla n(x)L) \quad (1)$$

where $T(x)$ is the amplitude transmittance, k stands for the light wave vector and L represents the acousto-optic interaction length. In addition, $k\nabla n(x)L$ is defined as the relative phase delay after light passes through the acousto-optic crystal with

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$\nabla n(x) = \nabla(n)_m \sin(-k_s x).\nabla(n)_m$ is the refractive index variation of medium, k_s stands for the sound wave vector and x is defined as the propagation direction of ultrasonic wave.

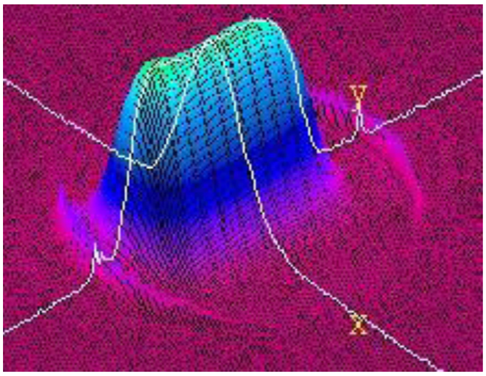

Fig. 1. Excimer laser spot stereogram.

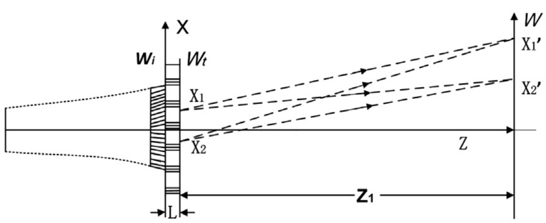

Fig. 2. Diagram of excimer laser passing through an ultrasonic grating.

Here the acousto-optic medium we used is fused quartz whose transmissivity is very high at 351 nm wavelength. In the frame, $T(x)$ can be approximated as 1, while out of the frame, $T(x)$ can be approximated as 0, so $T(x)$ is a rectangle function. Assuming that the aperture is a, the amplitude transmittance is given as

$$T(x) = \mathrm{rect}\left(\frac{x}{a}\right) \tag{2}$$

We know that in isotropic homogeneous medium, the refractive index variation of medium is $\nabla(n)_m = n_0^3 PS/2$, where n_0 is the refractive index of medium without sound field interaction. P is elastic-optical coefficient and S is elastic strain of the medium, which can be expressed as $S = \sqrt{2I_s}/\sqrt{\rho V_s{}^3}$. I_s is sound field intensity. ρ is density of the medium. v_s is sound velocity in the medium. So, we obtain the complex amplitude transmittance of the medium given by

$$t(x) = \mathrm{rect}\left(\frac{x}{a}\right)\exp\,[jV\ \sin(k_s x)] \tag{3}$$

where $V = n_0{}^3 PSkL/2$ denotes the Raman–Nath comprehensive parameter of the acousto-optic medium.

We have taken a picture of the output light spot of XeF excimer laser (351 nm) with a Beam Quality Analyzer. The spot size is approximately 18 mm × 8 mm. As shown in Fig. 1, we can see that the light intensity distribution in the X direction is a near-Gaussian profile and it is a flat Gaussian distribution profile in the Y direction. Therefore, it can be seen as a uniform distribution in the Y direction. We need to consider the beam uniformity only in the X direction. For simplicity, considering only a dimensional case (Fig. 2), the cross-spectral density function of the Gaussian

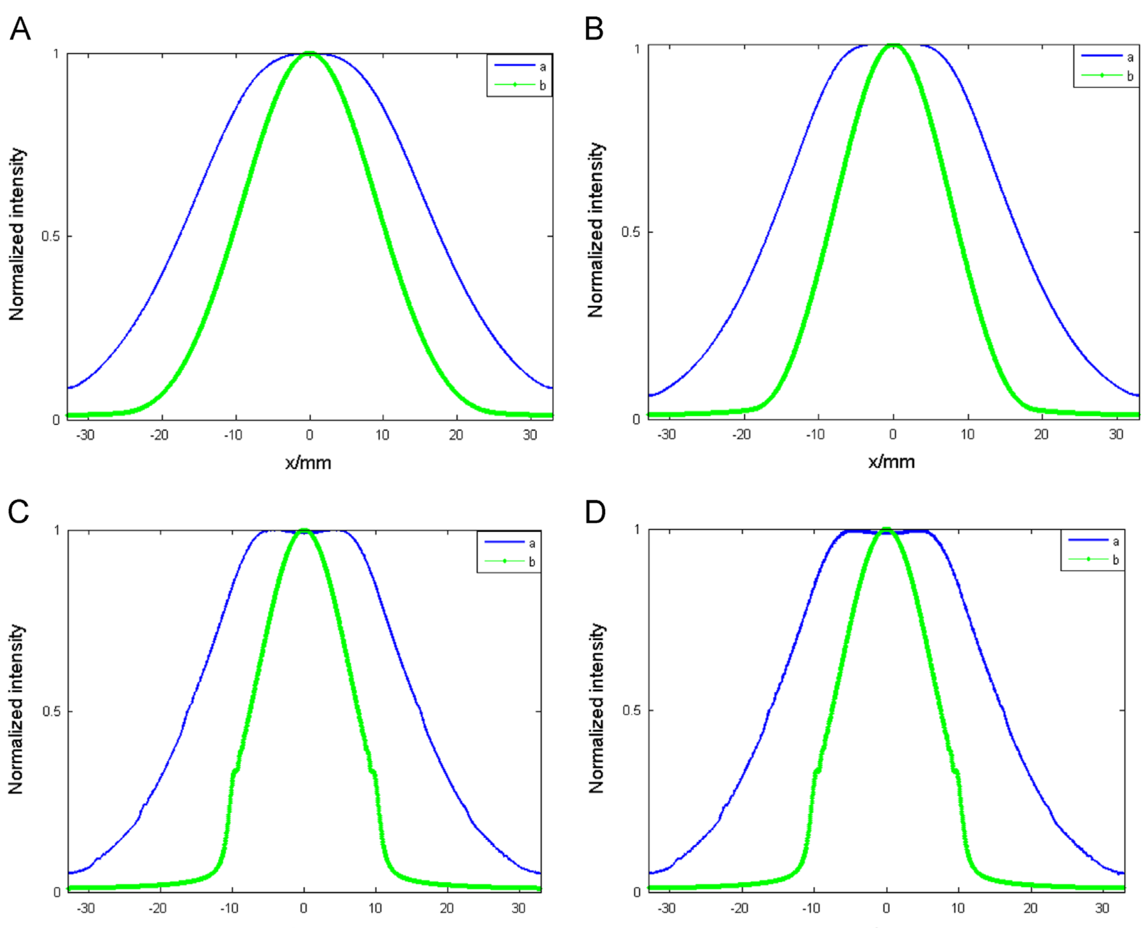

Fig. 3. Influence of coherence width. (a) Ultrasonic grating and (b) without ultrasonic grating; (A)$\sigma_\mu = 0.01$ mm, (B) $\sigma_\mu = 0.05$ mm, (C) $\sigma_\mu = 0.1$ mm and (D) $\sigma_\mu = 1$ mm.