OPTICAL WAVE FRONTS

Efficient Mode Conversion of Laser Beams

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In recent years, the formation of laser beams with specific intensity and phase distributions has attracted considerable attention. The formation of such laser beams has been efficiently achieved by various intracavity mode selection techniques[1] or by external conversion of a given laser beam distribution into the desired one.

Recently Machavariani *et al.* presented a new method for efficiently converting a Gaussian beam into a helical Laguerre-Gaussian beam.[2] This could be of particular importance in applications such as optical-fiber communication systems, newly developed high-power fiber lasers or optical tweezers, for which high-order helical modes would be advantageous. The method is based on the use of a pair of axicons to produce a doughnut intensity distribution that is then passed through a spiral phase element [Fig. 1(a)]. It was shown that the conversion efficiency can be as high as ~98%, with far-field intensity distributions of the output beams close to the corresponding pure Laguerre-Gaussian intensity distributions.

Operating a given laser in a single high-order mode results in higher output power with regard to the fundamental TEM_{00} mode, but the beam quality (M^2) deteriorates. The beam quality of a single high-order mode beam can be further improved by its efficient transformation into a nearly Gaussian beam.[1] Such a transformation can be performed, in principle, by means of two specially designed external phase elements,[3] but it is rather difficult to design and fabricate such elements. In a recent publication, we demonstrated a relatively simple method for the efficient conversion of a high-order Hermite-Gaussian TEM_{10} laser beam into a nearly Gaussian beam.[4] The method is based on dividing the mode into equal parts that are then combined coherently [Fig. 1(b)]. A phase-tuning plate is inserted into the path of one of the beams to adjust the phase between them by a slight tilting of the plate. The calculated M_x^2 of the output beam is 1.045 (compared with a value of 3 for the initial TEM_{10} mode), with a calculated conversion efficiency of 98.5%. The method was verified experimentally with a cw Nd:YAG TEM_{10} laser beam, with results close to what had been predicted.

Moreover, we recently realized this method in a rather compact and easy manner using a single interferometric element [Fig 1(c)].[5] The element is composed of a high-precision plane-parallel plate, with specially designed coatings. Half of the front surface was coated with an antireflection coating, the other half with a 50% beam-splitter coating, and the rear surface was coated with a highly reflective coating. When the beam enters the element, the beam is split into two parts that are subsequently coherently combined when they exit the element. The thickness of the element is designed to obtain optimal overlap between the two parts, and one can adjust the relative phase by tuning the angle of the element. Using this element with a TEM_{10} Nd:YAG laser beam, we obtained a nearly Gaussian beam with ~90% conversion efficiency. In principle, this method of dividing the beam into several parts and then coherently recombining them can easily be extended to other high-order modes.

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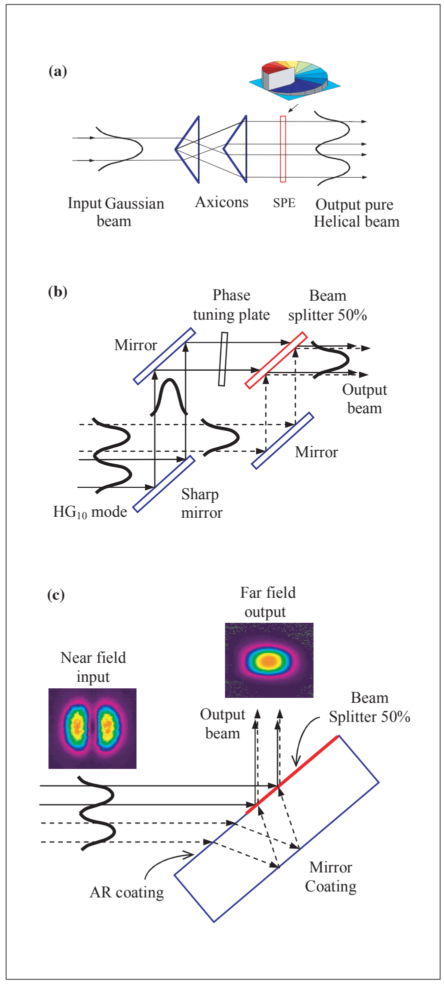

Figure 1. Laser beam conversion configurations: (a) conversion of a Gaussian beam into a helical Laguerre-Gaussian beam by use of two axicons and a spiral phase element; (b) conversion of a high-order Hermite-Gaussian TEM_{10} laser beam into a nearly Gaussian beam by use of three mirrors, a 50% beam splitter, and a phase-tuning plate; (c) conversion of a high-order Hermite-Gaussian TEM_{10} laser beam into a nearly Gaussian beam by use of a single interferometric element.

Electromagnetic Field Distribution Measurements In the Soft-X-Ray Range: Full Characterization of a Soft-X-Ray Laser Beam

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The development of tabletop coherent soft-x-ray sources opens a wide field of applications in several disciplines by use of techniques such as interferometry, phase contrast imaging and microscopy. Surprisingly, despite its key role in applications, the wave front of these sources has not been measured. With this objective in mind, we developed and used, for the first time to our knowledge, a wave-front sensor for the soft-x-ray wavelength range for complete characterization of the electromagnetic field distribution in a soft-x-ray laser beam.[1] This sensor is based on the Shack-Hartmann concept and is composed of 20 × 20 diffraction Fresnel lenses etched on and overcoated with a reflective multilayer (Bragg-Fresnel lenses). This design avoids optical aberrations and overcomes the limitations imposed by the strong absorption of all materials in this spectral range. The estimated peak-to-valley wave-front resolution is λ/20 at 13 nm and the dynamic range is 8λ per subaperture. The wave front of the neonlike Ar soft-x-ray laser (λ = 46.9 nm)[Ref. 2] was fully characterized in a single shot with an estimated resolution of λ/100. Figure 1 shows the experimental setup used for the measurements. The wave-front characteristics of the capillary discharge soft-x-ray laser were observed to be dependent on the discharge pressure and on the capillary length as a result of beam refraction variations in the capillary plasma. The results show a dramatic improvement of the soft-x-ray laser beam wave front with increased capillary plasma column length, leading to an improvement of the focal spot. Figure 2 illustrates the results that we obtained by operating the discharge pump at a pressure of 420 mTorr, which is near the optimum for maximum amplification. The measurements show that, for a 34-cm capillary, approximately 70% of the soft-x-ray laser beam energy could be focused into an area approximately four times the size of the diffraction-limited spot and reach intensities of ~ 4 × 10^{13} W/cm^2. The achievement of such high intensity in the soft-x-ray wavelength range with a tabletop device opens the possibility of new applications. Development of this soft-x-ray wave-front sensor will be beneficial for use in the soft-x-ray range of many techniques for which adaptive optics, closed-loop optical system alignment or beam optimization are now used.

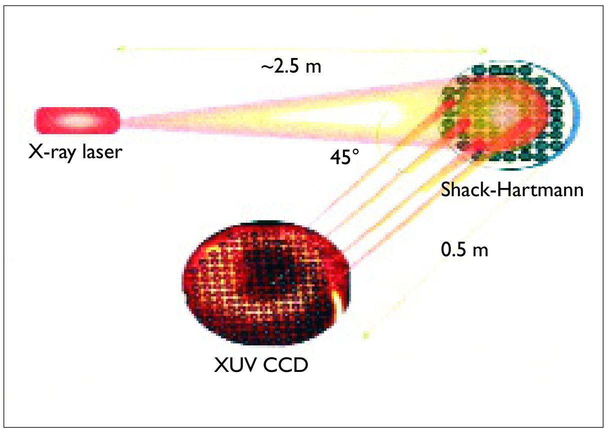

Figure 1. Schematic representation of the experimental setup that we used to measure the wave front of a 46.9-nm capillary discharge soft-x-ray laser showing the lens array and a measured image of the focal spots.

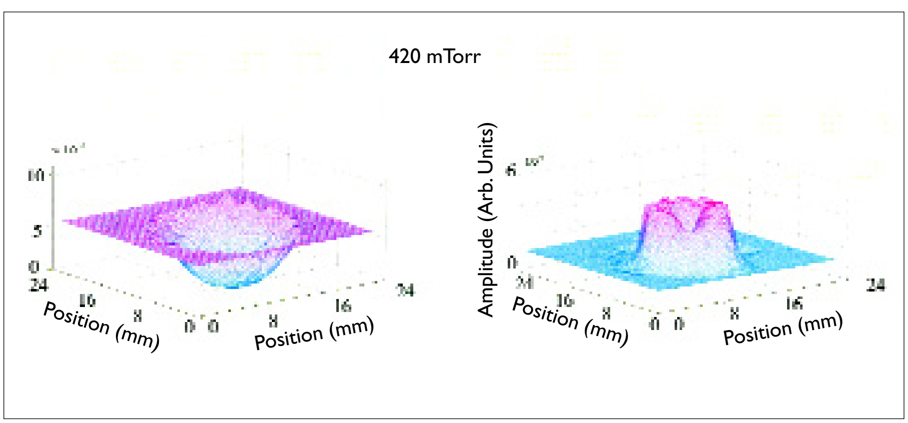

Figure 2. (a) Measured wave-front shape and (b) corresponding intensity distribution for the laser beam produced when we operated the discharge at an argon pressure of 420 mTorr. The radius of curvature of the wave front is 6.5 m. The annular shape of the beam is due to the refraction of the laser beam as it travels through the capillary plasma.

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