Wavefront measurement of double-clad pulsed ytterbium fiber laser

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Because of high efficiencies, compact structure, and excellent heat dissipation, high-power fiber lasers are extremely useful for applications such as cutting, welding, precision drilling, trimming, sensing, optical transmitter, material processing, micromachining, and so on. However, the wavefront of the double clad fiber laser doped with ytterbium is still unknown. In this paper, wavefront of a fiber laser is measured and the traditional Hartmann-shack wavefront sensing method is adopted. We measured a double clad fiber laser doped with ytterbium which produces pulse wave output at infrared wavelength. The wavefront shape and contour are reconstructed and the result shows that wavefront is slightly focused and not an ideal plane wavefront. Wavefront measurement of fiber laser will be useful to improving the lasers' performance and developing the coherent technique for its applications.

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Because of high efficiencies, compact structure, and excellent heat dissipation, high-power fiber lasers are extremely useful for applications such as cutting[1], welding, precision drilling, trimming, sensing, optical transmitter, material processing, micromachining and so on. Currently, fiber laser development appears to fall into three directions: high-power continuous-wave (CW)[2], pulsed[3] and ultrafast sources[4]. Though fiber lasers use various optical fibers as their lasing and delivering medium, by use of double-clad gain fiber, fiber lasers doped with ytterbium are capable of generating higher powers than other fiber lasers and the potential of short-pulse Yb fiber lasers is very large, the double-clad ytterbium fiber lasers have attracted much attention[5]. However, the wavefront of the double clad fiber laser doped with ytterbium is still unknown.

As to wavefront sensing technology, there are various methods, such as slope wavefront sensing technology[6], curvature wavefront sensing technology[7] and intensity sensing technology[8]. Currently, Hartmann-shack wavefront sensor, curvature sensors, and other wave-front sensors (shearing interferometer[9] and pyramid wavefront sensor[10]) are widely used. Among these methods, Hartmann-shack wavefront sensor is a low-cost and high-precision wavefront sensor and thoroughly studied.

In this paper, wavefront of a double-clad fiber laser, which is developed by the Novel Laser Technique and Application System Laboratory of SIOM, is measured for the first time to our knowledge, and the traditional Hartmann-shack wavefront sensing method is adopted. We measured a double clad fiber laser doped with ytterbium which produces pulse wave output at infrared wavelength. The wavefront shape and contour are reconstructed and the result shows that wavefront is slightly focused. Wavefront measurement of a double-clad fiber laser will be useful to improving the lasers' performance and developing the coherent technique for its applications.

The principle diagram of Hartmann-shack wavefront sensing technology is shown in Fig. 1. When plane wavefront is focused through lenslet, the spot of image is located at the optical axis of each sub-aperture. However, when distorted wavefront is focused, the spot of image is displaced from the optical axis. The displacement of the image centroid can be estimated from[6]

$$x = \frac{\Sigma_{i,j} x_{i,j} I_{i,j}}{\Sigma_{i,j} I_{i,j}}, \tag{1}$$

$$y = \frac{\Sigma_{i,j} y_{i,j} I_{i,j}}{\Sigma_{i,j} I_{i,j}}, \tag{2}$$

By use of Eqs. (1) and (2), the slopes x, y can be calculated as

$$g^x_{i,j} = \Delta x_{i,j}/f, \tag{3}$$

$$g^y_{i,j} = \Delta y_{i,j}/f. \tag{4}$$

Adopted the Southwell model, the average phase in every sub-aperture is depended on the slope of phase point adjacent to the object phase point as[6]

$$\frac{1}{2}(g^x_{i,j+1} + g^x_{i,j}) = \frac{1}{h}(\phi_{i,j+1} - \phi_{i,j}), \quad i = 1\text{—}N,\ j = 1\text{—}(N-1); \tag{5}$$

$$\frac{1}{2}(g^y_{i+1,j} + g^y_{i,j}) = \frac{1}{h}(\phi_{i+1,j} - \phi_{i,j}), \quad i = 1\text{—}(N-1),\ j = 1\text{—}N; \tag{6}$$

$$\frac{1}{2}(g^x_{i,j} + g^x_{i,j-1}) = \frac{1}{h}(\phi_{i,j} - \phi_{i,j-1}), \quad i = 1\text{—}N,\ j = 1\text{—}N; \tag{7}$$

$$\frac{1}{2}(g^y_{i,j} + g^y_{i-1,j}) = \frac{1}{h}(\phi_{i,j} - \phi_{i-1,j}), \quad i = 1\text{—}N,\ j = 1\text{—}N, \tag{8}$$

where h is the width of the sub-aperture and N is the phase point number. Finally, according to Eqs. (5)–(8), phase of each point can be obtained accurately by use of matrix algorithm or iterative algorithm.

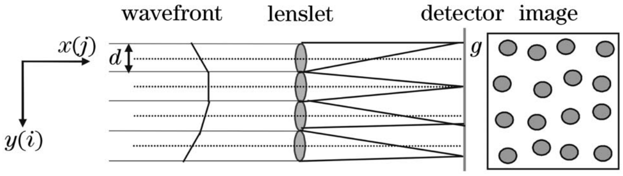

Fig. 1. The principle diagram of Hartmann-shack wavefront sensing technology.

The schematic of the experimental setup is shown in Fig. 2. According to Fig. 2, there are a lenslet array, a charge-coupled device (CCD) camera, and a PC. The input light source is extended and then focused by a series of sub-apertures, the spot array is detected by a CCD and analyzed by using a computer. The double-clad pulsed ytterbium fiber laser in this paper generates 33-ns pulses at repetition rates between 20 kHz and 100 MHz and produces 10.3 W of average power and peak powers in excess of 15 kW at repetition rates over 20 kHz. With the iterative algorithm, the reconstructed wavefront shape and contour are shown in Figs. 3 and 4, respectively.

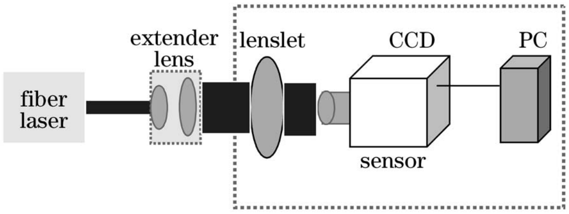

Fig. 2. Schematic of the experimental setup.

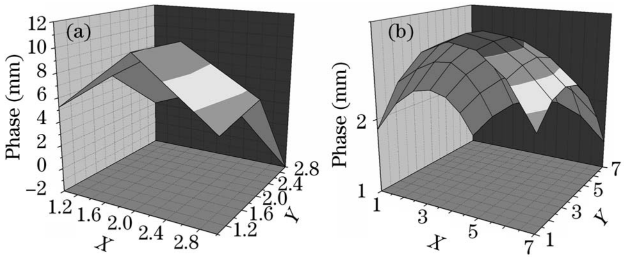

Fig. 3. Wavefront shape of the reconstructed result. (a) Before expansion; (b) after expansion.

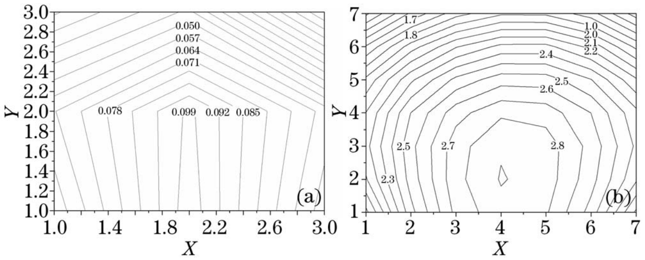

Fig. 4. Contour of the reconstructed result. (a) Before expansion; (b) after expansion.

According to Figs. 3 and 4, it is not difficult to see that the wavefront shape of this double-clad fiber laser beam is slightly focused and not an ideal plane wave. Moreover, the beam after expansion is badly distorted. Before expansion, the difference between the maximum and minimum phase points is 50 μm or so in the central region. After expansion, the difference exceeds 1000 μm. In conclusion, wavefront measurement of this fiber laser is useful to improve the beam equality for increasing the intensity for coherent applications.

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