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طراحی سیستم تغییردهنده پروفایل باریکه لیزر به منظور ایجاد پروفایل تخت برای استفاده در سامانه دمش لیزر دیسک

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یکی از تأثیرگذارترین پارامترها در عملکرد لیزرهای دیسک، پروفایل دمش آن‌ها بوده که توزیع دمایی درون دیسک را ایجاد می‌کند. به دلیل وابستگی ضریب شکست به دما و همچنین انبساط گرمایی، جبهه‌موج لیزر متناسب با توزیع دمایی درون دیسک تغییر می‌کند. هرچه پروفایل دمش، تخت‌تر باشد یا از لحاظ ریاضی ضریب سوپرگوسین پروفایل دمش بزرگ‌تر باشد، توزیع دمایی یکنواخت‌تر و در نتیجه تغییرات جبهه‌موج لیزر کمتر می‌گردد. در این مقاله یک سیستم اپتیکی شکستی شبیه‌سازی و طراحی شده است که پروفایل دایروی با قطر لکه ۱۲٫۴۸ میلی‌متر با ضریب سوپرگوسین ۱۶٫۴ بر روی دیسک تشکیل می‌دهد. همچنین سیستم به صورت تجربی تحت آزمایش قرار گرفت که نتایج آن تطبیق قابل قبولی با نتایج شبیه‌سازی داشته و قطر لکه ۱۲٫۴۲ میلی‌متر با ضریب سوپرگوسین ۱۸٫۶ به‌دست آمد.

کلید واژه– شکل‌دهنده پروفایل باریکه، پروفایل تخت، دمش لیزر دیسک

Design of refractive laser beam shaper to produce flat-top profile irradiance in order to use in pumping system of thin disk lasers

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Abstract- One of the most prominent parameters in thin disk lasers' performance is their pump profile making temperature gradient in disk. This phenomenon is able to distort laser's wavefront, especially in high power operation, by two physical properties of disk including temperature-dependent refractive index and thermal expansion. It is clear that as the pump profile uniformity (super-Gaussian coefficient) increases, the amount of temperature gradient and wavefront distortion will proportionally reduce. In this paper, a refractive laser beam shaper has been simulated and designed in order to generate a circular flat-top profile on disk surface with 12.48 mm diameter and super-Gaussian coefficient of 16.4. The system has been, also, experimented practically that its results were similar to numerical ones, the spot diameter and super-Gaussian coefficient were 12.42 mm and 18.6, respectively.

Keywords: Beam shaper, Flat-top profile, Pumping system of thin disk laser

1. Introduction

Laser beam shaping is widely used in industrial laser material processing technologies, medical applications and even pumping system of high power solid state lasers like thin disk lasers [2]. In most cases, a laser beam with a Gaussian irradiance profile is reshaped to have a uniform output profile, usually called a flat-top profile [1]. From mathematical point of view, the flat-top profile is a super-Gaussian distribution in which higher order super-Gaussian coefficient produces more uniform profile.

There are various proposed techniques for laser beam shaping. The simplest one is either to truncate an expanded Gaussian beam or to use an apodized absorption filter. Such a technique allows to generate uniform intensity patterns but is rather energy-inefficient [1]. Typical energy-efficient approaches include diffractive elements, holograms, microlens arrays and refractive or reflective systems [2]. Among these techniques, refractive laser beam shapers, which are used ray mapping method, are commonly used due to their high optical efficiency and simple structure [1].

Because disk temperature distribution is proportional to pump profile, it plays an important role in beam quality of thin disk lasers [3]. More exactly, some part of absorbed pump light converts to heat and increases the temperature of disk locally. On the other hand, due to the facts that dependence of refractive index to temperature and thermal expansion, temperature gradient is able to destroy laser beam’s wavefront and quality. Therefore, in order to reduce the negative impacts of temperature gradient, generating a super-Gaussian irradiance with higher order coefficient is crucial [3].

In this article, a refractive beam shaper has designed which is able to transform a collimated semi-Gaussian irradiance of fiber coupled diode laser disk into a collimated super-Gaussian profile. This structure, also, has placed in pumping system of thin disk laser including parabolic and folding mirrors in order to make multiple image of the generated flat-top profile on disk. Finally, a circular flat-top profile with 12.42 mm diameter and super-Gaussian coefficient of 18.6 has been made on disk surface after 16 passes.

2. Design Method

The overall design of this work is constituted of two parts. The first one is a refractive flat-top beam shaper which produces a collimated flat-top irradiance. The second one is imaging part that makes image of flat-top profile on disk surface.

The typical refractive flat-top beam shaper, which aims at converting a Gaussian profile to flat-top ones, should be consist either two plano-aspheric lenses or one single thick lens with two aspherical surfaces [1]. The first aspherical surface redistributes the beam irradiance while the second aspherical surface recollimates the beam. However, because the profile of our source is not completely Gaussian (actually, it is semi-Gaussian with 23.7 mm diameter and 0.42° divergence), we can reach to flat-top profile only by one aspherical surface and a spherical lens. The general optical design approach of such refractive beam shapers is based on ray mapping within the framework of geometric optics. This method is clearly illustrated in [1] with details. By using this method in commercial optical design software, Zemax 2013, we can design an appropriate telescopic flat-top beam shaper. The properties of spherical and aspherical lenses are mentioned in table I and table II, respectively.

An efficient, well-known pumping mechanism in thin disk lasers was introduced in 1999 by Erhard et.al [4]. In this method, an image of appropriate pump irradiance is made on the disk surface by using imaging part which includes some lenses and a parabolic mirror (Fig.1)

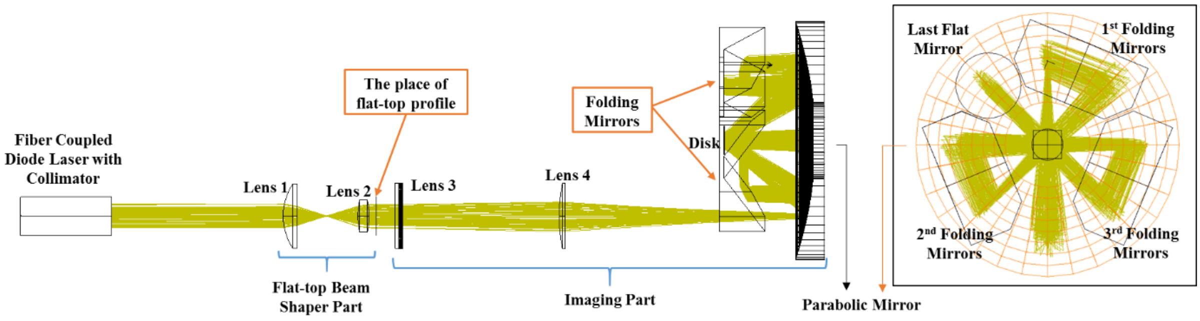

Figure 1. Left picture shows the schematic of the designed optical system, and the right one illustrates the configuration of folding mirrors.

Table I. Properties of spherical lenses. All of them are made of fused silica.

Number of Lens	Type	Radius of Curvature (mm)	Thickness (mm)
2	Spherical (bi-convex)	38.1	12.5
3	Cylindrical (plano-convex)	76.3	8
4	Spherical (plano-convex)	92	6.6

Table II. Properties of aspherical elements. Lens 1 was made of S-LAH64.

<table>
<tr><th>Element Name</th><th colspan="2">Type</th><th colspan="2">Radius of Curvature (mm)</th><th>Thickness (mm)</th><th>Conic Constant</th></tr>
<tr><td>Lens 2</td><td colspan="2">Plano-convex</td><td colspan="2">31.075</td><td>15.5</td><td>-0.744</td></tr>
<tr><td>Parabolic Mirror</td><td colspan="2">Mirror</td><td colspan="2">200</td><td>-</td><td>-1</td></tr>
<tr><th colspan="7">Aspheric Coefficient of Lens 2</th></tr>
<tr><td>A_4</td><td>A_6</td><td>A_8</td><td>A_{10}</td><td>A_{12}</td><td>A_{14}</td><td>A_{16}</td></tr>
<tr><td>4.4×10^{-7}</td><td>-2.3×10^{-10}</td><td>-1.7×10^{-13}</td><td>-3.7×10^{-17}</td><td>8.9×10^{-21}</td><td>1.8×10^{-23}</td><td>-6.3×10^{-27}</td></tr>
</table>

The incident light is focused by parabolic mirror on its focal plane, where the disk is placed. After passing the light through the disk, some percent of its power is absorbed and the residual light is reflected toward other part of parabolic mirror by a high-reflection coating on the backside of disk. Then, the parabola makes the light collimated and send it toward first folding mirror. Their duty is returning light to parabola and disk again. By this method, the number of pump light's pass through the disk is increased to enhance the absorption efficiency. There are two other folding mirrors which operate like the first one. At the end of beam's pass, a flat mirror is placed to reverse the beam's direction for doubling the total number of pump beam's pass. The pump light, finally, passes 16 times through the disk by this system. There are some technical points about imaging part. Firstly, the spot size on disk surface is specified by the parameters of lenses located before parabola. Secondly, due to the fact that the parabola is not positioned in the same axis with entrance light, so the magnification of system in Y direction is higher than X ones [5]. Therefore, a cylindrical lens, which converges light in X direction, is executed to equalize the magnification of both directions. The parameters of imaging elements are written in table I and table II.

3. Results

3.1. Numerical

Firstly, an appropriate irradiance was obtained at the flat-top place (as shown in Fig.2). Next, we should make an image of this profile on disk surface by using the imaging part of optical setup shown in Fig.1. The results for both cases in which pump light passes through the disk for once and 16 times are shown in Fig.3a, b. In case of sixteen-pass, the spot diameter, which was measured via second order intensity moments, equals to 12.48 mm. Also, coefficient of super-Gaussian function was obtained by fitting intensity distribution into a one-dimensional super-Gaussian equation (Eq.1) for x and y direction separately. Then, the average of them became 16.4.

$$y = y_0 + a \times \exp[-0.5 \times |(x - x_0)/b|^c] \quad (1)$$

where y and x equal to intensity and position, x_0 and y_0 are distance of coordinate origin and ambient intensity, respectively. While *a* and *b* correspond to slope and radius of profile, *c* is the super-Gaussian coefficient.

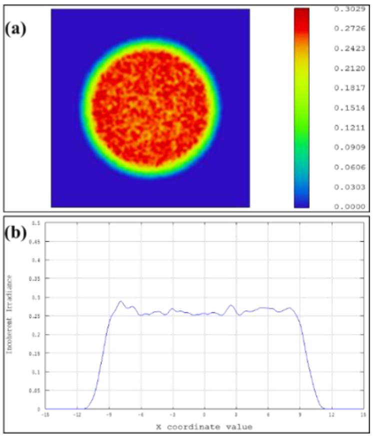

Figure 2. Irradiance distribution at flat-top position: a) two dimensional, b) cross section row (X coordinate)

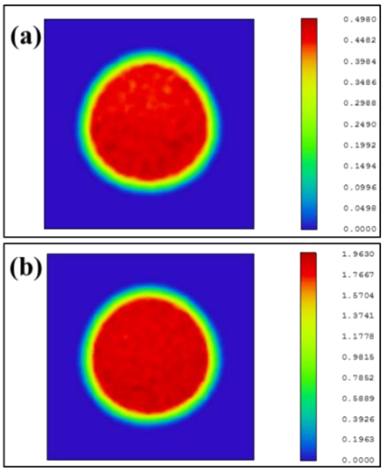

Figure 3. Numerical profile of pump beam on disk surface in both cases of one-pass (a) and sixteen-pass (b)

3.2. Experimental

After finding the most appropriate design for our goal, it was experimented practically. The flat-top pump profile was measured by a commercial Profile meter. The spot diagram and super-Gaussian coefficient of sixteen-pass profile were calculated via the manner mentioned in previous section. The results were in the proper agreement with numerical once. The experimental spot diameter and super-Gaussian coefficient were obtained 12.42 mm and 18.6. Fig.4 shows the profile of pump laser beam in both cases of one-pass and sixteen-pass.

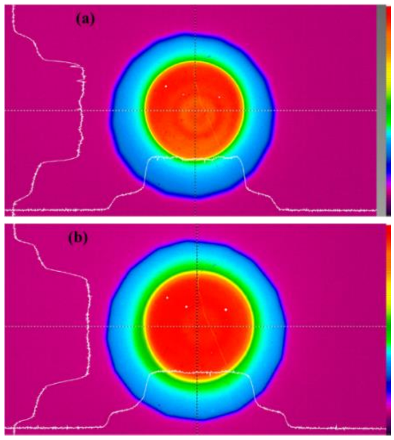

Figure 4. Experimental profile of pump beam on disk surface in both cases of one-pass (a) and sixteen-pass (b)

Conclusion

Fiber coupled diode lasers with non-uniform irradiance are mostly executed as pump light of disk lasers. Hence, it is needed to reshape the profile of them. Here, a ray mapping based beam shaper, which is a powerful energy-efficient has been designed and experimentally tested, which provides a 12.42 mm-diameter flat-top profile with super-Gaussian coefficient of 18.6 on disk surface.

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