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Advanced beam shaping for high power cutting and welding

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Abstract

Beam shaping of light from high power fiber lasers to improve cutting or welding performance can be challenging, due to (i) high power density; (ii) short length optical train; (iii) uniformity of the shaped beam over the tolerance range of the application. We present novel approaches to the design and manufacture of high efficiency beam shaping elements for multi-mode and single-mode fiber lasers. Beam structures that are emerging as important for industrial processing – such as rings – are considered. Importantly, these designs can be manufactured with sufficient low loss and low scatter by a laser-writing freeform optical manufacturing technique.

Keywords: beamshaping; freeform

1. Introduction

PowerPhotonic uses unique laser-based optical fabrication process to produce freeform structures that are directly written in fused silica substrates. The process does not require masks or molds. Fabrication process consists of two stages. The first stage of the process uses a pulsed laser system to create the desired surface profile, superimposed with a tooling pattern due to pulsed ablation of material. In the second stage of the process the surface is laser polished by reflowing the fused silica to remove the tooling pattern while preserving the desired freeform surface profile.

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1.1. Optically smooth surfaces for high power laser applications

PowerPhotonic’s laser smoothing process produces extremely low surface roughness of Rq ~1nm (at cut-off wavelength of profile filter 0.08mm).The laser-smoothed surfaces produce very low scatter that enables high transmission efficiency reaching >99.8% for AR coated optics. The same process also maintains the high laser induced damage threshold (LIDT) of bulk fused silica by removing defects and microcracks that lead to surface damage when used with high power laser sources. In tests at 1070nm we have demonstrated CW LIDT of >100kW/cm for AR-coated surfaces at 1070nm and 20ns pulsed LIDT of >5GW/cm2 or >100J/cm2 for uncoated surfaces. This combination of high LIDT, low surface roughness and freeform design freedom is ideal for fabricating beam shaping optics for high power applications.

1.2. Flexibility in design and manufacture of beam shaper for high power laser applications

As the direct writing process produces optical surfaces that are not constrained by translational or rotational symmetry, it offers design freedom to address a wide range of beam shaping requirements. Depending on targeted laser application, the spot shape, uniformity, or power in the bucket can be optimized for the best performance. Power distribution between the central lobe and outer circle in a trident spot (Fig. 1a) can be optimized for precession welding or additive manufacturing. Inverted Gaussian or annular profiles (Fig. 1b and c) can provide significant improvements to stable process windows and produce higher surface quality finish in laser welding (Rasch et al. 2019). In addition, annular profiles are beneficial for laser cutting of thick (> 6 mm) steel, by providing a larger kerf size without compromising edge intensity (Pang et al. 2020). Controlled distribution of power between the central lobe and a surrounding a pedestal (Fig. 1d) can reduce spatter in mild/stainless steel or copper welding applications (Punzel et al. 2020).

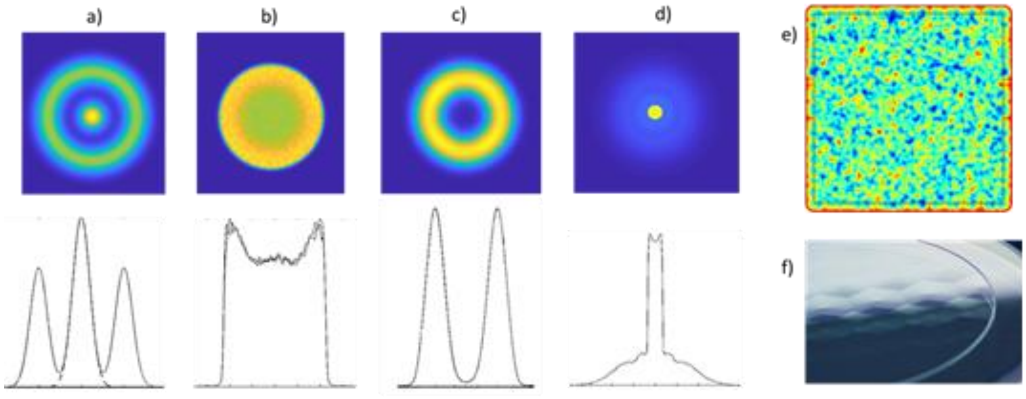

Fig. 1. Example spot shapes generated with refractive beam shapers (a) trident, (b) inverted Gaussian, (c) ring with high extinction level, (d) central lobe surrounded by intensity pedestal. Example of surface types (e) pseudo-random surface design, (f) axicon array.

2. Pseudorandom axicon array homogenizer

Axicon array homogenizers (Fig. 2(a)) can be used to produce a ring-shaped far field profile. Unlike traditional single axicons, axicon arrays are highly insensitive to input intensity distribution and positioning within the beam. Typically, the axicons are laid out in a hexagonal array to maximize the uniformity of the intensity distribution around the ring, but the light hitting the corners of each cell still adds to hot spots in the ring of the output intensity distribution. An example far-field intensity distribution produced by an axicon array is presented in Fig. 2(b), showing both, the azimuthal nonuniformity and a typical zeroth order spike.

PowerPhotonic's truly freeform design and manufacturing capability enables modifying the axicon array by adding a pseudo-random structure to the surface of the array. This is referred to as axicon-PRIME (Pseudorandom Refractive Intensity Mapping Element) with an example surface design shown in Fig. 2(c). The angular content of the additional structure is engineered using an iterative Fourier Transform (IFT) approach (Dixit et al. 1996), similar to that used to design diffractive optical elements, but without discretization of phase. By applying this algorithm to the axicon array, small adjustments to the sag profile are made that redistribute the annular intensity to produce a uniform ring with no zeroth order spike, as shown in Fig. 2(d). The resultant refractive optic maps intensity subsegments of the input beam over the whole of the output beam.

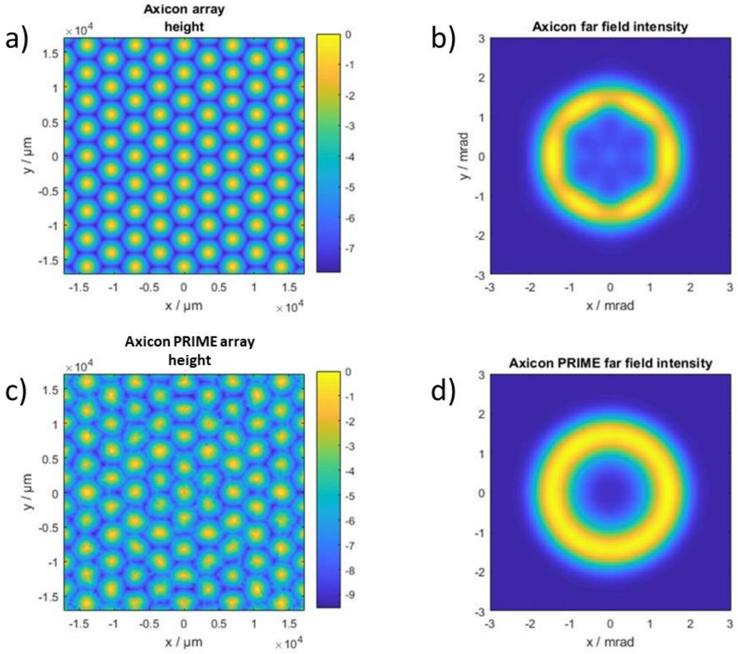

Fig. 2. Axicon array and pseudo-random axicon array with corresponding predicted far field intensity distributions. (a) axicon array on hexagonal grid, (b) far field distribution produced with axicon array on hexagonal grid, (c) axicon PRIME array, (d) far field distribution produced with axicon PRIME array.

3. Spiral surface ring generator

Axicon array homogenizers provide a uniform ring at the focal plane of a lens but the through focus propagation shows beam break up according to the shape of lens array sub aperture. In applications that require an annular beam through focus, such as laser cutting, this may not be the optimum solution. For this reason, a spiral surface ring generator has been developed. This surface, as shown in Fig. 3, is designed to generate a uniform ring around the focal plane of a lens.

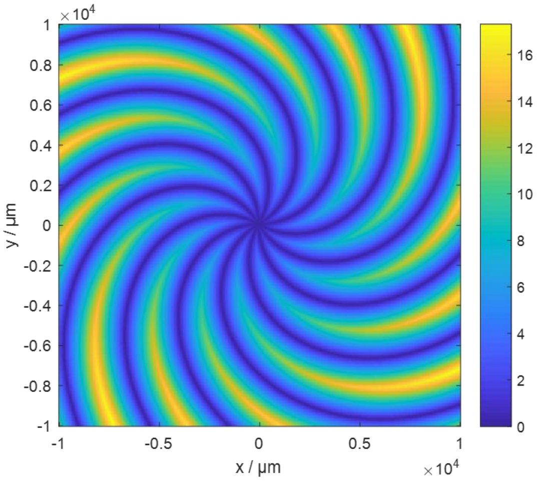

Fig. 3. False color image of a spiral surface ring generator, z values are sag in µm.

An example of the through focus pattern generated by one such beamshaper is shown in Fig. 4. If we consider the spot at the focal plane (150mm) we see a uniform and continuous annulus. The beamshaper works by dividing the input beam into sections, each section on the optic has the same absolute surface slope corresponding to the radius of the ring, the direction of the slope varies as a function of distance from the centre of the optic. This variation of slope direction has the effect of creating a small arc for each arm on the beamshaper, where the variation of slope direction is chosen correctly these arcs are joined to form a continuous annulus at focus. Depending on the input beam and the required depth of focus the number of arms and variation in direction of slope can be optimized to meet specific requirements.

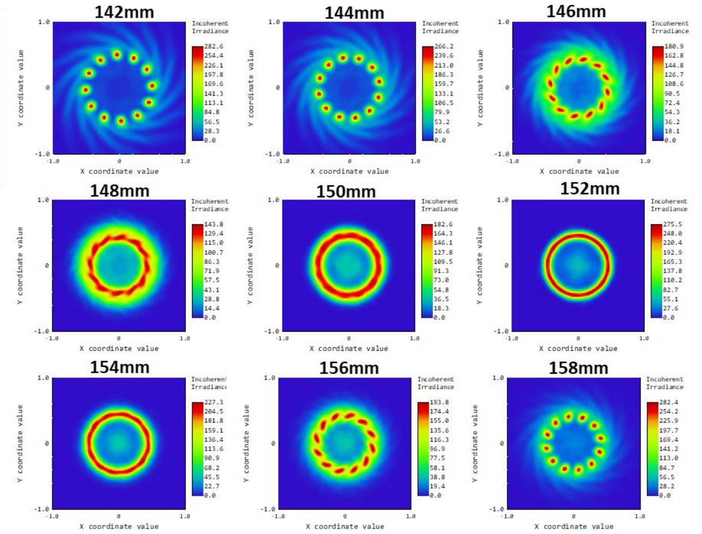

Fig. 4. Simulated spots at through focus of a 150 mm lens when using a spiral surface ring generator.

4. Conclusions

Laser-written and polished refractive elements with freeform optical surfaces offer a wide range of possible beam shapes and control over achieved intensity distribution. In particular, freeform surfaces producing annular focal images have been presented, with advantages in uniform output distributions, alignment insensitivity, and through focus propagation. Such components are suitable for high power laser application as high LIDT and high system efficiency is possible.

References

Dixit, S. N., Perry, M. D., Powerll, H. T., 1996. Designing fully continuous phase screens for tailoring focal-plane irradiance profiles, Optics Letters 21, p 1715 - 1717

Pang, H., Haecker, T., 2020. Laser cutting with annular intensity distribution, Procedia CIRP 94, p. 481-486

Punzel, E. Hugger, F., Dorringer, R., Dinkelbach, T. L., Burger, A., 2020. Comparison of different system technologies for continuous-wave laser beam welding of copper, Procedia CIRP 94, p. 587-591

Rasch, M., Roider, C., Kohl, S., Strauss, J., Maurer, N., Nagulin, K. Y., Schmidt, M., 2019. Shaped laser beam profiles for heat conduction welding of aluminium-copper alloys, Optics and Lasers in Engineering 115, p. 179-189.