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Laser processing by using fluidic laser beam shaper

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ABSTRACT

Laser beam shaping techniques are important to optimize a large number of laser material processing applications and laser-material interaction studies. The authors have developed a novel Fluidic Laser Beam Shaper (FLBS) with merits such as flexibility, versatility and low cost. This work presents a fundamentally new approach for laser beam shaping by using FLBS. A Gaussian beam profile is transformed to a flat top beam and an annular beam profile in the focal plane. The shaped laser beam is used for laser drilling to investigate the influence of the laser intensity profile in laser processing. The paper concludes with suggestions for future research and potential applications for further the work.

1. Introduction

Laser machining (drilling, cutting, carving, etc.) has been recognized to be a useful and competitive method of material processing especially for hard materials, curved surfaces and hard to access places. The most frequently employed lasers for material processing are CO_2, Nd:YAG and excimer lasers. These lasers have provided the microelectronics and automotive sector in particular, with an effective tool for producing high quality micro-holes. However, in the case of long pulsed lasers, it is well known that laser micromachining can be quite complicated by collateral thermal effect such as melt, recast and heat affect zone (HAZ) [1–3]. Important factors in the laser processing of materials include energy, fluence, spot size, wavelength, polarization, pulse duration and repetition rate [1–3]. The role of these parameters has been widely studied, both experimentally and theoretically [1–3]. However, most of the previous work has been done with Gaussian beam, which has a Gaussian transverse intensity profile with the spot area limited by a beam diameter (FW1/e^2M) contains only 86.5% of the laser beam power and intensity at the boundary is only 13.5% of the peak intensity. It means that, the energy in wings is lost or can even cause damage of surrounding material as well as a high-intensity central peak. Therefore, non-Gaussian beam should be able to give us more choice to determine the optimum processing conditions.

Although, non-conventional beam shapes have an advantage in which they can be explicitly designed to meet the requirements of a given material configuration or application, studies on the influence of the laser intensity profile in laser processing is still limited [4–8]. One reason is that it is difficult to control the beam shaping process. Current beam shaping technique require complex designs of optical systems which are very expensive. Most previous works are more concentrated in laser shaping techniques and still lack detailed discussion of thermal effect on processed product.

The authors have developed a novel FLBS with some merits as flexible, versatile and low cost [9,10]. This work presents a fundamentally new fabrication approach for laser beam shaping by using FLBS with long pulse (microsecond pulse). The Gaussian beam was transformed to a flat-top and annular beam. The shaped laser beam was applied for laser drilling to investigate the influence of the laser intensity profile in laser hole qualities such as: geometric features and HAZ.

2. Shaping of the processing laser beam

Fig. 1 shows the schematic of the experimental set up for shaping the Gaussian beam by using a single beam thermal lens system. Detail of laser beam shaping process was discussed in previous work [9]. A fiber laser (JenLas® fiber) is used as pump/processing laser (P_{max} = 100 W, λ = 1070 nm, Φ = 5.0 mm, TEM00). Laser is operated at pulse mode with pulse width of 30 µs and repetition rate of 10 kHz. The cuvette is a three-layer structure with a sheet copper sandwiched between two pieces of fused silica. The thick-

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Nomenclature

D	normalization hole diameter, mm	D_h	hole diameter, mm
D_b	beam diameter, mm	ΔD	normalization discoloration diameter, mm
D_c	discoloration diameter, mm		

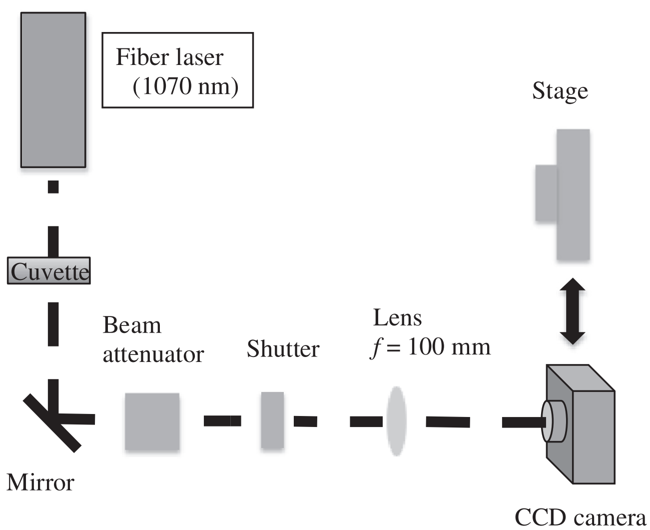

Fig. 1. Schematic illustration of the experimental set up for shaping the Gaussian beam and using it for laser processing.

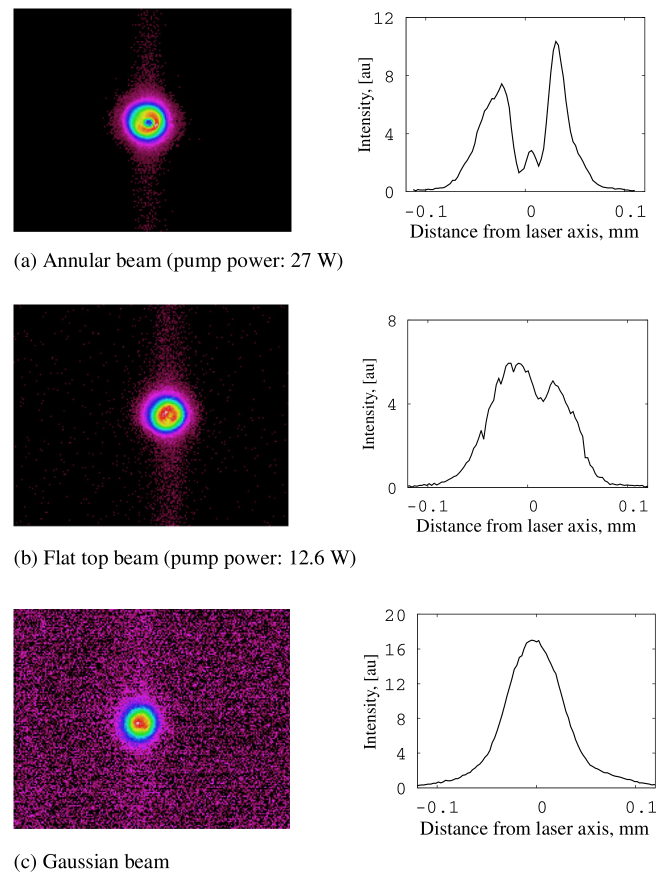

Fig. 2. Transverse beam intensity profile and its cross-section captured by the CCD camera at the difference power of the pump laser.

ness of the fused silica is 1 mm. The sheet copper has annular shape. The liquid that is contained inside the annular hole has the same height with the sheet copper thickness. By changing the thickness of the sheet copper, the liquid height can be changed. The ethanol solution dissolved dye (Sunset-yellow) was filled in the cuvette. In this experiment, the thickness of liquid is 0.3 mm, and the measure absorption coefficient of liquid is 0.05 cm^{-1}. The measurements of beam profile are made with a CCD camera (BeamStar FX 50) using a 4× beam expander with the spatial resolution of 2.5 μm × 2.5 μm.

The fiber laser irradiates the cuvette to form a FLBS. The pump power can be changed by current control. After passing through the cuvette, the power of laser is adjusted again by an external attenuator including a variable beam splitter and a correction plate. Then, the processing laser is directed towards the CCD camera located on the 2D stage position after focusing by a 100 mm focal length convex quartz lens. Details of the experimental parameters for beam shaping process are shown in Table 1.

Table 1
Experimental conditions.

Wave length, nm	1070 ± 10
Pulse width, μs	30
Repetition rate, kHz	10
Pump power, W	1–100
Processing power, W	9
Focal length, mm	100
M^2 value	<1.1
Beam waist, mm	4.5–5.5
Absorption coefficient, cm^{-1}	0.05
Distance from cuvette to lens, mm	435

As shown in the previous work, the intensity profile of the processing laser can be controlled by adjusting some parameters in thermal lens effect such as: the pump power, absorption coefficient and the propagation distance [9]. First, the pump power is fixed at 12.6 W and the CCD camera is scanned along the propagation axis to find the location of the flat top beam. Then, the CCD camera is fixed, and the pump power is increased to 27 W to generate an annular beam. Finally, the cuvette is replaced, and the CCD camera is scanned along propagation axis to find the location again in which Gaussian beam has a same beam waist as the flat top beam and the annular beam. Fig. 2 shows transverse beam intensity profile and its cross-section captured by the CCD camera at the difference power of the pump laser. The left figure shows the beam shape and the right figure shows the intensity distribution. In the right figure, the vertical and horizontal axes show intensity and distance from the laser axis respectively. With increasing pump power, the laser beam profile changes from Gaussian to flat-top and an annular beam profile respectively.