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Dual laser beam revising the separation path technology of laser induced thermal-crack propagation for asymmetric linear cutting glass

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ABSTRACT

Owing to the properties of high-transmittance, wear-resisting and lightweight brittle, glass plays an important role in various electronic equipment screens. The laser induced thermal-crack propagation (LITP) can separate the glass with the advantage of the high-quality, high-efficiency and high-strength. However, the deviation of the separation path (which means the material do not separate in the path of laser scanning) is one of the serious problems in asymmetric linear cutting glass with LITP. In this study, a dual laser beam revision the separation path technology (DLBRP) has been developed for the first time by skillfully arranging two defocused diode pump solid state laser (1064 nm). The principle of DLBRP is expounded. This paper studied several factors's effects on the cutting quality such as Master laser power (P_M), scanning speed (V_M) and laser spot diameter (D_M).The smaller the Master laser spot diameter, the smaller deviation of the separation path. The effects of revision factors including Accompanying laser power (P_A), Accompanying laser spot diameter on the material surface (D_A) and the horizontal relative distance between the Master laser and Accompanying laser (ΔX) were investigated. The optimum processing parameters were presented in this paper. The cambered separation path (which means the material gets separated in the arc way) in asymmetry linear cutting glass (which means the cutting path deviating from the symmetry axis of the material in a large scale, and the area of two separated parts is varied widely) could be revised into the straight one. A numerical simulation on the thermal stress and the dynamic propagation of crack in the DLBRP for asymmetric linear cutting glass with LITP was developed to analyze the revision mechanism, which is corresponding to the theoretical analysis and experimental results. The analysis of experimental results and numerical simulation results shows that the DLBRP technology can effectively revise the deviation of the separation path in asymmetry linear cutting glass with LITP. Besides, the clean surface without any pollution and surface damage can be achieved.

1. Introduction

Glass is a high-transmittance, wear-resisting and lightweight brittle material and has been tremendously applied in various electronic equipment screens. With the wide spread of smart phones, portable devices and flat panel displays, the high-quality, high-efficiency and high-strength cutting of the glass gradually becomes an important engineering problem [1–4].

Nowadays, the traditional mechanical way which depends on physical contact force of the hard metal tool to cut glass is widely used [5–7]. This contact scribing method usually induces many micro-cracks and even small chips on the cutting edge. In the subsequent processing, with the continuous acting force, the micro-cracks could be extended and relevantly, the product quantity could reduce sharply. Therefore, the traditional mechanical method to cut glass is gradually being replaced by non-conventional cutting methods. The LITP is a non-traditional and competitive method to treat the glass, which owes the characteristics of non-contact, high-quality, high-efficiency and high-strength machining.

The LITP cutting brittle materials was firstly proposed by Lumley. The alumina ceramic and glass substrates were processed by a CO_2 laser [8]. The CO_2 laser energy is absorbed by the glass surface. The machining process cannot complete directly, and following subsequent breaking process is required. Koji Yamamoto used the CO_2 laser with elliptical laser spot and water cooling to cut the soda-lime glass, aluminosilicate glass and quartz glass, the influence of the distance between the laser spot and water cooling spot and the thermal expansion coefficient of the material were studied [9]. Tsai added the pre-bending into the process to improve the separation stress and successfully cut the LCD glass with the CO_2 laser [10]. Junke Jiao used a dual-laser-beam method to cut glass substrates, where a focused CO_2 laser beam was used to scribe a straight line on the substrate, and a

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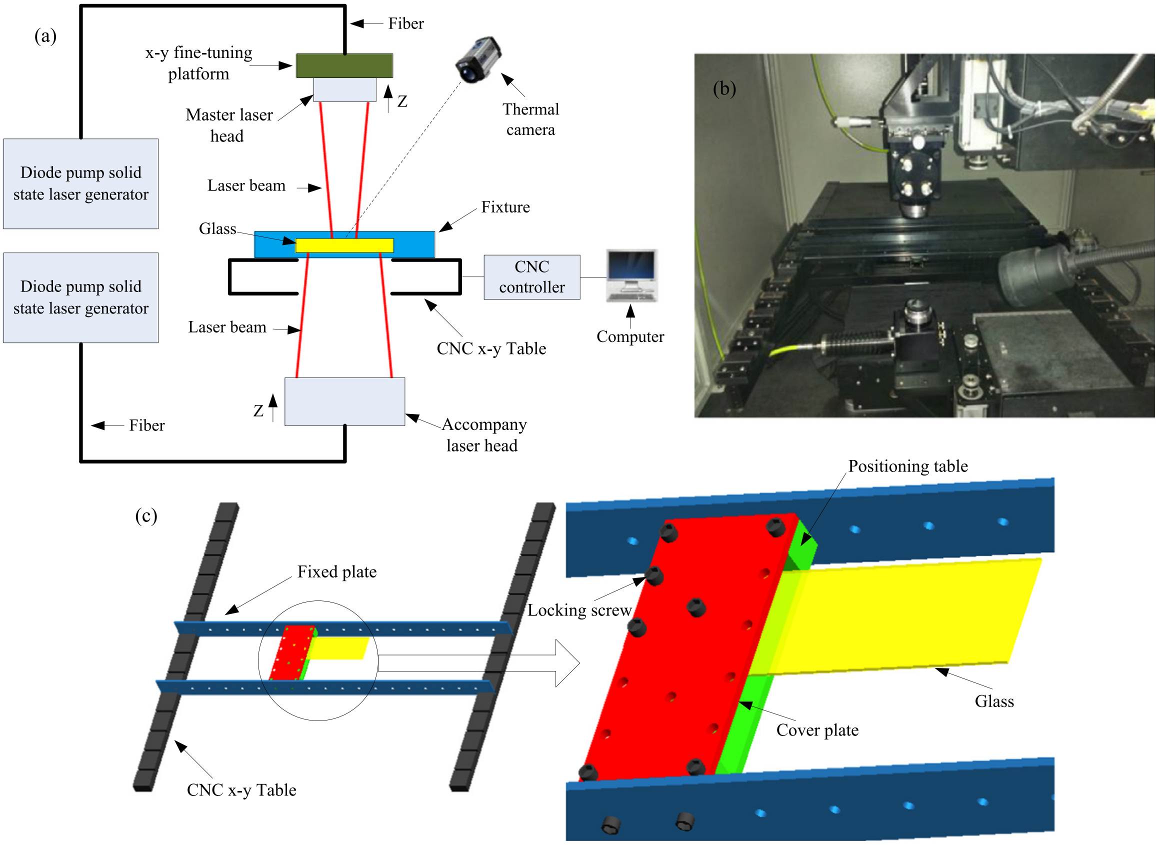

Fig. 1. Experimental apparatus for DLBRP in asymmetry linear cutting glass with LITP. (a) schematic of the experimental apparatus, (b) dual laser beam cutting machine, (c) schematic of the fixture.

Table 1
Diode pump solid state laser specifications.

Working wavelength (nm)	1064
Output mode	Continuous
Output power (W)	0–350
Beam mode	TEM_{00}
Divergence angle (mrad)	≤ 10
Output power stability (RMS)	$< 2\%$

Table 2
Physical properties of soda-lime glass.

Density (kg/m^3)	2480
Specific heat (J/(kg K))	836
Thermal conductivity (W/(m K))	0.8
Expansion coefficient ($\times 10^{-6}$ K^{-1})	9.1
Poisson's ratio	0.23
Softening temperature (K)	993
Crack fracture strength (MPa)	30
Young's modulus (GPa)	74

Table 3
Separation parameters of Master laser.

Laser spot diameter D_M (mm)	2, 3, 4, 5
Laser scanning speed V_M (mm/s)	2, 4, 6, 8, 10
Laser power P_M (W)	30, 40, 50, 60, 70

defocused CO_2 laser beam was used to irradiate on the scribing line to generate a tensile stress and separate the substrate [11]. Yen-Liang Kuo used the CO_2 line-shaped laser to preheat the glass, then the Nd-YAG pulsed laser was applied to separate the glass [12].

The YAG laser can penetrate through glass which means laser energy can be absorbed by the entire glass, and the machining process can complete directly. Kojiro Karube used the YAG laser to cleave the glass as the full-body cutting. The qualities of cutting surfaces were compared among the mechanical breaking, CO_2 laser cutting and full-body cleavage. The superiority of full-body cleavage is apparent [13]. Yukio Miyashita studied the crack nucleation and propagation conditions with different initial crack size in YAG laser thermal stress cutting glass [14]. Salman Nisar analyzed the reasons of the cutting deviation at the leading and the trailing edges of the glass sheet during diode laser symmetric cutting [15]. Then, the effects of cut deviation at the leading and trailing edges of the glass in symmetric cutting with different diode laser beam geometries, laser modes and processing parameters have been studied [15–18]. Lijun Yang utilized the characteristics that the YAG laser can penetrate glass to separate the multi-layer glasses, which leading to the improvement of the cutting efficiency and quality [19]. Each of these methods can achieve good processing quality and high-efficiency using LITP to cut glass. Meanwhile, these methods also have a limitation. That is the achievements can only be used for symmetric cutting glass (which means the cutting path is the symmetry axis of the material, the glass is cut into two symmetrical shapes).

In the actual processing, the asymmetric linear cutting (which means the cutting path deviating from the symmetry axis of the material in a large scale, and the area of two separated parts is varied widely) is more common. For instance, due to the cracks on the edge of glass, the processing is usually undertakes to remove it. And the small piece of sample is obtained from the big glass substrate. These processing required to be cut in an asymmetric linear way. However, there are scarcely any researches about the asymmetric cutting of glass. Especially, the problem of the separation path deviating from the scanning path is ignored. In asymmetry linear cutting, the laser