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Hybrid Laser Cutting for Flat Panel Display Glass

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A new laser glass cutting technology using femtosecond and CO_2 lasers is presented. Mechanical breaking after scribing using a femtosecond laser was evaluated and compared with the hybrid method for the cutting of flat panel display (FPD) glass. Various laser fluences were tested to determine the threshold energy and optimum grooving conditions without microcracks. The hybrid method was very effective for the FPD glass microfabrication and for performing full cutting without the mechanical breaking process. Consequently, it was found that the FPD panel was clearly cut using the method and the methodologies were very effective even for a mass-production cutting system. [DOI: 10.1143/JJAP.47.6978]

KEYWORDS: laser glass cutting, hybrid laser cutting, flat panel display glass

1. Introduction

After a pattern defects "repair" system for flat panel display (FPD) was developed, laser application systems became more popular in the electronics area. There are many laser applications in the FPD industry such as "indium tin oxide (ITO) direct patterning" for plasma display panel (PDP) using a very high power infra red (IR) laser, low temperature polycrystalline silicon (LTPS) process using a XeCl excimer laser, maskless lithography using a 405-nm wavelength violet diode laser, and titler which makes the identification code for PDP and liquid crystal display (LCD) panel.[1)] In addition, a "thermal shock" laser glass cutting technology using a CO_2 laser and liquid or gas coolant is now standard for LCD and organic light emitting diode (OLED) glass cutting.[2–4)] The chemical process under hydrofluoric (HF) or hydrochloric (HCL) gas environment is one of the reliable processes that can improve the etching rate.[5)] The laser glass cutting process is required for each FPD glass as well as a two-sided glass. It is well known that the laser cutting method for a single glass panel is acceptable for a mass-production system. However, there are still problems for a two-sided FPD glass cutting using laser.[6)]

In this paper, we present a new hybrid technology that is defined as a combined method consisting of two different laser processes (femtosecond laser + CO_2 laser) to solve this problem without a wet etching process, and we found that the methodology is effective even for a mass-production laser cutting system.

2. Laser System Configurations and Experiments

A femtosecond laser is prepared and installed with special optical systems for glass scribing. The laser specifications are shown in Table I. The femtosecond laser has very a short pulse duration of 100 fs. Because the energy transfer time from electrons to ions by Coulomb collisions is significantly longer than this duration, the conventional hydrodynamics and thermal analysis theory cannot be applied to analyze this ultrashort interaction.[9)] The system configurations are presented in Fig. 1. The radiation from the femtosecond laser goes through a shutter (SH), neutral density filter (ND), and aperture, and the energy is delivered using mirrors (M) and focused with 20× object lens. The beam splitter (BS) is used for real-time charge coupled device (CCD) camera sensing. The spot size for all the experiments is set at 8 µm. Because the power of the femtosecond laser was controlled using the ND filter, we could use only six fluences per pulse, namely, 0.12, 0.76, 3.18, 13.9, 67.7, and 181.1 J/cm^2 for the experiments. In addition, a 30 W CO_2 laser is used for the hybrid cutting method. Since the CO_2 laser has a very long wavelength ($\lambda = 10.6\,\mu m$), actually 10 times longer than that of the Nd:YAG laser's, some energy of the laser is absorbed into the FPD glass and heats it up. The optical transmission characteristic with respect to the wavelength is plotted in Fig. 2. The cooling using tap water through a syringe after the localized heating causes the thermal stress,

Table I. Femtosecond laser specifications.

Laser source	Ti:sapphire
Wavelength λ (nm)	790
Pulse energy (mJ/kHz)	3.5
Pulse duration (fs)	100
Beam diameter (µm)	8
Beam quality	≤1.8
Beam mode	TEM00 Gaussian

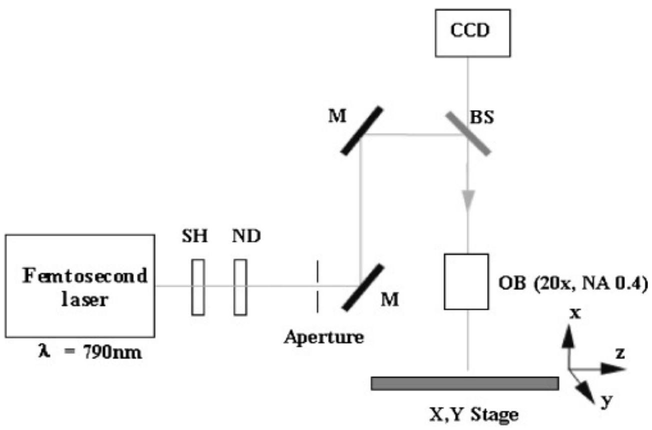

Fig. 1. System configurations for femtosecond laser.

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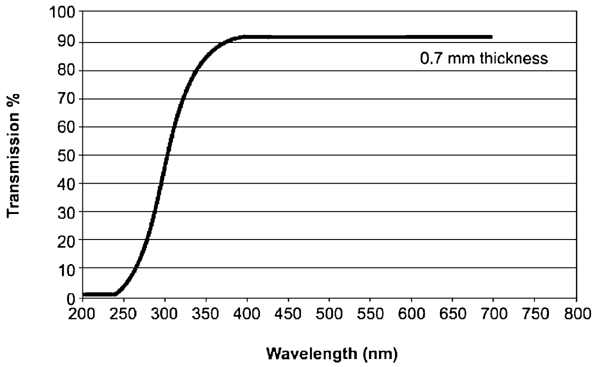

Fig. 2. Optical transmission of glass with respect to wavelength (provided by glass vendor).

Table II. CO_2 laser specifications.

Laser source	CO_2
Wavelength λ (μm)	10.6
Laser power for experiments (W)	25
Pulse duration	CW
Beam diameter (mm)	2.5
Beam quality	≤1.1
Beam mode	TEM00 Gaussian

rapid expansion and thermal shock. The detailed CO_2 laser specifications are shown in Table II. The 100 μm spot size that has Gaussian energy distribution is used for this experiment.

3. Results and Discussion

The laser threshold fluence for the ablation of the material is defined as[7)]

$$F_{\mathrm{th}} = \frac{3}{4}(\varepsilon_{\mathrm{b}} + J_{\mathrm{i}})\frac{l_{\mathrm{s}} n_{\mathrm{e}}}{A}, \tag{1}$$

where J_{i} is the ionization potential, ε_{b} is the binding energy of the ions, A is the ratio of the absorption, n_{e} is the electron number density, and l_{s} is the skin layer. By estimating the laser threshold fluence using the following parameters[7)] at wavelength 790 nm [$n_{\mathrm{e}} \approx 7 \times 10^{22}$ cm^{-3}, $(\varepsilon_{\mathrm{b}} + J_{\mathrm{i}}) \approx (3.7 + 13.6)$ eV, $l_{\mathrm{s}}/A \approx 1.33 \times 10^{-5}$ cm], the threshold fluence for the glass is found to be approximately 1.9 J/cm^2. This value matches with some previous experimental results for the sub-picosecond laser.[8,9)]

The ablation depth d_{ev} is of the order of the skin depth if we create a hole with the fluence near the ablation threshold of the femtosecond laser. Because of the exponential decrease of the incident electric field and electron temperature in the target material, the ablation depth increases logarithmically with the laser fluence as[7)]

$$d_{\mathrm{ev}} = \frac{l_{\mathrm{s}}}{2} \ln \frac{F}{F_{\mathrm{th}}}. \tag{2}$$

The experimental results are plotted in Fig. 3 and compared with those obtained using eq. (2). Although the equation we derived used some approximations, the relationship between laser fluence and ablation depth results is well-matched. Because the fluence was controlled using the ND filter, we used only six fluences per pulse, namely, 0.12, 0.76, 3.18, 13.9, 67.7, and 181.1 J/cm^2. Since the threshold fluence for the glass was 1.9 J/cm^2, only four experimental points were obtained.

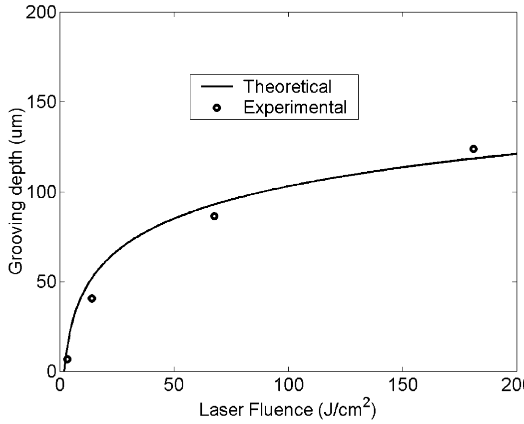

Fig. 3. Comparison of experimental and theoretical results for relationship between the laser fluence and grooving depth.

Since the femtosecond laser is used as a precise cutting initiator and marker while the CO_2 laser is used as a cracking tool, research on the initiator should be performed for more clean cutting edges. These experiments to obtain clean and deep grooves for the glass were performed using a 3 W femtosecond laser. We presented the relationship between the input energy and scribing depth as well as threshold energy.[10)] A total of four experimental points were obtained and compared with the theoretical results. It was found that the ablation depth for the FPD glass increases logarithmically with the laser fluence. In addition, the ablation rate for the glass was theoretically investigated and presented as an approximate value.

The mechanical breaking tests after the laser scribing were performed. Various scanning velocities from 1 to 20 mm/s ware tested with a maximum power of 910 mW, because the speed is related to the creation of the micro-cracks at the cutting edge of the glass. We presented three results of cutting edges of the glass which are created under the scanning speeds of 5, 10, and 15 mm/s, and a cross-sectional view of the 15 mm/s result in Fig. 4. Since the repetition rate for the femtosecond laser that we used is only 1 kHz, some discontinuity could occur. Because of this pulsed laser phenomenon, some sharp edges were shown between the laser-ablated area and cutting edge of the glass. We found that the scanning speed was correlated with the size of the sharp edges, and the faster speed resulted to decrease of the size. More quantitative analysis of the relationship between scanning speed and edge quality remains as a future work.

Generally, the LCD device consists of thin film transistor (TFT) and color filter panels. After the fabrication processes, the two panels should be combined and sealed together. It is called a two-sided LCD panel. Experiments were also performed with a two-sided LCD panel, and the results are summarized in Fig. 5. Both Figs. 5(a) and 5(b) show the cross-sectional view of the cutting edges and the side view of the glass edge of the mechanical breaking process after four laser passes under maximum power. Here, the termi-

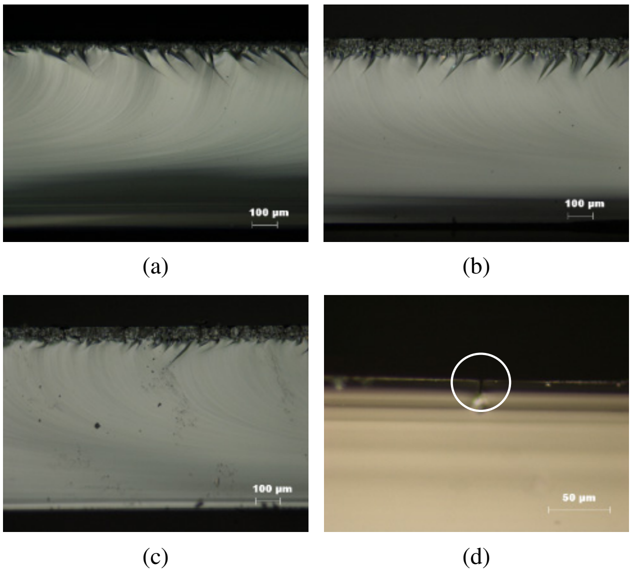

Fig. 4. (Color online) Cut edge view of femtosecond laser scribing followed by mechanical breaking with 0.7-mm-thick glass: scanning speeds of (a) 5, (b) 10, and (c) 15 mm/s, and (d) cross-sectional view of the 15 mm/s speed groove.

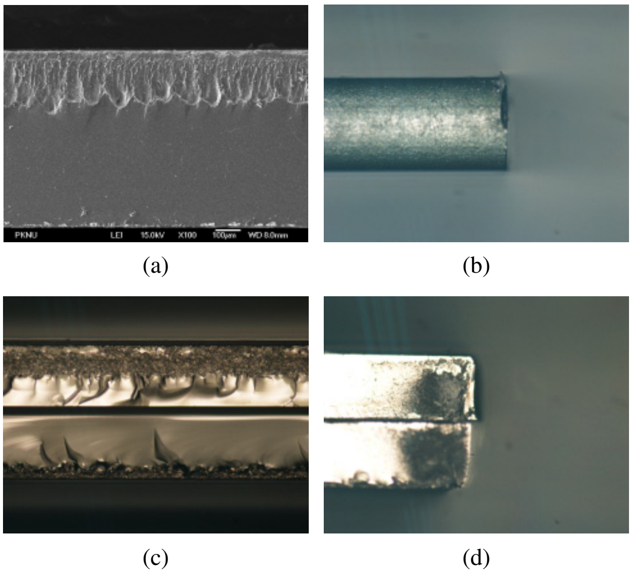

Fig. 5. (Color online) Cross-sectional and side views of femtosecond laser scribing followed by mechanical breaking: (a,b) single-side panel after four laser passes, and (c,d) double-sided panel after six laser passes (lower left and right).

nology "passes" denotes that multiple laser energy scans follow same path repeatedly. The conditions of the cutting edges and the side edge are acceptable for the edge grinding process, which is the next fabrication process for LCD manufacturing. We also tried the method after six laser passes for a two-sided LCD panel. The results are shown in the Figs. 5(c) and 5(d). The conditions of the cutting edges and the side edge for the two-sided panel are also acceptable for the mechanical edge grinding process.

A thermal shock glass cutting method using a CO_2 laser and coolant was tested after the scribing process, and the scanning electron microscope (SEM) cross sectional views are shown in Fig. 6. We used a femtosecond laser as a cutting marker and a CO_2 laser as crack propagator. The

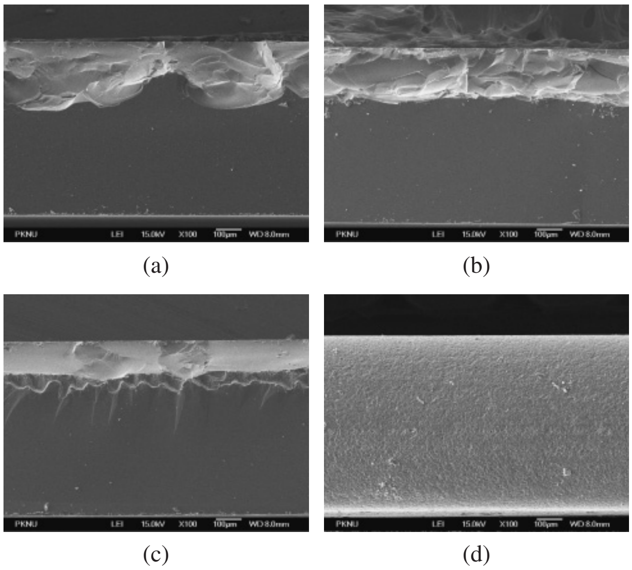

Fig. 6. Cross-sectional view of femtosecond laser scribing followed by CO_2 laser heating and rapid cooling: (a) after one laser pass, (b) after five laser passes, (c) after six laser passes, (d) initial crack propagation.

Gaussian beam spot size of the CO_2 laser for the experiments was approximately 100 µm and the beam was controlled using a galvanometer. In addition, "a thermal shock cutting after an initial crack" experiment was carried out and the results are presented in Fig. 6(d). The initial 1 mm crack was created using the femtosecond laser, and the CO_2 laser was used to produce the thermal shock through the laser cutting edge. The clean and smooth surface result shown in Fig. 6(d) was similar to that obtained by the conventional laser cutting method.[11] The scanning speed was 100 mm/s and the power of the CO_2 laser was 25 W for both experiments. The SEM images shown in Fig. 6(a) show the results after one laser pass, and Figs. 6(b) and 6(c) show the results after five and six laser passes, respectively. The initial crack result is presented in Fig. 6(d). As we can see, the cutting quality improved, but the penetration depth is very saturated which can lead us to conclude that five passes can be the best choice for production purposes. The cross-sectional views for each experiment show that all the cutting edge conditions using the methods are clean for edge grinding processing, although the hybrid method made some sides irregular owing to the sharp edges. A novelty of this approach is that the femtosecond laser can precisely locate the cutting position, and the CO_2 laser can propagate the cracks.

4. Conclusions

Experiments for hybrid laser glass cutting for the LCD glass were performed using a 3 W femtosecond laser and 30 W CO_2 laser. It was found that the ablation depth for the FPD glass increases logarithmically with the laser fluence. We found that the higher scanning speed could prevent sharp edges and make them smaller. The cutting quality using thermal shock after the femtosecond laser scribing is acceptable for the grinding process.

It was found that the LCD glass panel was clearly cut using the hybrid laser cutting method, and the methodologies were very effective even for mass production cutting systems for FPD glass panel.

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