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# Patterning electrode for cholesteric liquid crystal display by pulsed laser ablation

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ABSTRACT

An ultraviolet wavelength laser is used to manufacture the metal electrode of a cholesteric liquid crystal display (Ch-LCD) without a shadow mask. The proposed method effectively ablates the metal layer without damaging the liquid crystal layer and underlying indium tin oxide electrode. The width and morphology of the laser ablated sections were investigated as a function of laser power as well as scan speed. The minimum ablated line is around 43 μm and the laser system operates at 1.5 W at a scan speed of 200 mm/s. The characteristics of a Ch-LCD prepared using laser patterning under the optimum ablation process conditions are similar to those of a Ch-LCD prepared using the screen printing method.


## 1. Introduction

Flexible reflective cholesteric liquid crystal displays (Ch-LCDs) have been recently developed. The conducting electrodes are used on stacking structures to fabricate the devices [1]. Flexible bistable-display media are becoming as practical as displays for some niche products. In general, the two dimensional electrodes of flexible displays are usually manufactured by traditional wet etching process. Conventional lithography is a multi-step wet process, which includes resist coating, resist exposure, resist etching, indium tin oxide (ITO) etching, and resist stripping [2]. However, the liquid crystal layer or dark layer cannot be exposed to organic solvents, so the metal electrode cannot be patterned by the conventional wet etching process. Thus, electrodes patterned using the screen printing technique are currently applied to form the metal row conductor [3]. The metal conductor must be completely ablated to avoid the two metal lines from linking together. Furthermore, the patterning process cannot damage the liquid crystal layer and the underlying ITO electrode. With the development of laser micromachining techniques, diode pumped Q-switched neodymium-doped yttrium lithium fluoride (Nd:YFL) laser has been applied to ablate ITO films on glass substrate. The characteristics of ITO thin films patterned at different laser wavelengths have been investigated. Improved pattern morphology at higher processing speeds can be obtained using UV irradiation or a short pulse laser [4–8]. Lasers provide high resolution and do not require a mask, which makes it possible to ablate a conductor layer without damaging the liquid crystal layer and underlying ITO electrode.

In the present study, the properties of the metal conductor of a cholesteric liquid crystal display produced using laser ablation are investigated. The effects of the laser power and scan speed on the quality of patterning are evaluated. The characteristics of a Ch-LCD prepared using laser patterning are compared to those of a Ch-LCD prepared using the screen printing method.

## 2. Experimental

Fig. 1 shows a schematic diagram of the workstation used for electrode patterning with laser ablation. The system for laser patterning consisted of a Q-switched DPSS 355 nm laser (Coherent), which had a pulse duration of 30 ns, a repetition rate of 40 kHz a stability of less than 5%, a scanner (Scanlab) at the focus of a 250 mm focal length lens, and an XYZ stage. The metal conductor patterning was carried out at a laser power of 1–6 W; the scan rate was varied from 200 to 500 mm/s.

In order to increase the resolution of the pattern, the size of the laser spot was decreased. The diameter of the laser spot, $D_0$, is expressed as

$$D_0 = 1.22\left(\frac{\lambda F}{nW_d}\right)M^2 \quad (1)$$

where $\lambda$ is the laser wavelength, $F$ is the focal length, $n$ is a refractive index, $W_d$ is the diameter of the incident laser, and $M^2$ the laser-quality factor. Eq. (1) indicates that the diameter of the laser beam is directly proportional to the wavelength and focal length. For the experiment, the spot size was 40 μm for the laser

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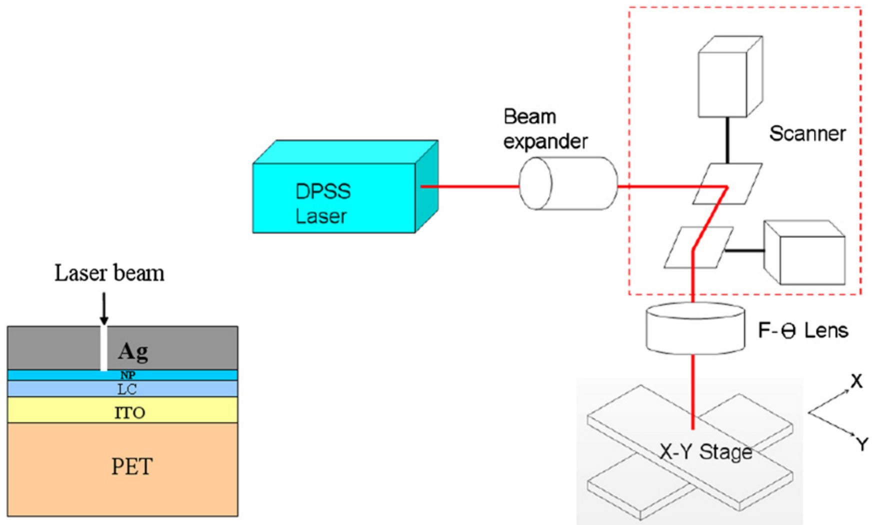


**Fig. 1.** Schematic diagram of the workstation used for electrode patterning with laser ablation.

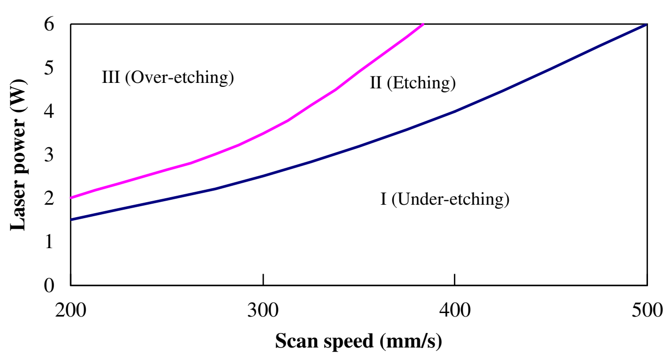


**Fig. 2.** Relationship between scan speed and laser power.

system. The electrode on the Ch-LCD was ablated using the laser etching process. The optical profile image and cross-sectional profile of the ablated sections were measured using an optical imaging profiler (PLμ2300, SENSOFAR, SPAIN). In order to study the effect of the metal conductor patterning method on Ch-LCD performance, displays were prepared using laser patterning method and a screen printing method. The Ch-LCD panel was driven by a Keithley 2410 power supply and the reflectance measurements were performed using an X-Rite 938 spectrodensitometer.

## 3. Results and discussion

Due to the high power of the laser, not only the silver layer but also the underlying liquid crystal layer and ITO film can be etched away. If the ITO film is etched away, electrical current cannot flow. Material removal occurs only if the pulse energy is above an ablation threshold, which strongly depends on material characteristics. For multilayer structures, the ablation threshold of each layer is the most important factor for the selective removal of an interested layer. Therefore, the laser power and scan speed must be controlled so that the pulse energy is above the ablation threshold of the silver layer and below those of the liquid crystal layer and ITO film.

Fig. 2 shows the relationship between scan speed and laser power. There are three distinct regions in the figure. Under the conditions of Region I, low laser power and high scan speed led to no ablation of the silver layer. Under the conditions of Region II, a metal conductor pattern was easily produced. The appropriate laser power and scan speed led to no damage of the underlying organic layer and ITO film. Under the conditions of the Region III, the high laser power ablated the silver layer; however, the underlying organic layer and ITO film were damaged, which resulted in no current flow. From these results, whether the etching process could be realized strongly depended on laser power and scan speed.

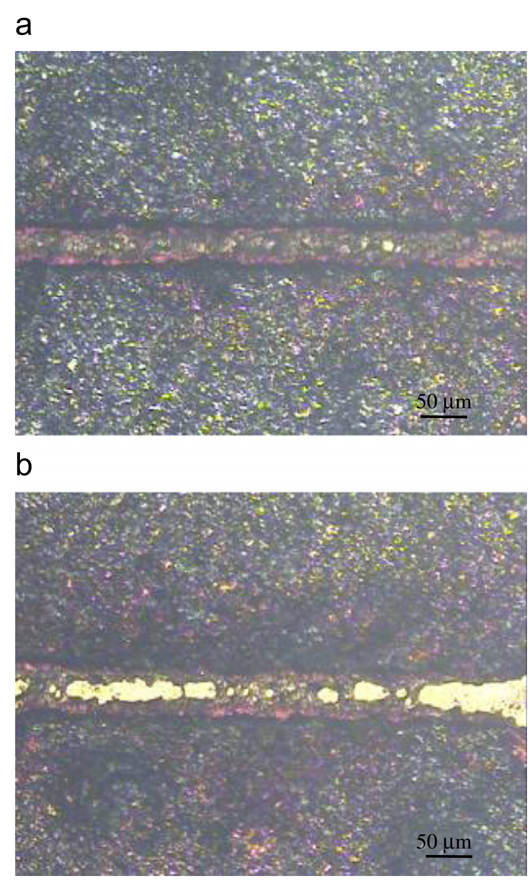


**Fig. 3.** Optical micrographs of the laser ablated silver layer tested at a scan speed of 400 mm/s with laser powers of (a) 4 W and (b) 6.5 W.

Fig. 3 shows the optical micrographs of the laser ablated silver layer tested at 400 mm/s at various power levels. At a laser power of 4 W, the metal conductor layer was completely ablated without damage to the underlying liquid crystal layer and ITO film. However, at a laser power of over 6.5 W, the incoming pulse was intense enough to ablate not only the silver layer but also the underlying organic layer and ITO film. The ablated width increased with increasing laser power. The widths of the etching sections were 44 and 55 μm. These results show that selecting appropriate parameters is important for patterning the silver layer.

The optical profile images of the ablated trench were also evaluated using an optical imaging profiler; the results are shown in Fig. 4. With increase in laser power, the ablated depth of the trench increased. When patterning at 4 W and 400 mm/s, the ablated depth was around 16 μm. At a laser power of 6.5 W, the depth of the ablated trench increased to 27 μm. However, the coated metal layer was only 16 μm, which indicates that damage occurred on the underlying liquid crystal layer and ITO film under these conditions.

Fig. 5 shows the electro-optical response of Ch-LCDs prepared using two kinds of electrode patterning methods. There are only small differences between the two kinds of Ch-LCD with regard to applied voltages and the reflectance characteristics. These differences result from the manufacturing processes. Fig. 6 shows an image from a Ch-LCD prepared using the laser patterning method after an AC voltage was applied. The laser ablation profile has only a slight influence on the informational area of the Ch-LCD. Manufacturing a fine metal mask with a complex pattern is expensive and time-consuming. Unlike the screen printing method, the laser patterning method requires no

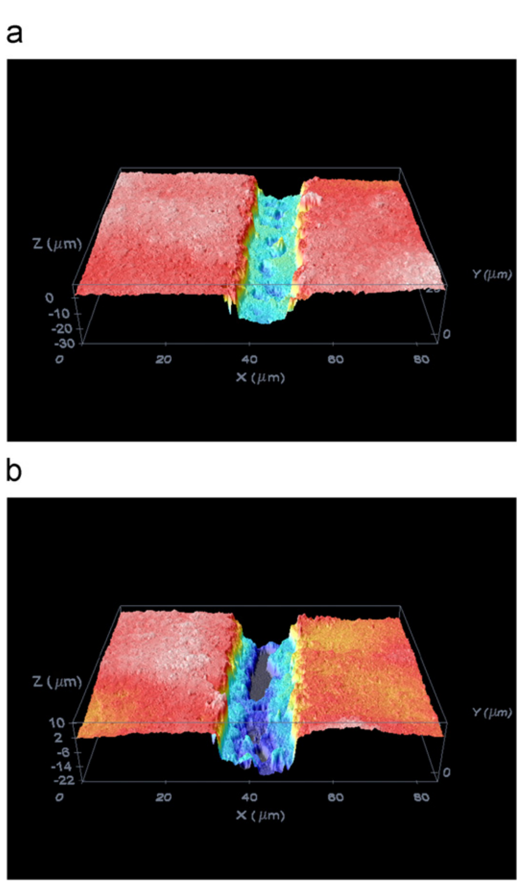


Fig. 4. Optical profile images of the ablated trench patterning at a scan speed of 400 mm/s with laser powers of (a) 4 W and (b) 6.5 W.

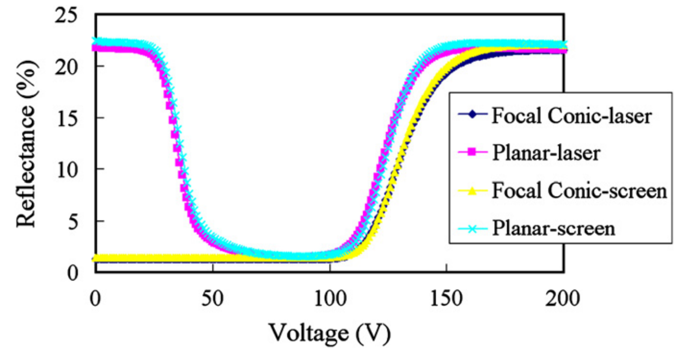


Fig. 5. Electro-optical response of Ch-LCDs prepared using two electrode patterning methods.

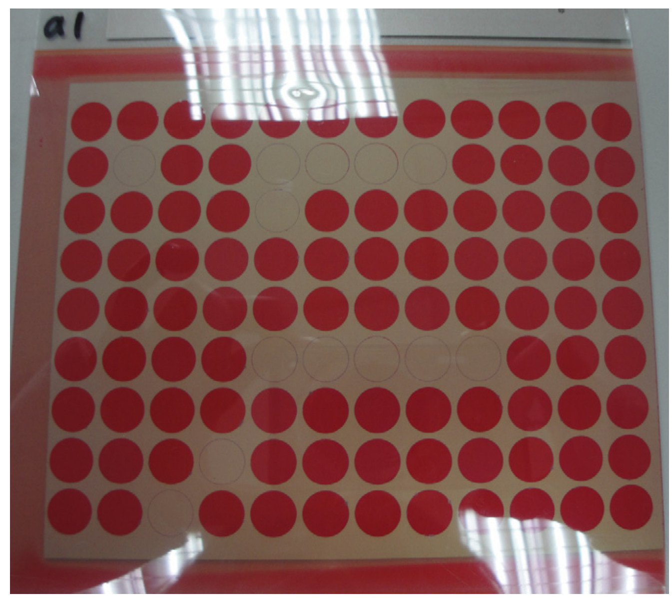

Fig. 6. Image (127 × 88 mm$^2$) from Ch-LCD prepared using the laser patterning method with AC voltage.

mask. The laser process can be used to pattern large panels by using a scanner or servo motor to move the stage. Most importantly, the laser patterning method does not negatively affect the performance of the device.

## 4. Conclusion

A patterning process for the metal electrode layer on Ch-LCDs using laser technology was proposed. Good quality trenches were obtained by adjusting the laser power and scan speed. Furthermore, electro-optical characteristics of the Ch-LCD prepared using the laser ablation method are the same as those of a Ch-LCD prepared using the screen printing method. Therefore, laser patterning has potential as a method for manufacturing the electrode of Ch-LCDs.

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