“Dry-Etching System” with Q-switched DPSS Laser for Flat Panel Displays

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Laser-dry-etching method has attracted a great deal of interest in industry because of the many potential benefits such as enormous cost reduction and chemical-free manufacturing environment. The authors have been developing various laser-dry-etching systems for large-scale Flat panel displays (FPDs). All these systems try to balance between etching speed and etching quality. It is crucial to have high-quality processes in the mass production lines, which operate 7 days per week, 24 hours per day. In this paper, the etching qualities of liquid crystal displays (LCDs) that are the representative of FPDs are outlined. Especially in laser-dry-etching for color filter (CF) substrate of LCD, the selective removal of indium tin oxide (ITO) films at black matrix (BM) position is much more difficult than at other positions. The authors have developed a new etching method so called “grazing incidence method with laser-dry-etching (GI-LDE)”. The selective removal of ITO films at black matrix position has become possible by using this method.

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1. Introduction

FPDs are used in many electrical products, such as cellular phones, car-navigation systems, personal computers, slim profile televisions and so on. With the population of these productions, the market of FPDs has expanded rapidly. The industry trends of FPD productions are: improvement of picture quality, increase of multifunction capabilities, pursuit of the cost reduction, environmental conservation and so on.

There are many etching processes for LCD production. Most of these processes are performed by a wet etching method. Using this method, when panel manufacturers have to exchange pattern they have to suspend etching work as long as making new pattern etching mask. Moreover, this method needs large-scale machinery. And it needs many chemicals. Thus, there are many problems in the current etching process that relates to cost and environment issues. Laser-dry-etching method may replace the wet etching method because it has fewer processes, a low running cost, and creates low environmental pollution [1-8].

Recently, with the development of ultrafast laser oscillators, the selective removal of thin films became easier. The laser beam is suitable for removing thin films selectively from multi-layered film because thermal affections occur rarely around laser irradiation areas [4-8]. With this, the goal in researching laser-dry-etching method is to further improves it ability to remove film from multi-layer film substrate.

However, the laser-dry-etching method takes a long time to process a large area due to the high energy needed to concentrate on a small area. On the other hand, it is clear that the laser beam with huge power oscillators is usually unstable and has low beam quality because of thermal optics effect and optics device degradation.

CF substrates consist of multi-layered film. The selective removal of ITO films at a black matrix position is much more difficult than at other positions because the black matrix position consists of layers whose material characteristics with regard to light are different.

The authors have developed a new etching method in which ITO films can be removed without damage to the lower-layers of multi-layered structures. In this paper, the etching qualities for CF substrates are outlined and qualities by the new etching method are discussed.

2. Development of the selective removal method

2.1 Etching qualities for CF substrate

Figure 1 shows the construction of CF substrate.

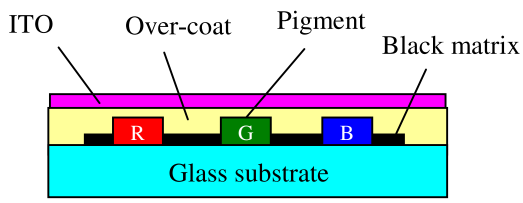

Fig.1 Construction of CF substrate

As shown in this figure, CF substrate consists of a multi-layered film on a glass substrate. CF substrate can be distinguishable in the following positions, which are (A) RGB position, (B) Black matrix position and (C) Transparent position. However, the ITO layer and the over-coat layer are common regardless of those positions. The black matrix layer’s role is to block the backlight, so it has different characteristics from other layers which transmit the backlight to the front side. The selective removal of ITO films at the black matrix position is much more difficult than at other positions because the black matrix position consists of layers whose material characteristics interacts differently to light. The black matrix material has a much higher absorption rate, making the selective removal process of ITO layer more difficult.

The accuracy and the quality that are necessary for the pattern formation of ITO film on the black matrix are explained next. A liquid crystal module is bonded so that each pixel of a TFT substrate matches with each pixel of a CF substrate. A gap of these substrates is only 5 µm and liquid crystal is injected in this gap. Pixel size becomes less than 250µm, and sub-pixel size is equal to or less than 75µm. Demands for etching high qualities are the most important factor because the liquid crystal module assembly is a very fine process. Important factors of etching for selective removal of ITO film on black matrix position are: (A) the level of damage to the lower-layers, (B) degree of uneven etched ITO surface, (C) degree of etching accuracy and so on.

In this paper, the authors will discuss how and if etching method with processing damage of less than 100nm at the lower-layers, ITO surface smoothness of less than 5nm variation and linearity of less than 5µm can be achieved. Figure 2 shows images of etching qualities on black matrix position.

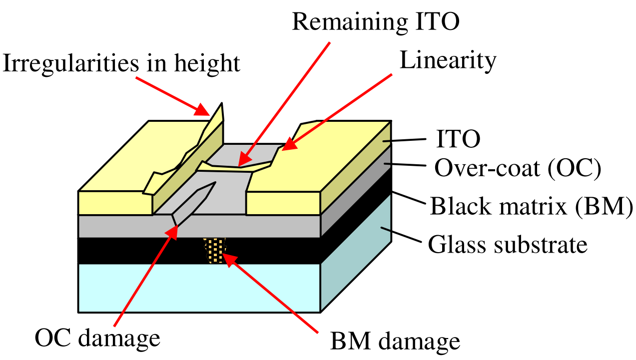

Fig.2 Image of etching qualities on BM position

CF substrates consisted of an ITO layer of 0.1µm thickness, a resin black matrix layer of 1µm and an over-coat layer of 1 µm thickness on a glass substrate of 0.7mm thickness are used as test pieces. The optical density (OD) at the black matrix position of this test piece is over 3.

2.2 New laser-dry-etching method

For the selective removal of ITO films of a multi-layered film, it is necessary to decrease the amount of transmitted laser beam to the lower-layers. Only ITO films in the top layer will be removed if the heat intensity is decreased at the lower-layers. It is possible to reduce the transmitted beam to the lower-layers by using a deep ultraviolet (DUV) laser beam that has a high absorption rate in ITO film. As well, it is well known that ultrafast laser processing can be used without a heat-affected zone around the laser irradiation area. The authors had examined both DUV laser-dry-etching and ultrafast laser-dry-etching for large-scale panels. In theory, using the DUV laser-dry-etching or ultrafast laser-dry-etching should yield good results. However, our tests showed that both methods do not meet our desired qualities. The results are discussed in the next paragraph as follows.

The results of DUV (λ=266nm) laser-dry-etching are described at first. In all our results, when using DUV laser-dry-etching, the ODs of the etching area were less than 3, and damage had occurred. Figure 3 shows one example of DUV laser-dry-etching results using pulse energy of 3.5µJ.

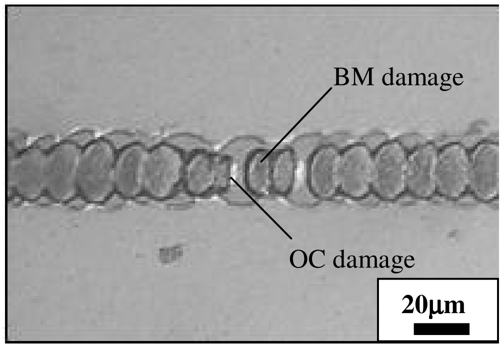

Fig.3 DUV laser-dry-etching

Light grey areas around the blackish areas in this figure are proper etching areas. Blackish areas are damaged parts of the black matrix layer. Small white dots between the blackish areas are damaged parts of the over-coat layer. The whitish parts at the edge of the light grey areas are not removed area of ITO films but separated into areas between the ITO layer and the lower-layer. From removed situations it is understood that DUV (λ=266nm) laser-dry-etching is neither ablation, melt nor evaporation but mainly phenomena that separate from differences of material characteristics between the ITO layer and lower-layers.

Next, ultrafast laser-dry-etching is described. The type of wavelength of 800nm, maximum frequency of 1kHz and typical pulse width of 150fs and maximum pulse energy of 1mJ was used as an oscillator, and an object lens of 100 magnifications was used. From several laser-dry-etching results, it was determined that the proper pulse energy is 0.03µJ, and area of 0.04µm^2 can be removed at that energy level. Figure 4 shows the results of etching 10µm-square (50 x 50 shots) with the XY table in the same conditions.

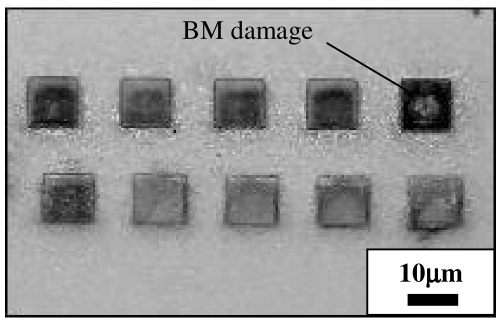

Fig.4 Ultrafast laser-dry-etching

Squares shown in this figure are areas where ITO films were removed by laser irradiations. The three squares in the center of the lower row are the results of proper etching. Black areas on other squares are damaged area in the black matrix layer. The OD of this area was less than 3. This kind of result represents the average result using ultrafast laser-dry-etching. It is understood that stable etching is difficult when using the ultrafast laser beam.

Moreover, the amount of etching for large-scale CF substrate is compared with the amount calculated from DUV laser-dry-etching or ultrafast laser-dry-etching results in the above examination. It is clear that machinery using the DUV laser-dry-etching or ultrafast laser-dry-etching is very expensive. It can be said that introduction of these machines has few advantages for panel manufactures.

A high power oscillator is necessary to etch a large area on a large-scale substrate. The Q-switched diode pumped solid state (DPSS) Nd: YAG laser oscillator has high power. It is well known however, that IR laser beams might be unsuitable for selectively removing thin films from multi-layered film because thermal affections easily occur around the laser irradiation areas.

The authors have examined a new method of removing thin film using an IR laser beam with experimental configurations called the “grazing-incidence method with laser-dry-etching (GI-LDE)”. When an IR laser beam irradiates ITO film, some parts of the IR laser beam are absorbed in the film inside and other parts are transmitted through it and up to the lower-layers. The more obtuse the irradiation angle is, the greater the distance that light must travel through the ITO film. Therefore, the distance that the laser beam passes through to the ITO film is increased, and the amount of absorption of the laser beam into the ITO film is increased. The amount of transmitted beam to lower layers is decreased by this method, and the damage of lower-layers is prevented.

First of all, the optical features of ITO film have been simulated [7,8]. In this simulation, mean value of P wave and S wave has been used because the beam of a high powered laser beam is a randomly polarized light generally. Figure 5 shows the relationship between the reflection intensity, the absorption intensity and the transmission intensity. The refractive rate of 1.45 of the ITO film at IR beam has been used.

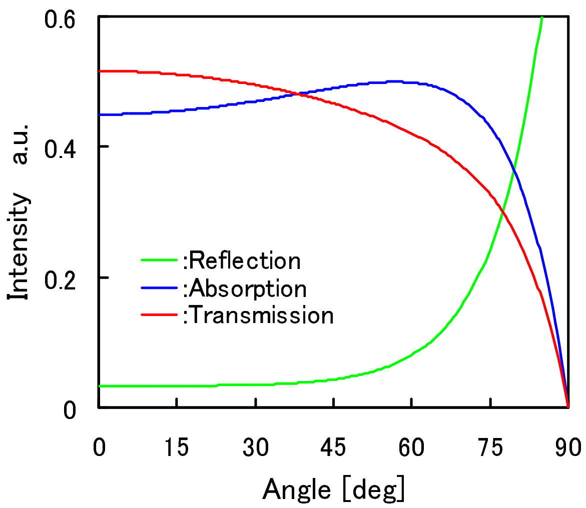

Fig. 5 Relationship between reflection, absorption and transmission of ITO film

It is understood that the reflection intensity rises rapidly near 70degrees as shown in the figure. The absorption intensity decreases at around 60degrees where there is a peak and the angle increases to more than 60degrees. At over 75degrees, the absorption intensity at this angle is smaller than absorption intensity of the normal angle. Transmission intensity decreases as the angle increases.

It can be said that the larger the ratio of absorption intensity to transmission intensity is, the easier the selective removal of ITO film becomes. The ratio of the absorption intensity to the transmission intensity is shown in figure 6.

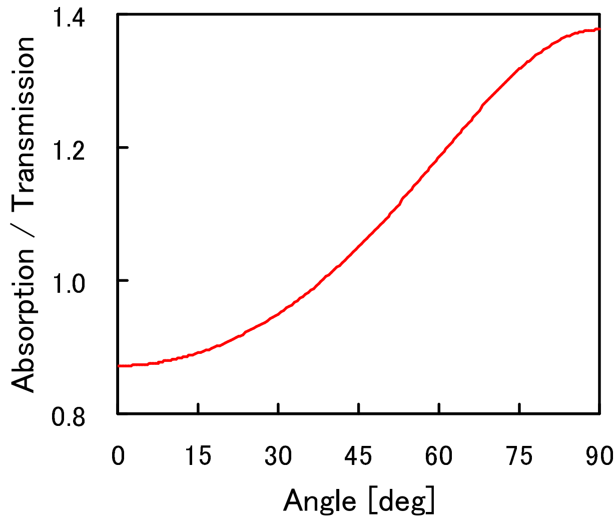

Fig.6 Absorption per transmission along with irradiation angle

As shown in this figure, absorption intensity per transmission intensity increases as the irradiation angle is increased. The ratio of normal angle is 0.85, the ratio of 40degrees is 1.0, and the ratio of 75degrees is 1.35.

Absorption intensity per transmission intensity is increased 1.5 times in the case of 75degrees compared with case of the normal angle, which makes removal of the ITO film easier than the normal angle etching. However, the absorption intensity at over 75 degrees is smaller than absorption intensity of the normal angle. Moreover, the optical system interferes with a substrate when irradiation angle is greater than 75degree. At 75degrees, the absorption to transmission ratio is relatively high while maintaining good absorption intensity. However, angles such as near 90degrees may have higher absorption to transmission ratio, but the absorption intensity is low.

Next, the etching results of “GI-LDE” are described. Etching results are evaluated by a resistance across etched groove and the OD of etching area. Proper etching is needed to fulfill the resistance of over 2,000MΩ and OD of over 3. As a result of having been OD of equal to or less than 3, it is decided as high excess of etching. As a result of having been resistance of equal to or less than 2,000MΩ, it is decided as shortage of etching. Figure 7 shows the etching results with irradiation angles.

The green mark in this figure shows proper etching. The red mark is high excess of proper etching, so damage has occurred. The blue one is shortage of the etching. When comparing 65degrees to 75degrees, proper etching area is much bigger at 75degree.

Considering the above-mentioned, irradiation angle of 75degrees is adopted for this method. And at 75degree, the fluence of 0.5J/cm^2 is necessary for proper etching.

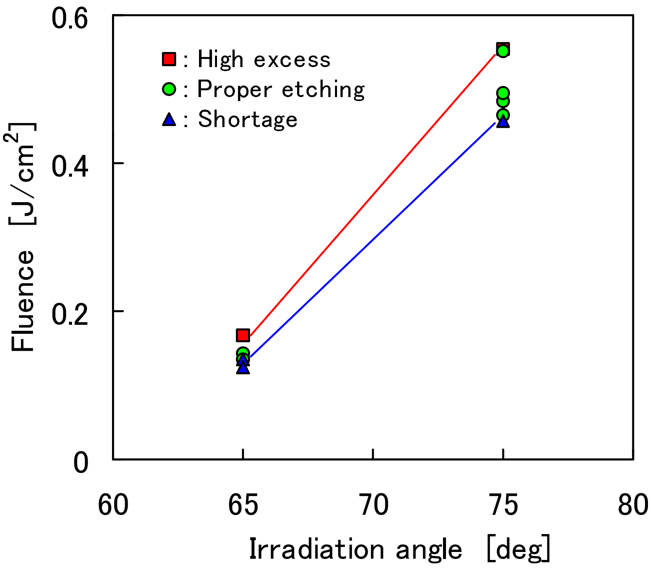

Fig.7 Etching result with irradiation angle

2.3 Beam characteristics for fine etching

Beam characteristics for the increase of etching rate and high quality etching are discussed. High pulse stability and homogenized beam distribution intensity are most important for selective removal of ITO films at black matrix positions. It is clear that the laser beam with huge power oscillators is usually unstable and low beam quality due to thermal optics effect and optics device degradation. Therefore, for our machine, a 50W DPSS Q-switch YAG laser is used, which does not use a huge amount of power. This oscillator is adjusted so it yields beams that are high stability. To make an etching width to 1,000µm per path, an optics system was constructed in consideration of the oscillator characteristics. Figure 8 shows an experimental setup.

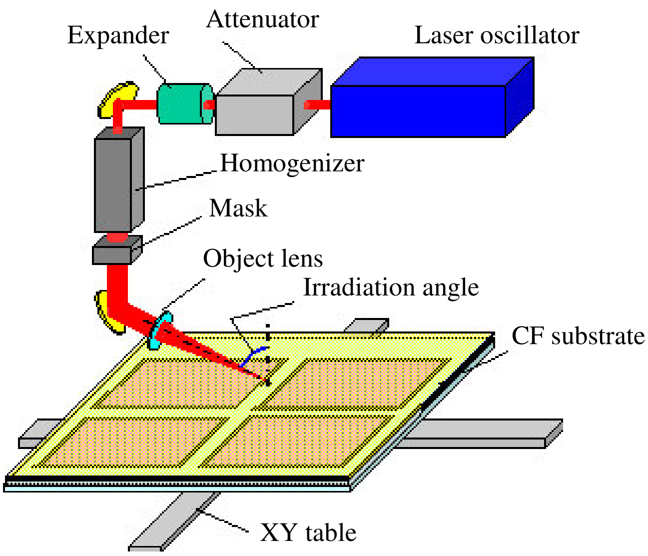

Fig.8 Experimental setup

The optical system is constituted by an attenuator, an expander, a homoginizer, a mask and an object lens. The homoginizer makes a line beam of 2,500µm length. The object lens of 2.5 magnifications is used. An irradiation beam of 75 degrees is adjusted with a mask so that one shot of pulsed laser beam creates a etched shape width of 1,000µm and the length of 80µm

.This setup can process substrate sizes of 600mm by 720mm of the 3.5th generation. Maximum XY table speed of the machine is 1,000mm/s.

The removal of ITO films by using this system with "GI-LDE" is performed. Figure 9 shows the intensity distribution of the laser beam of the system used for a test.

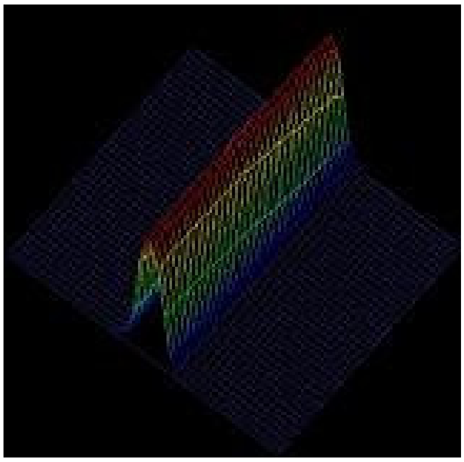

Fig.9 Intensity distribution of laser beam

The intensity distribution has an error margin of less than 3%, and the beam stability of this system is less than 1% in Pk-Pk. Since the final lens system is the imaging optics system, the irradiation beam width can be changed freely, and the use of a mask is also possible.

3. Etching qualities by "GI-LDE"

From above etching results, it is determined that proper fluence is 0.5J/cm^2. Figure 10 shows the result of wide width etching of 1,000µm for a large-scale CF substrate. For this etching, the table speed was 800mm/s and a pulse repetition rate was 10,000Hz.

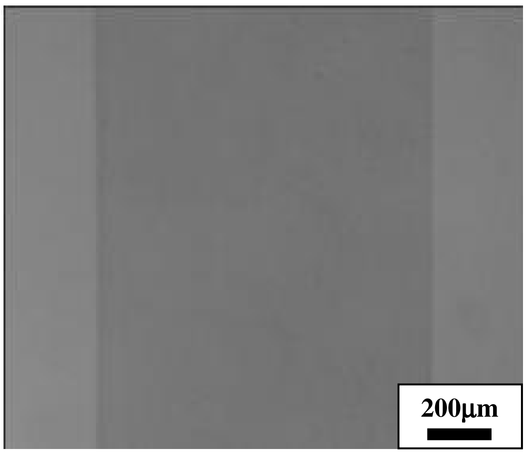

Fig. 9 Wide width etching of 1,000 µm per path

It is proven that ITO films at the black matrix position are finely removed without any damage as shown in this figure. The resistance across etched groove is over 2,000MΩ. The optical density (OD) of the etching area is over 3, which is equal to the non-etching area. In addition, the integrated etching rate is $500mm^2/s$ when using the substrate of 600mm x 720mm. The rate took into consideration acceleration and deceleration.

The surface roughness of the etched groove bottom was measured by a non-contact three-dimensional optical surface profiler (Zygo NewView 5000). The results are shown in figure 11.

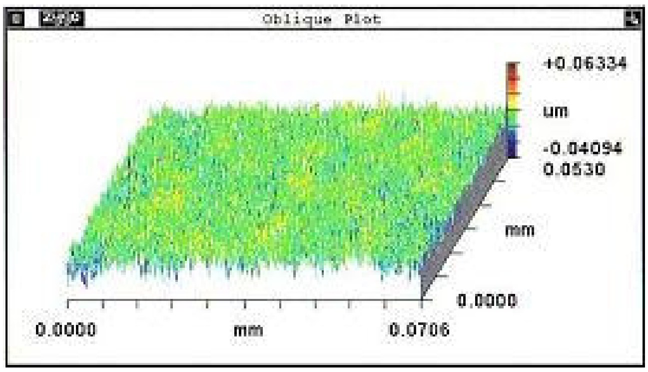

Fig.11 Deviation of the surface flatness of etched groove bottom

It is clear that surface roughness Ra is 7nm, and that damage has not occurred in the lower-layers nor the black matrix layer.

A scanning electron microscope (SEM) photograph taken at the edge of etched groove is shown in figure 12.

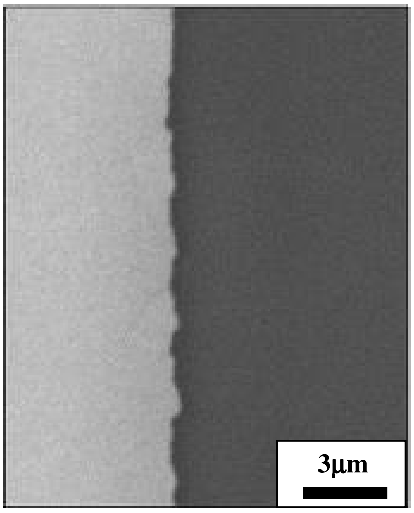

Fig.12 SEM photograph at etched groove's edge

Linearity of less than 1μm is obtained in the etched groove edge as shown in this figure. In addition, proper spacing between the ITO layers is made. However, with the DUV laser-dry-etching, those spacing are not properly created.

The surface height across the etched groove edge was measured every 40nm by a contact surface profiler (α-step). The height resolution of this profiler is 0.81nm. The result is shown in figure 13.

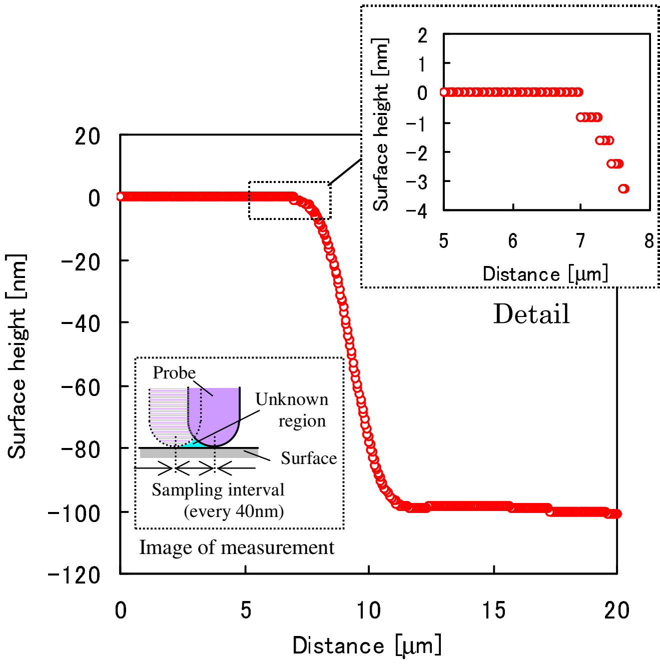

Fig.13 Groove edge shape

There is no ridge from the ITO film surface at the groove edge as shown in this figure. The probe of the profiler is round-tipped shape with 5μm radius. By calculating the gap between the probe and the ITO film along the probe shape from contact points, the error of 0.04nm height may occur in the center of adjacent data that are measured every 40nm. From the resolution of 0.81nm and the height error of unknown region of 0.04nm, the measurement deviation of height against a ridge from a flat surface is less than 0.85nm. Considering the error margin, the data shows that deviation from the surface is no greater than 0.85nm on the ITO film.

From figure 12, the groove edge is not actually showing traces of melting, but rather, it shows the edges that brittle surfaces that has come off. Therefore, the temperature of the groove edge has not reached melting point. Moreover, GI-LDE makes transmission intensity decrease and reflection intensity increase as shown in figure 5. Considering these features, GI-LDE does not give the material excess energy and works to reduce thermal affection.

The selective removal of the ITO film from within multi-layers, which is difficult when using a DUV laser or ultrafast laser, became possible by using the "GI-LDE". The grazing-incidence method produces very good results for both etching accuracy and quality of the selective ITO removal on the black matrix position. Moreover, its ability can be said that "GI-LDE" is very useful for thin film etching, not only for the use of LCD panel production.

4. Conclusions

The laser-dry-etching of ITO films from multi-layers by Q-switched DPSS laser is experimentally investigated. The main conclusions obtained in this study are as follows.

(1) The developed “grazing incidence method with laser-dry-etching (GI-LDE)” is very useful for the selective removal of thin film.
(2) ITO films at the black matrix position are finely removed without damage.
(3) The resistance across etched groove is over 2,000MΩ.
(4) The optical density (OD) of the etching area is over 3, which is equal to the non-etching area.
(5) A high quality etching that produces a surface roughness Ra of only 7nm in the etched groove bottom is accomplished.
(6) Linearity of less than 1 nm is maintained in the etched groove edge.
(7) The surface height of less than 0.85nm from ITO film surface is obtained at the etched groove edge.

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