Characteristics of Indium–Tin–Oxide (ITO) Glass Re-Used from Old TFT-LCD Panel

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In this study, glass substrate was re-used from old TFT-LCD, and characteristics of the re-used glass substrate were investigated. For the characterization, ITO layer was separated from the glass substrate by decomposing the color filter layer which is located between ITO layer and glass substrate using color filter stripping solutions. Surface roughness and optical transmittance of the glass substrate after removal of ITO and color filter layer were measured, and they were compared with those of newly produced one. As a result, surface roughness of re-used glass substrate between the two samples was rarely different. As well, difference in optical transmittance between the two samples was rarely different attributed to the surface roughness. Therefore, glass substrate was clearly re-used from old TFT-LCD panel. For more investigation, new ITO layers were coated onto the two glass substrates using ITO ink, respectively. After coating, electrical resistance and optical transmittance was investigated to observe effect of the roughness on the characteristics. [doi:10.2320/matertrans.MBW201122]

Keywords: indium tin oxide (ITO) glass, re-use, surface roughness, electrical resistance, optical transmittance

1. Introduction

Thin film transistor-liquid crystal display (TFT-LCD) is representative of flat panel displays. As the market of TFT-LCD has been steeply raised, lots of materials have been used to assemble TFT-LCD. Glass substrate is one of the key materials for TFT-LCD. Role of glass substrate is to support major components such as color filter, TFT device, and indium tin oxide (ITO), etc. Thus, the price of glass substrate is about 8% of total price of TFT-LCD panel. Among the components, ITO is widely used as transparent conductive oxide (TCO) electrodes.\(^1\) TCO electrode is one of the essential parts of flat panel displays including TFT-LCD. ITO is used in coated form onto glass substrate on which color filters or TFT devices are already formed. The characteristics of ITO glass have been stabilized through the continuous improvement for long time.

Unfortunately, in recent, old TFT-LCD panels are accumulated as new types of TFT-LCDs with fancy design and performance come out. Available ITO glass substrates are still included in the old TFT-LCDs, and recycling of the ITO glass substrates are paid attention. However, most of TFT-LCD is crashed for recycling. The crashed waste glasses are attempted to produce glass-ceramics\(^2\) or ceramic tiles\(^3\) from waste glass of old TFT-LCD panel. Most of the crashed glass is dissolved in molten bath for purification, and it is rebuilt as glass substrate or other glass products. The conventional recycling process of glass substrate is inefficient with high processing cost and long processing time. In this study, new approach to re-use without crushing was attempted. ITO glass substrate was separated from old TFT-LCD in its form, and glass substrate was re-used by separating ITO layer from it. After that, surface roughness and optical properties of the re-used glass substrate was characterized in order to determine whether it is still available to apply to ITO glass substrate. Also, the properties were compared with newly produced glass substrates. Finally, ITO ink was coated onto the re-used glass substrate followed by post heat-treatment, and characterization was conducted to compare with those under re-used states.

2. Experimental Procedure

Experimental flow is shown in Fig. 1. For re-using glass substrate, 7 inch sized old TFT-LCD panels were used. First, upper and lower plane was separated by cutting the edge of the old TFT-LCD panel. After cutting, the two planes were well separated by removing residual liquid crystal with alcohol. Using upper plane, glass substrate was re-used by separating ITO layer. ITO layer was lifted off by removing color filter which is located between them with alkaline chemicals. After that, physical and optical properties of the glass substrate was investigated by observing surface roughness and optical transmittance with atomic force microscope (AFM) and UV–VIS Spectrophotometer (JASCO, V-560), respectively. In final, characterization was performed after formation of ITO layer by using ITO ink. ITO ink contains 30 mass% ITO nanoparticle, and it was coated by spin coating onto the re-used glass substrate followed by heat-treatment at 400°C for 1 h. Then, electrical properties were characterized with above instruments and 4 point probe electrical measurement system (Mitsubishi Chemical Analytech, MCP-T610), respectively.

3. Results and Discussion

A part of upper plane separated from old TFT-LCD is shown in Fig. 2. In Fig. 2(a), edges of the glasses were sharply cut using the cutting machine, and the upper plane was well separated away from the lower plane of old TFT-LCD. Also, from revealed ITO layer on color filter shown in Fig. 2(b), it is shown that residual liquid crystal and polymeric rubbed layer on the ITO layer on color filter was clearly washed away by using alcohol. The removal of the polymeric layer is important for re-use of ITO as well as glass substrate. Then, in order to separate glass substrate out of

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ITO layer, the upper plane was put into color filter removing solutions which is commercially available. The solution is strongly alkaline containing some inorganic ions such as K components, etc. The dissolution was carried out by dipping the upper plane sample as seen in Fig. 3(a). As a result, the ITO and color filter layer was clearly removed out of the glass substrate of upper plane sample. The re-used glass substrate was compared with newly produced one as shown in Fig. 3(b). The bigger sized sample is newly produced glass, and small sized sample is re-used one. As seen in the figure, state of the glass is similar, i.e., the re-used glass is very clear. For more detail investigation, surface of the re-used glass was observed with optical microscope. As seen in Fig. 3(c), the surface is very clear indicating that residuals on the surface are rare. In fact, electrical resistance of the glass surface was measured with digital voltameter after re-use process. If color filter is still exist, resistance is measured owing to metallic black matrix components contained in color filter. However, in this case, the resistance was not measured indicating that the residuals do not exist. Thus, it is known that the glass was well re-used without any fracture.

After completion of re-use of glass substrate, surface roughness of the re-used side of the glass substrate was measured by using AFM system. As a result, shown in Fig. 4, the roughness of the re-used glass substrate was somewhat increased compared to that of newly produced one. That is, $R_a$ value of the re-used glass was 1.135 nm, and it is...
slightly higher than that of newly produced one, 0.399 nm. It is owing to fabrication of color filter layer on glass substrate for TFT-LCD. In general, surface of the glass substrate pre-treated with diluted chemical solutions in order to enhance adhesion of coated layer onto it. The roughness is assumed to be generated from the pre-treatment process. Thus, effect of the roughness on the characteristics of the re-used glass substrate is very important, and optical transmittance was observed. As a result, shown in Fig. 5, difference between the two glasses was not obvious. That is, optical transmittance of the re-used glass substrate was about 90\% at 550 nm, and it is similar with that of newly produced one. From the results, it is known that optical transmittance is rarely influenced by slight difference in $R_a$ of glass substrate. It is attributed that optical transmittance is mainly dependent upon materials, thickness and roughness of the substrate$^{4,5)}$. That is, rough surface morphology decreases optical transmittance due to increased optical absorption and surface scattering. However, in this case, it is supposed that the surface roughness did not strongly affect the optical transmittance. The reason for rare effect on the property is being investigated.

For more detail investigation, ITO ink was prepared for coating onto the two glass substrates. Detailed preparation procedure of ITO ink is reported in the previous literature$^{5)}$. ITO ink was spin-coated onto the two glass substrates followed by heat-treatment at 400°C for 1 h, respectively. After that, surface roughnesses of the samples were observed. As shown in Fig. 6, the roughnesses of the two samples were increased. That is, $R_a$ values of re-used and newly produced glass substrates with ITO layers are 7.361 nm and 9.088 nm,

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Fig. 4 Surface roughness of (a) newly produced glass substrate (b) re-used one.

Fig. 5 Optical transmittances of newly produced and re-used glass substrates.
respectively. It shows similar tendency with that of samples without ITO layer. In case of optical transmittance, shown in Fig. 7, the values of the two samples with ITO layer were very similar as well as without ITO layer. That is, optical transmittance of the re-used glass substrate was about 89% at 550 nm, and it is similar with that of newly produced one. From the results, it is known that optical transmittance is rarely influenced by ITO ink coating as well as slight difference in Ra of glass substrate. Also, it is reported that higher value of surface roughness is good for solar cell system. That is, surface with higher roughness reduces reflection of incident light leading to enhancement of efficiency. In case of electrical properties, difference in sheet resistance between the two samples was rarely observed. That is, as shown in Fig. 8, average sheet resistance of ITO coated layer on newly produced glass substrate of is $1.631 \times 10^3 \Omega/\text{sq}$ with deviation of $0.254 \times 10^3 \Omega/\text{sq}$. As well, average sheet resistance of ITO coated layer on re-used the glass substrate is $1.824 \times 10^3 \Omega/\text{sq}$ with deviation of $0.248 \times 10^3 \Omega/\text{sq}$. These phenomena are also owing to the slight difference in surface roughness between the two glasses leading to stabilization. From the result, it is known that re-use of glass substrate from old TFT-LCD is possible for sustainable development of flat panel display industries. In order to improve those optical properties with the improvement of the electrical properties, studies are being continued with the investigation on other parameters.
4. Conclusions

In this study, re-use of glass substrate from old TFT-LCD was attempted, and characteristics of the re-used glass substrate were investigated. As a result, glass substrate was well re-used by separating ITO layer from the glass substrate by decomposing the color filter layer using color filter stripping solutions. Also, surface roughness of re-used glass substrate was rarely different compared with that of newly produced one. Difference in optical transmittance between the two samples was rarely different as well. In addition, surface roughness, optical transmittance, and electrical sheet resistance between the two samples after coating of new ITO layers with ITO ink were rarely different. Therefore, it is expected that the re-used glass substrate is useful for the recycling of old TFT-LCD panel.

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REFERENCES