Development of High Resistivity Transparent Conductive Oxide Electrode using Sputtering Process

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For the In-Cell type touch screen panel, a high resistivity transparent electrode that can work as anti-static without affecting touch sensing is required. ULVAC selected Sputtering Process which is high in productivity and suitable for large size and successfully developed a high resistivity transparent conductive oxide electrode satisfying required specification.

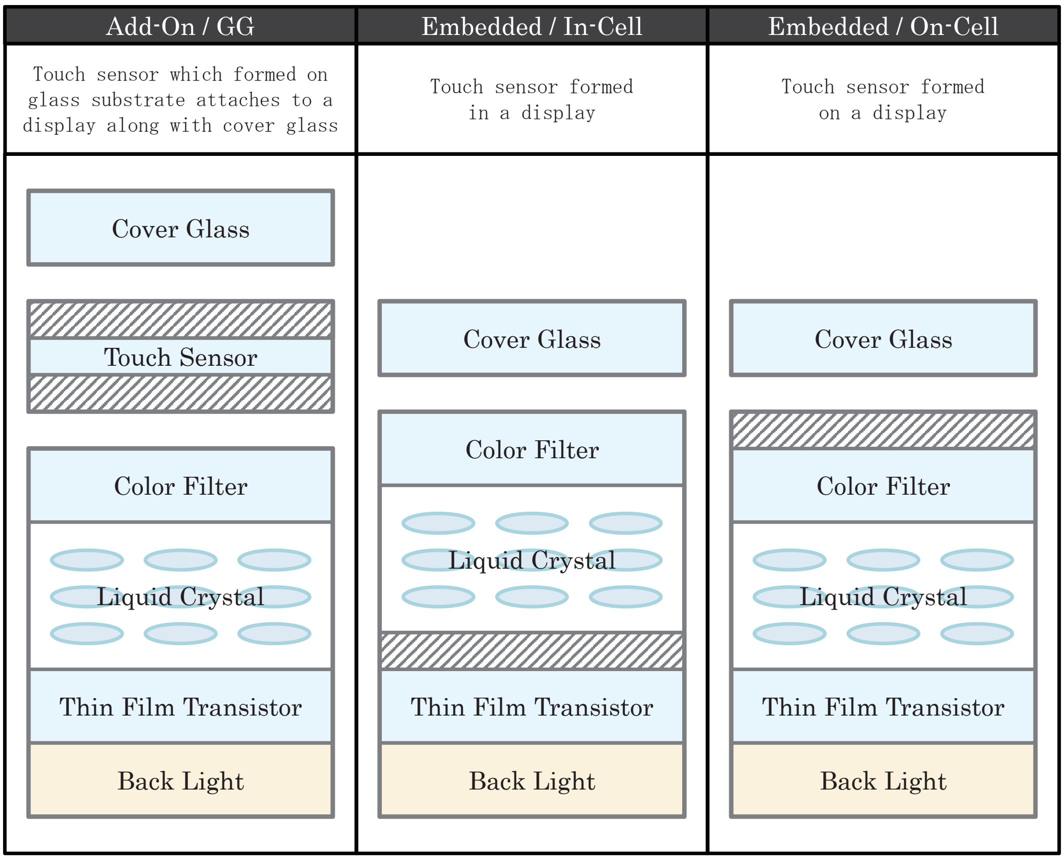
1. Introduction

Touchscreen panels have become familiar pointing devices since the appearance of mobile terminals, such as iPhones. Various electrode structures are employed to make touchscreen panels for smartphones and tablet terminals. As shown in Table 1, touchscreen panels of conventional smartphones have popularly adopted GG-based add-on structures, wherein touch sensors were attached to displays along with cover glass. In response to the market demand for thinner and lighter touchscreen panels, embedded structures were developed. Examples include in-cell design with a touch sensor formed inside a display, as well as on-cell design with a touch sensor formed on a display[1, 2]. In order to achieve both smooth display operation and high touch sensitivity, in-cell touchscreen panels need anti-static transparent electrodes that transmit high-frequency signals for touch sensing and shield against the interference of display operation caused by low-frequency or DC voltage.

2. The need for a transparent high-resistivity electrode

Liquid crystal displays on mobile devices with touchscreen panels employ in-plane switching (IPS) or fringe field switching (FFS) as the molecular orientation of liquid crystal is less affected by pressure on the display (applied by fingers and so forth) thanks to the horizontal molecular rotation along the glass substrate[3, 4]. In general,

Table 1 Touch Screen Panel Structure.



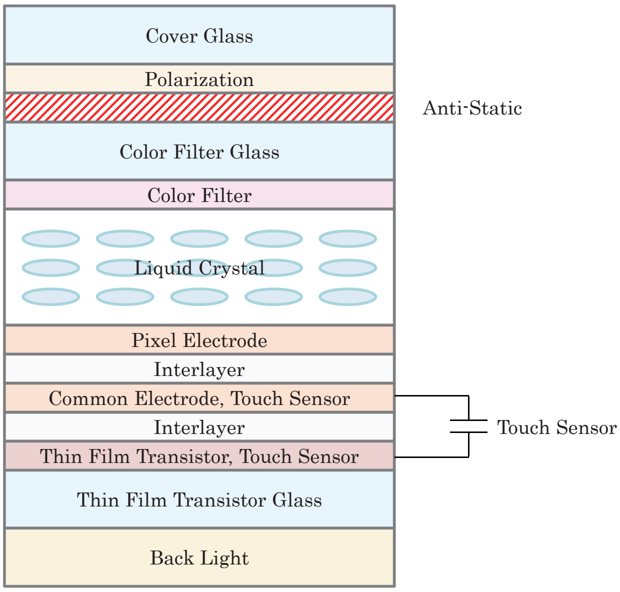


Figure 1　Structure of In-Cell type Touch Screen Panel.

liquid crystal displays based on IPS or FFS tend to suffer deterioration of their display performance as a result of static buildup on the glass substrate or of external electric fields. To address this problem, anti-static transparent electrodes made of indium-tin-oxide (ITO), for example, are employed at the back of the color filter glass. With reference to the touch sensor in the in-cell touchscreen panel in Figure 1, a low resistance of the anti-static transparent electrode near the cover glass touched by fingers and so forth leads to reduced sensitivity as high-frequency signals needed for touch sensing are also inadvertently shielded. Therefore, transparent high-resistivity electrodes are needed to transmit high-frequency signals for touch sensing and to shield against the interference of display operation caused by low-frequency or DC voltage[5, 6].

3. Specifications of a transparent high-resistivity electrode

The target sheet resistance for a transparent high-resistivity electrode was set to between 10^7 and 10^{11} Ω/□ given the required range from 200 MΩ to 2 GΩ/□ for integrated touchscreens[5] according to Japanese Patent No. 4741026. The target value for reliability assessment was a change of less than a factor of 10 in sheet resistance before and after the test with a constant temperature of 60℃ and a constant humidity of 90% for 240 hours. The transmittance was required to be no less than 95% according to the thin ITO film used for removing noise in the backlight (glass reference with wavelength of 550 nm).

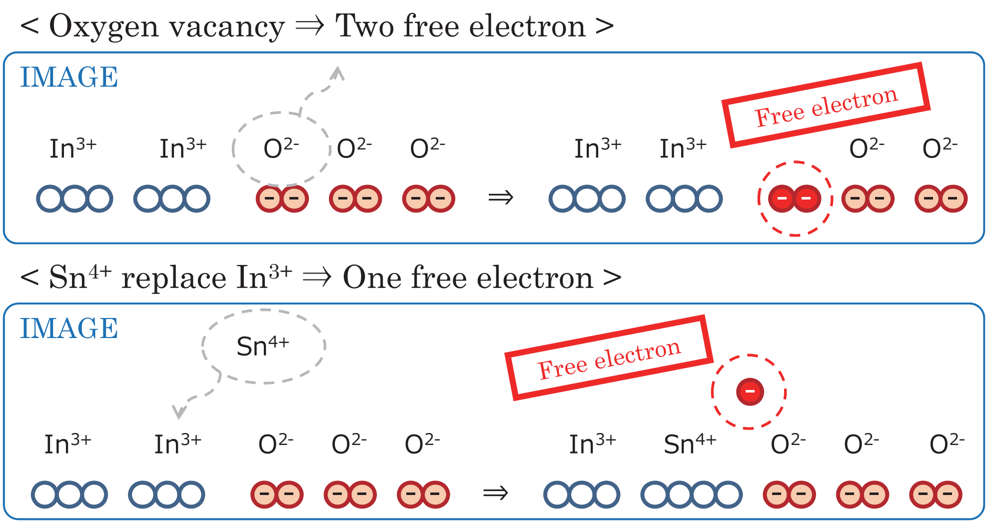
4. Evaluation of the usage of ITO with transparent high-resistivity electrodes

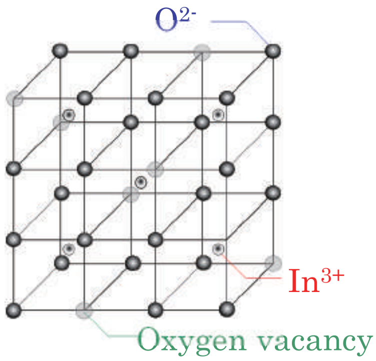
ITO is a semiconductor material made from indium oxide (In_2O_3) by doping tin oxide (SnO_2) as an impurity. It is widely used for making transparent low-resistivity conducting electrodes by sputter deposition. Figure 2 shows the conductance mechanism of ITO[7, 8]. Two In_2O_3 indium atoms release a total of six electrons and three oxygen atoms accept those six electrons to maintain stability. In the absence of an oxygen atom, two electrons released by an indium atom become redundant and free. Any replacement of an indium atom that releases three electrons by a tin atom that seeks stability by releasing four electrons results in a conductive property with one free electron. This release of free electrons can be suppressed by introducing extra oxygen during deposition to prevent oxygen defect formation, as well as oxidization of tin to avoid its ionization. Figure 3 shows the results from the evaluation of a transparent high-resistivity electrode made with ITO while adjusting the sheet resistance through the introduction of oxygen. The sheet resistance after deposition was able to achieve the target level between 10^7 and 10^{11} Ω/□ by setting the film thickness to 10 nm and adjusting the amount of oxygen introduced. However, after the test with a constant humidity under a high temperature, both of the values of sheet resistance on the order of 10^8 and 10^{10} Ω/□ dropped by a factor of 10 or more. This phenomenon is believed to be a result of stabilization away from an overabundance of oxygen because of the tendency of In_2O_3 materials to reduce themselves.

The evaluation results pointed to the limited reliability of a transparent low-resistivity electrode after the deposition of ITO even when the sheet resistance is adjusted by the introduction of oxygen.

5. Development of a deposition process for making transparent high-resistivity electrodes

Based on the results in Section 4 "Evaluation of the usage of ITO with transparent high-resistivity electrodes," it was deemed too difficult to make a transparent high-resistivity electrode that achieves the target by adjusting the deposition process of transparent low-resistivity electrodes made with ITO and so on. The development of an optimized process was deemed essential in order to provide manufacturing equipment to handle the task. Accordingly, basic development was conducted so that the new





< Unit cell of In_2O_3 >

	13(3B)	14(4B)	15(5B)
	5 B Boron	6 C Carbon	7 N Nitrogen
12(2B)	13 Al Aluminium	14 Si Silicon	15 P Phosphorus
30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic
48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony
80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth

< Periodic Table >

Figure 2 Conductivity Mechanism of ITO.

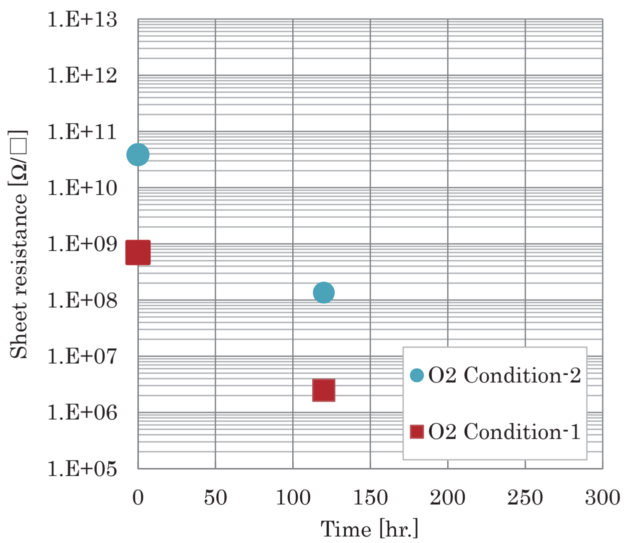


Figure 3 Sheet Resistance Stability of High Resistivity ITO Film.

deposition process satisfies the following requirements.

[1] Enhance base resistance by using conductive materials with greater resistance than that of ITO

[2] Expand the process window by reducing reactivity during the process

[3] Adjust the resistance by introducing a reactive gas

[4] Use different gases to adjust the resistance and enhance the transmittance

The development sought the application of a conductive material with a higher resistance than ITO while ensuring high productivity as an important advantage of the sputtering process without using radio frequency or other special power supplies. The process window was expanded by reducing the reactivity in the deposition process. The amount of one oxidization gas was kept to the necessary minimum to enhance the transmittance of the oxidized film. Another oxidization gas was used for adjusting the sheet resistance in pursuit of a deposition process that reliably achieves the target transmittance and sheet resistance.

Figure 4 shows the sheet resistance of the transparent high-resistivity electrode developed by ULVAC by means of sputtering. The sputtering targets had the same compositions under Conditions-A, -B, and -C. The film thickness was set to 10 nm. The sheet resistance was able to be adjusted in the target range between 10^7 and 10^{11} Ω/□. The change in sheet resistance was less than a factor of 10 in a

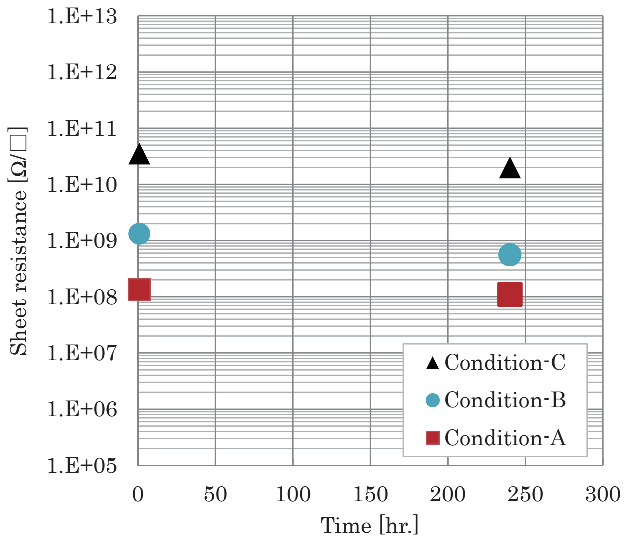


Figure 4　Sheet Resistance Stability of High Resistivity Transparent Conductive Oxide Electrode using Sputtering Process.

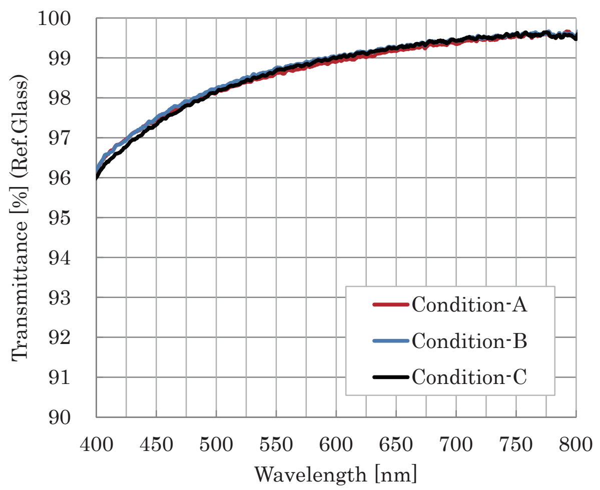


Figure 5　Transmittance of High Resistivity Transparent Conductive Oxide Electrode using Sputtering Process.

comparison before and after the test with a constant temperature 60℃ and a constant humidity of 90% for 240 hours. Figure 5 shows the transmittance spectrum of the glass reference. The sheet resistance under Conditions-A, -B, and -C change in the range between 10^7 and 10^{11} Ω/□. But there were no marked changes in transmittance, which greatly surpassed the expected level of 95% (glass reference, wavelength of 550 nm).

6. Technology required by manufacturing equipment of transparent high-resistivity electrodes

In a reactive sputter deposition process of a transparent high-resistivity electrode using a conductive material, the target must be conductive (i.e., low resistance) and the deposited film must have a high resistance in order to achieve a sheet resistance between 10^7 and 10^{11} Ω/□. The use of a DC sputter system suffers from unstable discharge between the cathode and anode when the performance of the anode is compromised by the deposition of high-resistivity film on it. A solution to this problem is a technique used in the reactive sputter process for optical film deposition. Using this technique, a film of silicon oxide (SiOx) can be obtained on the target surface, in plasma space, and on the substrate by introducing an oxidizing gas to the metal silicon (Si) target doped with boron (B), phosphorus (P), and so forth. In such a reactive sputter process for optical film deposition, ULVAC's unique Alternate Current (hereinafter "AC." AC is regarded as being medium frequency) cathodes is employed. The AC cathode shown in Figure 6 applies AC power from a power supply to two sheets of targets. Each target repeatedly changes its potential to that of cathode and anode. Even if a high-resistivity film is deposited on the target that serves as anode, the potential switches to that of the cathode in the next moment causing the deposited high-resistivity film to sputter away. In this manner, the anode can be permanently maintained to obtain stable discharge[9].

Transparent high-resistivity electrodes are attached with color filter glass and thin-film transistor glass by using an adhesive. Then, they are directly deposited on a display that underwent the slimming process to make the glass thinner. The deposition temperature must be lowered because the thin glass after the slimming process and the use of an adhesive bring down the upper temperature limit of the display. In order to make this possible, ULVAC's unique low-temperature sputtering technology

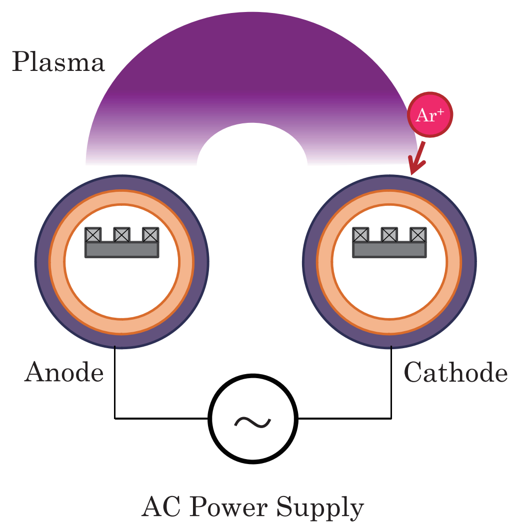


Figure 6　Schema of AC Sputtering Cathode.

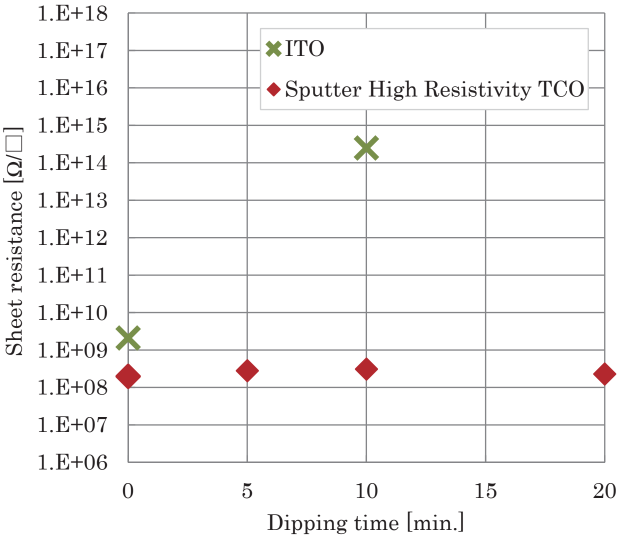


Figure 7 Chemical Corrosion Resistance Test.

is effective in preventing the rise in the substrate temperature. Such a process with a restricted deposition temperature poses another challenge of reduced chemical resistance due to insufficient crystallization. Figure 7 presents the change in the sheet resistance after soaking the sputtered transparent high-resistivity electrode in Section 5 "Development of a deposition process for making transparent high-resistivity electrodes" made with the ITO mentioned in Section 4 "Evaluation of the usage of ITO with transparent high-resistivity electrodes" when it is soaked in a mixture of phosphoric acid (73%), nitric acid (3%), acetic acid (7%), and water (17%) at room temperature. The film deposition of both ITO and the sputtered transparent high-resistivity electrode was performed at a temperature no greater than 80℃. The etching of the ITO thin film is assumed from the increase in the sheet resistance over the time it is soaked in the mixture. In contrast, there are no marked changes in the sheet resistance of the sputtered transparent high-resistivity electrode, which indicates a greater degree of freedom in handling in later processes and greater environmental resistance. Thus, the sputtered transparent high-resistivity electrode developed by ULVAC is expected to have wide application.

7. Conclusion

This article has described the development of a deposition process for transparent high-resistivity electrodes needed to make in-cell touchscreen panels. Sputtered transparent high-resistivity electrodes are made with a new deposition technique that is distinct from transparent electrode sputtering techniques that typically use ITO or reactive sputtering of silicon oxide used for making optical films. Unfortunately, it is very difficult to provide new manufacturing equipment without knowledge and experience in sputtering with ITO and silicon oxide. ULVAC will exert its development capabilities mainly in sputtering processes to launch new electrode deposition technologies on the market and drive further evolution of touchscreen panel production.

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