Sensors and Materials, Vol. 29, No. 9 (2017) 1285–1290
MYU Tokyo

S & M 1422

Fabrication of Single-Layer Touch Screen Panel with Corrosion Resistant Metal-Mesh Electrodes

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(Received April 27, 2017; accepted May 18, 2017)

Keywords: touch screen panel, metal-mesh, corrosion, transparent, sheet resistance

We demonstrate a 7-inch single-layer touch screen panel (TSP) using highly conductive, flexible, and transparent metal-mesh electrodes. Our touch sensor shows a transmittance of 86.3% at 550 nm and high corrosion resistance in 85/85 and salt spray testing. The 85/85 test was chosen to evaluate the combined effects of high humidity and high temperature. The combined stress of 85 °C and 85% relative humidity (RH) did not cause failure in the TSP.

1. Introduction

Touch sensors on many IT devices such as smartphones, tablets, and monitors are manufactured using indium tin oxide (ITO), which has high light transmittance(1) and no pattern visibility. However, one limitation of ITO is the requirement of a large area due to its high surface resistance. Additionally, a lack of physical flexibility makes it difficult to use in flexible displays. As alternatives, copper or silver-based metal meshes with high conductivity and excellent flexibility have been developed and actively studied.(2–4) To commercialize an opaque metal electrode using a touch sensor, it is necessary to improve the transmittance and to form a pattern that cannot be recognized. In addition, it is necessary to overcome its sensitivity to the heat and corrosive chemicals used in conventional photolithography processes.

The transmittance can be increased by decreasing the mesh line width and increasing the pitch as shown in Fig. 1.(5) The visibility can be improved by a black-oxide treatment to reduce the amount of light reflected from the metal surface.(3) However, the results of studies on improving the corrosion resistance of metal-mesh electrodes in 720 h 85/85 testing(6) are not promising.

In this study, we developed a single layer 7-inch touch screen panel (TSP) with high corrosion resistance. The causes of corrosion in metal-mesh electrodes and bus lines of the passivation/conduction/passivation (PCP) structure(7) used to improve the corrosion resistance were analyzed. Based on the analytical results, an experiment was then conducted to determine the optimal thickness of the top passivation layer to improve the corrosion resistance of the metal-mesh electrodes. Using a metal layer with the optimized PCP structure, a TSP could be fabricated that is corrosion free after being subjected to a 720 h 85/85 test.

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http://dx.doi.org/10.18494/SAM.2017.1633

ISSN 0914-4935

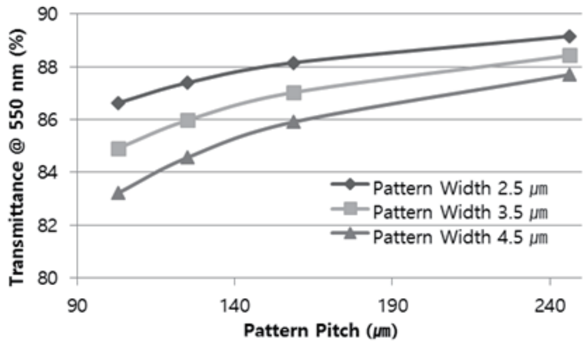


Fig. 1. Variation of transmittance of metal mesh sensors with respect to pattern density.

2. Fabrication of Single-Layer TSP

We fabricated a 7-inch single-layer TSP using metal-mesh electrodes on a flexible substrate (Fig. 2). The metal-mesh electrodes were deposited as PCP structures. The TSP was then evaluated for corrosion resistance and for its optical and electrical properties. The touch sensor for the TSP was fabricated by an R2R process consisting of the following steps: sputtering, lamination, exposure, development/etching/strip (DES), and inspection. Figure 3 illustrates the R2R process. To produce the PCP structure, a 20 nm-thick Cu-Ni alloy layer is first deposited on PET film. After sputtering the bottom alloy layer, a 100 nm-thick Cu layer is sputtered on the bottom alloy layer. Then, varying thicknesses of a top Cu-Ni alloy layer are deposited on the Cu layer. After the deposition process, the metal layer is patterned using post processing, and a flexible printed circuit board (FPCB) is attached to the pattern using anisotropic conductive film (ACF).

3. Failure Analysis in Environmental Reliability Test

Figure 4 shows the results of cross-sectional analysis of a corroded region from the 85/85 test. As a result of the enlargement of the pore area shown in the figure, it was found that the inner conduction layer was corroded and only the top passivation layer remained. In the transmission electron microscope (TEM)-bright field (BF) image, a small hole in the top passivation layer was detected, and it was confirmed that there was corrosion in a wide area of the lower conduction layer. From these results, it was concluded that typical pitting corrosion[8] occurred.

Among the many causes of metal corrosion, pitting corrosion refers to rapid corrosion that progresses inward through the protective layer of a surface. It does not occur in areas where widespread corrosion is present. This corrosion characteristic is consistent with the TEM image observed, especially where the uppermost passivation layer is perforated and the corrosion of the internal conduction layer is relatively intense. Pitting corrosion is a major failure mode in 85/85 testing.

In addition to these observations, elemental analysis using a scanning transmission electron microscope (STEM) was performed on the area where pitting corrosion was observed. As shown in Fig. 5, Cl^- ions were present in the area where the pore exhibited pitting corrosion and absent in the areas that were not corroded. This result is observed on both the right and left lower images of Fig. 5. This clearly indicates that Cl^- ions play an important role in the pitting corrosion.

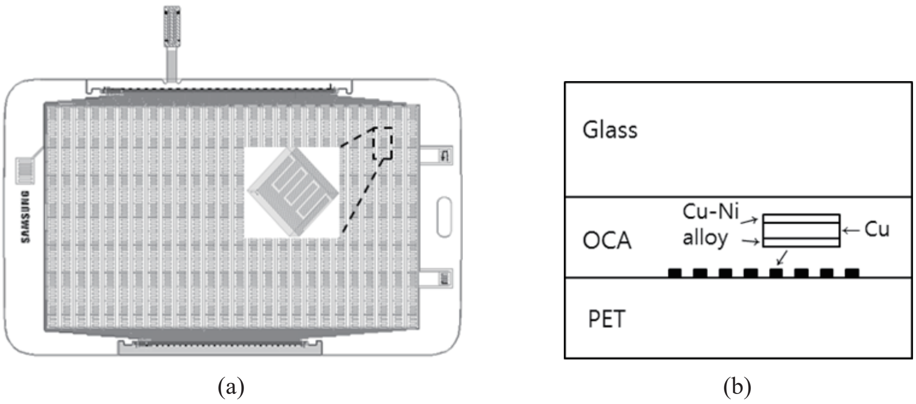


Fig. 2. An overview of the proposed TSP: (a) schematic and (b) structure.

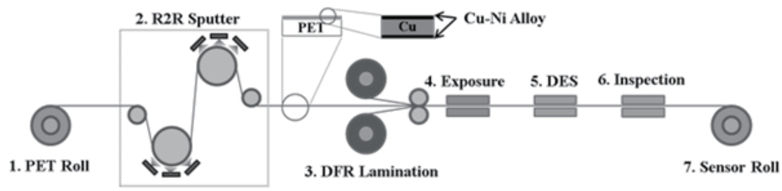


Fig. 3. R2R process used for the fabrication of touch sensors.

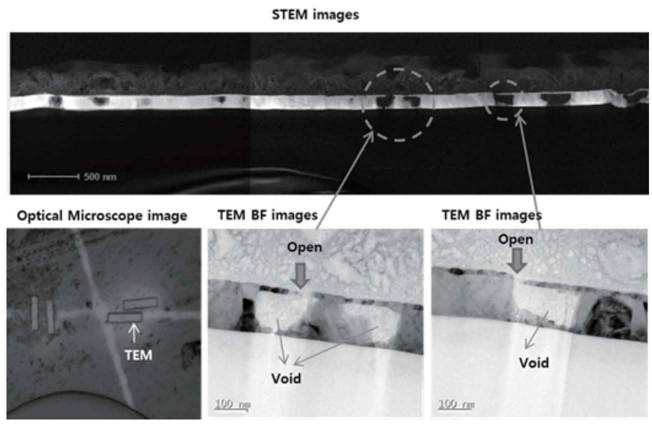
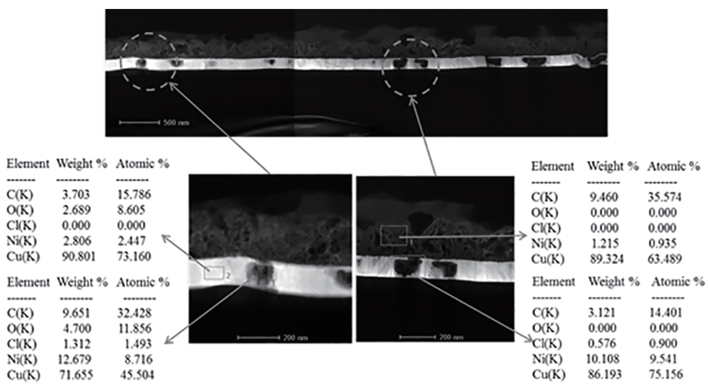


Fig. 4. Results of TEM section analysis in defective area.



Element	Weight %	Atomic %
C(K)	3.703	15.786
O(K)	2.689	8.605
Cl(K)	0.000	0.000
Ni(K)	2.806	2.447
Cu(K)	90.801	73.160

Element	Weight %	Atomic %
C(K)	9.651	32.428
O(K)	4.700	11.856
Cl(K)	1.312	1.493
Ni(K)	12.679	8.716
Cu(K)	71.655	45.504

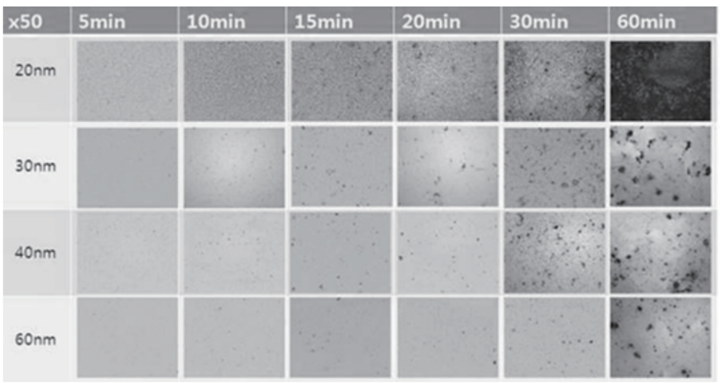
Element	Weight %	Atomic %
C(K)	9.460	35.574
O(K)	0.000	0.000
Cl(K)	0.000	0.000
Ni(K)	1.215	0.935
Cu(K)	89.324	63.489

Element	Weight %	Atomic %
C(K)	3.121	14.401
O(K)	0.000	0.000
Cl(K)	0.576	0.900
Ni(K)	10.108	9.541
Cu(K)	86.193	75.156

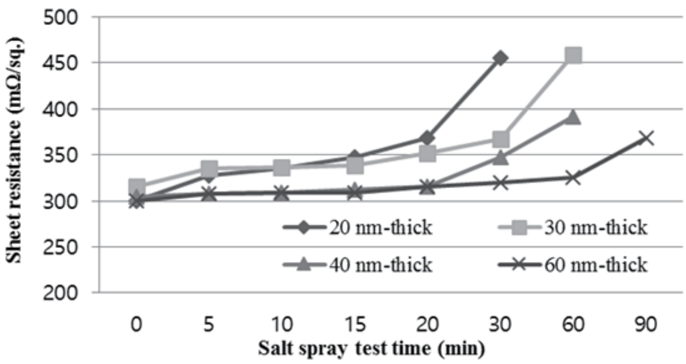
Fig. 5. Results of energy dispersive X-ray analysis (EDX) in the defective areas and surrounding areas.

From this analysis, it was concluded that pitting corrosion proceeds rapidly through the surface of the top passivation layer damaged by dissociated Cl^- ions which react with moisture. Therefore, we chose to increase the thickness of the top passivation layer, which acts as a barrier, to improve the resistance to pitting corrosion. A barrier film(9,10) can be applied to prevent penetration of moisture into the passivation layer, but this was not done in this study due to the mechanical problems associated with increasing the ultimate thickness of the TSP.

To verify the integrity of the passivation layer, the pitting corrosion resistance to salt spray was evaluated by increasing the deposition thickness of the top passivation layer from 20 nm to 30, 40, and 60 nm. The salt water spray consists of a 5 wt% aqueous solution of NaCl, and the TSP was kept in an accelerated corrosive environment where oxygen, Cl^- ions, and moisture were continuously supplied. The passivation layer was then cleaned with pure water. A sample dried at room temperature with an air blower was then observed under an optical microscope. For a top passivation layer thickness of 20 nm, it was confirmed that pitting corrosion occurred over the entire surface within 5 min. As the passivation thickness was increased, the frequency and density of pitting corrosion decreased. Therefore, it was confirmed that increasing the thickness of the top passivation layer delays damage due to pitting corrosion. Figures 6(a) and 6(b) show the surface of the top passivation layer and the sheet resistance of the thin metal film of the PCP structure versus exposure time to salt spray.



(a)



(b)

Fig. 6. Time dependences of (a) the state of surface and (b) sheet resistance after spraying with 5 wt% aqueous NaCl.

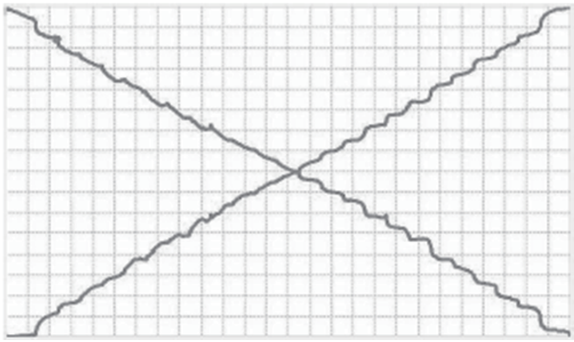


Fig. 7. Linearity results for a single layer 7-inch TSP with 4Φ cooper stick.

4. Results

4.1 The 85/85 test of single-layer TSP

The steady-state temperature humidity bias life test is known as the 85/85 test. The temperature is held at a constant 85 °C and at a RH of 85%, and the test "is performed for the purpose of evaluating the reliability of non-hermetic packaged solid-state devices in humid environments. It employs conditions of temperature, humidity, and bias that accelerate the penetration of moisture through the external protective material or along the interface between the external protective material and the metallic conductors which pass through it".[6]

The TSP was fabricated on thin metal film with a top passivation layer deposited at various thicknesses and the 85/85 test was performed for 720 h. Only the TSP with a PCP structure of metal-mesh electrodes with a top passivation layer thickness of 60 nm had no failures. For the 60-nm-thick passivation layer, it is clear that the combined conditions of 85 °C and 85% RH did not constitute a high enough stress to cause the TSP to fail.

4.2 Optical, electrical, and operational properties of single-layer TSP

The optical transmittance and the sheet resistance of the samples were investigated. Throughout the optimization of deposition conditions, we obtained a transmittance value of 86.3% at a wavelength of 550 nm and a sheet resistance of 40 Ω/sq.

After attaching the TSP to a smartphone, a touch operation test was performed with a 4Φ stylus. As shown in Fig. 7, we confirmed that the TSP works normally in terms of touch sensitivity. The linearity, however, is poor. This will be improved later with a modified touch electrode pattern.

5. Conclusion

We have developed a single layer 7-inch TSP using a highly conductive and transparent PCP electrode. A touch sensor with a metal-mesh PCP structure was fabricated using an R2R process. The linewidth of the fabricated electrode was 3.5 μm, the sheet resistance was 40 Ω/sq, and the transmittance was 86.3% at 550 nm. To strengthen the corrosion resistance, the main causes of corrosion were analyzed. Based on the results, the thickness of the top passivation layer was optimized and the TSP was able to withstand the 720 h 85/85 test.

Acknowledgments

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by Ministry of Education (NRF-2015R1D1A1A01057278).

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