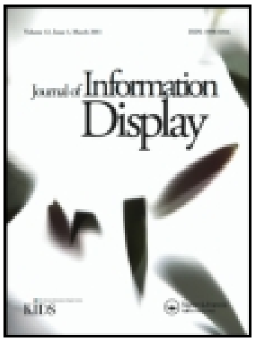

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Fabrication of a single-layer metal-mesh touchscreen sensor using reverse-offset printing

Young-Man Choi*, Kwang-Young Kim, Eonseok Lee, Jeongdai Jo and Taik-Min Lee

Department of Printed Electronics, Korea Institute of Machinery and Materials, Daejeon, South Korea

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The touchscreen sensor is one of the most innovative parts of modern electronic devices. Transparent conductive materials such as indium-tin oxide, silver nanowire, carbon nanotube, and metal mesh are used for the capacitance-sensing electrodes of touchscreen sensors. For patterning, most transparent conductive materials require a conventional patterning process of thin-film deposition or coating, photolithography, and etching to form sensing electrodes, and additional fabrication processes for routing electrodes. Printing techniques, however, can simplify the fabrication process of touchscreen sensors. Especially, reverse-offset printing can implement an ultra-fine pattern of even less than 1μm, and an excellent surface quality, regardless of the pattern size. In this paper, the fabrication process of a 6.5-inch single-layer metal-mesh touchscreen sensor printed on a transparent plastic film is described. Using silver nanoparticle ink, the sensing and routing electrodes are printed at once in a single layer using the reverse-offset-printing technique.

Keywords: word; touchscreen sensor; reverse-offset printing; metal mesh

1. Introduction

Touchscreen sensors have been made of transparent conductive materials like indium-tin oxide (ITO) because ITO has good electrical conductivity and optical transmittance. The conventional photolithography and wet etching processes are generally used to pattern ITO thin films for the formation of touch-sensing electrodes. The patterned ITO electrodes are connected to driving IC through metal routing electrodes. Considering the future displays, ITO has a couple of drawbacks. First, it is not compatible with flexible devices because it is weak when subjected to mechanical stress at bending. Second, for large displays, the conductivity of ITO cannot meet the required response time for touch sensing. Finally, the complex fabrication process of ITO electrodes increases the total cost of the touchscreen panel. As such, alternatives to ITO have been proposed, such as metal mesh [1], carbon nanotube [2], and silver nanowire [3]. Among them, metal-mesh electrodes have the highest conductivity and have good optical transparency and flexibility. Silver or copper is often used to satisfy the conductivity requirement. The metal mesh consists of fine line patterns with large openings. For hand-held devices, the line width of the metal electrodes should be less than several micrometers so as to be invisible to the human eye. As electronic devices like mobile phones and wearable devices are becoming slimmer and lighter, a single-layer touchscreen sensor has been developed [4,5]. The single-layer touchscreen sensor has only one transparent conductive layer, which has a grid or matrix of electrodes that makes the fabrication process simple and cost-efficient. The single-layer touchscreen sensor is also lighter and thinner, and it achieves higher transmittance compared to the conventional two-layer touchscreen sensors [5].

Printing techniques like inkjet, gravure-offset, and screen printing have been studied as alternative patterning methods for electronic circuits [6]. Direct printing using functional inks can reduce the number of processes and the equipment costs. Metal meshes are printed using metal nanoparticle inks and are sintered by hot air or infrared light. The printed metal mesh shows good flexibility because it consists of thin and narrow lines. If the printing technique is adopted as a fabrication method for touchscreen sensors, the single-layer metal-mesh touchscreen sensor can be a promising technology for overcoming the drawback of ITO and can meet the requirements of flexible devices.

In this paper, a single-layer touchscreen sensor fabricated via reverse-offset printing is demonstrated. The active sensing area and the routing electrodes are printed at the same time. Using silver nanoparticle ink, a highly defined pattern and a smooth surface are obtained.

2. Reverse-offset printing

Reverse-offset printing [7–10] is a printing technique that is capable of patterning very fine lines with a uniform thickness. Thus, it has been studied for application to

*Corresponding author. Email: ymchoi@kimm.re.kr

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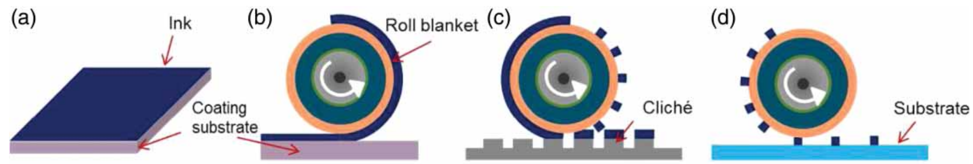

Figure 1. Reverse-offset process: (a) coating; (b) transfer; (c) off; and (d) set.

thin-film transistors for liquid crystal display backplanes [7–9]. Figure 1 describes the process of reverse-offset printing. First, silver nanoparticle ink is spin-coated on a coating substrate, which has very low surface energy. During the spin coating, the solvent in the ink is mostly evaporated, making a semi-dried ink film (Figure 1(a)). Then the blanket roll, a cylinder wrapped with a poly-dimethylsiloxane (PDMS) blanket, rolls over the coating blanket to transfer the silver film (Figure 1(b)). For patterning, the blanket roll moves over a cliché with proper pressure. The cliché has the intaglio pattern of a touchscreen sensor. As the cliché has higher adhesion compared to the blanket, all the unnecessary parts in the Ag film are taken away from the blanket roll (Figure 1(c)). Finally, the blanket roll moves over a substrate to transfer the patterned Ag film (Figure 1(d)). In typical contact printing techniques like gravure, the ink is separated inside during the transfer from a gravure cell to a substrate. Thus, it cannot achieve 100% ink transfer, and the transferred ink forms an arbitrary shape. In the reverse-offset printing, the patterned ink film is completely transferred from the blanket to the substrate, without any deformation. The surface roughness is maintained or is improved by impressed rolling.

In reverse-offset printing, the printing quality is determined by two factors: the adhesion and cohesion of the ink film. In every step, the two factors need to be controlled delicately. At the transfer and set step, the adhesion difference plays an important role. At the off step, the ink cohesion must be overcome by the adhesion to the blanket to have the ink film cut at the edges of the trenches of the cliché. From the viewpoint of the printing parameters, except the ink properties, these two factors can be adjusted by the printing pressure and the printing speed. Normally, a high printing pressure helps in the facture of the ink film, reducing the ink cohesion, and improves the adhesion to the substrate. The printing speed can adjust the adhesion of the PDMS blanket due to its viscoelastic property [11].

Figure 2 shows a lab-made reverse-offset-printing equipment. It has three stages for coating the substrate, cliché, and substrate. The blanket roll moves, rolling over the three stages in a regular sequence. A customized PDMS blanket sheet (R16, KNW) is wrapped over the blanket roll. The cliché is made of an 8-inch silicon wafer using photolithography and dry etching to have deep anisotropic trench patterns. The touchscreen sensor has a 6.5-inch active area, which consists of the metal-mesh pattern with 86% transmittance. The line width of the metal-mesh patterns is set to 10 μm. Ag nanoparticle ink (RO ink 39 wt%, Advanced Nano Products) is spin-coated at 8000 rpm for 10 s. Samples are printed on a transparent polyimide (PI) film (Neopulim®, MGC) for high-temperature thermal sintering. After printing, the printed touchscreen sensor is sintered in a furnace for 30 min at 280°C, below the 303°C glass transition temperature of the PI film. As the PI film has 90% optical transmittance, the ideal transmittance is about 77.4%. The spectral transmittance is measured at 200–1000 nm with a UV-VIS spectrometer (S-3100, Scinco). To check the distribution of the optical transmittance over the touchscreen sensor, the total transmittances at different points are measured with a haze meter (HM-150L2, MCRL).

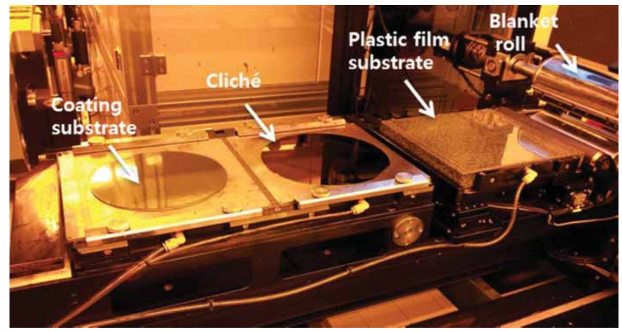

Figure 2. Reverse-offset-printing equipment.

3. Results

As shown in Figure 3, the whole touchscreen sensor is printed on a flexible transparent film. As with the routing electrodes, the metal-mesh patterns in the sensing area are perfectly formed on a single layer. Due to the thin and uniform thickness, the pattern maintains its shape, without shrinkage. Figure 4(a) demonstrates the metal-mesh electrodes in the sensing area. The edges of the metal mesh are clearly defined. The line width is slightly larger than 10 μm because the trenches in the cliché are overetched. Thus, the optical transmittance of the metal mesh itself is about 85%, which is slightly smaller than the designed value. Even with small spaces between lines, the routing electrodes are printed clearly, with the same surface quality as with the metal meshes, as shown in Figure 4(b). The resistivity of the electrodes is 30–60 μΩ cm, which is enough for the touch applications.

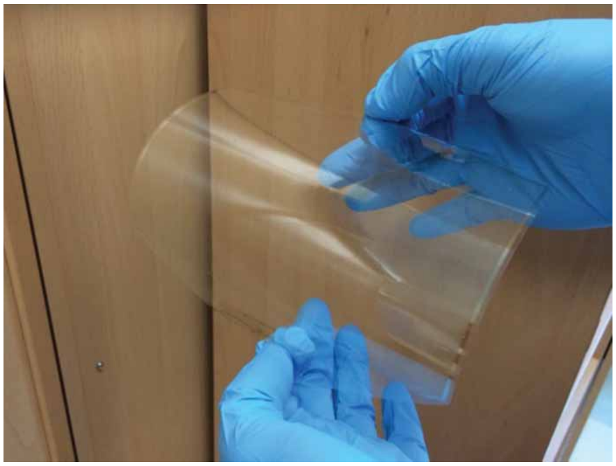

Figure 3. 6.5-inch single-layer touchscreen sensor module printed on a flexible PI film.

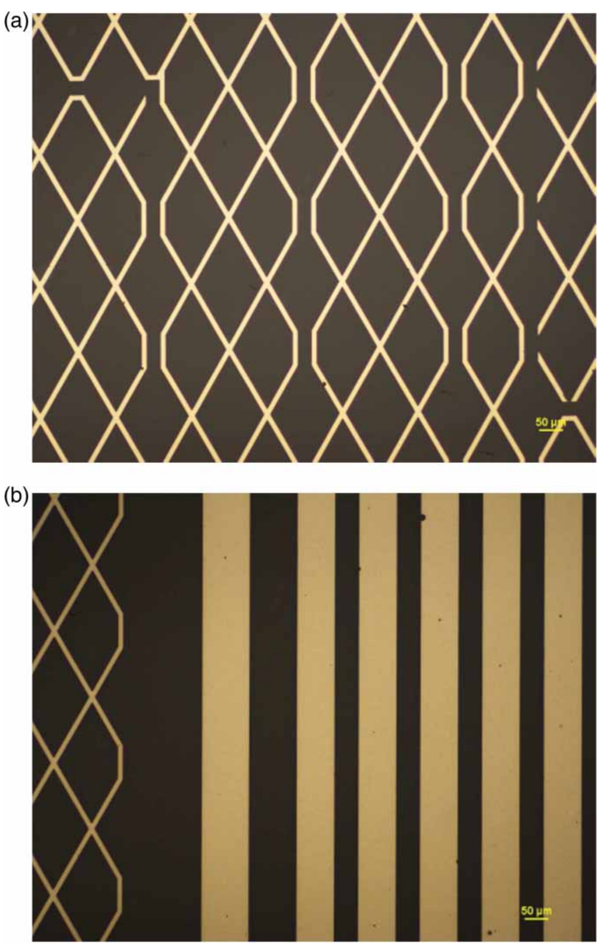

Figure 4. Printed metal-mesh patterns: (a) sensing electrodes and (b) routing electrodes.

Figure 5 shows the optical transmittances of a PI film and the printed metal mesh. The transmittance of the printed metal mesh shows a flat top profile. The general ITO films show a large transmission loss in the red and

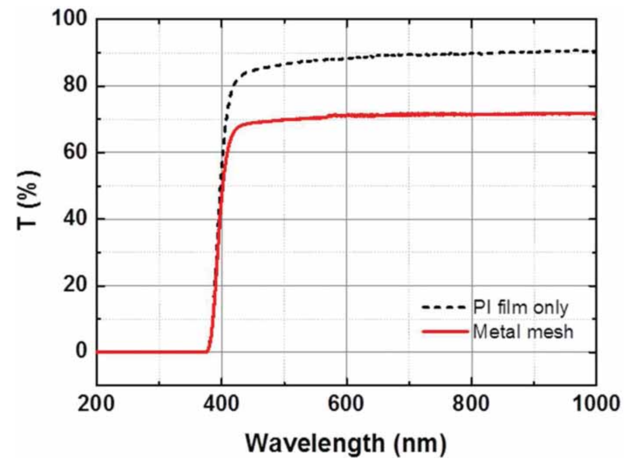

Figure 5. Optical transmittance of the printed metal mesh.

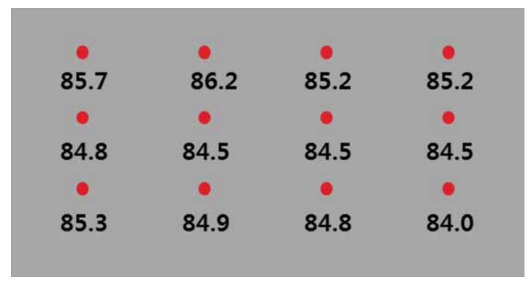

Figure 6. Distribution of the optical transmittance (%).

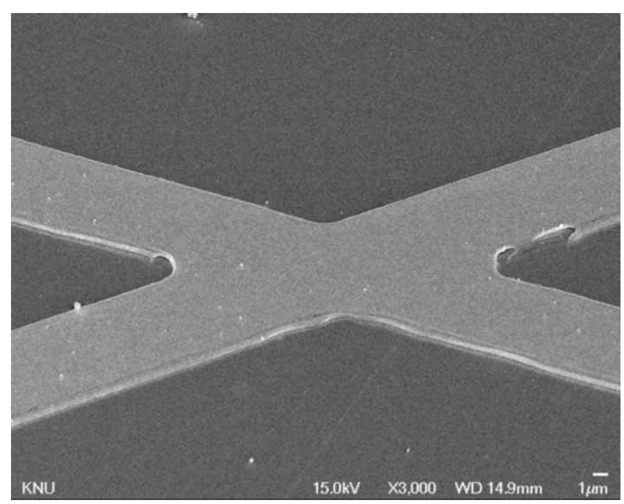

Figure 7. SEM image of a metal-mesh electrode (× 3000).

blue regions [12]. Thus, the metal mesh has a superior color quality when a display panel is integrated.

To verify the uniformity of the printing process, the distribution of the optical transmittance of the touchscreen sensor was checked. The total transmittances were measured at 12 points over the touchscreen sensor. Figure 6 presents a quite uniform distribution within 85 ± 1%. As the line width distribution can be predicted from the

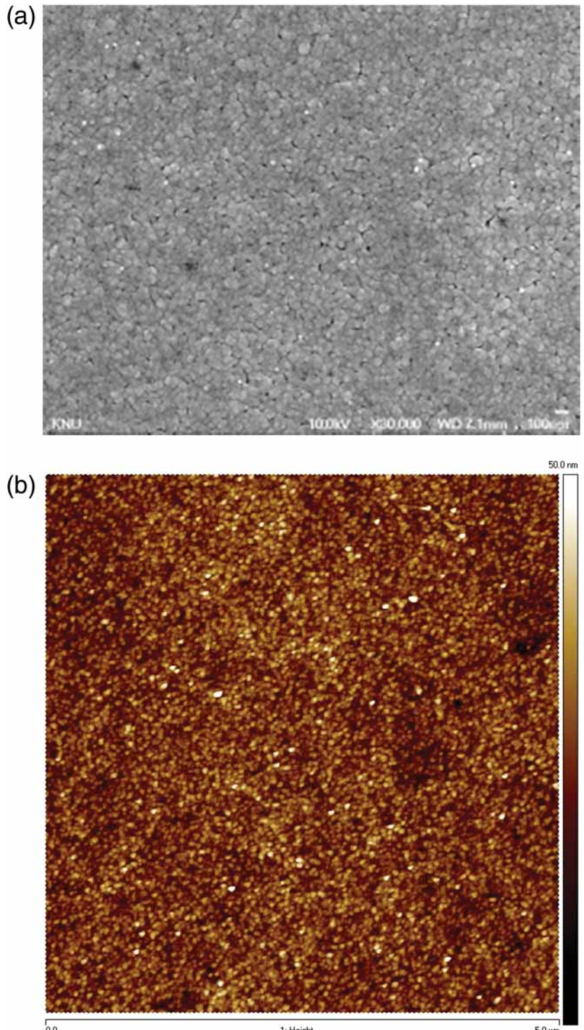

Figure 8. Surface images of the printed electrode: (a) SEM and (b) AFM.

transmittance distribution, it may be guessed that the line width distribution is 10.5 ± 0.6 μm.

Excellent surface quality is the main advantage of reverse-offset printing. Figure 7 shows the scanning electron microscopy (SEM) image of the metal mesh. The surface is very smooth, and the thickness is uniform across the line pattern. Figure 8(a) shows the microscopic structures of the Ag nanoparticles formed, necking one another. The sintered particle size is quite uniform, about 40 nm in diameter. As can be seen in Figure 8(b), the atomic force microscope (AFM) measurement of the electrode surface agrees with the SEM result. The surface roughness (R_a) was found to be about 4.3 nm.

4. Conclusions

In this paper, a new touchscreen sensor fabrication method is demonstrated. As a prototype, a 6.5-inch single-layer metal-mesh touchscreen sensor is fabricated in only one printing process of reverse-offset printing. The printed metal mesh has an ultra-fine pattern definition and an excellent surface quality. Also, it has superior electrical conductivity, enough for capacitance sensing. In the future, the reverse-offset-printing process will be applied to larger panels (over 12 inches) with a metal-mesh electrode line width of less than 5 μm.

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Notes on contributors

Young-Man Choi received his B.S., M.S., and Ph.D. degrees from the Department of Mechanical Engineering of Korea Advanced Institute of Science and Technology (KAIST), Republic of Korea in 2002, 2004, and 2008, respectively. From 2008 to 2011, he worked with National Institute of Standards and Technology (NIST), USA, particularly on the project on MEMS nanopositioning and metrology systems for nano electromechanical systems (NEMS)/micro electromechanical systems (MEMS). Since he joined Korea Institute of Machinery and Materials (KIMM), he has been working on precision machines and processes for printed electronics.

Kwang-Young Kim received his Ph.D. degree in mechanical engineering from Dong-A University, Republic of Korea in 1992. At present, he is a principal researcher in the Printed Electronics Department of KIMM. Since he joined KIMM in 1981, he has been working on machine and device design for printing electronics. His interests are offset printing machines, organic thin film transistors, flexible display, and sensor application for printed electronics devices.

Eonseok Lee received his B.S. and M.S. degrees from Pukyung National University in 2011 and 2013, respectively. Since 2013, he has been working with the Printed Electronics Department of KIMM. His main research interests are transparent conductive electrodes, touchscreen sensors, and the development of overlay accuracy for multilayer printing.

Jeongdai Jo received his Ph.D. degree in nanomechanics from Tohoku University, Japan in 2008. Since 1996, he has been working with KIMM, particularly on printed organic devices of organic thin film transistors and organic photovoltaics. He is interested in developing a new fabrication process inspired by the conventional printing/ coating technologies.

Taik-Min Lee received his Ph.D. degree in mechanical engineering from KAIST, Republic of Korea in 2002, was a post-doctoral associate at Micro & Nano System Laboratory of Massachusetts Institute of Technology (MIT), Boston, USA in 2002–2003, then joined KIMM. He is now the head of the Department of Printed Electronics of KIMM. His research interests lie in the fields of printing processes and equipment for printed electronic devices, sensors, and actuators. Since 2013, he has been the convener of Working Group 3 (Equipment) of IEC-TC119 (Printed Electronics).

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