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[Invited Paper]

An application of ESD technology for the R2R printing process †

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Abstract

The conductive coating method is used for various industrial fields. For example, the sputtering process is used to coat the ITO layer in LCD or OLED panel manufacturing process and fabricate a base layer of substrate of an electric printing device. However, conventional coating processes (beam sputtering, spin coating etc.) have problems in the industrial manufacturing process. These processes have a very high cost and critical manufacturing environment as a vacuum process. Recently, many researchers have proposed various printing processes instead of conventional coating processes. We propose an ESD printing process in ITO coating layer and apply to fabricate a conductive coating film. Furthermore, the effect of the nozzle and also the applied voltage on different configurations of the nozzle head was also studied for better understanding of the electro static deposition process.

Keywords: Coating method; Electro Static Deposition (ESD); Conductive polymer; Roll-to-Roll (R2R)

1. Introduction

PEMS (printed electro-mechanical system) is fabricated by means of various printing technologies. Passive and active components in 2D or 3D such as conducting lines, resistors, capacitors, inductors and TFT, which are printed with functional materials, can be classified in this category. And the issue of PEMS is applied to a R2R process in the manufacturing process.

In many electro-devices, the vacuum process is used as the manufacturing process. However, the vacuum process has a problem: it is impossible to apply to a continuous process as an R2R printing process.

Transparent electrode has been used in the various industrial fields. For example, it is being used as a base layer in LCD, OLED and Touch panels. Also, it has a high conductivity and high transparency. Therefore, many developers have applied the ITO coating layer. However, process ofof the ITO coating have process has a very high cost and critical manufacturing environment as a vacuum process. Therefore, recently, many researchers have proposed a various printing processes instead of conventional coating processes. In this paper, we propose an ESD (electro static deposition) printing process has been used to apply a conductive polymer. ESD is a method of liquid atomization by electrical forces. The r atomizer nozzle is usually made in the form of a metal capillary, which is biased by a high voltage. The shear stress on the liquid surface, due to the established electric field, causes elongation of a jet and its disintegration into droplets. The droplets obtained by this method can be extremely small, in special cases down to nanometers. The advantage of the ESD is that droplets are highly charged, up to a fraction of the Rayleigh limit. The Rayleigh limit [1] is the magnitude of charge on a drop, which overcomes the surface tension force that leads to the drop fission. In the c electrostatic deposition process the droplet diameter (for dripping mode) or spray (nanoparticles) depends on the applied voltage. As the voltage increases, the diameter of the droplet decreases, which helps in fine thickness deposition on the substrate.

2. ESD printing method

2.1 Introduce of ESD

An electrostatic atomizer sprays micro-drops from the solution injected into the capillary, with electrostatic force generated by electric potential of about tens of kV. Such devices have been widely used in physics laboratories since the 1950s and as the ionizer for mass analyzers, recently [2]. As shown in Fig. 1, the device consists of a capillary containing solution,

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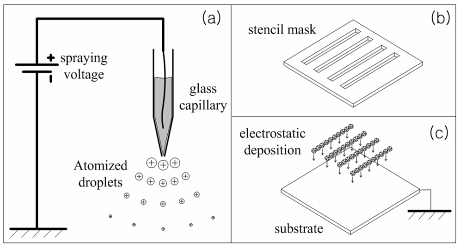

Fig. 1. ESD system.

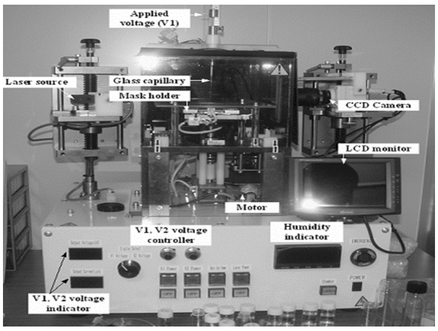

Fig. 2. Small area coating ESD system.

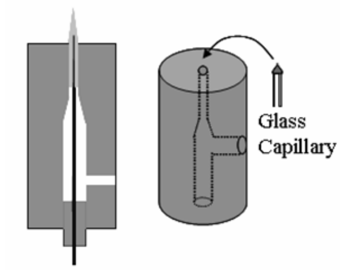

Fig. 3. PDMS head.

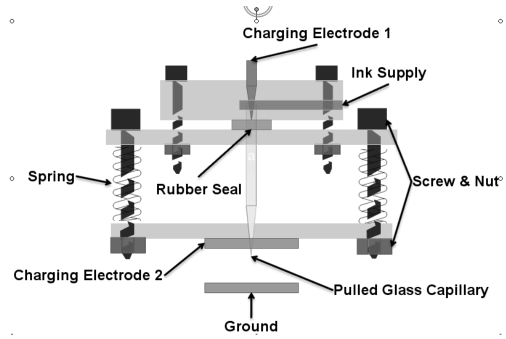

Fig. 4. Acrylic head.

corresponding substrate electrode, and high voltage power source. High electric potential applied to the capillary generates an extremely strong electric field at the tip of the capillary by the focusing effect of the electric field. The electric field strength at the end of the capillary Ec can be calculated by the following [2]:

$$E_c = \frac{2V_c}{r_c \ln(4d / r_c)} \tag{1}$$

where, Vc: high voltage, rc: outer diameter of capillary, d: distance between capillary and corresponding electrode. The field strength becomes larger when the applied voltage is higher and the outer diameter of capillary tip is smaller.

Fig. 2 shows a small area coating ESD system. The ESD device incorporates a capillary holder, a guide ring, guiding gauze, Teflon shield, and sample substrate in the acryl chamber.

High voltage applied inside the capillary generates focused electrostatic force which ejects the charged particles in micron-sized drops.

Charged particles are divided sequentially by repulsion force of the charge and guided towards the mask by the electrostatic field. Fine particles pass through the mask deposit on the substrate below.

The ESD method was developed to deposit protein or electrically charged nanoparticles on a specific area of the conductive substrate by electrostatic field control. Deposit quantity can be controlled by drop size, concentration of specimen and injection time. Multiple patterns can be formed simultaneously on wide area at high speed. ESD has been widely used in various fields. A very well known application of ESD is the preparation of samples for mass spectrometry. Other applications include the formation of metal oxide films, polymer film coating on the electrode and plastic substrate, DNA sample preparation, and protein films.

2.2 Lab head design experiments

For better coating process, two types of nozzle configurations have been studied, results have been compared with each other, and the behavior of the spray was evaluated by using water, water-acetone mixture and ethanol. In PDMS head design the glass capillary nozzle is inserted into the PDMS modeled part as shown in Figure 3. A charged electrode is inserted in the glass capillary to provide the electric potential.

The other investigated design has two charging electrodes; the distance of the second electrode can be adjusted according to the experiment requirements and behavior of the spray. The main body of the nozzle holder is made of acrylic and a glass capillary is used as a nozzle. The detailed configuration of the acrylic head design is shown in Fig. 4.

For experimental purposes 30um glass capillaries were used. To have a uniform coating on the substrate, it is important to invesitgate the parameters of the stable spray region for coating. The thickness of the coating can also be controlled through a patterning mask;, however, in order to get a uniform thickness a stable spray region is required. The results for the acrylic and PDMS heads are shown in Table 1.

As shown in Table 1, the acrylic head configuration is performing better than the PDMS due to the 2-electrode configuration and has more electric field as compared to the PDMS head; moreover, the second electrode also helps in disintegrating the jet.

Fig. 5 shows the image of the spray from the capillary fixed

Table 1. Results of different head for ESD coating.

Head	Voltage kV	Fluid	Remarks
Acrylic	4	Water	Stable spray
Acrylic	4.14	Water + acetone	Stable spray
Acrylic	2.8	Ethanol	Stable spray
PDMS	4.2	Water	Stable spray
PDMS	4.6	Water + acetone	Stable spray
PDMS	3.14	Ethanol	Stable spray

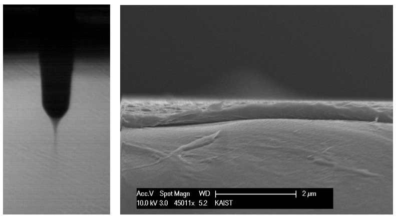

Fig. 5. Stable spray of Ethanol from 30um capillary nozzle.

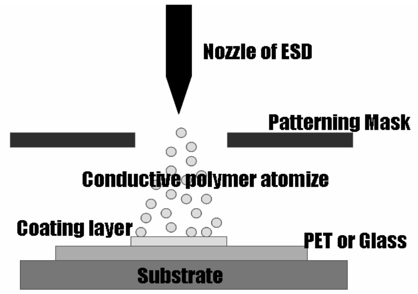

Fig. 6. Conductive coating process using ESD.

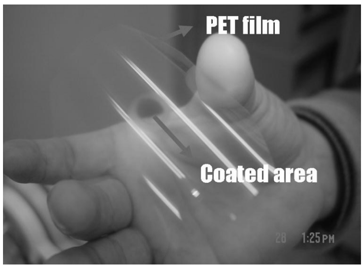

Fig. 7. Small area transparent electrode film.

on the PDMS head;, the applied voltage is 3.14kV and capillary diameter is 30um.

2.3 A manufacturing method of transparent electrode using ESD

Fig. 6 shows a conductive coating process using the ESD method. This process is possible to apply on a continuous coating process. Thus, the ESD coating process will be possible to use on the roll-to-roll printing system. And as shown in Fig. 7, a transparent electrode is fabricated by conductive polymer. PET film was coated on a conductive polymer using the ESD method. Conductive polymer used was a PH500 (Baytron corp.) and glycerol as an additive solution. Applied voltage is 5KV and spray time is 1hr or 2hr (this is a case of a small single nozzle).

Table 2. Performance of small area transparent electrode.

Printing system	ESD system with nozzle dia. of 80um
Spray material	Conductive polymer(PH500)
Additive material	Glycerol
Substrate	3M PET film
Apply voltage	5KV
Spray time	2hr
Curing time	30min at 120℃
Layer thickness	650~700nm
Transparent	70%
Surface resistance	150Ω /□

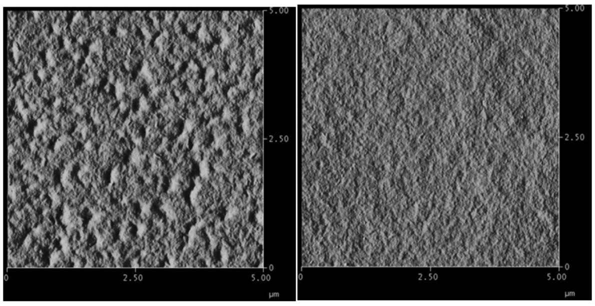

Fig. 8. AFM image of electrode (left is 1hr, right is 2hr).

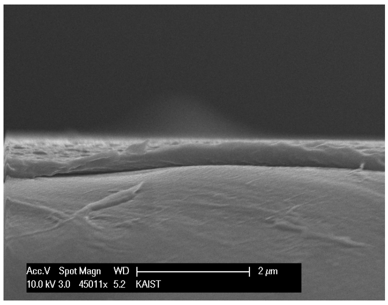

Fig. 9. SEM image of electrode.

2.4 Result of experiment

We experimented on a transparent electrode with the ESD method at a 1hr and 2hr spray coating time. From the result of the experiment, we know that the conductive polymer was coated with very high density. Fig. 8 shows the AFM image of the fabricated transparent electrode. The transparent electrode has a high conductivity and high density of surface in the case of 2hr.

Fig. 9 shows a SEM image of electrode, it has a thickness of about 650 to 700nm. Table.2 presents a performance of small area transparent electrode. Electrode has a surface resistance of 150Ω /□ and transparent of about 70%. These results of experiment is possible to apply on the applications of touch panel or OLED.

2.5 Large Area Coating ESD System

In the small area coating experiment, we knew that the ESD

Table 3. Performance of large area transparent electrode.

Printing system	ESD system with nozzle dia. of 30um
Spray material	Conductive polymer(PH500)
Additive material	DMSO
Substrate	3M PET film, glass
Apply voltage	10KV
Spray time	30min
Curing time	30min at 120℃
Layer thickness	360~180nm
Transparent	73%
Surface resistance	66Ω /□

Fig. 10. Large area coating ESD system.

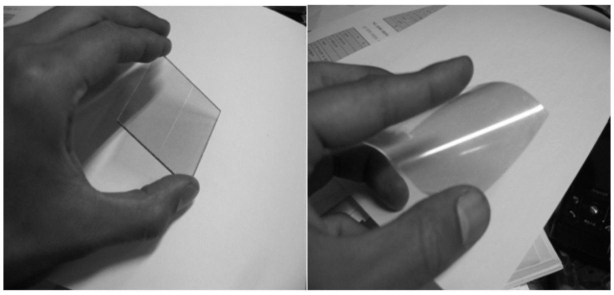

Fig. 11. Fabricated electrode (Left is glass, right is PET film).

method needs a shorter manufacturing time and higher conductivity. Therefore, we developed a large area coating ESD system. Fig. 10 shows a large area coating ESD system with a substrate size of 200mm X 200mm, and we applied a smaller nozzle diameter. The effect of the smaller nozzle diameter is higher conductivity as a generated smaller micro-drop. Also, we applied a more high voltage for a short manufacturing time.

Fig. 11 shows a fabricated electrode on the PET film and glass. We applied a voltage of 10KV. Its condition had an effect on the shorter manufacturing time of 30min. And then, surface resistance was 66Ω /□ in a transparency of 73%.

2.6 Touch key test

We experimented on a touch key with our transparent electrode. Fig. 12 shows the result of the experiment. Touch key chipset (Quantum corp.) was used by electric capacitance method. Glass was coated by conductive polymer as ESD printing method.

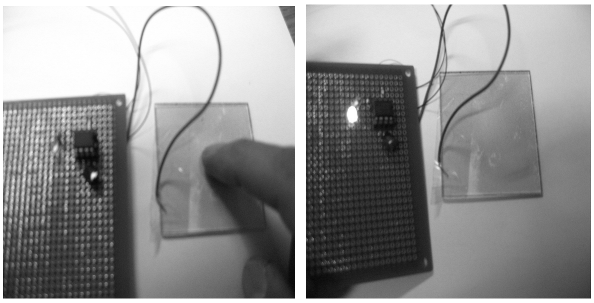

Fig. 12. Touch key test (Left is ON, Right is OFF with a Touch).

LED is normally an ON operation. If the finger touched the glass, the LED was rapidly operated OFF. So, it is presented a one key touch system.

Transparent electrode using an ESD printing method showed very good performance and potential because of a surface resistance of about 66Ω /□. The advantage of this touch system is a very low manufacturing cost and that is possible to apply on the roll-to-roll printing process.

3. Conclusions

In this study, we applied a transparent electrode to the conductive polymer coating process. Coating process used was by ESD method. The main advantage of the ESD method is that no vacuum process is required to apply the coating. As also shown in the lab experiment results, by modifying the conventional type of electrospray phenomena, a stable and fine spray can be achieved at lower voltage, as in case of acrylic head as compared to PDMS head. This study will also help in designing a better head for ESD coating equipment.

Result of experiment: we had a transparent electrode which was coated by conductive polymer in PET film and glass. Our transparent electrode had a surface resistance of about 66Ω/□ and transparency of 73% in the wavelength of 550nm. This transparent electrode manufacturing process will be applied to roll-to-roll process. And it will bring down the manufacturing cost. We will apply it to a touch panel by using the ESD method in further research.

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