Flexible EL Display Printed on a Paper

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Abstract

This paper presents the fabrication of an electro-luminescence display, which is wholly-printed on a flexible paper substrate. We expect that the printed EL display can be a powerful alternative for general advertisement which is printed only with media ink.

1. Introduction

Recently, research for the micro 3D printing technology [1-4] has begun to get into the spotlight as a new manufacturing technology in many industrial fields including printed electronics, flat displays, flexible circuits, RFID-tag, etc.. It is due to the superior price competitiveness to the existent semi-conductor process. Semi-conductor processes and MEMS fabrication methods need long manufacturing time, high price implement and ultimate process technology. Therefore, in spite of worse resolution and limited application areas, the printing method has been focused more than that of semi-conductor processes or MEMS fabrication methods, in the respect of manufacturing time, mass production, low cost, and so on[5].

The word, "PEMS" stands for "Printed Electro-Mechanical System" which 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. PEMS products also include assemblies of printed passive and active components, such as RFID tags, E-paper displays, solar-cell devices and printed sensors. The figure 1 shows an example of PEMS product and a roll-to-roll printing system. Such PEMS products have not been commercially available yet but disposable electronics products at a low cost, such as RFID tags, E-paper displays, solar-cell devices and etc., would have the market size of $20B per annum in 5 years and $100B per annum in 10 years, according to the predictions of international market researches, such as DARPA in 2004[6].

The definition of "PEMS printing system for fabrication" is the system which fabricates PEMS components and products. Flexible substrates are fed into the system by means of Roll-to-Roll web transporter or any other transporter in a batch type. On top of the flexible substrate, functional materials such as conducting, semi-conduction and insulating are deposited with various printing technologies such as screen, gravure/flexo, pad and inkjet printing and eventually the mass production of the aimed product is enabled at a low cost.

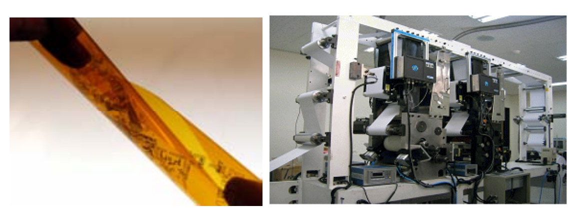

Fig. 1. Example of PEMS device and roll to roll printing system.

For the exemplary development cases of PEMS processes and systems, the corporate R&D center of GE and ECD Ovonic Corp. which has gained the pronounced reputation with solar-cells launched a joint project for the development of the printing system which enables the production of polymeric devices in September of 2003. The fund of $1.3B was granted by NIST, USA for the period of 4 years[7].

The system to develop is announced that the world first Roll-to-Roll based printing system in combination of gravure and screen printing technologies for the mass production of printed electronics products. GE will take a part of the design of printed electronics products and Ovonic will develop the printing system in size of 23 m by 4 m. This joint project of GE and Ovonic is considered as a milestone to prove two fundamental engineering suspicions, whether the Roll-to-Roll based system suits for the production of printed electronics and whether all multi-layered printings can be done on the single in-line system. If their efforts are proven successful, then GE and Ovonic will be the pioneer in this field which opens a new market in printed electronics.

PolyApply is the name of the consortium which ties up with 20 members of companies, research institutes and universities in Europe. The core members of this consortium are Philips in Netherland, Plastic Logic in UK, Chemnitz university, Motorola, Merk and Fraunhofer research institute in Germany, Lego in Denmark, STM in Italy and 12M Euro among the total funds of 24M Euro granted by EC was put into the research and development of all-polymer printed RFID tags for the period of 4 years from January 2004, which realizes the era of ubiquitous computing. It is noteworthy that this consortium excludes the production of RFID tags based on silicon technologies which acts as a huddle for its final aim. Its main aims are the development of in-line processes and protocols for RFID tags with all polymeric materials at an ultra-low cost.

Man Roland Corp. in Germany is considered as one of the leading groups in the field of printing systems. It has gained a good reputation in various kinds of printing systems such as screen, gravure/flexo, and offset printing. The feeding system takes both types of sheet and roll. As the market of PEMS production systems gains attention from industries, Man Roland Corp. announced the concepts of its next generation printing/packaging systems and it puts a main focus on the research and development for the patterning method of PEMS components such as RFID and smart packaging with functional materials. The total packaging concept proposed by MAN Roland Corp. is, (1) printing electronics such as circuits, antennas, low end active and passive components, (2) repeating the same procedure for the next printing layers, and (3) completing the final product by placing and bonding a chip on the printed components. This will be the ultimate goal for the production of PEMS components and assemblies[8].

Fraunhofer IZM institute in Germany belongs to one of leading groups in the world, which made the prototype for the Roll-to-Roll based lithography system for the production of PEMS devices. It devised numerous Roll-to-Roll based systems for etch-rinse-cleansing, electroplating and screen printing too. These systems are equipped with the precise alignment mechanism, enabling the multi-layer printing of different materials on top of each other. Diverse PEMS passive and active components such as ring oscillator, invertor, RFID tag and OTFT were produced at the precision of 10 μm[9].

In this paper, we present several kinds of printing process for PEMS device and an electro-luminescence light, which is wholly-printed on a flexible paper substrate.

2 Screen Printing Process for Large Area Micro Pattern Printing

In order to print fine pattern in large area through screen printing method, the most critical thing is to understand the relationships between precisely grinded squeegee, adequate ink formulation, printing process technology, screen of fine mesh, and precise screen printer. The figure 2 shows the schematic picture of screen printing process in which patterns are generated after off-contact between the screen and the panel. In this figure, the section C and D are the most critical processes, in which the ink is transferred from the screen to the panel. Therefore, it can be seen that the off-contact speed should be kept invariant, if we want same patterns through all over the panel

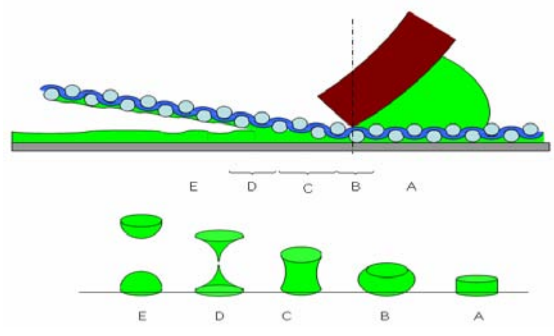

Fig. 2. Screen printing process.

3. Gravure Printing Process for Micro Pattern Printing

In order to realize PEMS device on paper substrate, gravure printing is very desirable method. Because gravure printing process can be equipped with roll to roll web transfer system, the productivity is very high in comparison with screen, pad, and inkjet printing method.

The gravure printing process uses a gravure roll engraved into concave shape cell. The roll is dip into an ink and the cells of roll are filled with ink. After that, the roll is doctored by blade for removing the ink stuck at the outside of the cell. A substrate is located between the gravure roll and pressure roll, which presses the substrate into the gravure roll. Thus, the ink located inside of the cells is transferred to the substrate.

The gravure offset printing process is almost same as gravure printing process except blanket offset roll. The ink covered at the gravure roll is transferred to the blanket offset roll and the ink of the blanket offset roll is transferred onto the substrate successively. In the gravure offset printing process, the printing quality is dependant on the blanket offset roll significantly. In case of general media printing, pattern size is comparatively large. Therefore, the surface roughness of the blanket offset roll does not affect on the printing quality. Sometimes, blanket surface may have roughness on purpose in order to increase the transferring rate between blanket and ink.. By the way, in case of PEMS device printing, the resolution is very important factor. If the line pitch should be less than 50 ㎛, surface roughness of the blanket roll should be much more less than 50 ㎛. Surface energy induced by the surface roughness is also important factor.

The figure 3 shows the one of the printing result of gravure offset printing. We printed a silver nano particle ink both on the film substrate and paper substrate. The printing speed was 50mm/sec, the pressure between gravure roll and the blanket offset roll was 300kg/m, and the pressure between the blanket offset roll and pressure roll was 500kg/m. Consequently we can obtain the fine silver nano conductive line pattern.

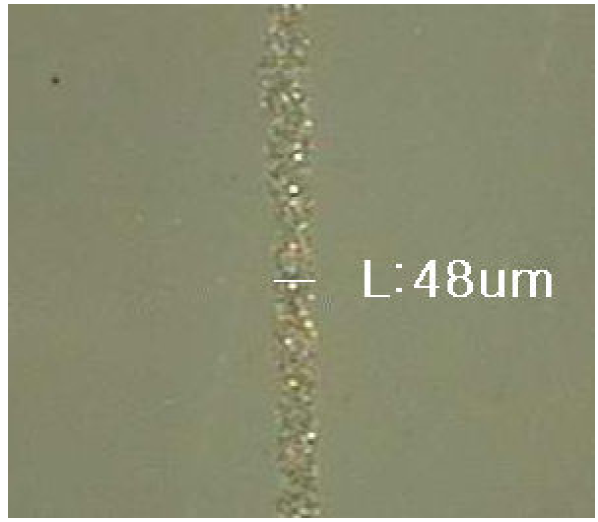

Fig. 3. Gravure offset printed silver nano conductive line pattern.

4. Paper Shrinkage Test

In order to realize a PEMS device on a paper, the phenomenon of paper shrinkage should be fully understood, because several kinds of electrical ink are printed, dried, and cured repeatedly at different temperature.

Paper made by Advance Paper Co., Ltd was experimented for paper shrinkage test. It is double-side printable general paper for laser jet, ink jet, and copy machine. On the paper, 2 dots were marked at approximately 200 mm interval. The temperature of oven was 120^{o}C. Figure 8 shows the paper shrinkage according to the curing time. The distance between the dots was measured three times by micro calipers and was averaged. As the time in the oven increases, the paper shrinkage makes steady progress. This experiment was continued till 1200 minutes. After 1200minutes, the paper was carried out of the furnace and was left at room temperature. We measured that the distance of the dots after 7000 minutes and the shrinkage of the paper is recovered.

The meaning of this figure 8 is that the 200mm paper may experience the shrinkage of several hundreds of micron even during 15minutes in the 120^{o}C furnace. Therefore the less time in the oven, the better and the finer resolution can be obtained.

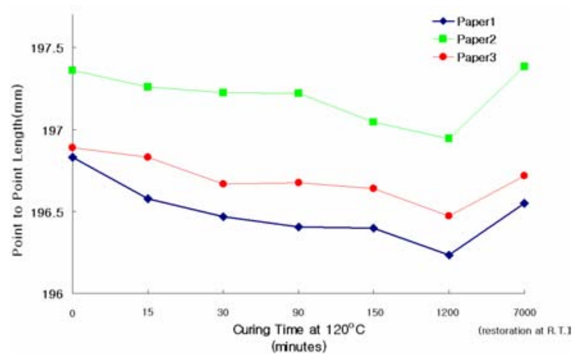

Fig. 4. Contraction of paper according to the curing time.

5. Printed EL on Paper

The EL 7 segment display, of which size is 110mm × 60mm and the total thickness is around 260 ㎛ including paper thickness, is printed on a paper substrate. The substrate used is single-side-coated 90gsm paper which is generally applicable to a color inkjet printer. The bottom and top electrode is silver and transparent conducting electrodes, respectively. Consequently, printed EL which is more flexible than the radius of curvature, 5mm can be obtained.

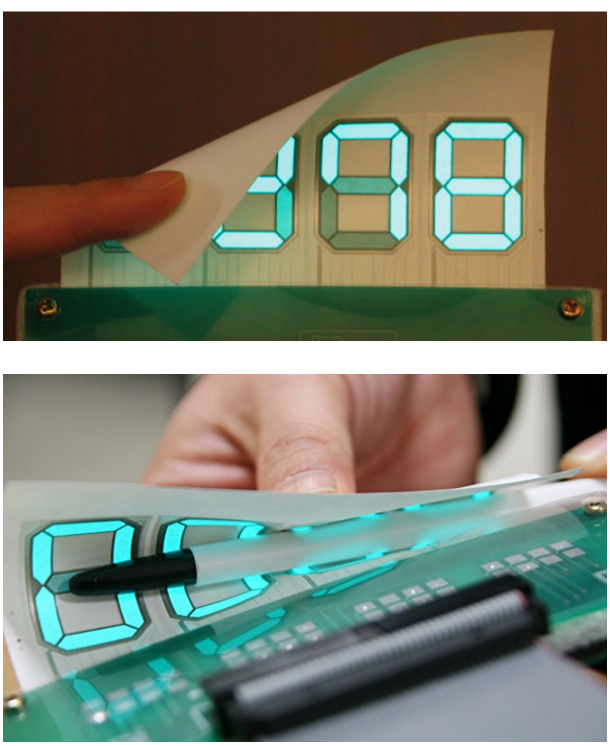

Fig. 5. EL segment display printed on a paper.

6. Conclusion

In this paper, we present the design and fabrication of the printed EL segment display, which is wholly-printed on a flexible paper substrate. The screen printing process and gravure printing process for obtaining fine line printing pattern in large area substrate are described. Phenomenon of paper shrinkage is also examined according to the time in the furnace.

Consequently, we obtained fully printed EL 7 segment of which size is 110mm × 60mm and the total thickness is around 260 ㎛. The bottom and top electrode is silver and transparent conducting electrodes, respectively.

As a result, we expect that the printed EL can be a powerful alternative for general advertisement which is printed only with media ink. The printed EL on a flexible paper substrate can also be applied to disposable paper-display.

7. References

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