The Application of Inkjet for the Printing of PDLC Display Cells

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Abstract

New applications for ink jet printing are constantly being developed in fields such as electronics, optics, manufacturing, photonics, displays and medicine. VTT Information Technology is interested in developing manufacturing methods for electronic papers and other flat display technologies by using inkjet printing. In the near future, low-cost and flexible displays such as LCD or OLED displays can be wholly or partially inkjet manufactured from conductive polymers and metal particles. We are also investigating inkjet printing with regard to display components on flexible substrates, like paper, from the materials mentioned above.

The aims of the work presented in this paper were to: 1) Gain understanding and knowledge of printed and especially inkjet printed display applications, 2) Develop an inkjet LCD display pixel element and 3) Develop an inkjet one-digit alphanumeric LCD display element without control electronics. One of the most challenging aspects of the work was to find the right materials to be used in the printing series. In some cases materials could be selected and unsuitable ones eliminated due to their chemical and physical properties (e.g. viscosity), but in most cases the only reliable way to test the materials was to arrange printing tests. Material tests were carried out, the right materials for the printed PDLC display were found and a novel manufacturing method with eight different process phases for the production of the inkjet PDLC display was developed during the project.

Introduction

The work described in this paper is a part of an international co-operative effort between the VTT (Technical Research Center of Finland) and the University of California, Berkeley. This work was carried out as a part of the PRINTO (Printed Optics and Electronics) project in the University of California, Department of Electronic Engineering and Computer Sciences, Organic Electronics Group. In the USA, this work is also related to a larger National Science Foundation project - ICT4B (Information and Communication Technology for the 4 Billion Poorest People on the Planet) at Berkeley and its sub-project called "Low Cost Integrated Displays".

The PRINTO project, within the framework of Tekes' (National Technology Agency of Finland) ELMO (Miniaturizing Electronics Programme) is seeking to evaluate roll-to-roll related mass production techniques such as gravure printing, embossing, digital printing and offset for the fabrication of optical, electrical and optoelectrical components. Integration of these simple elements allows the cost-effective fabrication of functional circuits suitable for use in product packages and printed matter to increase their information content, enhance their visual impression, and to provide new and interesting effects. These printed circuits can also serve as a link between a package and an intelligent environment.

In the future, demand for low-cost, durable and flexible displays will increase. Forecasts show that as electronic devices become more compact, the displays will be the only visible user interface. And as the price of the displays drops dramatically, the number of displays in circulation will increase. Low-cost display applications would also be beneficial in developing areas, where their use could help to increase the quality of life.

Experimental Setup

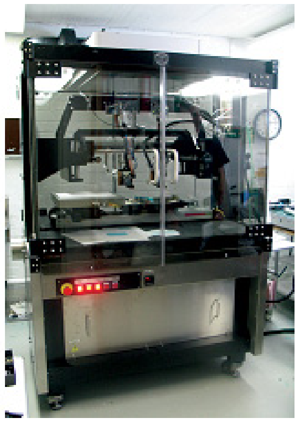
Research Environments

The University of California, Berkeley utilizes Microfab inkjet printing systems in its research. The printhead assemblies and the printer system consist of a fluid reservoir, a dispensing device, fluid interconnections between the reservoirs and dispensing devices, filter elements, connections to the pneumatic controller and inert gas source, connections to the electronics controller and a heating element, which is a heatable xy-table and connections to temperature controllers, where cold water circulation is used. In the test series described in this report, only printing heads without heating were available.

The inkjet research environment of VTT Information Technology is based on an up-to-date industrial piezoelectric printing system manufactured by Spectra and a xy-table manufactured by iTi. A laboratory-scale testing environment for the high-speed imaging of inkjet drops is also integrated with the printer system. The impact, spreading, absorption and drying of the ink droplets on the samples can be observed in this testing environment on a time scale of microseconds up to several minutes. Our approach in the inkjet research is that all the printheads and printing systems are production-scale devices, so that the results obtained within the environment can be up-scaled to industrial production.

Materials

One of the most challenging aspects of the work was to find the right materials to be used in the printing series. In some cases materials could be selected and unsuitable ones eliminated due to their chemical and physical properties (e.g. viscosity), but in most cases the only reliable way to test the materials was to arrange printing tests. This also created many challenges, because difficult materials like high-viscosity adhesives and PDLC materials needed special attention, because in many cases they jammed the printer heads or other parts of the printing system.



Picture 1. Spectra inkjet printing system integrated with xy-table manufactured by iTi.

Experimental Work

Printing Tests with Optical Adhesives

The best way to build the walls of a display element - or indeed any 3D topographic structure - is to use an inkjet head that uses heating and utilizes thermoplastic materials. VTT Information Technology uses this kind of technique for the purpose, but in the University of California, there was no possibility to introduce this technology in the required period of time, so only inkjet heads that utilize liquid materials and UV curable inks were used.

Norland Optical Adhesives materials were utilized in the test series. These materials are clear, colorless, one part adhesives that contain no solvents. When exposed to ultraviolet light, they gel rapidly and full cure occurs in minutes to produce a resilient bond. These adhesives are designed for fast bonding where low strain and optical clarity are required.

A wide range of adhesives was tested in the inkjet research environment, but because of the high viscosity of materials it was impossible to print them, so several different kinds of adhesive mixtures with solvents were tested. A frequent problem in these tests was that it was impossible to mix adhesive with solvent - several materials like isopropanol were tested, but without success. The first successful mixture was accomplished with acetone, which at first seemed to work well, but the problem was that acetone evaporates too quickly and this blocked the printing heads.

Finally, a mixture of NOA65 and 50% Anesol was found to be the best possible solution. The problem with this mixture is that the final optical properties of the printed optical element are not as good as they could be if only pure, one part optical adhesive were used. But in this case, the printed elements were only meant to be spacers between pixels, so the optical quality of the structure wasn't critical. A small amount of this material was mixed before printing. The quantities were measured in a small bottle and a small magnetic stir rod was used on a hot plate to mix it.

Printing Tests with Polymer Dispersed Liquid Crystal Materials

There was also a problem in the selection of the Polymer Dispersed Liquid Crystal (PDLC) material. In some cases optical transparency of a printed layer was too small, so the change between the two on and off stages was almost unnoticeable. In other cases the inkjet ability of the PDLC material was so bad, that the formation of the inkjet droplets failed. After several tests, two PDLC materials were found to work in the printer. These materials were Merck Licristal E8 (Art. 30672) and Merck Licristal E7 (Art. 28656). E8 in particular produced a good optical change in transmittance and its printability was also reasonably good.

The Development of the Inkjet Printing Process for a PDLC Display

After the material tests, a manufacturing method for inkjet printed PDLC displays had to be developed. A special approach for the liquid inkjet printing process was developed with eight different process phases.

In the first process phase, a wax mask was made manually and placed on a conductive ITO plastic sheet. The size and the shape of the mask determines the final size and the final shape of the pixel.

Figure 1. The first process phase: Construction of the mask.

In the second process phase, the first layer of optical adhesive was printed onto the ITO plastic sheet. The thickness of the adhesive layer can be used in the thickness control of the final pixel.

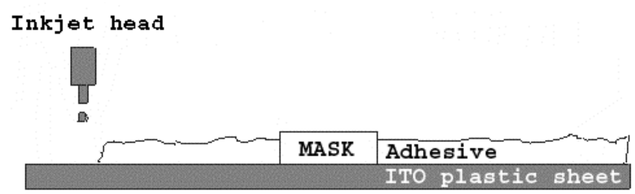


Figure 2. The second process phase: Printing the first adhesive layer.

In the third process phase, the first layer of optical adhesive was dried on the ITO plastic sheet using UV light.

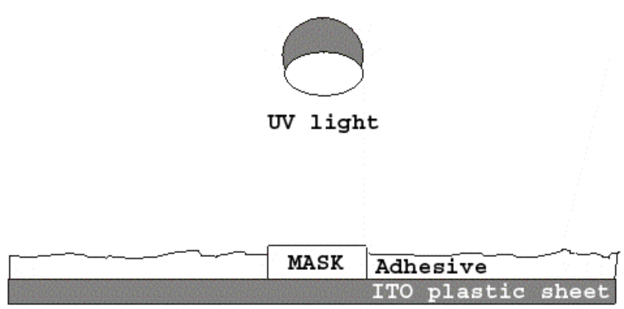


Figure 3. The third process phase: Drying the first adhesive layer.

In the fourth process phase, after the drying of the first adhesive layer, the wax mask was mechanically removed and the hole in the optical adhesive layer shapes the mould of the pixel.

Figure 4. The fourth process phase: Removing the mask.

In the fifth process phase, the mould of the pixel was filled with PDLC material utilizing inkjet printing.

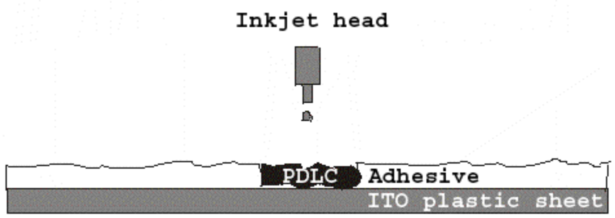


Figure 5. The fifth process phase: Filling the mould.

In the sixth process phase, a thin layer of adhesive material was printed on top of the first adhesive material layer.

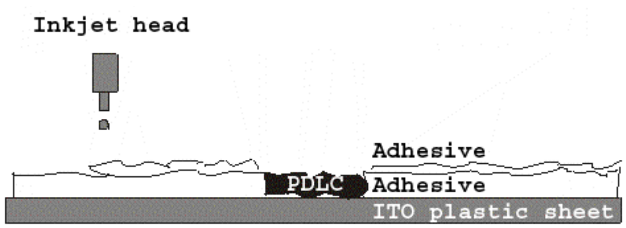


Figure 6. The sixth process phase: Printing the second adhesive layer.

In the seventh process phase, the second ITO plastic sheet was piled on top of the second adhesive layer. The materials were pressed tightly together to achieve a good contact between materials.

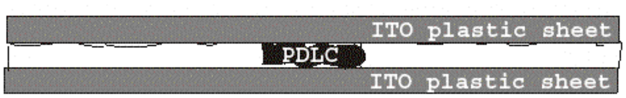


Figure 7. The seventh process phase: Piling the second ITO plastic sheet.

In the eighth process phase, the whole display element was exposed to UV light to create a mechanically durable display. Pictures 2 and 3 show the prototypes of an all-inkjet LCD display pixel element and an all-inkjet one-digit alphanumeric LCD display element.

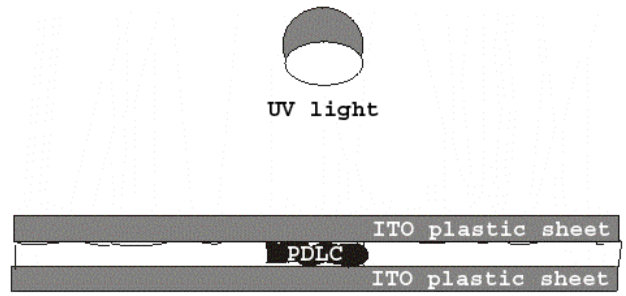
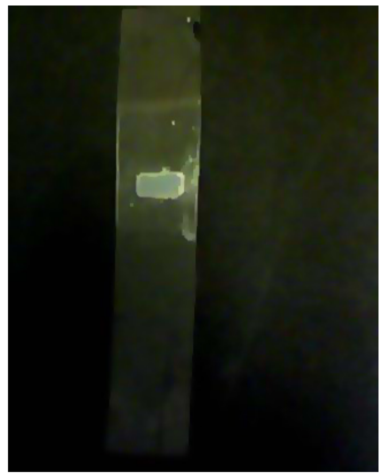
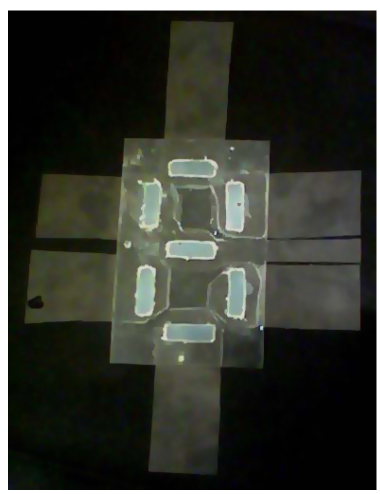


Figure 8. The eighth process phase: Exposing the display to UV light.



Picture 2. An all-inkjet LCD display pixel element.



Picture 3. An all-inkjet one-digit alphanumeric LCD display element.

Conclusions

Extensive material tests were carried out, the right materials for the printed PDLC display were found and a novel manufacturing method with eight different process phases for the production of the inkjet PDLC display were developed during the project.

Acknowledgements
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References
1. Jali Heilmann, Helene Juhola, Hannu Linna, and Liisa Hakola, Image quality measurements in the quality control of printed electronics. Printing for Manufacturing. TAGA Microtech 2003,Swansea, Wales, UK 10-12 Nov. 2003. The Welsh Centre for Printing and Coating (2003), 8 p.

Author Biography
Jali Heilmann (MSc.) is a Senior Research Scientist at VTT Information Technology's Media Department. In his Master of Science thesis, he developed new research methods for color electrophotography and he is also very well acquainted with other digital printing technologies, especially inkjet printing. His current research activities also incorporate technical solutions, uses and appliances for smart packages, printed electronics, electronic book technology and other new information carriers like flexible displays. He has also worked as a Visiting Scholar at the University of California, Berkeley between August 2003 and September 2004.