A Novel Pneumatic Dispenser Fabrication Technique for Digitally Printing Electroluminescent Lamps on Fabric

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Summary

A planar electroluminescent (EL) lamp has been printed using a novel pneumatic dispenser fabrication technique directly on to woven fabric to create a smart-fabric lamp. The fabrication technique relies on a pneumatic dispenser mounted on linear translation stages to deposit uniform m films of ink. In this work the process is referred to as 'dispenser printing' and is a digital process, depositing ink in a pattern determined by a specific image on a PC. The EL lamp consists of five individually printed and cured layers, highlighting the complex structures achievable with dispenser printing. The lamps are printed with the aim of providing new possibilities in the application of architectural fabrics; examples include advertising, signage and decoration. Because the dispenser printer is a digital printer, the lamp developed in this work is only printed in the desired area on the fabric and the process does not affect the properties of the underlying fabric, such as the mechanical strength and flexibility. Distinct printed layers are produced with layer thickness ranging from 12µm to 100 µm depending on the dispenser print settings and the ink used. Pneumatic dispenser printed EL lamps have been achieved with a printed ink thickness of just 190µm on polyester woven architectural fabric of thickness 210µm. The lamps can be controlled individually or in an array using a Supertex driver combined with an Arduino controller for easy lighting sequence programming.

1. Introduction

Dispenser printing is a new rapid additive manufacturing process which will have a number of commercial applications due to the wide range of electrically functional inks that can be printed, as well as the ability to easily change the design without the requirement for masks or screens. The ability to change the design rapidly is appealing in prototyping applications and dispenser printing can use more viscous materials than other direct write technologies such as inkjet printing offering greater functionality of the printed layer. Dispenser printing is a drop on demand technology – meaning ink is only deposited in the areas required. Drop on demand technology also reduces environmental impact through effective materials usage and allows printing on complex geometries as it is non-contact.

Dispenser printing is used in this work to additively deposit uniform thickness films of a variety of materials. The deposited materials, known as 'inks' to differentiate them from screen-printing pastes, are mostly functional particles dispersed in a polymer binder to make them a suitable viscosity for printing (3-300 Pa.s depending on the nozzle used). However, all screen-printing pastes can also be dispenser printed making the fabrication method compatible with existing screen printing device manufacturing processes.

Electroluminescent lamps, while not a new technology, have seen an increase in interest lately due to smart fabric applications [1]. EL lamps operate by forming a capacitor structure with an emitting phosphor layer sandwiched between the two electrodes. One of the electrodes is transparent to allow the light to exit the structure, and a dielectric layer is printed between the electrodes to prevent short circuits. A total of five discrete layers are required for a printed EL lamp. They offer a low power (43.5mW/cm^2), thin, and robust light source that can be entirely constructed using printable materials. Traditional printed EL lamps are made using screen printing and require a glass or plastic substrate completely coated in Indium Tin Oxide (ITO) regardless of the shape of the lamp. Combining dispenser printing with EL lamps offers the ability to print all the layers and a range of flexible light sources on fabric in varying shapes using all polymer based inks.

We present a novel method of fabricating electroluminescent lamps by dispenser printing directly onto woven fabric for use in architectural applications. Architectural fabrics are already commonly used to produce exciting and cost-effective temporary and permanent structures that are quick to construct [2].

2. Method

The dispenser printer developed at the University of Southampton involves a syringe containing the ink, mounted on XYZ translation stages; pneumatic or mechanical force is applied to the top of the syringe to deposit the ink when desired. A number of mechanisms can be used to force the ink from the syringe; this work focused on time pressure dispensers, which operate by forcing ink stored in a syringe through a nozzle using pulses of pressurised air. A vacuum pressure is applied to the syringe when not printing to maintain a suitable meniscus at the outlet of the nozzle and thus prevent ink being erroneously dispensed. The dispense pressure, dispense duration and vacuum pressure can be adjusted using the dispenser controller. The substrate can alternatively be mounted on an XYZ translation stages stage so the substrate moves under a stationary syringe. The X and Y stages are controlled to deposit ink in the desired area of the substrate. The Z stage is programmed to maintain a defined Z height above the substrate across a varying surface topology, allowing substrates to be curved or uneven. Figure 1 below highlights the process differences between dispenser and screen-printing a series of conductive tracks. The advantages make dispenser printing attractive to industries where ink costs are high or where the print design often changes.

We have previously developed a method allowing screen-printing of conductive tracks directly onto fabric [3]. This work has now been applied to dispenser printing, allowing electroluminescent lamps of any shape to be quickly printed onto fabric. In this work the lamps were printed onto a PVC coated Polyester woven fabric, a material commonly used in architectural applications.

The printed lamps are fabricated in a capacitor structure using five individually, sequentially printed and cured layers are described in Table 1 below. The FabInks range of inks was selected as they are all suitable for printing onto fabric and have been developed to maintain the flexibility of the fabric.

Table 1. *A summary of the printed layers in the prototype EL lamp, describing each layer, the ink used, and the target print layer thickness.*

Layer Name	Layer Description	Ink Used	Print Layer Thickness
Bottom electrode	Provides on side of the capacitor structure and evenly distributes the charge.	FabInks TC-C4001	12μm
Dielectric	Prevents short circuits across the capacitor structure and acts as a light reflector.	FabInks TC-D9001	100μm
Phosphor	Emits light under the influence of a strong alternating electric field ($2^6 Vm^{-1}$).	FabInks TC-P0001	60μm
Bus electrode	Provides connection to the top electrode and helps to produce an even distribution of charge across the lower electrical performance semi-transparent electrode.	FabInks TC-C4001	12μm
Semi-transparent electrode	Provides the top electrode across the phosphor layer whilst allowing light to be transmitted out from the phosphor layer.	FabInks TC-C4006	18μm

Curing requirements are essential when selecting the inks, as printing onto fabric places constraints on the maximum tolerable temperature for each specific fabric. Inks were selected to allow curing at 125ºC for ten minutes after each layer was printed, to reduce chances of possible damage to the fabric.

3. Results

The EL lamp has an illuminating area of 30 x 30 mm in a rectangular shape, however other shapes could be printed using the dispenser by altering the design input. The full layer by layer design for the EL lamp is shown in Figure 2, along with the sizes of the layers and the individual screen designs. The lamp was designed conservatively with a large overlap for the dielectric layer to prevent any possibility of short circuiting in this initial prototype.

Considerable work has been undertaken to construct and program the dispenser printer to achieve a stable platform for fabrication. The device fabrication process can be seen in Figure 3, where each sequentially printed layer is shown. The print settings used vary depending on the ink properties and nozzle sizes can be selected based on the desired flow rate. A constant separation distance of 300µm was maintained between the nozzle and substrate for all printed layers.

The printed lamps were driven at 180 Vac at a frequency of 400Hz and can be seen illuminated in Figure 4. The printed devices were characterised using an SEM to check layer thickness and uniformity. The SEM micrograph showing a cross-section overview is shown in Figure 5(a) and a view of the thin printed layers above the woven fabric is shown in Figure 5(b). The average total device thickness is 190µm of printed ink, making the overall fabric and printed ink thickness 400µm.

4. Conclusions

The lamps were printed onto a standard PVC coated Polyester fabric that is commonly used in tensile fabric structures. The ability to quickly produce complex fabric structures that can be illuminated provides exciting opportunities for architects. The technology could also be used to print onto other fabrics finding applications in safety workwear, one-off event management clothing, fashion and automotive applications. EL lamps are well suited to architectural applications as they provide a large area low power lighting solution, which could create visually appealing tensile structures at night.

Dispenser printing is a novel and flexible direct write fabrication method suitable for printing a wide range of inks when compared to other print methods. Functioning EL lamps were dispenser printed onto PVC coated polyester. Future work will focus on increasing the print speed and improving the layer thickness control.

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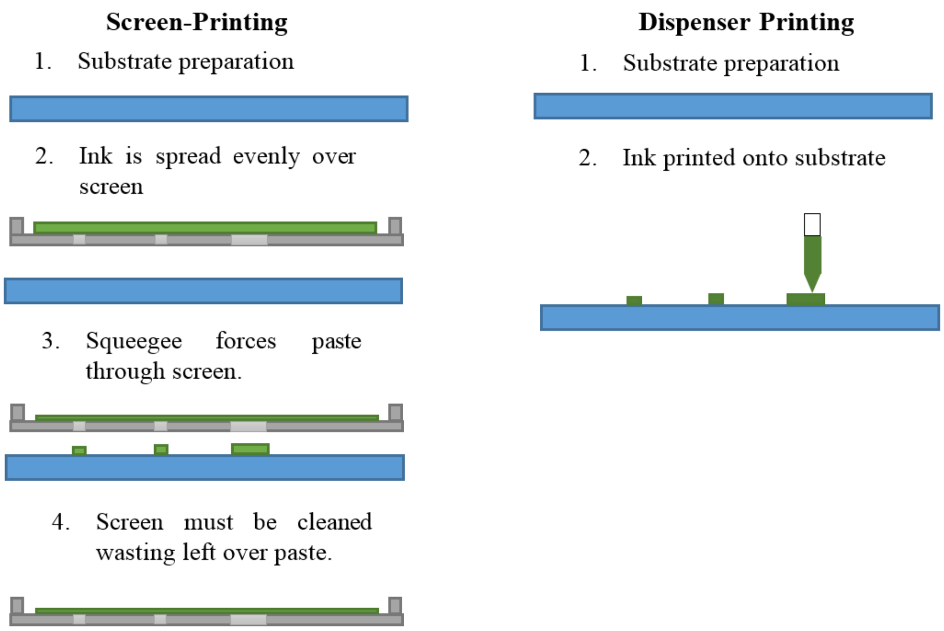

Figure 1. *Comparison of printing process for screen-printing (left) and dispenser printing (right).*

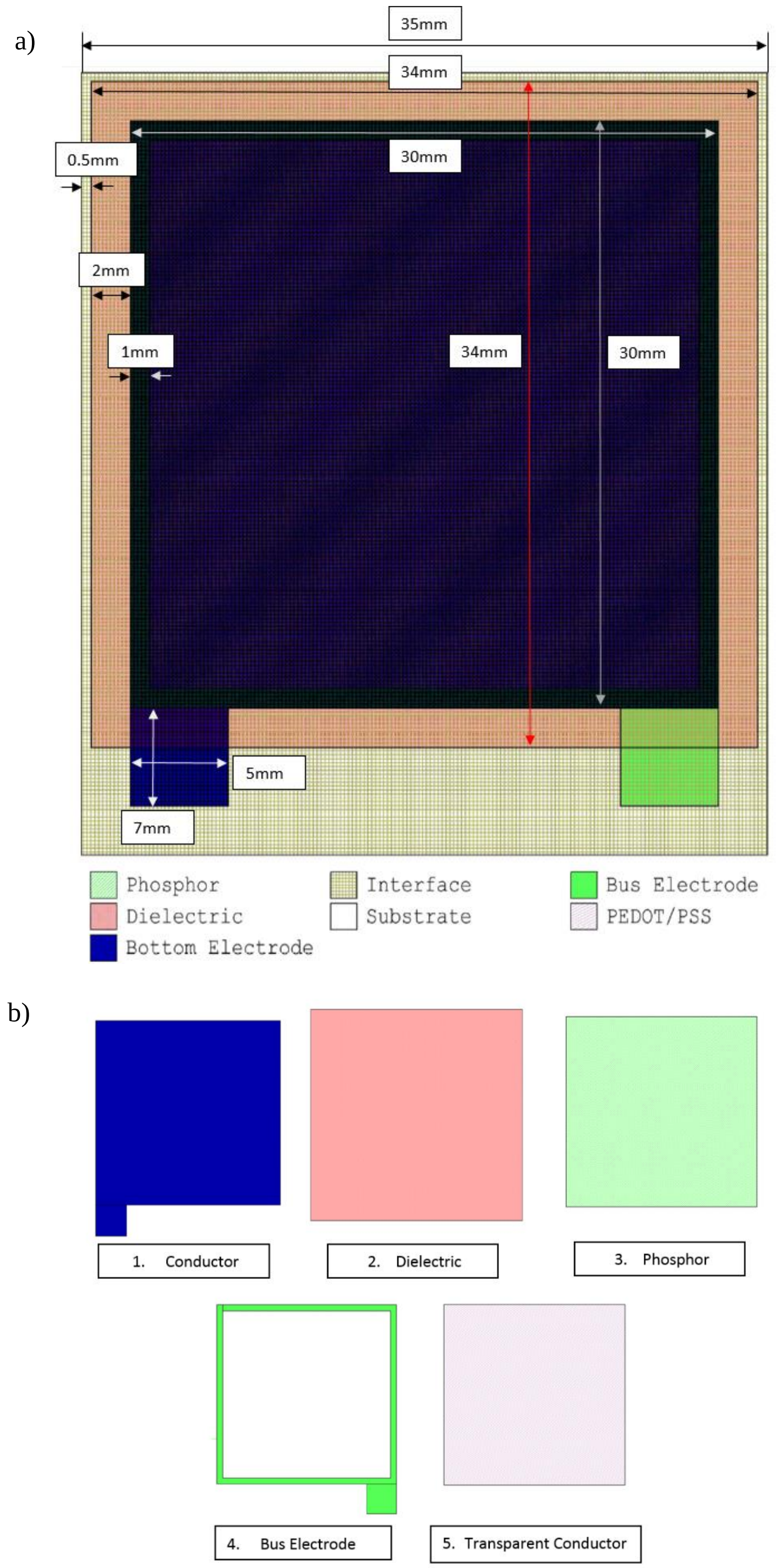

Figure 2. *Screen design for an EL lamp with an emitting area of 30 x 30 mm, a) full design showing all screens and sizes, b) individual screen designs.*

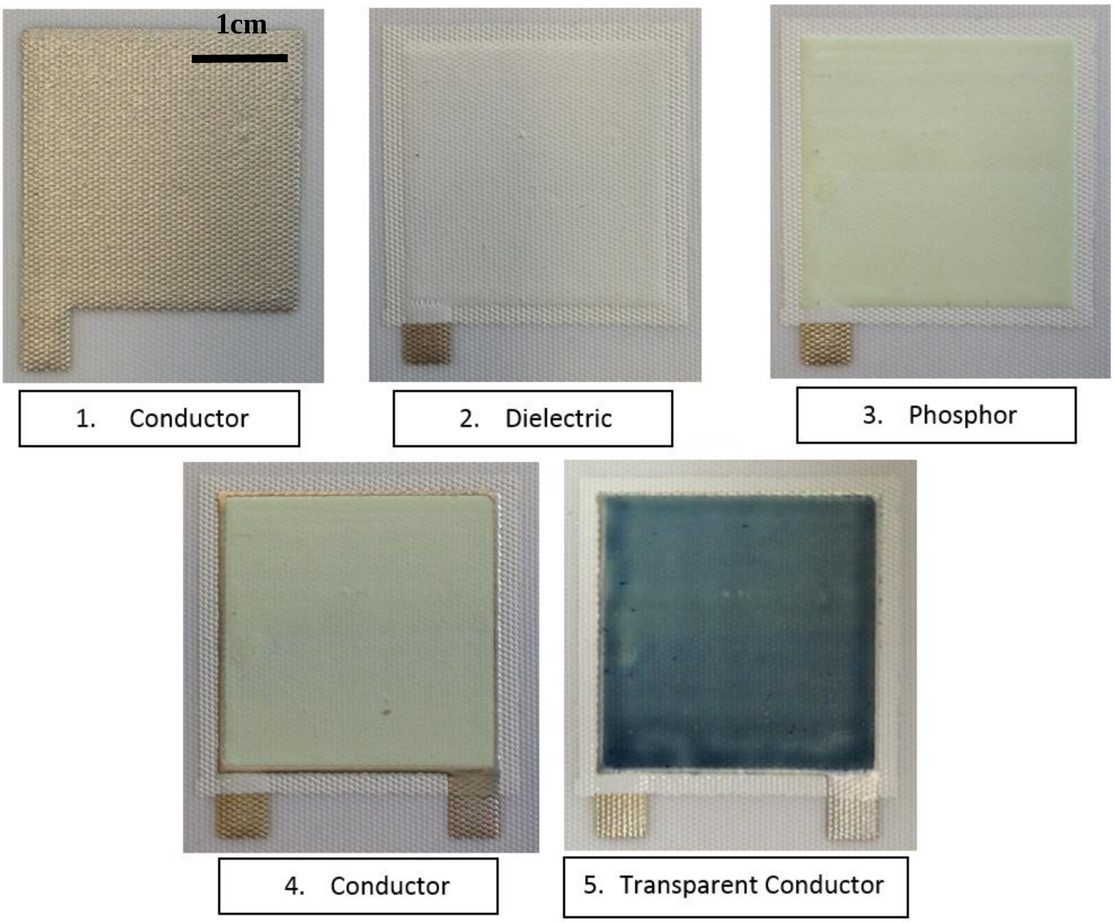

Figure 4. *The print process showing the layer by layer deposition of inks to form the EL lamp.*

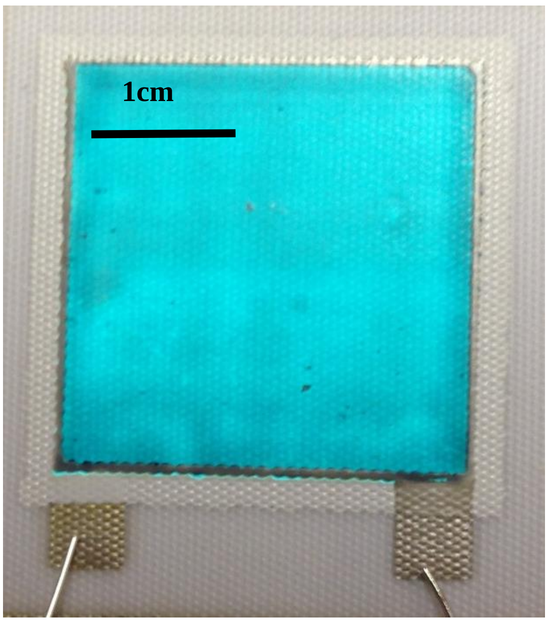

Figure 3. *A powered dispenser printed EL lamp – driven at 180 Vac, 400Hz.*

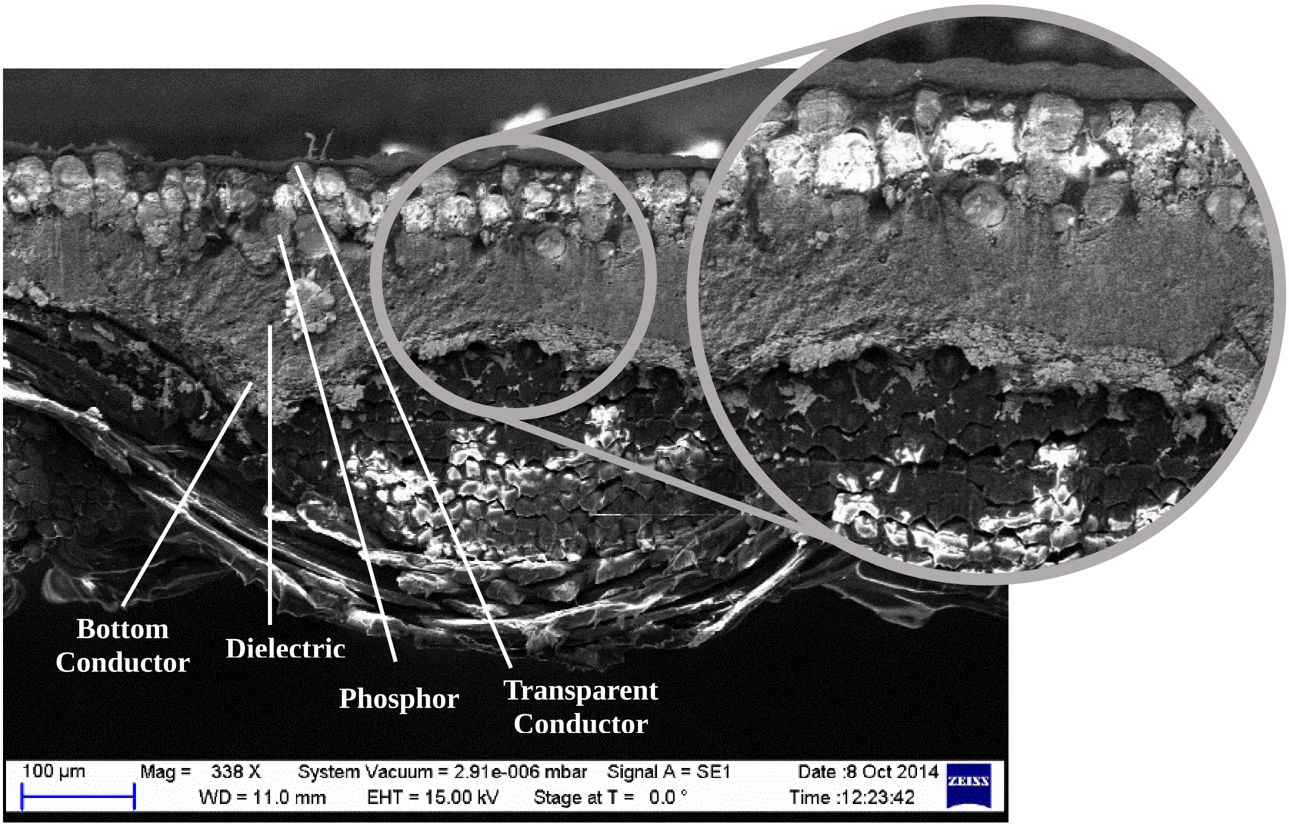

Figure 5. *SEM image showing distinct dispenser printed layers - total layer thickness 307µm.*