

Visible and Ultraviolet Light Emitting Electrochemical Cells Realised on Woven Textiles [†]

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Abstract: Spray coated organic light emitting electrochemical cells (LECs) have been fabricated on a standard woven polyester cotton textile for wearable display applications. The textile is first pre-smoothed by screen printing an ultra-violet (UV) curable polyurethane layer, termed an interface layer, before fully spray coating the functional device. The spray coating technique was then used to fabricate the flexible OLECs on the textile. The textile devices were then encapsulated prior to testing in an ambient environment. Commercially available yellow emitting polymer and a UV emitting small molecules have been utilised as LEC active layers. Fully functional yellow coloured OLECs have been achieved on the woven textile substrate. Preliminary results with the UV emission molecule have demonstrated its solubility for solution processing and shown UV emission via photoluminescence induced by laser excitation, offering the potential to migrate to textile to realise UV OLECs.

Keywords: light emitting textile; e-textiles; light emitting electrochemical cells (LEC), light emission

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1. Introduction

Electronic textiles (E-Textiles) research has been intensive on light emitting textiles since 2010, alongside other e-textiles applications' development. Light emission within the visible wavelengths is normally used to communicate and signal information. It is also widely deployed as decorative home textiles with significant applications in the creative industries [1]. Light emitting textiles can be achieved by weaving optical fibres into textiles, but the light emission area is limited and constrained to the fibre geometry [2]. Off-the-shelf light emitting diodes (LEDs) can be manually sewn into textile or integrated into a yarn [3], but the approach is limited in achieving single point light sources [4]. The most challenging approach to date is to deposit light emitting devices directly on the conventional woven textiles. Early examples demonstrated flexible inorganic electroluminescent functionality on textiles [5], and flexible organic LEDs (OLEDs) have also been achieved on textiles [6]. However, there are significant challenges to adding light emission directly on woven textiles, due to difficulties caused by the textile's intrinsic properties, for example, surface roughness, porosity, and flexibility. To date, using the OLEC approach to achieve light emission on textiles has met with very limited success [7].

Light emitting electrochemical cells (LECs) and LEDs are thin film devices fabricated on flexible substrates to emit light. The main difference is the external addition of salts in

the LEC's active layer, while the LED's active layer uses a pure organic semiconductor for device operation. A LEC device consists of a single active layer sandwiched between two air stable electrodes [8]. In LECs, the salts are blended externally with the organic semiconductor in the active material. When the device is biased, these salts redistribute across the junction in the active layer, so that electrons and holes can be efficiently injected into the LEC active layer to achieve light emission [9]. However, during light emission the device needs to be protected by the encapsulation layer from the ambient air. Because the organic semiconductor in the active material is doped, it is in an unstable state and the excitons formed in the active layer readily react with oxygen and water particles in ambient environment [10].

The first LEC devices were reported by Pei et al. in 1995. The light emitting devices were fabricated on glass substrates and emitted an orange colour [11]. In recent years, Edman's group reported state of the art LEC devices using slot die coating [12], spray coating [13], and also utilising other printing methods such as inkjet [14], roll-to-roll, gravure [15], and screen printing [16]. Lanz et al. reported LEC fabrication on a polyurethane formed textile sheet integrated with a copper wire matrix. The devices emitted yellow light at 5 V with a brightness of 4000 cd/m², a current efficiency of 3.4 cd/A, and a lifetime of 180 h. Although the results are notable, the substrate used is a technical textile, which has a completely different texture and feel to standard wearable woven polyester cotton textiles. Research on UV light emission on textiles has not been reported to date. However, there is a strong application motivation for a UV emitting textile. UV light emission can be used to kill bacteria and viruses in a wearable textile. It can also be used in a smart bandage to maintain a hygienic environment for the wound and to accelerate the healing process. In addition, a textile colour change can be realized using the photochromic effect triggered by the textile's UV emission. The synthesis of a novel UV emitting molecule was reproduced in this research work, based on the literature [17]. This research therefore aims to achieve both UV and visible light emission on textiles through spray coating of OLECs.

2. Materials and Fabrication Methods

Visible yellow LEC on textiles: Fabrication of a visible yellow light LEC devices on a woven 65/35 polyester cotton textile substrate is described in this section. The fabrication process started by planarising the woven textile substrate. Screen printing is used to deposit a polyurethane layer (UV-IF-1004, FabInks Ltd, UK) directly on top of the woven textile substrate in the desired pattern. This planarising process reduces the surface roughness of the woven textile from hundreds of microns to less than ten microns. UV curing is carried out to cross link and solidify the polyurethane layer. Then, the entire LEC device is fabricated solely by spray coating. The device structure on top of pre-treated woven textiles is shown in Figure 1a. The bottom electrode of the LEC device is a silver layer, which is deposited by spray coating the silver (Ag) nanoparticles suspension (SilverJet, Sigma Aldrich, UK) with a bottom electrode mask. The curing condition for silver layer is 120 °C for 30 min in a conventional box oven. Then, the next subsequent functional layer is the LEC active layer. Then a PEDOT:PSS suspension in toluene (Heraeus) is spray coated on top of the silver layer, followed by the LEC active layer. The PEDOT:PSS layer was dried at 120 °C for 20 min in a conventional box oven. The active solution was prepared from several solutions of the electroluminescent polymer, superyellow (SY, Livilux PDY-132, Merck, Germany), the ion-dissolving polymer, poly (ethylene oxide) (PEO, Sigma-Aldrich), and the salt, potassium trifluoromethanesulfonate (KTF, Sigma-Aldrich). The PEO and KTF were individually dissolved in cyclohexanone solution to form the master solutions, and both solutions have 10 mg/ml concentration. The SY solution was prepared in a 10 mg/mL concentration in toluene (anhydrous, Sigma-Aldrich). To achieve the blended SY active solution, 1ml of each of PEO and KTF were added into the SY solution, and then cyclohexanone was added to achieve the SY master solution with a concentration of approximately 5 mg/ml. To achieve a homogenous solution, a 20 min magnetic stirring

process was undertaken, and the active solution was pre-heated to 60 °C prior to deposition. The LEC active solution was then spray coated and cured at 60 °C for 10 min on a hotplate inside a nitrogen glovebox. The last functional layer is the top electrode, which is a semi-transparent thin layer of silver nanowires (AgNWs), deposited by spray coating using a top electrode spray coating mask. Curing is at 60 °C for 10 min on a hotplate inside a glovebox. Silver epoxy is used to form robust contact points for testing. The last stage is the deposition of a heat curable encapsulation layer on top of the device against decomposition.

Ultraviolet LEC on glass: Ultraviolet LEC on textiles research is carried out in a staged approach. Successful electroluminescence is required prior to a process investigation of the UV LEC on textile. Therefore, the research work first investigates the realization of the UV LEC on ITO pre-coated glass slides. The device structure is shown in Figure 1d. The pre-coated ITO is the bottom electrode in the LEC. The first deposited active layer is PEDOT:PSS, spin coated with process parameters of 2000 rpm for 30 s. Curing for PEDOT:PSS layer is 120 °C for 15 min. Then, the second deposited functional layer is the active layer, SY master solution, spin coated with process parameters of 2000 rpm for 30 s. Curing for the active layer is 70 °C for 4 h in a nitrogen oven. Then, the final functional layer is the top electrode, which needs patterned deposition. Masked sputter coating is used to give a controllable thickness of the silver of around 100 nm. There is no curing required for the sputter coated silver layer. Subsequently, a UV curable encapsulation epoxy is used to seal the device with an additional coverslip on top. The same silver epoxy is used to form a robust contact point for testing purposes.

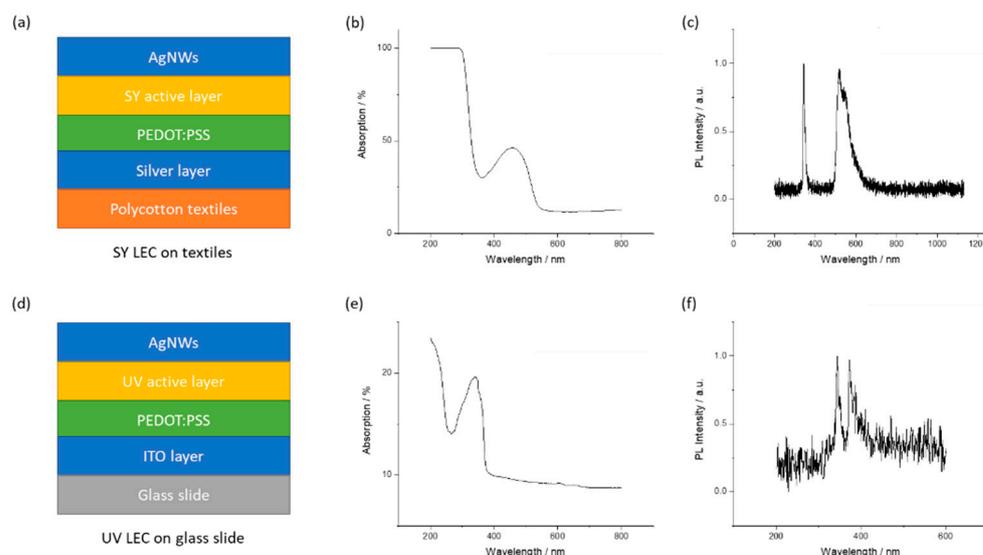


Figure 1. (a) Device architecture of SY (superyellow) OLEC, and (d) device architecture of UV OLEC, (b) absorption plots of the spray coated SY film on a glass slide, and (e) spray coated UV emitting molecule on a glass slide, (c) PL spectra of spray coated SY film on a glass slide, and (f) spray coated UV emitting film on a glass slide.

3. Results and Discussion

UV-Vis absorption and Photoluminescent (PL) measurements were taken on the super yellow active material to demonstrate its optical properties without electrical bias, but with excitation by laser. The PL curve indicates the ability of the active material's potential electroluminescent (EL) to emit the correct wavelength under an electrical bias. However, the PL peak wavelength can vary within a tolerance of a few percent. Figure 1b,e shows the absorption plots of the spray coated SY film on a glass slide and the spray coated UV emitting molecule on a glass slide. 450 nm and 360 nm absorption peaks were observed for the SY and UV emitting molecules. Figure 1c,f shows the PL spectra of the spray coated

SY film on a glass slide and the spray coated UV emitting film on a glass slide; both PL emissions were excited by a laser source of wavelength 340 nm. 540 nm and 380 nm PL peaks were observed for the SY and UV emitting molecules. The two sets of the absorption and PL excitation measurements demonstrate the two light emitting molecules' optical properties in both absorption and emission. Then after fabrication the electroluminescent performance is compared to their absorption and PL emission peaks. Figure 2a,b is a top view photograph of the SY LEC devices on woven textile in both off and on state. Each set of the spray coated textile SY OLEC contains 8 pixels defined by the top AgNWs electrode pattern. Each of these eight pixels is a light emission area and can be individually controlled on and off. Figure 2(c) shows the top view photo of the UV OLEC devices on an ITO pre-coated glass slide in an off state. The UV OLEC I/V curve and PL/electroluminescent (EL) response demonstrate the potential to migrate the device to a woven textile substrate to achieve a UV OLEC on textiles.

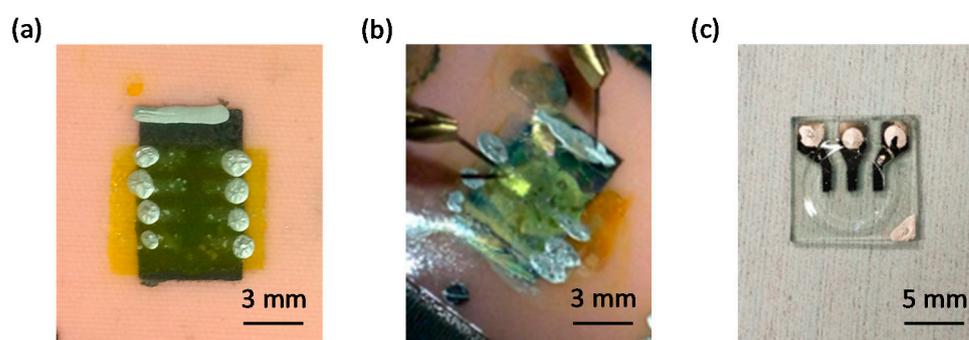


Figure 2. Top view of spray coated SY OLEC devices on textile. (a) Light emission off state, (b) light emission on state, and top view of spin coated UV OLEC devices on glass slide, (c) UV light emission off state.

4. Conclusions

SY OLEC devices have been successfully fabricated solely by spray coating technique on a flexible woven polyester cotton textile substrate. However, the textile LEC have not yet been successfully encapsulated due to the textile flexibility. Future work will focus on the fabrication of the LEC on a textile substrate with a suitable encapsulation layer to enhance the lifetime on the light emission. UV OLECs have been successfully fabricated and demonstrated by conventional spin coating process on ITO pre-coated glass slide with full encapsulation. Future work will migrate the UV OLEC devices onto the woven polyester cotton textiles via spray coating.

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