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# EXPLORING INNOVATIVE SCALE-UP SOLUTIONS FOR LIGHT INTEGRATION IN TEXTILES USING ELECTROLUMINESCENT FIBERS

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## Abstract

*In this work, we present our results on one-dimensional (1-D) light-emitting devices and their textile integration. Indeed, light integration in textiles is very challenging and thanks to their unique 1-D configuration for possible miniaturization in the lateral direction, light-emitting fibres are promising since they present higher flexibility and adaptability than planar devices and can be easily integrated into textile processes. Therefore, this work is dedicated to studying and optimising these structures to achieve flexibility, stability, suitability for large-scale production and their integration into textiles. 1-D light-emitting devices consisting of electroluminescent (EL) fibres with different structures will be studied. Although the dip-coating method presents several challenges, it turns out that this method is the most promising for the scalability of the process.*

**Keywords**

Light integration, Electroluminescent fibres, Textiles, Dip-coating

## 1. Introduction

The evolution of materials, design and technologies are propelling the development of smart and multifunctional components for daily life applications. Among these applications, light-emitting fabrics are an emerging technology for displays (Yang et al., 2020), clothing and personal safety, fashion accessories, the automotive sector, home textiles, textile architecture, but also for wearable devices such as sensing and communication devices (Zhang et al., 2018), as well as photodynamic therapy for the treatment of dermatologic diseases (Mordon et al., 2020; Oguz et al., 2016).

## 2. Literature Review

Several approaches were investigated to achieve light-emitting fabrics. The first approach consists of flexible plastic optical fibres illuminated by injecting light at each end of the fibres gathered in a bundle. By integrating the plastic optical fibres within knitted or woven structures, light emission can be obtained over flexible textile surfaces (Brochier Technologies). The second approach consists of fabricating the light-emitting fabrics directly onto woven or knitted textiles. This technique consists in laminating the emissive layer sandwiched in between isolated conductive textiles serving as electrodes (Lanz et al., 2016; Schlingman et al., 2021). While the above approaches provide large-area illumination, the third approach consists of a single emitting fibre or electroluminescent (EL) fibre (Zhang et al., 2015; Ben Sedrine et al., 2021). Several methods were used to realize EL fibres such as dip-coating, spray-coating, extrusion and even 3D printing (Yang et al., 2020).

Light integration in textile is very challenging (Schlingman et al., 2021) and the third approach consisting of EL fibres would be very suitable. Indeed, thanks to their unique 1-D (one-dimensional) configuration for possible miniaturization in the lateral direction, light-emitting fibres are promising since they present higher flexibility and adaptability than planar devices and can be easily integrated into textile processes. Therefore, this work is dedicated to studying optimising these structures to achieve flexibility, stability, suitability for large-scale production and their integration into textiles.

## 3. Research

The electroluminescent (EL) fibres were elaborated by dip-coating, using the following structure: first electrode (anode) - represented by a conductive core, an electroluminescent layer (EL paste), a second electrode (cathode) - twisted over the whole structure, and a protective layer encapsulating the EL fibre.

The dip-coating approach was used to maximize the electroluminescent effect by taking advantage of commercially available solvent-based materials and dispersions containing a high content of electroluminescent pigment. However, the commercially available EL pastes are optimized for process applications such as screen printing with a demonstrated efficiency when applied in 2-D configuration for films and coatings. One of the challenges of this technique includes processing the solvent-based EL paste in a 1-D configuration in the form of a fibre. Since this process is scarcely explored at the industrial level, the application of these EL materials requires specific equipment to guarantee the uniformity of the different layers constituting the EL fibre. To solve these issues, we have established the following protocol: i) development of the experimental setup to validate the concept, ii) optimization of the process conditions in terms of coating and curing processes. Although the dip-coating method presents several challenges, it turns out that this method is the most promising for the scalability of the process.

## 4. Methods and Results

In the following section, we will provide further details on the fabrication of the EL fibres and the materials and experimental parameters, and the corresponding results in terms of the illuminance of the obtained EL fibres. After optimization of all parameters and achieving the best performance of EL fibres in terms of current-voltage-illuminance, we will provide a scale-up of the solution for the large-scale product as well as a preliminary validation of the EL fibres integration in textiles.

### 4.1. Fabrication of the EL Fibers

For the fabrication of the EL fibres, we have developed a setup shown in Figure 1, composed of the different components: dip-coating system, curing system (oven), and reeling (tension control) system. The dip-coating system containing the EL paste is represented by three stages: (a) cleaning stage including a container with acetone; (b) dip-coating stage including a container with the EL paste; and (c) a stage for removing the excess EL paste to obtain a diameter of 0.8 mm. We have also built a vertical tubular oven, with two heating zones and independent temperature controls. After dip-coating, the coated fibre enters the bottom of the oven successfully through the first heating and second heating zones, then is collected in the reel.

The temperatures of the oven and the pull speed of the reel are adjusted so that the EL paste deposited on the fibre is cured. Furthermore, in addition to the curing time parameter, the coating speed of the fibre influences the thickness of the EL layer because of the changes in the capillarity and evaporation rate of the EL paste. Therefore, the parameter related to the speed of the dip-coating process was also evaluated.

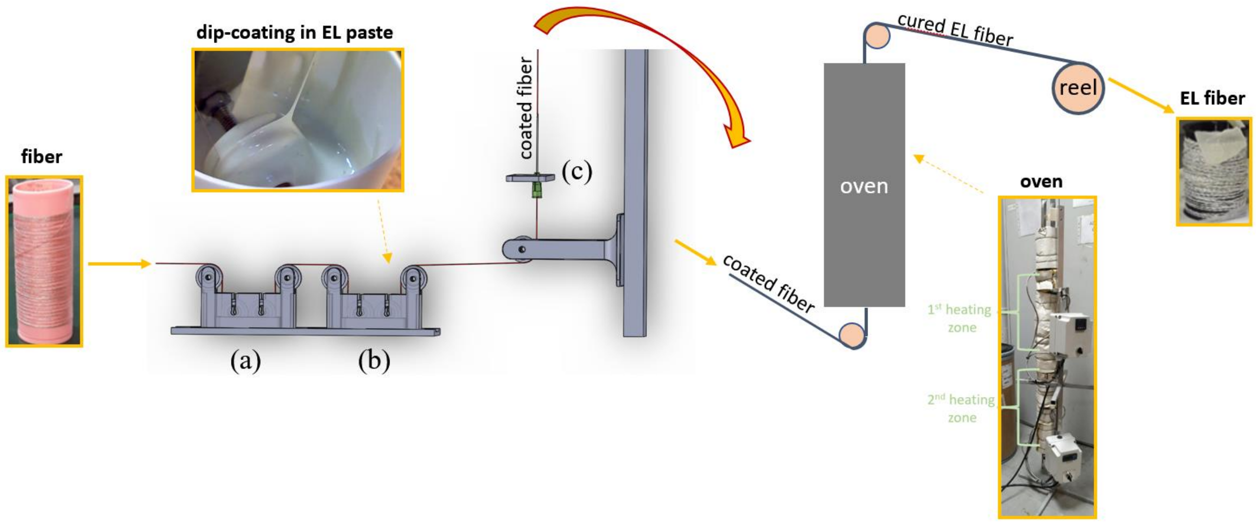


**Figure 1:** *Setup developed for the fabrication of the EL fibres: dip-coating, curing, and reeling systems.*

*(Source: Self)*

## 4.2. Materials and Experimental Parameters

The choice of materials is very critical to obtaining a flexible EL fibre. Indeed, the flexibility is provided not only by the internal and external metallic conductors, the polymer used in the dielectric and protective layer, but also by the EL material and other additives. The ability of light emission from the EL fibre is proportional to the percentage of EL material in the EL layer. However, the higher the EL material percentage, the more fragile (i.e. less flexible) the EL layer will be. The performance of the EL fibre is limited by factors such as the size and concentration of the EL pigment, the dielectric constant of the polymer in which the pigment is dispersed, and finally the total thickness of the EL layer. These factors need to be optimized to maximize the light emission, also considering the deformation and stress cycles to which the EL wires are submitted. The materials are listed in Table 1.

The materials used as core electrodes are conductive fibres: polymeric and metallic (copper). The EL layer consists of a commercial paste containing encapsulated phosphors, which viscosity was optimized by using agents based on polyvinylpyrrolidone (PVP) and polyethene glycol (PEG). The second electrode is composed of conductive metallic fibres (copper).

To establish the best EL response, different combinations of electrode materials were studied in detail, as summarized for samples #S1-S4 in Table 2. The different structures were dipcoated in EL paste under the same conditions: dip-coating at 24°C and the temperatures were kept at 80°C and 140°C in curing zone 1 and zone 2, respectively.

It was reported that the contact area of the electrodes with the EL layer plays an important role in the performance of the EL devices (Wang et al., 2017; Lipomi et al., 2012). Being a transparent conductive polymer with the highest reported conductivity among solution-processed polymers, we proposed to use PEDOT: PSS (poly(3,4-ethylene dioxythiophene) polystyrene sulfonate) as an additional coating (as shown in Table 2, red region). PEDOT: PSS was applied to the EL fibres and cured the over at 110°C for 20 minutes. A non-enamelled copper wire (Elektrisola TW-A, with a diameter Ø= 0.063 mm) was twisted and acted together with the PEDOT: PSS as an external electrode.

For EL fibres with and without PEDOT: PSS, a silicone-based material (Table 1) was used as an external protective layer (encapsulant).

**4.3. Illuminance of the EL fibres**

Illuminance quantification is one of the most important characterizations for EL devices. In this work, the illuminance characterization was realized in the same conditions for the different EL fibres, using the LT300 Luxmeter, from Extech Instruments. The samples were placed parallel to the lux meter, with a constant distance (D = 450 mm) between the sample and the lux meter, as shown in Figures 2 (a) and (b). The typical electroluminescence response of an EL fibre when applying a tension of 110 V AC (frequency of 2 kHz) is shown in Figure 2 (c).

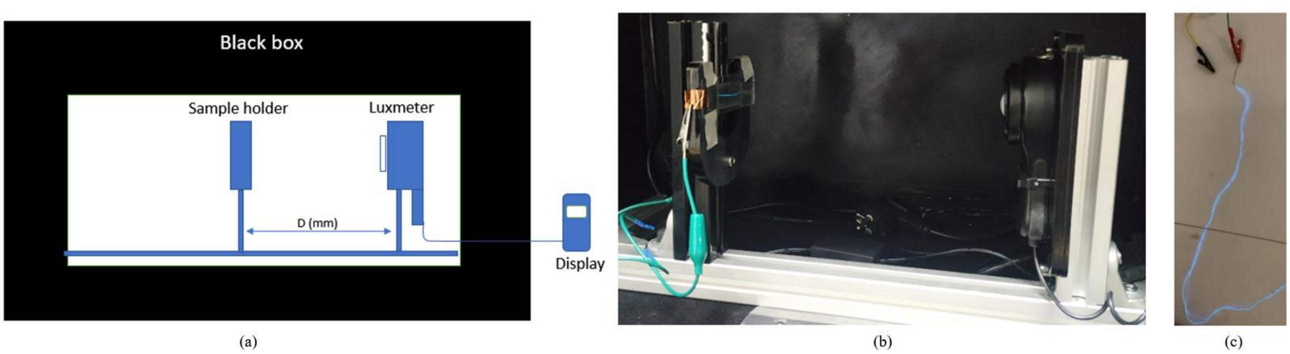


**Figure 2:** *Schematics (a) and photography (b) of the setup for illuminance measurements. Typical electroluminescence response of an EL fibre (c).*
*(Source: Self)*

Figure 3 shows the illuminance measurements performed in the same conditions, in the dark and ambient lighting, for the different samples. When comparing the results obtained for the different samples, we demonstrate that illuminance values increase from #S4, #S1 to #S3, being the highest for sample #S2. Therefore, it can be concluded that the EL fibres with a high number of filaments would be more suitable. Sample #S2 with a core electrode formed by 8 enamelled copper wires twisted together presents the most suitable solution. When comparing the illuminance results of the EL fibres without and with the layer of PEDOT: PSS, we observe an increase in the EL response. This can be explained by the fact that the external transparent electrode renders the distribution of the electric field in the EL fibre more homogeneous, therefore enhancing light emission on the fibre surface. For instance, an illuminance of ~0.01 lux was measured for sample #S2 without PEDOT: PSS. However, after adding the PEDOT: PSS layer for sample #S2, the illuminance value of ~1.23 lux was measured. In addition, it is important to notice that the EL fibres and corresponding illuminance values were found to be stable after several ON/OFF cycles. Further developments are being pursued to increase the performance of the EL fibres in terms of illuminance values.

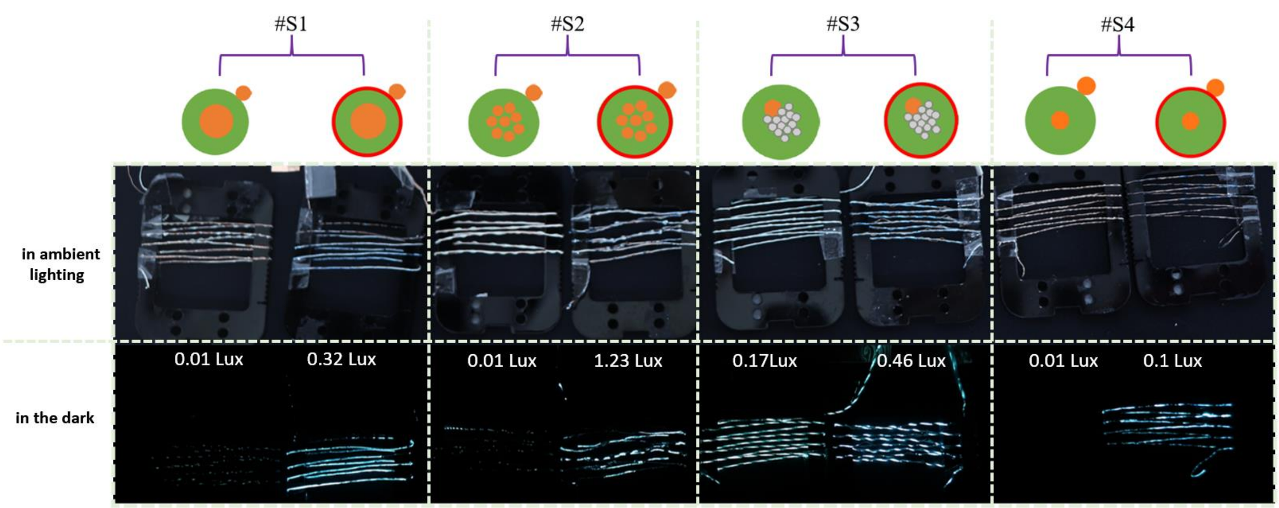


**Figure 3:** *EL Response of The Different EL Fibers with And Without PEDOT: PSS (Red Region) Measured in The Dark and In Ambient Lighting (Illuminance ± 0.01 Lux).*

*(Source: Self)*

### 4.4. Scalability of the Solution

After optimization of all parameters and achieving the best performance of EL fibres in terms of current-voltage-illuminance, we have realized a scale-up of the solution for large-scale production. Figure 4 shows the scale-up solution corresponding to 5 meter-long EL fibre. The supplementary file shows a video representing ON/OFF cycles of the EL fibre of five meters (https://www.youtube.com/watch?v=vp-mqURaib4).

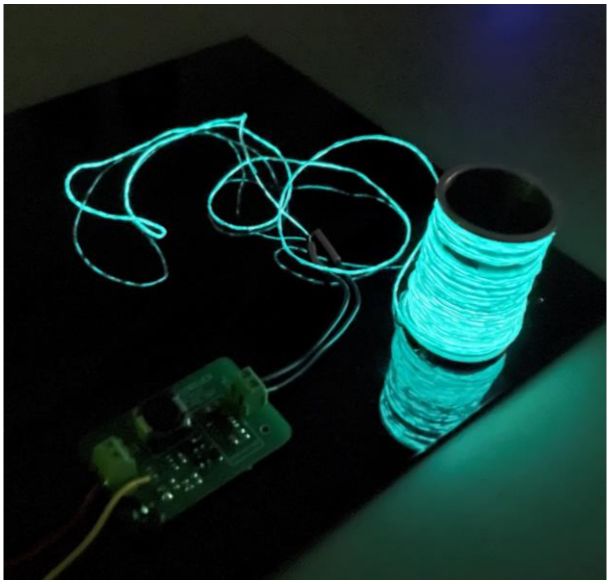

**Figure 4:** *Scale-Up Solution: EL Fiber of Five Meters*

*(Source: Self)*

### 4.5. Integration in Textiles

Preliminary validation of the EL fibres integration in textiles was carried out manually embroidered as shown in Figure 5. We present the EL fibre as inserted in the textile in Figure 5 (a), the electrical connections in Figure 5 (b), and the EL response observed in the dark in Figure 5 (c). Despite being a manual process no breaks in the electrical connections were observed, therefore we validate the stability of the EL fibres by manual embroidery. Further tests will be performed for the weaving and knitting processes.

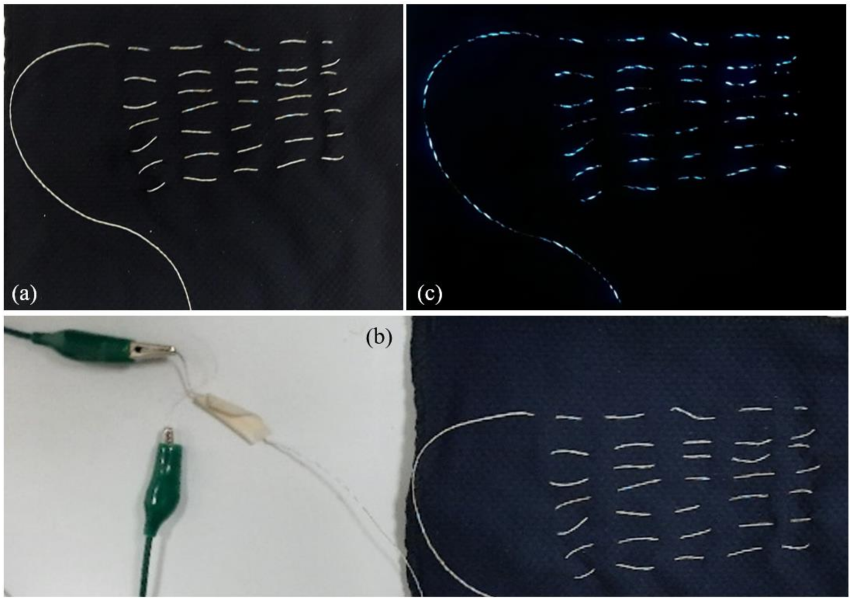


**Figure 5:** *EL Fibers Manual Integration in Textiles*

*(Source: Self)*

## 5. Conclusions

The flexibility, adaptability and scalability of the present solution are one of the most valuable and innovative characteristics of our EL fibres since it allows seamless and versatile integration in textile materials. Being flexible (with a fibre section below 1mm), the developed 1-D light-emitting devices can be easily integrated into textile structures and products, such as the automotive sector, fashion accessories, home textiles, and textile architecture.

Scope of Future Research and Research Limitations: Our solution is suitable for large-scale production and embroidery integration in textile, and further developments are being pursued for its use in industrial processes.

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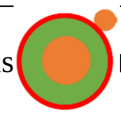
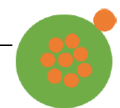
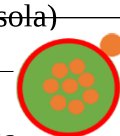
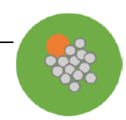
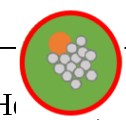
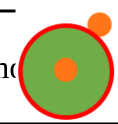
* https://www.tme.eu/Document/01b6e6e2080e2fbdb643802489e9266c/DN1E_EN.pdf
**http://www.textile-wire.ch/fileadmin/download/Techn_Brosch_TW_en_def_may2011.pdf

**Table 1** *List of the materials used to fabricate the EL fibers.*

**Table 2** *EL fibers with different core electrodes. The green region corresponds to the EL material. The red region corresponds to PEDOT: PSS.*

| Type | Material | Reference |
|---|---|---|
| EL paste | Blue-Green EL phosphor | LuxPrint® 8152B (DuPont) |
| Thinner | Polyvinylpyrrolidone | PVP40 (Sigma-Aldrich) |
| Thinner | Polyethene glycol | PEG 2000 (Sigma-Aldrich) |
| Conductor | Copper wire* | D[illegible] (Transfer Multis[illegible]tronik) |
| Conductor | Copper wire** | TW-A (Elektrisola) |
| Conductor | Silver-coated polyamide wires | STATEX – SHIELDEX (SHIELDEX®) |
| Conductor | PEDOT: PSS | [illegible]LEVIOS SV4 (H[illegible] |
| Encapsulant | Silicone | [illegible]gon skin-20 (Sm[illegible] |

| Sample | Core electrode (anode) | EL fibre structures with additional enamelled copper wire (cathode): without PEDOT: PSS | with PEDOT: PSS (red) |
|---|---|---|---|
| #S1 | Single enamelled copper wire DN 1E 200 with Ø=0.25 mm |  |  |
| #S2 | 8 enamelled copper wires TW-A, with Ø=0.10 mm each |  |  |
| #S3 | Silver-coated polyamide wires |  |  |
| #S4 | Single enamelled copper wire TW-A, with Ø=0.10 mm |  |  |