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Fabric opto-electronics enabling healthcare applications; a case study

L. van Pieterson, F. A. van Abeelen, K. van Os, E. Hornix, G. Zhou, G. Oversluizen *Member, IEEE*

Abstract— **Textiles are a ubiquitous part of human life. By combining them with electronics to create electronic textile systems, new application fields emerge. In this paper, technology and applications of light-emitting textile systems are presented, with emphasis on the healthcare domain: A fabric substrate is described for electronic textile with robust interwoven connections between the conductive yarns in it. This fabric enables the creation of different forms of comfortable light therapy systems. Specific challenges to enable this use in medical applications are discussed.**

I. INTRODUCTION

Textiles are a ubiquitous part of human life. By combining them with electronics to create electronic textile (e-textile) systems, new application fields emerge.[1-18] One application that has gathered considerable attention are wearable e-textile systems.[1-18] Such systems have the requirements of being both lightweight and comfortable. These conditions imply that the system must be robust enough to survive the stresses associated with body movements.

Currently, several research directions can be distinguished, either focusing on the sensing of body signals such as ECG, or on heating applications for e.g. outdoor clothing or car seats or on light emission.[19]

This paper deals with electronic textiles for light emission. Light is of particular interest; it can have a variety of functions, ranging from providing visibility and safety, to influencing moods, to signage, to displays, and so on. In addition, light can interact with living organisms; light influences plant growth, influences the biorhythm and provides warmth. When integrating light into fabrics, benefit can be taken from the large area nature of textiles,

There are various fabrication methods that can be used in order to create an e-textile.[1-13,16-18] One method is to weave conductive yarns in both the warp and weft directions in order to create a conductive circuit textile backplane.[3,7-8,17-18] Components such as light-emitting diodes (LEDs) can be attached to create a light-emitting fabric. Crucial are the selection of the conductive yarn and the fabrication process. This is explained in the next section (II).

In previous publications we have reported on the use of such light-emitting fabrics for applications such as wearable displays [20]. Here, we focus on applications in the healthcare domain, in particular on light therapy applications. Light therapy is known already since centuries. Real interest increased in the 19th century with the use of ultraviolet irradiation in the treatment of various diseases.[21] This reached a climax when Niels Finsen received the Nobel Prize in 1903 for his therapeutic results with lupus vulgaris. This marked the start of modern phototherapy. It was used in thermal stations for treatment of tuberculosis, in the treatment of leg ulcers in wartime, and in the treatment of skin diseases. Also nowadays, light therapy is widely used in the treatment of skin diseases such as psoriasis, neonatal jaundice, pain and in photodynamic therapy.

Light integrated in fabrics enable comfortable, wearable light therapy. This has important advantages in terms of time, space, and treatment efficacy. However, there are also technical challenges in bringing the light so close to the body, such as light homogeneity, heat management and reliability. These topics are discussed for a light-emitting blanket in section III.

II. THE CONDUCTIVE FABRIC SUBSTRATE

Very important in the realization of electronic textiles is the conductive yarn. Lighting applications using LEDs require low voltage, but considerable current and therefore good conductivity is important. Several types of conductive yarns exist: there are the metal wires, such as from Elektrisola, depicted in Fig. 1 (a), and there are metal-coated textile multifilament yarns (e.g. Statex, Elitex), Fig. 1(b).

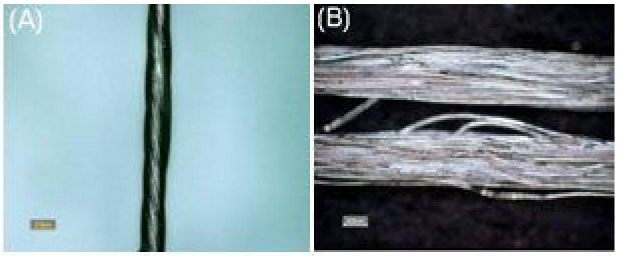

Fig. 1: (a) metal stranded wire (Elektrisola), (b) Ag-coated polyester multifilament yarn (Elitex)

The construction of a yarn has large consequences for the processability and suitability for use in smart fabrics. For instance, metal wires tend to break easily in textile fabrication, while multifilament yarns can give rise to shorts

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L. van Pieterson, F. van Abeelen, K. van Os, E. Hornix, G. Zhou, G. Oversluizen are with Philips Research, High Tech Campus 34, 5656 AE Eindhoven, The Netherlands (corresponding author L. van Pieterson, tel: +31 40 2744659; fax:; e-mail: Liesbeth.van.pieterson@philips.com).

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when adjacent wires are too close. Properties can be improved by a proper design of the yarn, e.g. by means of wrapping, stranding and twisting.

We have selected Elektrisola 20x0.04mm CuAg wires for our conductive fabrics. These wires have a conductivity of about 0.5 Ω/m, ensuring limited resistive losses. The wires are interwoven in the warp direction on an automated weaving loom. LEDs are attached at regular intervals in an automated process. The current in every LED textile is controlled. The power source is not integrated in the blanket; a standard external current source is used to power the device. Fig. 2 shows a picture of the resulting fabric.

Fig. 2: Woven fabric with integrated conductors in the warp direction and LEDs attached.

III. EVALUATION

For the experiments described in this paper, we have integrated the light-emitting fabric into a blanket. The light-emitting fabric is covered by a light spreading layer and a cover fabric in order to ensure a more or less homogeneous illumination of the skin. Requirements for homogeneity in light therapy devices are described in the medical devices standard IEC 60601-2-57 [22]. This standard requires that the spatial variation of the device over the treatment area shall not deviate from the average irradiance or radiant exposure by more than ±20% when the device is Risk Group 3. Risk group refers to a hazard classification. Risk Group 3 has the highest risk: devices with this classification may pose a risk even for momentary or brief exposure. Our light-emitting blanket is not in this high Risk Group, but the given maximum deviation of ±20% nevertheless is a good guideline for homogeneity. The optical profile of the light-emitting blanket, as measured with a Joey Dosimeter from Respironics, is shown in Fig. 3. The spatial variations measured in this manner are well within a ±20% limit.

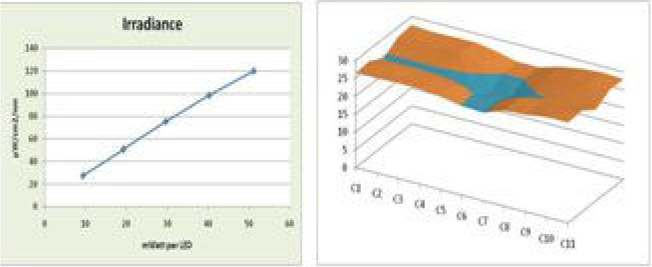

Fig. 3: Irradiance (on the left) and homogeneity (on the right) of the light-emitting blanket. Irradiance was measured in an integrating sphere at 15 mW/ LED. Homogeneity was measured with a Joey Dosimeter from Respironics at 9 mW/LED.

In addition to homogenizing the illumination, the light spreading layer also prevents overheating of the skin by direct (or close) contact with the LEDs. Temperature was measured by two thermocouples, as shown in Fig. 4. The maximum temperature increase was 1.5 ^{0}C after 30 minutes when exposed to air (to 24.5 ^{0}C). Inside the blanket, the maximum temperature increase was 5.3 ^{0}C after 30 minutes to 28.3 ^{0}C, indicating that temperature control would be beneficial for future prototypes.

According to the medical devices standard IEC 60601-1 [23], parts in contact with the skin for 10 min. or longer may have a surface temperature of 41 °C without any special justification and even 43 °C if additional justification is given. This means that our light therapy blanket is safe with respect to temperature exposure of the skin, even if used in climatized conditions such as in an incubator.

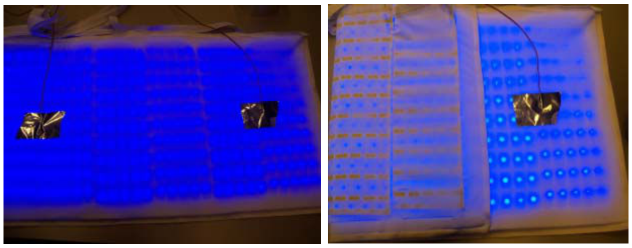

Fig. 4: Light-emitting blanket with thermocouples on top. On the left: exposed to the ambient. On the right: one thermocouple is 'rolled' in the blanket to measure the temperature inside.

In an earlier publication we have published extensively on the reliability of the conductive fabric substrate.[20] Here, we present simulated storage and use tests for the blanket, consisting of conductive fabric substrate with attached LEDs, light spreading layer and cover fabrics.

For storage, we assumed folding of the blanket, as this is very well possible because of its textile nature. We have folded the blanket in the length and width direction, see Fig. 5. After 200 times, all LEDs were functioning with unchanged characteristics.

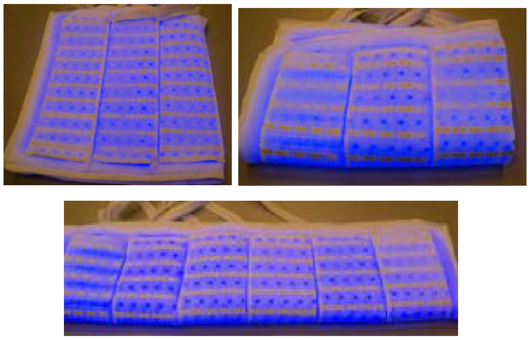

Fig. 5: Storage test of the light-emitting blanket; the blanket is folded in the length and width direction for 200 times.

We have simulated use by rolling the blanket around a 2 kg cylinder with diameter of 12 cm, as shown in Fig. 5. In the experiment, the cylinder was placed on the blanket, and the blanket was rolled around it. After 500 times, the LEDs were inspected and observed to emit with unchanged characteristics.

Fig. 5: Use test of the light-emitting blanket; the blanket is rolled around a 2 kg cylinder with diameter of 12 cm for 500 times.

IV. CONCLUSION

We have shown a fabric substrate for electronic textile with robust interwoven connections between the conductive yarns in it. This fabric has been used to create a phototherapy blanket. Optical and thermal performance was shown to be according to the standards for light therapy products. Reliability has been proven in simulated use and storage tests.

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REFERENCES

[1] E. R. Post, M. Orth, P. R. Russo, and N. Gershenfeld, “E-broidery: Design and fabrication of textile-based computing”, *IBM Syst. J.* **39**, 840 (2000).

[2] S. Wagner, E. Bonderover, W. B. Jordan, and J. C. Sturm, “A woven inverter circuit for e-textile applications”**,** *Int. J. High Speed Electron. Syst.* **12**, 1 (2002).

[3] D. Marculescu, R. Marculescu, N. H. Zamora, P. Stanley-Marbell, P. K. Khosla, S. Park, S. Jayaraman, S. Jung, C. Lauterbach, W. Weber, T. Kirstein, D. Cottet, J. Grzyb, G. Tröster, M. Jones, T. Martin, Z. Nakad, “Electronic textiles: A platform for pervasive computing”, *Proc. of the IEEE* **91**, 1995 (2003).

[4] J. B. Lee and V. Subramanian, “Weave patterned organic transistors on fiber for e-textiles”, *IEEE Trans. Electron Devices* **52**, 269 (2005).

[5] M. Maccioni, E. Orgiu, P. Cosseddu, S. Locci, and A. Bonfiglio, "Towards the textile transistor; assembly and characterization of organic field effect transistor with a cylindrical geometry", *Appl. Phys. Lett.* **89**, 143515 (2006).

[6] M. Hamedi, R. Forchheimer and Olle Inganäs, “Towards woven logic from organic electronic fibres”**,** *Nature Materials* **6**, 357 (2007).

[7] I. Locher and G. Tröster, "Fundamental Building Blocks for Circuits on Textiles", *IEEE Trans. on Adv. Pack.* **30**, 541-550 (2007).

[8] I. Locher and G. Tröster, “Screen-printed textile transmission lines”, *Textile Research Journal* **77**, 837-842 (2007).

[9] M. Chandra, M. Jones, and T. Martin, “E-Textiles for Autonomous Location Awareness,” *IEEE Trans. on Mobil. Comput.* **6**, 367 (2007).

[10] Z. Nakad, M. Jones, T. Martin and R. Shenoy, “Using Electronic Textiles to Implement an Acoustic Beamforming Array: A Case Study,” *Perv. and Mobil. Comput.* **3**, 581 (2007).

[11] J. Liu, T. Lockhart, M. Jones, and T. Martin, “Local dynamic stability assessment of motion impaired elderly using electronic textile pants”, *IEEE Trans. on Autom. Sci. and Engin.* **5**, 696-702 (2008).

[12] T. Linz, R. Vieroth, C. Dils, M. Koch, T. Braun, K.-F. Becker, C. Kallmayer, S.-M. Hong, “Embroidered interconnections and encapsulation for electronics in textiles for wearable electronics applications”, *Adv. Sci. and Tech.*, **60**, 85-94 (2008).

[13] L. Buechley and M. Eisenberg, „Fabric PCBs, electronic sequins, and socket buttons:Techniques for e-textile crafts”, *J. Pers. Ubiquit. Comput.*, **13**, 133-150 (2009).

[14] C. Gopalsamy, S. Park, R. Rajamanickam, and S. Jayaraman, *J. Virtual Reality* **4**, 152 (1999).

[15] S. Park and S. Jayaraman, “Enhancing the quality of life through wearable technology,” *IEEE Eng. Med. Biol. Mag.* **22**, 41 (2003).

[16] D. Eves, J. Green, C. van Heerden, J. Mama, and S. Marzano, *New Nomads—An Exploration of Wearable Electronics*. Rotterdam, The Netherlands: 010 Publishers (2000).

[17] R. Bhattacharya, M. M. de Kok, J. Zhou, “Rechargeable electronic textile battery”, *Appl. Phys. Lett.* **95**, 223305 (2009).

[18] A. Dhawan, T. K. Ghosh, A. M. Seyam, J. Muth, “Development of woven fabric-based electrical circuits”, *Mat. Res. Soc. Symp. Proc.* **736**, 67-72 (2003).

[19] Smart Fabrics 2011, general impression of conference papers

[20] L. van Pieterson, P.C.P. Bouten, K, Kriege, R. Bhattacharya, “Robust fabric substrates for photonic textile applications,” *Res. J. Text. App.*, vol. 14, No. 4, Nov. 2010, pp. 54-62.

[21] R. Roelandts, The history of phototherapy: something new under the sun?, J. Am. Acad. Dermatol., **46**, 926-930 (2002)

[22] International standard IEC 60601-2-57, “Particular requirements for the basic safety and essential performance of non-laser light source equipment intended for therapeutic, diagnostic, monitoring and cosmetic/aesthetic use” (2011), Sec. 201.10.103.

[24] International standard IEC 60601-1, “Medical electrical equipment Part 1: General requirement for basic safety and essential performance” (2005), Sec. 11.1.2.2.