1. Ewa ŁADA-TONDYRA, 2. Kamil JURASZEK, 3. Adam JAKUBAS

Częstochowa University of Technology, Faculty of Electrical Engineering
ORCID: 1. 0000-0002-1087-2393; 3. 0000-0001-9302-9432

doi:10.15199/48.2023.01.38

Innovative textronics solutions using photovoltaic cells

Streszczenie. *Celem niniejszej pracy jest przetestowanie wykorzystania paneli słonecznych w połączeniu z tekstyliami i zastosowanie ich w odzieży. Przedstawiono prototyp kurtki z panelami fotowoltaicznymi. Panele ładują akumulator w postaci powerbanku, a zgromadzona energia jest wykorzystywana do zasilania systemu grzewczego w postaci mat grzewczych oraz do zasilania systemu oświetlenia nocnego z wykorzystaniem folii elektroluminescencyjnej i systemu zmierzchowego*

Abstract *The aim of this work is to test the use of solar panels in combination with textiles and apply them to clothing. A prototype of a jacket with photovoltaic panels is presented. The panels charge a battery in the form of a powerbank and the stored energy is used to power a heating system in the form of heating mats and to power a night lighting system using an electroluminescent film and a twilight system (**Innowacyjne rozwiązania tekstroniczne z wykorzystaniem ogniw fotowoltaicznych**).*

Słowa kluczowe: panele fotowoltaiczne, tekstronika
Keywords: photovoltaic panels, textronics

Introduction

Textronics has developed thanks to advances in textile technology and modern ways of constructing fabrics, but also thanks to the constant extension of the possibilities of using electronic circuits. The most popular examples of textronic products are clothes, seemingly ordinary, in which intelligent solutions have been applied to support and extend their utility and protective functions. Currently, scientists are focusing on the more utilitarian functionality of clothes for humans; thanks to today's capabilities they are able to create clothes that have properties such as music playback, communication, measurement of basic life parameters, and location [1].

There are many examples of application of textronic solutions, from those that increase the safety of the user to those that provide entertainment or facilitate communication. A few important features should be mentioned here, such as multifunctionality, understood as a solution which enables realization of many various functions concentrated in one system. Then, highly developed production technology, thanks to which it is possible to produce advanced systems.

This work shows the possibilities of using photovoltaic panels in textronics, with the example of a jacket, whose functionality has been extended by the use of solar energy to power heating mats and electroluminescent film, making the jacket using the accumulated solar energy to heat the person using it, as well as performing a safety function by increasing visibility through the light elements.

Photovoltaic Applications In Textronics

Photovoltaics seems to be a very young field; however, the beginnings of this field date back to the first half of the nineteenth century. Already in 1839, the French physicist Alexander Edmund Becquerel, during experiments with electrolyte and silver chloride electrodes, discovered a phenomenon called the photovoltaic effect [2]. Advances in technology have allowed photovoltaic cells to evolve, resulting in the emergence of new types of cells, which can be used to power a wide range of devices [3]. Among others, textronics is a field of science that, by combining clothing with electronic circuits and instrumentation, seeks new solutions for powering these systems. This is a key issue, undertaken at the stage of designing textronic products, so that in an efficient way the product should provide convenient use [1].

The use of textiles as substrates for photovoltaic panels brings several important issues, such as the loss of their original function, such as folding, flexibility, and texture. Such applications require consideration of the porosity, flexibility, transparency, and stability of the textiles.

The most decisive and limiting demand is the flexibility of the solar cells used for garment integration. Finding a trade-off between the minimum overall thickness and, thus, the maximum conformal flexibility of iPV modules on the one hand and the washability, mechanical resistance, and durability on the other is an important task that has not yet been solved for most flexible cell technologies [4].

Research on this type of solution has been ongoing for more than 20 years. Back in 2004, SCOTTeVEST and ICP Solar ICP unveiled a prototype at CES 2004 - a jacket with CIGS solar panels that allowed users to carry, connect, and charge portable digital devices [5]. Another solar jacket was produced by Pvilion, which partnered with Tommy Hilfiger to design and produce a jacket powered solely by solar energy for the 2014 holiday season [6]. The product featured removable solar panels that provided energy to power electronic devices such as cell phones and tablets; a cable running through the garment's lining connected the panels to a removable battery in the jacket's front pocket. When exposed to full sunlight, high-efficiency solar cells could fully charge the battery, which in turn can fully charge a standard 1500 mAh mobile device up to four times.

Another solution was the Solar Windbreaker, a denim coat made of recycled denim with integrated solar panels that can charge a phone in two hours [7]. In 2015, the first recycled Solar Parka with solar panels was created. As of summer 2016, the Solar Windbreaker is available, an improved version of the Solar Parka in which the solar panel is hidden in the side pocket and can be attached to the outside of the front pocket. The three solar panels are directly integrated into the garment through a laminating process.

The issue of miniaturization of functional solar cells, as one of the most relevant aspects of modern textronics-related projects, is the focus of a project currently underway at Nottingham Trent University (NTU) in the UK [8]. The project uses solar cells that are 3 mm long and 1.5 mm wide. Each cell is laminated with a waterproof resin to allow them to survive the washing process unscathed. An array of 200 mini solar cells embedded in a 5 cm^2 section of fabric can generate up to 80 milliwatts of energy, enough to charge a Fitbit wearable device or a basic cell phone.

I n 2017, researchers from the University of Tokyo and the RIKEN Research Institute unveiled a prototype ultrathin photovoltaic device covered with a waterproof and stretchable film, making it machine washable [9].

Project

In this paper, a jacket equipped with heating mats and an electroluminescent film that is powered by second-generation thin-film photovoltaic panels was designed and implemented. The main idea of the project was to create a jacket for the employees of an enterprise, which will warm the employee on cold days using the energy generated by the photovoltaic panels. A schematic of the layout connection in the jacket design is shown in Figure 1.

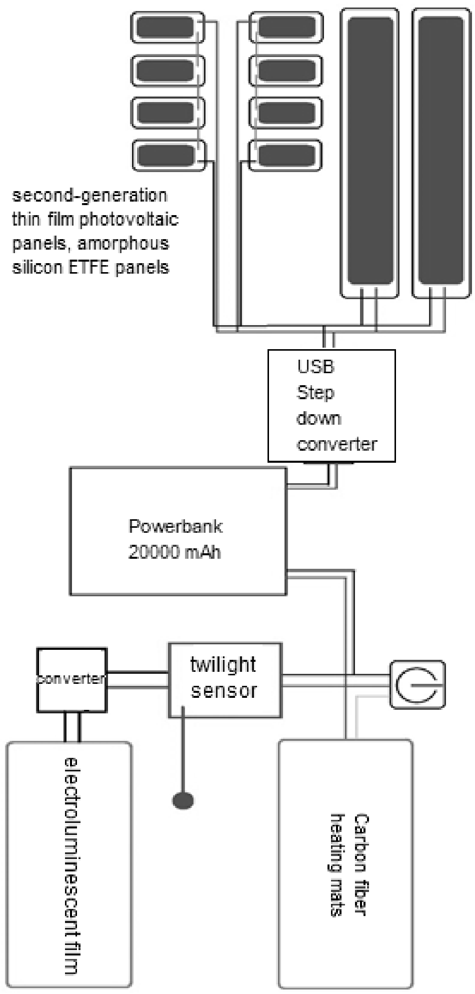

Fig.1. Schematic of the layout connection in the jacket design

The project uses second-generation thin film photovoltaic panels, amorphous silicon ETFE panels (Fig.2). The efficiency of the panel module fluctuates around 6-10% and the efficiency drop at high temperature is 0.18 - 0.25 % / K. The deciding factors for using amorphous panels for the project were their flexibility, low price, and low efficiency drop at high temperature. The downside of these panels is low efficiency.

Finally, after initial testing, it was decided to use two additional larger 36x8.5 cm panels in the design as shown in Figure 3. A single panel produces 6 V and approximately 200 - 250 mA.

Configurations of 2x4 12x6 cm panels and two 36x8.5 cm panels were created. This configuration produced 650 mA. Four 12x6 cm panels were connected in series to obtain 6-7 V DC. A pair of such panels was created and connected in parallel with the other larger panels. The voltage obtained on the circuit oscillated between 6 - 8 V DC.

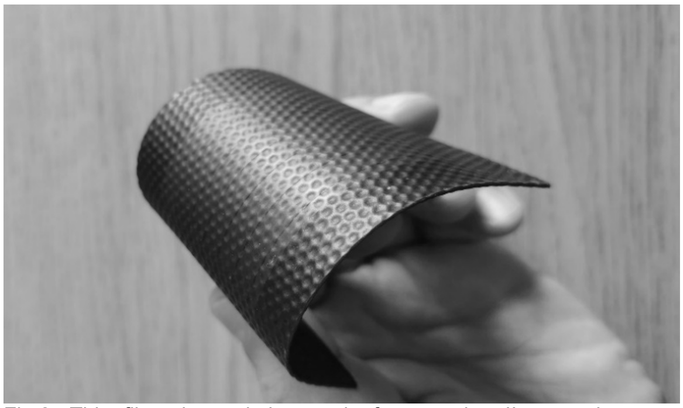

Fig.2. Thin film photovoltaic panel of generation II: amorphous silicon panel 12x6 cm.

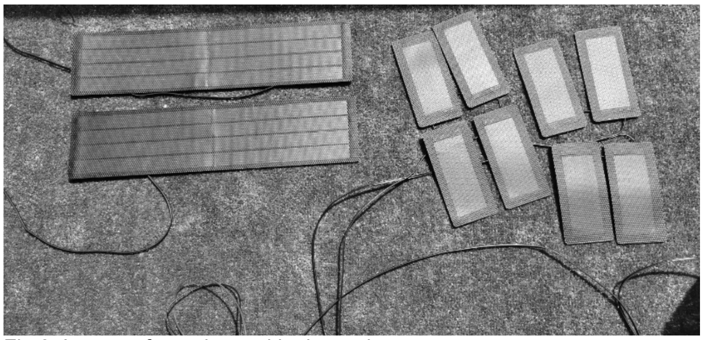

Fig.3. Layout of panels used in the project.

The voltage that was obtained from the 10 panel configuration allowed for the use of a USB step down converter. The output voltage values at the USB socket were obtained in the range of 5.05 -5.20 V and the current of 650 mA.

In the project, carbon fibre heating mats [Fig. 4] powered from the USB port with 5V DC voltage were used. In addition, the mats are connected to a button located on the jacket with the possibility of adjusting the degree of heating: red 100%, white 75%, and blue 35%. Longer holding the button turns the system on and off.

Mat Specifications:

- Temperature: 35 °C - 65 °C
- Supply voltage: 5 V (USB)
- Current consumption: 1,7 A

The jacket design uses a USB step down 5 V, ACS, model SD24V5V inverter. The inverter stabilizes the voltage from photovoltaic panels, making it possible to power a powerbank or other 5V-powered device. The input voltage of the inverter can be in the range of 6-24 V.

The maximum current of the inverter is 3 A and for continuous operation the maximum is 2.1 A. The converter can operate in temperatures of -40 °C to +85 °C. It also has a USB output socket which makes it easy to connect a Powerbank or other device.

An electroluminescent film was used for the project. A flexible film with the following technical parameters was used:

- Thickness: 0.2-0.5mm
- Bending radius: 0.25"
- Lifetime: 25,000 hours
- Capacitance: 2-5nF/sq.in
- Operating temperature: -30 ° c ~ 80 ° c
- Operating current (100V/400Hz): 1.5 ~ 2, 5mA/sq.in
- Applied voltage: DC12V or AC 40-240V

Figure 5 shows the structure of the electroluminescent film.

Fig. 4. Carbon fiber heating mats sewn into the jacket.

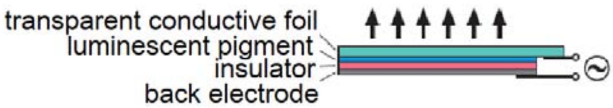

Fig.5. Structure of electroluminescent film.

The jacket has been fitted with a twilight sensor that will automatically activate our lighting whenever the brightness level falls below a set minimum. The twilight sensor connected to the electroluminescent film is an unusual convenience which will provide comfort, but also increase the level of safety. The automatic twilight device is equipped with a photoresistor that is responsible for analyzing the light brightness. When the intensity of the detected light is too low, the twilight sensor activates the switch and turns on the electroluminescent film. An important utilitarian aspect of the garment selected for implementation in the following work was to support the protective and heating function of the garment.

Fig. 6. The finished jacket design

The finished jacket design equipped with amorphous photovoltaic panels, heating mats, and electroluminescent film (Fig.6) moved to the use stage. Tests were conducted for charging, heating, and glowing. The photovoltaic panels charged the powerbank with a DC voltage in the range of 4.8 - 5 V and a current in the range of 420 - 580 mA. The powerbank used was a Xiomi brand, 10000mAh. The charging time of the powerbank was a couple of hours or so, depending on exposure and sunlight.

The next test was to check the performance of the heating mats. The mats were powered by a powerbank, previously charged with phytovoltaic panels. Using a Fluke Ti20 thermal imaging camera and a Caterpillar S60 phone, the temperature of the heating mats was measured and varied between 45 and 60 ° C. Figure 7 shows the performance of the mats and their temperatures.

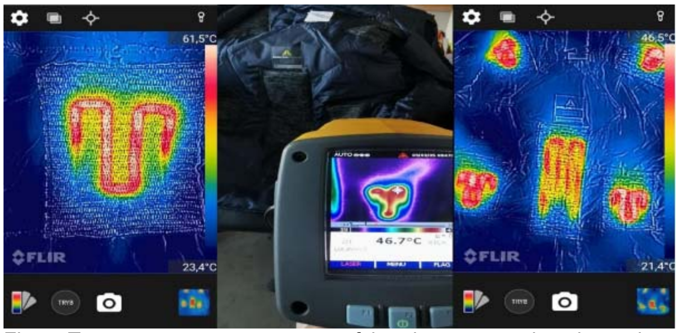

Fig.7. Temperature measurement of heating mats using thermal imaging.

The final element of the jacket design that was tested for performance was the electroluminescent film and the twilight sensor circuit that turns on the jacket lighting. Figure 8 shows the twilight system tripped with the electroluminescent film on at dusk.

Fig 8. Activation of the lighting system at dusk

Summary

The presented solution utilizes energy obtained from natural sources. After testing the functionality of panels in order to optimize the system used, it seems reasonable that in future projects using photovoltaics, newer types of panels should be used, such as CIGS or perovskites, which from the economic point of view require more expenditure, but would have a better efficiency and would give out more energy, which would accelerate charging of the battery and its more frequent replenishment, and thus longer use of energy. Further use of the solution applied in the described project seems to be practical and easy in production. Replacement of standard batteries will allow the user not only to save on costs but also to take care of the environment by reducing the amount of discarded standard batteries or stopping the use of energy from nonrenewable sources.

The project financed under the program of the Minister of Science and Higher Education under the name "Regional Initiative of Excellence" in the years 2019 - 2022 project number 020/RID/2018/19, the amount of financing 12, ,0000,00 PLN.

***Autorzy**: dr inż. Ewa Łada-Tondyra, Politechnika Częstochowska, Wydział Elektryczny, al. Armii Krajowej 17, 42-200 Częstochowa, E-mail: e.lada-tondyra@pcz.pl; inż. Kamil Juraszek, dr hab. Inż. Adam Jakubas, prof PCz,, Politechnika Częstochowska, Wydział Elektryczny, al. Armii Krajowej 17, 42-200 Częstochowa, E-mail: adam.jakubas@pcz.pl;*

REFERENCES

[1] Walczak S., Nowe kierunki integracji różnych dyscyplin nauki na przykładzie tekstroniki*, Acta Innovation*, 2013, nr 7: 49-55.
[2] Sarniak M.T., Podstawy fotowoltaiki, *Wydawnictwo OWPW*, 2008
[3] Klugmann-Radziemska E., Fotowoltaika w teorii i praktyce, *BTC*, 2014
[4] Wilson J., Mather R., Photovoltaic solar textiles, *Multidisciplinary Digital Publishing Institute Proceedings*, 2019, 32(1), 4
[5] Hanlon M., Solar Powered Jacket from SCOTTeVEST, Available at: https://newatlas.com/solar-powered-jacket-from-scottevest/2522/ (Accessed: 2th August 2022)
[6] Tommy Hilfiger's Solar-Powered Jacket, Available at: https://solaredition.com/tommy-hilfigers-solar-powered-jacket/ (Accessed: 2th August 2022)
[7] Solar Wind-Breaker Available at: http://paulienrouts.com/un-portfolio/solar-windbreaker/ (Accessed: 2th August 2022)
[8] Satharasinghe A., Dias T., Hughes-Riley T., Solar Energy-Harvesting E-Textiles to Power Wearable Devices, *Multidisciplinary Digital Publishing Institute Proceedings*, 2019, 32.1: 1
[9] Jinno, H., Fukuda, K., Xu, X., Park, S., Suzuki, Y., Koizumi, M., Yokota, T., Osaka, I., Takimiya, K. & Someya, T., Stretchable and waterproof elastomer-coated organic photovoltaics for washable electronic textile applications, *Nature Energy 2*, 780−785, 2017