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Electrochromic Material Based Poly-3,4 ethylene dioxythiophene: Polystyrene Sulfonate (PEDOT:PSS) Utilization as Smart Military Textiles: A Review

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ABSTRACT

In this increasingly modern era, innovation in the main tool of the defense system (defense equipment) is the main support in the process of maintaining the sovereignty of the Unitary State of the Republic of Indonesia (NKRI). One of them is the innovation applied to TNI uniforms using electrochromic-based materials, namely PEDOT: PSS. PEDOT:PSS is known to be included in the classification of conductive polymers which have relatively good compatibility in terms of physical and chemical. The application of PEDOT:PSS as smart military textiles is carried out through a three-dimensional (3D) fabrication method, namely die-coating and ink-jet printing with a fabrication process speed of 20 meters per minute. Both of these methods are capable of producing high quality products, easy to design, and able to control the thickness of the substrate in the range of 80 to 750 nm.

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I. Introduction

Fabric fibers are the main component in the striped uniform of a TNI soldier. This material is the main combat clothing that has long been used as a form of disguise during military operations. TNI uniforms generally have a number of standard requirements, including flexibility, not easy to tear, color does not fade, comfortable to wear, provides a feeling of coolness when the sun is hot and feels warm when it is cold, and is reliable when used in bush or forest fields.

The current model and composition of the TNI uniform still uses a material composition of polyester and precision cotton (P/C) with a ratio of 35/65%. This affects the characteristics of washing and wear (wash and wear) so that the wearer still feels cool when the weather is hot and warm when the weather is cold. Currently, polyester fiber is the main reference for the manufacture of TNI uniforms because this fiber has hydrophobic properties, which is resistant to mold and has high tensile and stretching strength.

In today's era, as the times develop, science and technology will also develop. Likewise with the development of basic materials in the manufacture of TNI striped uniforms as the main topic that will be discussed comprehensively in this paper. The modern TNI uniform designed will be based on smart military textiles using polymer materials, namely PEDOT: PSS. PEDOT:PSS is a synthetic polymer which has the ability to produce an electrochromic effect. In addition, this type of polymer is also easy to apply to clothing with relatively good fabrication efficiency.

Basically, electrochromic is one of the properties of materials that shows a change in the absorption or transmission spectrum of light when a voltage is applied to the material. One of the potential applications of this electrochromic material is alphanumeric display and layers (Dong et al., 2020). Electrochromic materials have a transmission spectrum that changes reversibly when an electric potential is applied. The existing potential changes will change the translucent state (transparent) to opaque or vice versa (Novita and Nugrahani, 2017). To have the ability to change color, the electronic material must be reversible. From the research conducted by [16], one of the conductive glass materials that can be used as a substrate in research is Indium-tin-Oxide (ITO). This material is needed in the production of electrochromic materials which will determine the color change due to changes in the potential color differences of the thin film.

The electrochromic layer has the characteristic that it is able to reversibly vary its color and transparency to solar radiation when subjected to a small electric field in the 1-5 V range. The electrochromic layer also has certain characteristics, namely the transmission spectrum which can change when an electric voltage is applied. This change occurs in a reversible manner, namely by changing the state from the original opaque to a transparent state or vice versa. This causes the electrochromic layer to be used to regulate the amount of light that hits a surface (Luo et al., 2020).

The types of polymers discussed comprehensively in this paper are Poly (3,4-ethylenedioxythiophene): Polystyrene sulfonate, known as PEDOT: PSS. These polymers are classified as conductive polymers having the best specifications in practical applications. PEDOT doping in PSS (poly styrene sulfonate) is able to increase the conductivity so that this material can be applied as an active ingredient in electronic devices. This type of polymer has an energy range of about 1.5 eV to 3 eV and is both a semiconductor and an insulator. PEDOT: PSS has several advantages in terms of material, namely its ability to form high-quality films using general fabrication techniques and has a wide range of applications, superior optical transparency in visible light, relatively high electrical conductivity, good intrinsic and physical performance. and in air has good chemical stability and compatibility. PEDOT:PSS can be applied in various ways such as in terms of energy conversion and storage devices, organic solar cells, color sensory solar cells, supercapacitors, fuel cells and thermoelectric devices.

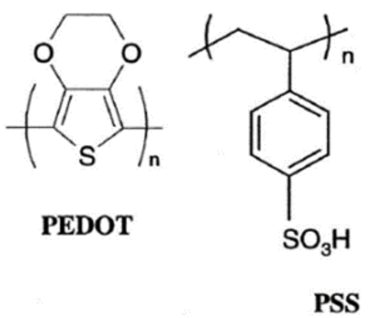


Fig. 1. PEDOT and PSS structure. Image Source: Journal of Physics Applications

II. Methods

A. *PEDOT:PSS synthesis mechanism*

PEDOT:PSS was synthesized through the following mechanism. In the initial stages, the initial PET substrate is used. Next, PEDOT:PSS was sprayed with a solution of 5 mL of the dispersion onto the PET substrate. The distance between the steel tip and the substrate is 10, 20, and 30 cm. Then given an air flow of 3.5 bar, and 3 scfm. After deposition, the films were taken at various 90, 100, and 100 degrees on a hotplate until completely dry.

B. *Mechanism of electrochromic occurrence in materials*

Electrochromic is a reaction that occurs due to the presence of an electric voltage source applied to the material, causing a change in color or opacity. Electrochromics can be used to control the amount of light transmitted into the material. Electricity is used as an input to change the opacity characteristics of a material. In electrochromic materials there are two screen areas consisting of two electrodes. There is one electrode on each side, and two transparent layers located on each side. The reaction that occurs in the material is a redox reaction. Under normal conditions, the electrode is not given a voltage so that the light rays emitted on the material are not absorbed or reflected. Then when the electrode is powered by an electric voltage source, the lithium ions in the inner layer move towards the anode. When the lithium ion is in the position of the outermost layer, the radiation in the light rays is reflected by the outermost layer material and changes the color of the material. This is because no light penetrates the electrochromic material.

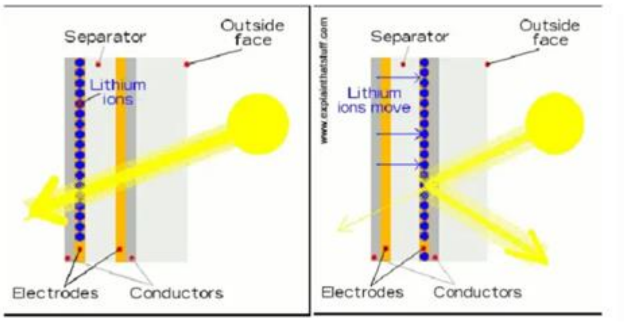


Fig. 2. The mechanism of action of electrochromic materials.
[Image source: https://doi.org/10.1016/B978-0-08-100574-3.00024-2]

C. Mechanism of PEDOT:PSS fabrication on clothing

To achieve a high level of transparency, flexibility, and conductivity, it is necessary to have the right fabrication techniques as well as effective and efficient. In addition, the right fabrication technique also determines the formation of a planar structure that affects the ease of delocalization of phi (π) electrons. Currently, several studies have tried to shift the 2-dimensional fabrication technique into 3 dimensions. This further simplifies the design process of the conductive polymer-based products to be manufactured. There are several polymer fabrication mechanisms of poly-(3,4-ethylenedioxythiophene):polystyrene sulfonate (PEDOT:PSS) including dip coating, spraying, chemical in-situ polymerization, vapor phase polymerization (VPP) (Sedighi et al., 2018), lyophilization (Solazzo & Monaghan, 2022), ink-jet printing [8] and die-coating [2].

The PEDOT:PSS fabrication mechanism on fabric fibers is carried out through two experimental scales, namely the micro scale (laboratory scale) and macro scale (mass production scale). On a micro scale, only a small part of the sample is used to test the effectiveness of the fabrication method used. If the product on a micro scale gives significant results, then the fabrication is continued on a macro scale, which refers to mass production, namely the fabric fiber printing process that has been integrated with PEDOT: PSS.

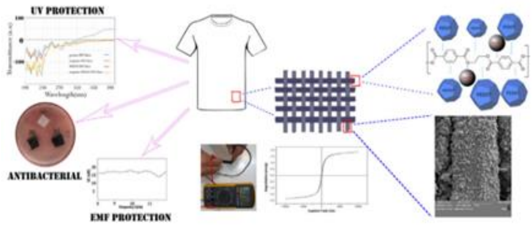


Fig. 3. PEDOT:PSS Fabrication Mechanism on clothing fibers:
[Image source https://doi.org/10.1016/j.matdes.2018.08.046]

In the early stages of the micro scale, the polyester fiber (fabric) was washed using distilled water (aquadest) and non-ionic detergent at a temperature of 50℃ for 20 minutes. Furthermore, the polyester fiber was washed again using acetone solvent and then continued with washing with distilled water. Then, the polyester fiber was cut into 10x10 cm2 in size and then allowed to stand in normal environmental conditions for 12 hours (Sedighi et al., 2018). Furthermore, a die-coating process was carried out on polyester fiber to the PEDOT: PSS film by controlling the pressure condition to keep it constant [2]. This is done so that the polyester fiber integrated with PEDOT:PSS produces a fairly low thickness level. At this stage, the coating speed achieved for fabricating the entire surface of polyester fiber with PEDOT:PSS reaches 20 m/min.

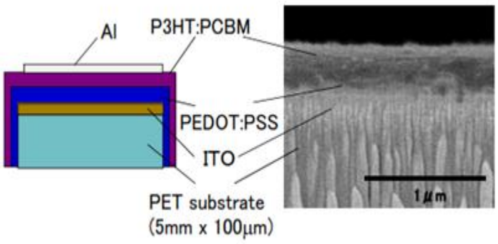
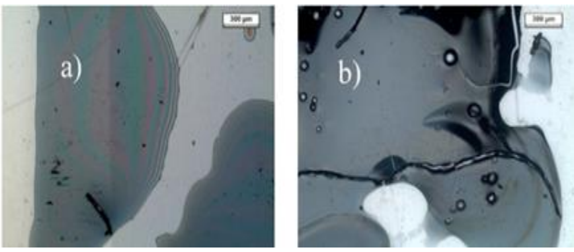


Fig. 4. PEDOT:PSS die-coating mechanism on polyester fibers on a micro scale
[Image source: https://doi.org/10.1016/j.proeng.2012.09.194]

Furthermore, for a macro scale which refers to mass production, an ink-jet printing fabrication mechanism is used. Prior to the ink-jet printing process, the polymer fibers were washed in an isopropyl alcohol solution for 15 minutes. Furthermore, the Dimatix DMP-2831 ink-jet device was used to carry out the fabrication process by reviewing several parameters such as variations in substrate temperature, namely 25, 40, and 60℃ and voltage settings namely 20, 30, and 40V. The fabrication process with the ink-jet printing mechanism is carried out under normal environmental conditions [8].



Effect of temperature on the homogeneity of polyester fiber and PEDOT: PSS (a. temperature 25℃, b. temperature -25℃)
[Image source: https://doi.org/10.1016/j.phpro.2013.04.016]

III. Result and Discussion

A. Characteristics of Electrochromic Materials

In general, electrochromic materials refer to materials that can change, emit or remove color. This electromagnetic material has been studied since before the 1900s and its main applications are in the photochromic, thermochromic, and electrochromic fields such as paints, inks, tiles, glasses, windows, and other applications. (Cho-han Fan., 2005). Electrochromic materials are capable of changing their optical properties by transmittance or reflectance under an applied electric potential. This phenomenon is called electrochromism, which is a reversible and visible change in the transmittance or reflectance associated with an electrochemically induced oxidation-reduction reaction [14].

B. PEDOT:PSS efficiency on clothes

PEDOT efficiency: PSS in other applications has good efficiency, especially applications in solar cells and electrical objects. In efficient solar cells, PEDOT: PSS is used as an active layer to replace fossil energy as a new alternative in the world of solar panels. Based on the experiment, it was found that the efficiency of using PEDOT: PSS in solar cells increased its energy efficiency up to 1.6% from the standard state of using fossil energy with the spin coating method (Sarung., 2015). This method is used with the aim of coating an electrically conducting substrate so that it can carry electricity without short-circuit disturbances and the initial layer of making screen printing for a new layer on the next layer.

Efficiency PEDOT:PSS in electrical objects has the use of conducting electricity because of its ability to conduct very well. Efficiency PEDOT:PSS is known as a conductive polymer which has the effectiveness and efficiency of outstanding work performance. This is influenced by good film-forming properties, high transparency, adjustable conductivity, and excellent thermal stability. Various interesting physical and chemical approaches that can increase the electrical conductivity of

PEDOT:PSS are summarized with a particular focus on the mechanism of increasing the conductivity and application of PEDOT:PSS films. Its efficiency can increase up to 3.56% (Xu et al., 2015). Based on this, it can be explained that PEDOT: PSS is a conductive polymer that can increase efficiency in conducting electricity as a good conductor, especially if this type of polymer is used in clothing that utilizes electrical conductors.

C. Efficiency of PEDOT:PSS fabrication technique on clothing

Based on several fabrication techniques that have been described previously, two types of fabrication techniques are used, namely die-coating and ink-jet printing. The use of these two techniques is based on the advantages possessed by each technique. Fabrication of PEDOT:PSS on polyester fibers using a die-coating technique has been proven to increase the speed of integration between the two types of polymers. As one of the fabrication techniques commonly used in the industrial world, using only low production costs, die-coating fabrication techniques are able to produce materials with a high level of thickness and flexibility as well as light weight [2].

The fabrication technique using ink-jet printing also provides significant results for the integration process of polyester fiber with PEDOT: PSS. Through the use of low energy, the ink-jet printing technique is able to produce high quality products, easy to design, and can be applied on a macro scale, namely the roll to roll process (R2R). The use of ink-jet printing techniques is also able to control the thickness of the substrate, which is in the range of 80 to 750 nm [8].

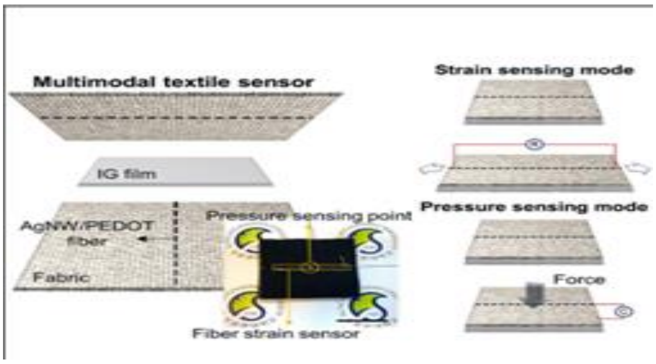


Fig. 5. PEDOT:PSS application on polyester fiber.
[Image source: https://doi.org/10.1016/j.isci.2022.104032]

IV. Conclusion

The innovation in the application of PEDOT:PSS polymer to polyester fibers in TNI uniforms is one thing that should be taken into account in designing a defense system system that is integrated with modern technology. By utilizing the electrochromic properties of PEDOT:PSS polymer, the TNI uniforms produced will have a relatively good level of camouflage through the mechanism of color change that occurs. In addition, by utilizing the conductivity properties of the PEDOT:PSS polymer, the future TNI striped uniform will be designed to meet energy needs that support the work performance of various technologies that require electricity supply. In the future, innovation and penetration of smart military textiles into TNI uniforms is expected to make a significant contribution to the modernization of the defense system in Indonesia..

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