Fluorescence in Smart Textiles

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Fluorescence has been identified as an advantageous feature in smart fabrics, notably for the protection of humans during outdoor athletic activities, as well as for preventing counterfeiting and determining authenticity. Fluorescence in smart fabrics is achieved using dendrimers, rare earth metal compounds, and fluorescent dye. The principal method for producing fluorescent fabrics is to immerse the sample in a solution containing fluorescent agents. However, covalent connections between fluorophores and textile substates should be established to improve the stability and intensity of the fluorescent characteristics. Fabric can be fluorescent throughout, or fluorescent fibers can be woven directly into the textile structures, made of natural (cotton, silk) or synthetic (polyamide- and polyester-based) fibers, into a precise pathway that becomes visible under ultraviolet irradiation.

Keywords: fluorescence ; textiles ; fluorophores ; functionalization

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Smart textiles are intelligent fabrics or fibers that can respond to external stimuli and adapt to environmental changes [1]. Light, pH, temperature, polar solvents, chemicals, and electricity are some of the physical stimuli with which these materials can interact [2]. Smart textiles are classified into three types: (i) passive smart textiles, which can only sense the environment via sensors; (ii) active smart textiles, which may respond to an external stimulus from the environment by combining an actuator function and a sensor; and (iii) very smart textiles, which can perceive, react, and adjust their behavior in response to the surroundings [3][4]. Smart fibers include [5] (i) shape memory fibers, which can return to their original shape after being deformed by external factors such as pressure and temperature [6]; (ii) photochromic fibers, which are photosensitive fibers that change color under the effect of light [7]; (iii) temperature sensitive fibers, whose characteristics are altered with temperature in a reversible manner [8]; (iv) pH sensitive fibers, which change volume or shape as the pH changes [9]; (v) healthy smart fibers, which safeguard human health by performing antibacterial or deodorant functions, or can be used in health monitoring, personal thermal therapy, and wearable electronics [10].

Shape memory fibers are frequently used to create smart clothing, i.e., deformable clothes that can change shape by changing the temperature, due not only to their good shape memory capabilities, but also to their mechanical strength and elasticity [11]. A luminescent shape memory fiber membrane, made from polyvinyl acetate (PVA) and indocyanine green (ICG), was prepared by electrospinning [12]. When the fibers were immersed in water at 25 °C or heated at 50 °C, shrinkage was achieved. These characteristics were thought to be helpful for medical devices such as gastroesophageal tubes and catheters. Indocyanine green has a near-infrared (NIR) excitation and emission wavelength. It was used as a dye to allow a near-infrared fluorescence (NIRF) imaging system and the detection of the device’s spatial position. Polyurethanes (PU) containing soft segments were discovered to be temperature-sensitive due to soft segment crystal melting [13]. The water vapor permeability of the PU membranes rose considerably as temperature climbed within the crystal melting range of 10 to 40 °C. Over the years, this form of polyurethane was explored by US Army soldiers in order to build an amphibious diving suit that allows comfortable wear both in and out of water [13]. Textiles can be utilized as sensors to determine the pH of the environment by simple visual color observation [14]. For example, because the pH of burn patients’ skin changes during the healing process, the color shift of the bandage made of smart textiles can be utilized to follow the recovery process, allowing the gauze to be removed without damaging the wound [15].

Brief History

During the Elizabethan era (circa 1600), the first conductive gold threads were woven onto textiles for a fashionable touch. The concept of employing metallic strands to adorn linens has been around for millennia [16].

The first wearable computer was created in 1955, and since then, significant effort has been devoted towards embedding electrical functionality into textiles [2]. In 1989, Japan was the first country to coin the concept of smart textiles. The earliest smart textiles were made of silk thread with shape memory characteristics [16].

The design evolution of smart textiles could be divided into three periods [17]. From the 1980s to 1997, the design approach was considered technology-driven, as a lot of studies concentrated on wearable computing and advanced technological applications. A first attempt was made in the experimental lab of the Massachusetts Institute of Technology to link computer hardware to clothing [18]. However, fashion design and commercial inputs were overlooked, and the products were more ‘portable’ than ‘wearable’ [17].

Competence and interest in the fashion and textile industries rose considerably between 1998 and 2000. As a result, the number of initiatives merging the electronic and fashion industries has increased dramatically. Despite the fact that the applications became more wearable, the majority of the results remained prototype clothes due to the immature technologies [17]. To build ready-to-wear electronics, collaborative ventures such as the one between Philips Electronics and Levi Strauss were born. The CD+ jacket included a cell phone, MP3 player, headphones, and a remote control in a jacket [19].

The number of smart textiles on the market expanded considerably from 2001 to 2004. Smart garments became more wearable as a result of a new approach focused on users and consumers. However, modern applications are designed for specific purposes (i.e., health monitoring) rather than adhering to day-to-day activity [17].

From 2006 until the present, the fourth stage has seen rapid advancements in the miniaturization and smart materials spaces, as well as witnessing the maturity of wearables entering the market [20].

The value of the global smart textiles market is estimated around $3.8 billion in 2022 [21]. Looking ahead, the market is expected to attain $15.9 billion by 2028, with a compound annual growth rate (CAGR) of 26.94% from 2022 to 2028 [21]. The expanding trend of device downsizing, together with the increasing combination of smart textiles and wearable devices, became the driving factors in the worldwide smart textiles market. The smart textile business is segmented into North America, Asia Pacific, Europe, Latin America, and the Middle East and Africa, with North America dominating the worldwide market. Adidas AG, AiQ Smart Clothing Inc., Clothing+, Dupont De Nemours Inc., and Gentherm Incorporated are among the leading companies in the global smart textiles market [21].

The rapid emergence of the coronavirus disease 19 (COVID-19) pandemic had a significant impact on the textile and garment industries, as well as on smart textiles. The latter can detect body movements, alterations in size of the rib cage during respiration, electrical impulses from organs such as the heart (i.e., electro-cardiography) and skeletal muscles (i.e., electro-myography), or can screen components in biofluids (sweat, saliva, urine, etc.) [22].

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