# Smart Nanotextiles

## Wearable and Technical Applications

Edited By
Nazire Deniz Yilmaz

Scrivener Publishing

WILEY

# Table of Contents

## List of Tables

## List of Illustrations

**Scrivener Publishing**
100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

*Publishers at Scrivener*

Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

# Smart Nanotextiles

## Wearable and Technical Applications

Edited by

**Nazire Deniz Yilmaz**

Scrivener Publishing

WILEY

This edition first published 2022 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA



For more information about Scrivener publications please visit www.scrivenerpublishing.com.



**Wiley Global Headquarters**

111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

**Limit of Liability/Disclaimer of Warranty**



***Library of Congress Cataloging-in-Publication Data***

ISBN 978-1-119-65478-0

Cover image: Pixabay.Com

Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

# Preface

The landscape of the last several decades, especially the last one, has been dotted with natural disasters, such as earthquakes, tsunamis, tornados, droughts, floods, and other extreme weather events often attributed to global warming; in addition to international disputes and a pandemic unprecedented in a century. This has taught us two things—the importance of self-sufficiency and the fact that Earth's resources are not limitless.

In order to survive in hard times, countries, cities, neighborhoods, families and individuals need to develop increased levels of self-sufficiency in terms of energy, communication and protection, among other things. This can be realized without exhausting Earth's resources by using smart technologies to produce nanomaterials that allow obtaining great performance from very small amounts.

It is possible to scavenge energy present in a medium or body and transform it into a useful form of energy, mainly electrical energy, via smart nanotextiles. Smart nanotextiles also allow remote health monitoring and disease diagnosis via wearable nanobiosensors; and can detect toxic gases and infection in wounds, defend against approaching substances and bullets, and protect against radiation, fire and other hazards. Moreover, it is possible to achieve tunable filtering performance for clean water production and air climatization via smart nanofiltration. And smart houses empowered with nanotextiles not only offer energy savings, but also allow energy scavenging, protect the elderly from falls, enable early detection of building failures and so on.

Not only are smart nanotextiles useful in difficult times, but also for making everyday life experiences more satisfying in areas such as recreation and sports, well-being, and fashion. And they are not only capable of affecting our lives today, but also of shaping life in the future. For example, smart nanotechnology holds the possibility of contributing to starting life on different planets.

As can be seen from the above, it is impossible to write about all the application fields of smart nanotextiles in only a page. During the process of reviewing the literature, deciding on content, and editing manuscripts from the outstanding contributors, I was constantly amazed by the possibilities smart nanotextiles offer. I hope the reader also enjoys and gets inspired by the wonders of the smart nanotextiles world.

This book was completed in a time frame exceeding two and a half years interrupted by my change of affiliation, move to a different city, and a global pandemic, I would like to thank the contributors for their dedication and hard work. Thanks also to Martin Scrivener, president of Scrivener Publishing, to whom I am very indebted for his patience and support. I recently read Romeo and Juliet, the famous play by William Shakespeare, and would like to conclude with a line spoken by the Prince in Scene 3, Act V of the play:

"And let mischance be slave to patience."

**Dr. Nazire Deniz Yilmaz**
Textile Engineering Department
Uşak University, Uşak, Turkey
May 2022

## Section 1

# INTRODUCTION

# 1
# Smart Nanotextiles Applications: A General Overview

**Nazire Deniz Yilmaz***
*Department of Textile Engineering, Faculty of Engineering, Uşak University, Uşak, Turkey*

***Abtract***

Smart nanotextiles form a novel group of materials that are utilized/can be utilized in an array of application areas, such as biomedicine (health monitoring, controlled drug release; wound care, and regenerative medicine), communication, sports, fashion, energy harvesting, protection, filtration, civil and geotechnical engineering, transportation, and so on, including wearable and technical fields. Whereas textiles provide a convenient platform for smart functionality, nanotechnology assures that the favorable characteristics of the textile structure are not impaired by the smart functioning components. Furthermore, based on superior characteristics of nanostructured components in comparison to macro materials and micromaterials, nanomaterials provide augmented smart functionality. Despite the fact that immense research efforts have been devoted to smart nanotextiles, most of them have not been yet transcend commercialization stage due to challenges comprising high cost, difficulty in large-scale production, low reliability, potential detrimental effects of nanomaterials for human health and the environment. If these issues can be addressed soundly, smart nanotextiles, as a member of smart nanomaterials, can be considered as the material of the future possessing the capability to improve people's living standards immensely.

***Keywords***: Smart nanotextiles, intelligent textiles, e-textiles, smart textiles, electronic textiles, applications, nanotechnology, wearable

## 1.1 Introduction

Textiles have been utilized by humankind for millenia for clothing due to their outstanding properties, including breathability, flexibility, durability and washability [1]. In recent years, textiles have started to be utilized as a platform for personal electronics, such as sensors, displays, batteries; in addition to their conventional uses. Textiles carry great promise for smart functionalities to serve as smart textiles. Development of nanotechnology has allowed better integration of smart functionality components in textiles for better comfort and aesthetic performance. Thus, smart nanotextiles merge the possibilities of textiles and the potential of nanotechnology to provide improved quality service in different areas including wearable and technical applications [2, 3].

Hence, smart nanotextiles have become the topic of intense research efforts. Smart nanotextiles have found/may find use in different areas like medicine & healthcare, drug delivery, tissue engineering, sports, communication, fashion, energy harvesting, protection, filtration, civil & geotechnical engineering, and transportation fields among others. Accordingly, development of smart nanotextiles is the result of multidisciplinary research efforts including textile technology, materials science, electrical engineering, computer engineering, chemistry, electronics, nanotechnology, and others [3, 4].

Smart textiles mean fibrous structures that are able to sense and react to external stimuli, such as the changes in the mechanical, electrical, optical, chemical, etc., properties of the environment. Furthermore, smart textiles allow generation of communication; power harvesting, storage and transmission; provide interconnection so that a network of information processing devices is established to carry out smart functions [3, 5].

The miniaturization of smart textile components allows seamless incorporation of smart functionalities. This has led to increased penetration of smart textiles in the market

[6] due to enhanced mechanical flexibility, user-friendliness, aesthetics, comfort, noninvasiveness [7]. Advancement in nanotechnology accelerates miniaturization and carries this concept into a further extent [8]. Whereas textiles provide a convenient platform for smart functuality, nanotechnology assures that the favorable characteristics of the textile structure are not impaired by the smart functioning components.

The feature that renders the smart textiles revolutionary is their capability to carry out functions that conventional fabrics cannot do, such as communication, energy generation, and information processing [9].

Conventional wearables, such as smart-wristbands, watches, glasses, mostly include rigid components, which impair comfortable and effective use. This situation limits their use in daily life outside the lab. It is essential to get rid of these bulky rigid devices to achieve better wearability and improved usefulness [7]. Thanks to miniaturization, which is fueled by emergence of nanotechnology, it has been possible to seamlessly integrate smart devices in textiles [2].

More and more people demand to obtain real-time information related to their health status, physical performance, and data related to the environmental conditions, such as environmental pollution or presence of hazardous substances. Furthermore, the rise in the population of elderly people, increased burden on healthcare delivery system, as well as the search for detection of pathologies with reduced risk of contracting or transmitting diseases, like COVID-19 infection, has lent impetus to development of remote health monitoring by use of smart textiles [2].

Studies on smart textiles, supported by miniaturization fueled by nanotechnology, provides novel noninvasive conformal solutions without impairing the exceptional textile and aesthetic features in different areas, like everyday life, healthcare, and technical applications, where textiles serve outside the “wearable” region, such as filtration, transportation, and civil engineering applications [2, 3].

In order to build a smart textiles product, some components are needed. These are sensors, actuators, connection components, as well as data processing and power supply elements. Sensors sense physical, chemical, and biological differences in the medium; actuators react to stimuli via actions, like color and shape changing or light emitting. Connection components convey signals, like electricity, radio frequencies, and others. They include conducting elements, antennae, radio frequency identification (RFID), circuits and alike. Data processing units, which execute program directives, store data, whereas power supply provides energy that is necessary to carry out smart functionality [2, 10, 11].

These smart functioning components can be integrated into textiles by different means: (1) classical electronic devices can be attached to textiles, (2) miniature components can be embedded onto textiles, (3) textiles themselves can be produced as smart functioning devices. By use of microelectronic devices, the second approach can be taken. Emergence of nanotechnology allows realization of the third approach [2, 11]. With the accelerated miniaturization fueled by advanced nanoscience and nanotechnology, now it is possible to impart smart functionality on a single fiber alone. With cost-efficient textile production processes; one-dimensional, two-dimensional, and three-dimensional smart textiles can be obtained [1].

The emergence of smart nanotextiles is timely and groundbreaking as the possibilities they offer are inconceivable. Smart nanotextiles combine opportunities brought by miniaturization of electronics, well-established textile technology practices, and developments in nanotechnology, to name a few. Research in smart nanotextiles forms a nascent field which is influenced by and have the potential to influence different disciplines, including materials science, data analytics, and fashion [3, 12].

This chapter attempts to provide an introductory overview of smart nanotextiles in terms of their current and future applications. The application fields for which the use of smart nanotextiles are investigated include medicine and healthcare (health status monitoring [13], targeted drug release [14, 15], and wound dressing & regeneratative medicine [16]), communication [17], sports [18], fashion [19, 20], energy generation [21], protection & defense [22], filtration [23], civil & geotechnical engineering [24], and transportation [25] areas.

This chapter has been organized as follows. The remainder of the chapter starts with presenting general information on textiles and discussing the features rendering textiles ideal for smart functionality. The following section introduces a brief history of smart nanotextiles succeeded by sections referring to terminology and classification related to smart nanotextiles. The following sections, presenting general information on nanotechnology, nanomaterials, and nanocomposites, comes before the section related to materials selection elaborating on characteristics required by smart functionality applications and sensors, which possess utmost important part in smart functionality. The succeeding section provides insight to the current status of global smart textiles and nanotextiles market, followed by sections highlighting their different wearable and technical application fields. The last two sections discuss challenges and opportunities in relation with the future advancement of smart nanotextiles and conclude the chapter. It is obviously impossible to present all relevant work in a book, let alone a chapter. Thus, findings of some most recent research studies have been shared in order to provide a glimpse of the current trends in this emerging field. One goal of this chapter is to allow exchange of developments related to smart nanotextiles across different application areas and to stimulate generation of novel ideas so that novel smart nanotextiles can be developed, and new uses can be found in application fields they are underutilized.

## 1.2 Textiles

Textiles have been utilized by humankind for millenia for protection, warming, and aesthetic functions due to the fact that they are breathable, flexible, enduring, and washable. These properties endow them ease of use, comfort, and functionality as clothing materials. On the other hand, their use has not been confined to clothes [1, 26, 27], as they are also used in home applications, such as home textiles [28], automotives as automotive textiles [29]; and some of other applications can be given as geotextiles [30], industrial textiles [31], agrotextiles [32], acoustic textiles [33], and many more.

Textile structures present important properties to act as ideal substrates for smart functions. They are soft and show deformation with low external load or even by force of gravity as they are drapeable. Their Young’s modulus values generally lie between several MPas to KPas. Due to the surface roughness, their specific surface areas are high in the order of $10^2$ to $10^3$ $m^2$/kg. Their porosity values are close to 99%. The porosity is determined by packing density and fiber orientation. They are durable against wear and washing. They are able to be twisted, bent, pressed, stretched, and sheared in three dimensions. They are drapeable; thus, readily follow the contours of human body and provide close contact [1, 12, 27]. Their high porosity and great surface area allow them to trap air and render them heat insulator, as well as provide air and water vapor transport, and bestow breathability in consequence. Breathability is a major advantage of textiles against nonbreathable wearables plastics. Textiles show unique fatigue resistance and damage tolerance. Textiles do not allow crack propagation and catastrophic failure as commonly witnessed in solid films [1].

Another upside of textiles is that the textile production processes are well established and economic [1]. Furthermore, due to their ductility and flexibility, it is easy to manipulate them to serve for an array of different uses with different requirements [2].

Textiles are generally formed in a hierarchical order (fiber – yarn – fabric – clothing). This hierarchical order also brings some advantages for imparting smart functionality. The smart functionalities can be deployed as built-in or embedded into the textile structures. Textiles offer a platform to smart wearable devices, that is large-area and in close contact with the human body [1].

Textile structures are made of fibers, which are polymeric materials. By changing manufacturing parameters, it is possible to fine-tune characteristics of polymers, such as modulus of elasticity. While high Young's moduli refer to rigid materials, it is generally required that fibers to possess moderate modulus values so that they exhibit flexibility, drapeability, and bendability. Other than changing the fine structure of polymers; by producing them in porous geometry, it is possible to decrease modulus of elasticity and to increase breathability by enhancing