

Smart Nanotextiles

*Wearable and
Technical Applications*



Edited By
Nazire Deniz Yilmaz



 Scrivener
Publishing

WILEY

Table of Contents

[Cover](#)

[Title Page](#)

[Copyright](#)

[Preface](#)

[Section 1: INTRODUCTION](#)

[1 Smart Nanotextiles Applications: A General Overview](#)

[1.1 Introduction](#)

[1.2 Textiles](#)

[1.3 Nanotechnology and Nanomaterials](#)

[1.4 Materials Selection](#)

[1.5 Sensors](#)

[1.6 Application Areas of Smart Nanotextiles](#)

[1.7 Risks and Opportunities](#)

[1.8 Conclusion](#)

[References](#)

[Section 2: SMART NANOTEXTILES FOR MEDICINE AND HEALTHCARE](#)

[2 Smart Nanotextiles for Wearable Health Monitoring](#)

[2.1 Introduction](#)

[2.2 \(Bio\)Physical Monitoring](#)

[2.3 \(Bio\)Chemical Monitoring](#)

[2.4 Multimodal Monitoring](#)

[2.5 Conclusions and Future Remarks](#)

[Acknowledgments](#)

References

3 Smart Nanotextiles for Controlled and Targeted Drug Release

3.1 Nanomaterials and Drug Delivery Systems

3.2 Graphene: Properties and Applications in Biomedicine

3.3 Toxicity Studies of Graphene-Based Nanomaterials

3.4 Graphene Quantum Dots: Properties and Potential in Theranostics

3.5 Conclusion and Final Remarks

Acknowledgments

References

4 Smart Nanotextiles for Wound Care and Regenerative Medicine

4.1 Introduction

4.2 Nanotextiles in Healthcare Materials

4.3 Conclusions and Future Perspectives

References

Section 3: SMART NANOTEXTILES FOR EVERYDAY'S LIFE

5 Smart Nanotextiles for Communication

5.1 Introduction

5.2 Textile Wearable Devices

5.3 Nanoscale Body-Centric Communications

5.4 Challenges and Future Prospects

5.5 Conclusion

Acknowledgments

References

6 Smart Nanotextiles for Sports

[6.1 Introduction](#)

[6.2 Trends](#)

[6.3 Textile Innovation](#)

[6.4 Enabling Technologies](#)

[6.5 Discussion and Conclusions](#)

[References](#)

[7 Smart Nanotextiles for Fashion and Aesthetics](#)

[7.1 Introduction](#)

[7.2 Smart Textiles for Fashion and Aesthetics](#)

[7.3 Nanotechnology in Smart Textiles](#)

[7.4 Examples of Smart Nanotextiles on
Mainstream Fashion](#)

[7.5 Challenges for Smart Textiles with
Nanomaterials](#)

[7.6 Future Trends of Smart Nanotextiles](#)

[References](#)

[8 Smart Nanotextiles for Energy Generation](#)

[8.1 Introduction](#)

[8.2 Textiles Nanogenerators](#)

[8.3 Progress and Application of Textile
Nanogenerators](#)

[8.4 Hybrid Devices for Energy Harvesting and
Storage](#)

[8.5 Conclusions and Prospects](#)

[References](#)

[Section 4: SMART NANOTEXTILES FOR INDUSTRIAL
APPLICATIONS](#)

[9 Smart Nanotextiles for Protection and Defense](#)

[9.1 Introduction](#)

[9.2 Protective Textiles](#)

[9.3 Conclusion](#)

[References](#)

[10 Smart Nanotextiles for Filtration](#)

[10.1 Introduction](#)

[10.2 Process of Filtration and Properties of Filter Media](#)

[10.3 Operating Parameters of Filtration](#)

[10.4 Applications of Smart Nanotextiles in Filtration](#)

[10.5 Conclusions and Future Outlook](#)

[References](#)

[11 Nanotextiles in Civil and Geotechnical Engineering](#)

[11.1 Introduction](#)

[11.2 Geosynthetics](#)

[11.3 Common Traditional Applications of Geosynthetics in Civil and Geotechnical Engineering](#)

[11.4 Nanomaterial Application to Geosynthetics for Civil and Geotechnical Engineering](#)

[11.5 Conclusion](#)

[References](#)

[12 Smart Nanotextiles for Transportation](#)

[12.1 Introduction](#)

[12.2 Sensor Yarns for Composite Materials](#)

[12.3 Development and Application of Various Fibrous Sensor Yarns](#)

[12.4 Discussion](#)

[12.5 Conclusion, Perspectives and Suggestions
for Future Works](#)

[References](#)

[Index](#)

[Wiley End User License Agreement](#)

List of Tables

Chapter 2

[Table 2.1 Summary of nanotextiles for \(bio\)physical
monitoring.](#)

[Table 2.2 Summary of nanotextiles for
\(bio\)chemical monitoring.](#)

[Table 2.3 Summary of nanotextiles for multimodal
physiological monitoring.](#)

Chapter 5

[Table 5.1 Dimensions of the design parameters of
the flexible 5G MIMO antenna.](#)

[Table 5.2 Realized gain at switch configurations of
the flexible 5G MIMO antenna...](#)

Chapter 6

[Table 6.1 Summary of biological data that can be
obtained from body worn devices...](#)

[Table 6.2 Current smart nanotextile sports products
currently on the market. All...](#)

Chapter 9

[Table 9.1 Types of UV radiations and their
properties \[25\] \(reprinted from refer...](#)

[Table 9.2 Different fields of applications of antimicrobial textiles \[39\]_\(repri...](#)

Chapter 12

[Table 12.1 Parameters of fibrous reinforcement and composite material.](#)

[Table 12.2 Gauge factors by initial resistance range.](#)

List of Illustrations

Chapter 1

[Figure 1.1 Scheme of a nanobiosensor based on graphene and gold nanoparticles, n...](#)

[Figure 1.2 Some common nanomaterials used in smart nanodrug delivery systems. \(R...](#)

[Figure 1.3 Advantages of sustained and smart drug delivery based on nanotechnolo...](#)

[Figure 1.4 Schematic illustration of a smart wound dressing making telemetry of ...](#)

[Figure 1.5 Steps of preparation of a smart wound dressing with multifunctional s...](#)

[Figure 1.6 Electrospun fibrous layers used for skin substitution. \(a\) Bacteria c...](#)

[Figure 1.7 Body area network communication modes. \(Reprinted from reference \[152...](#)

[Figure 1.8 Fabrication route of carbon nanotube-based and carbon nanocrystal-bas...](#)

[Figure 1.9 \(a,b\) Schematic illustration of a face mask filter incorporating resp...](#)

[Figure 1.10 Nanogenerators in automotive systems and smart transportation. \(Repr...](#)

Chapter 2

[Figure 2.1 Smart nanotextiles for temperature monitoring. \(a\) An SEM image of th...](#)

[Figure 2.2 Smart nanotextiles for biopotential monitoring. \(a\) Photograph of rGO...](#)

[Figure 2.3 Smart nanotextiles for blood pulse monitoring. \(a\) SEM image of the g...](#)

[Figure 2.4 Smart nanotextiles for blood pressure monitoring. \(a\) Photograph of a...](#)

[Figure 2.5 Smart nanotextiles for respiration rate monitoring. \(a\) Respiration m...](#)

[Figure 2.6 Smart nanotextiles for biochemical monitoring in body fluids. \(a\) Sch...](#)

[Figure 2.7 Smart nanotextiles for biochemical monitoring in breath and body odor...](#)

[Figure 2.8 Smart nanotextiles for multimodal monitoring of skin deformation asso...](#)

[Figure 2.9 Smart nanotextiles for multimodal monitoring of physical biomarkers. ...](#)

[Figure 2.10 Smart nanotextiles for multimodal monitoring of physical and chemica...](#)

Chapter 3

[Figure 3.1 Applications and objectives of nanomaterials in biomedical studies \(o...](#)

[Figure 3.2 The primary applications of graphene-based nanomaterials in biomedici...](#)

[Figure 3.3 Representative optical microscopic images \(a-a3\) and confocal Raman s...](#)

[Figure 3.4 The photos of isolated organs including lung, heart, kidney, spleen, ...](#)

[Figure 3.5 Biodistribution of GQDs in male mice 6, 12, and 24 h postexposure and...](#)

[Figure 3.6 Schematic representation of targeted RBC-membrane enveloped nanospong...](#)

[Figure 3.7 Laser confocal microscopy images of GQDs inside the cancer cells. A-3...](#)

Chapter 4

[Figure 4.1 Photographic images of the extent of wound healing: \(a\) graphical ill...](#)

[Figure 4.2 In vitro wound healing efficacy of the four PCL, COL@PCL, bFGF-COL@PC...](#)

[Figure 4.3 Sections of pure PLA nanofiber sutures, pure PLA \(a\) and \(d\), PLA ble...](#)

[Figure 4.4 SEM micrograph of primary fibroblasts grown on a collagen infiltrated...](#)

[Figure 4.5 Proliferation of \(a\) rat PC12 cells, \(b\) human dermal fibroblasts \(HD...](#)

[Figure 4.6 Representative fluorescence micrographs of the \(a\) border and \(b\) cen...](#)

Chapter 5

[Figure 5.1 Wireless nanonetwork architecture \(The image has been prepared by I.I...](#)

[Figure 5.2 Wireless nanonetwork architecture for WNSNs \(The image has been prepa...](#)

[Figure 5.3 Magnified image of \(a\) sharp edge of rectangular shape \(b\) silver ink...](#)

[Figure 5.4 Graphene-soft antenna \(a\) CAD model with dimensions in mm; \(b\) Fabric...](#)

[Figure 5.5 Simulated vs measured \$S_{11}\$ of graphene-based antennas in off- and on-b...](#)

[Figure 5.6 Simulated vs measured \$S_{11}\$ of graphene-based antennas in off- and on-b...](#)

[Figure 5.7 Measured vs simulated radiation pattern of the graphene-based textile...](#)

[Figure 5.8 Measured vs simulated radiation pattern of the proposed graphene-base...](#)

[Figure 5.9 Proposed flexible frequency-reconfigurable two-element MIMO antenna: ...](#)

[Figure 5.10 Characterization of the inkjet-printed antenna prototype, \(a\) surfac...](#)

[Figure 5.11 Simulated and measured \$S_{11}/S_{22}\$ plots of the mm wave frequency-reconf...](#)

[Figure 5.12 Mutual coupling analysis of the flexible mm wave frequency-reconfigu...](#)

[Figure 5.13 Simulated and measured normalized radiation patterns of the mm wave ...](#)

[Figure 5.14 Molecular absorption coefficient as a function of the frequency of h...](#)

[Figure 5.15 Molecular absorption coefficient as a function of the frequency of h...](#)

[Figure 5.16 Background noise p.s.d. at the THz frequencies for different human t...](#)

[Figure 5.17 Self-Induced noise p.s.d. at the THz frequencies for different human...](#)

[Figure 5.18 Molecular absorption noise p.s.d. at the THz frequencies for differe...](#)

Chapter 7

[Figure 7.1 Examples of wearable technology worn at the Metropolitan Museum of Ar...](#)

[Figure 7.2 Model wearing Lekko's "Antipollution Scarf" \(Image used with permissi...](#)

Chapter 8

[Figure 8.1 Schematic of thermoelectric textile composed of \$\pi\$ -shaped yarns that c...](#)

[Figure 8.2 Schematic of a core-shell piezoelectric fiber with radial deformation...](#)

[Figure 8.3 Schematics of TENGs with \(a\) double electrode mode, and \(b\) single el...](#)

[Figure 8.4 A universal nanocoating technology enabled washable all-fabric-based ...](#)

[Figure 8.5 A skin-actuated stretchable and washable all-textile-based TENG with ...](#)

[Figure 8.6 A nanotextile with tuneable microarchitectures and transparencies for...](#)

[Figure 8.7 A nanotextile mat of core-shell nanofibers for static/dynamic pressur...](#)

[Figure 8.8 A transferrable nanotextile by electrospraying as stretchable TENG fo...](#)

[Figure 8.9 Mechanically interlocked stretchable nanofibers as a wearable TENG fo...](#)

Chapter 9

[Figure 9.1 Modes of action followed by organic \(left\) and inorganic \(right\) UV b...](#)

[Figure 9.2 \(a\) Classification of inorganic nanostructured antimicrobial material...](#)

[Figure 9.3 Mechanisms of ZnO nanoparticle antimicrobial activity \[58\] \(reprinted...](#)

[Figure 9.4 Mechanism of flame retardancy using graphene \[70\] \(redrawn from refer...](#)

[Figure 9.5 \(a\) ThermoculesTM absorbing excess heat, \(b\) ThermoculesTM releasing ex...](#)

[Figure 9.6 Mechanism of energy absorption of nanotechnology-based treated fabric...](#)

Chapter 10

[Figure 10.1 Representation of smart textiles and their categories \(recreated fro...](#)

[Figure 10.2 Operational differences between deep bed filtration and cake filtrat...](#)

[Figure 10.3 Schematic illustration of \(a-b\) RM-TENG; \(c\) respiratory mask attach...](#)

[Figure 10.4 Schematic diagrams for the switchable oil wettability of the P2VPb-P...](#)

Chapter 11

[Figure 11.1 Geosynthetics' roles in soil structure. \(Reprinted from \[14\] with pe...](#)

[Figure 11.2 Representing common geosynthetic materials used in civil engineering...](#)

[Figure 11.3 Different Fiber manufacturing methods. \(Reprinted from \[28\] with per...](#)

[Figure 11.4 Geosynthetic fiber filling between microfiber and nanofiber per unit...](#)

[Figure 11.5 Filtration rate maintenance of filters made of nanofibers. \(Reprinte...](#)

[Figure 11.6 Nanofiber and other fibers were used to compare fiber diameter and s...](#)

[Figure 11.7 Uses of nanotechnology to study the association between separation f...](#)

[Figure 11.8 To boost adsorption effectiveness, clay was mixed with geotextile. \(...\)](#)

[Figure 11.9 Vacuum panel layer with a core of fumed silica. \(Adapted from \[47\] u...](#)

[Figure 11.10 Polymer/MMT \(nano clay\) nanocomposites' structural morphology. \(Rep...](#)

[Figure 11.11 TenCate GeoDetect[®] S-BR sensor-enabled geotextile is equipped with ...](#)

[Figure 11.12 \(a\) Photograph of the conventional wind turbine generator. \(b\) Phot...](#)

Chapter 12

[Figure 12.1 CFYS in woven \(a\), knitted \(b\) and embroidered on semi-finished text...](#)

[Figure 12.2 \(a\) SEM images \(10,000 fold magnification\) of Ag coated monofilament...](#)

[Figure 12.3 \(a\) SEM micrograph of CNT growth on glass fiber \(Fuzzy fiber\), \(b\) c...](#)

[Figure 12.4 \(a\) GFRP specimen with grids of conductive silver ink electrodes on ...](#)

[Figure 12.5 \(a\) Carbon black coated sensor with polyethylene double-ply substrat...](#)

[Figure 12.6 Transversal section \(SEM\) of the sensor \(This image has been reprint...](#)

[Figure 12.7 Tensile strength test on MTS 1/2 tester using data acquisition modul...](#)

[Figure 12.8 Normalized resistance and stress against strain for sensor outside c...](#)

[Figure 12.9 Normalized resistance and stress against strain for sensor outside c...](#)

[Figure 12.10 Comparison of first and last cycle for 0.5% extension \(a\) 1st cycle...](#)

[Figure 12.11 \(a\) and \(b\): 3D fabric reinforcement with protruding sensor connect...](#)

[Figure 12.12 \(a\) Preparation of sub molds for vacuum bag infusion - \(b\) Vacuum b...](#)

[Figure 12.13 Composite specimens for tensile testing with integrated textile sen...](#)

[Figure 12.14 \(a-b\) Instron 8500 tensile strength tester with specimen loaded for...](#)

[Figure 12.15 Normalized resistance and stress against strain for sensor inside c...](#)

[Figure 12.16 Surface photographs on composite samples taken after tensile streng...](#)

[Figure 12.17 Tomographic images of sensor inside a tested sample near the zone o...](#)

[Figure 12.18 Evolution of the logarithm of the resistivity of a conductive solut...](#)

[Figure 12.19 Commingled yarns coated with latex for production of sensor yarn \(T...](#)

[Figure 12.20 Commingled yarns coated with latex and PEDOT-PSS \(This image has be...](#)

[Figure 12.21 Overview of the winding between the sensor yarn and the copper wire...](#)

[Figure 12.22 Overview of the commingled sensor yarn \(This image has been reprint...](#)

[Figure 12.23 Example of a calibration curve \(This image has been reprinted from ...](#)

[Figure 12.24 Representation of a preform with 3 planes; upper, middle and lower ...](#)

[Figure 12.25 Representation and photography of the experimental devices with cam...](#)

[Figure 12.26 Zones where the sensor yarns are located: red in warp direction and...](#)

[Figure 12.27 Comparison of sensor yarns and camera monitoring results during for...](#)

[Figure 12.28 Comparison of forming results using sensor yarns on the surface and...](#)

[Figure 12.29 Example of junction between CPC sensors and highly conductive wire,...](#)

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



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

© 2022 Scrivener Publishing LLC

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

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

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

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

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

Abstract

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 functionality, 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 & regenerative 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 m²/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