Printed and Flexible Sensor Technology

Fabrication and applications

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IOP Publishing, Bristol, UK

ISBN 978-0-7503-3439-6 (ebook)
ISBN 978-0-7503-3437-2 (print)
ISBN 978-0-7503-3440-2 (myPrint)
ISBN 978-0-7503-3438-9 (mobi)

DOI 10.1088/978-0-7503-3439-6

Version: 20211201

IOP ebooks

British Library Cataloguing-in-Publication Data: A catalogue record for this book is available from the British Library.

Published by IOP Publishing, wholly owned by The Institute of Physics, London

IOP Publishing, Temple Circus, Temple Way, Bristol, BS1 6HG, UK

US Office: IOP Publishing, Inc., 190 North Independence Mall West, Suite 601, Philadelphia, PA 19106, USA

Contents

Preface

The intervention of sensing systems within the modern world has revolutionized the quality of human life. Almost every aspect of day-to-day activities in today's world involves the implementation of sensors in some way. Their presence has not only made our lives easier, but has also allowed humanity to progress on a technological level. The sensing systems as we use them today are being developed and characterized mostly in academic and industrial contexts. Following the sensorial pyramid, different kinds of prototypes have been fabricated, varying in terms of their processed materials, operating principles, and respective applications. Each of these prototypes is being specialized to have high efficiency in terms of sensitivity and robustness for the targeted application. The advancement in technology has allowed highly functionalized equipment to be developed that can be mass-produced for point-of-care sensing systems. Among the sensors that are currently available, the flexible sensors have been able to perform in a much more dynamic manner in comparison to the conventional MEMS-based silicon sensors. The additional wearable nature of flexible sensors has allowed them to be used for ubiquitous monitoring purposes. These flexible sensors have been fabricated using a range of printing techniques, each of which has the capability to form high-quality thin-film sensors. These prototypes have revolutionized the world of flexible sensors due to their simple fabrication techniques, quick roll-to-roll production, and simple operating mechanisms. The choice of printing technique primarily depends on the specifications of the sensors, which in turn depend on their applications.

In recent times, with the conjugation of nanotechnology and printing techniques, these flexible sensors have increased their dynamicity for real-time applications. The developed printed and flexible sensors have been exploited successfully in biomedical, industrial, and environmental applications. With the advent of nanotechnology these printed flexible sensors have attained further heights with respect to their performance. Nanomaterials have been included in various forms using the available printing mechanisms to enhance the resultant functionality. 1D and 2D conductive materials have been utilized thoroughly to enhance the sensitivity and selectivity of prototypes. Flexible printed sensors have allowed us to further formalize entire systems to determine the interfacing circuits for conditioning and transmitting the sensed data. Market surveys have also presented a great need for these sensors, not only to increase the multifunctional nature of the sensing systems but improve their impact on the chosen application. The exponential increase of these printed flexible sensors in the near future can be justified by the need in automated systems for detection in sectors of prioritized significance.

This book contains a structured overview of the fabrication techniques of the various printed flexible sensors that have been formulated and devised. It also contains some of the significant applications of these printed flexible sensors, conducted in controlled and real-time scenarios. This book contains chapters contributed by experts in their respective fields who have studied and operated printed flexible sensors via designing and employing them. It also presents the technological growth in the field of printed flexible sensors by presenting current trends. Each of the presented works will not only allow the reader to obtain an understanding of this field but will also assist the reader to improvise and innovate something of their own. This book is organized in the following manner.

Chapter 1 presents an overview of the sensors and fabrication techniques that are currently available. It also presents a brief overview of the sectors in which these prototypes have been deployed. This is followed by chapter 2, which exemplifies the utilization of printed flexible sensors for a range of research-based applications. It also categorizes the applications, providing the advantages and reliability related to each of them. Chapter 3 highlights the work done on the fabrication of printed flexible sensors in terms of their issues and resolution. It deals with the fabrication of printed flexible sensors via highlighting some of the challenges related to their fabrication techniques and possible corresponding solutions. Chapter 4 showcases the potential of 3D wax printing technology to create sophisticated biomedical devices. It also explains the application of printable devices for point-of-care testing and various biosensing purposes and details some recommendations and future directions for improving sensing accuracy and robustness. Chapter 5 summarizes some of the laser induced graphene preparation methods and their broad-spectrum applications, in particular in electrochemical and biosensing. It also focuses on the future outlook and research gaps in the reported literature. Chapter 6 provides an overview of the significant development in wearable microfluidic devices in terms of their fabrication and characterization. It also shows different categories for its use in physical property and body fluid sampling, manipulation, and detection. Chapter 7 reviews the recent developments in assembly techniques, including printing processes for forming films or networks of single-walled carbon nanotubes (SWNTs). The challenges related to the processing and performance of SWNTs, along with the potential research that can be performed with SWNTs, are also presented. Chapter 8 presents the fabrication and implementation of flexible strain sensors using graphene and its composites. It analyzes the capability of the remarkable material graphene in developing high-quality flexible strain sensors. Chapter 9 presents an overall review of screen-printed electrochemical and impedance biosensors. This is achieved by presenting different cases involving the estimation of environmental contaminants, food toxins, protein molecules, bacteria, and viruses. Chapter 10 deals with the properties of cellulose paper and its use for flexible electronic device applications. It explains the design and technology of flexible electronics produced using cellulose paper. Chapter 11 explains the synthesis and characterization methods for printing/fabricating graphene-based implantable electrodes for various neural recording and stimulation processes. This is followed by chapter 12 which shows the work done on screen-printed electrode-based sensors for the detection of biological and chemical species. It highlights the potential of electrochemical methods of screen-printed electrodes for accurate measurements of trace level biochemical species in a sample solution using a rapid and cheap analysis method. Chapter 13 provides a brief overview of the role of 3D printing in microfluidic enzymatic biofuel cells, along with related recent work in upcoming research areas. Chapter 14 presents the work done on the use of an array of interdigitated electrodes for developing novel incontinence sensing systems. These devices consist of simulation using ANSYS finite element analysis (FEA) and printing of the conductive polymer PEDOT:PSS on PET substrates. Chapter 15 presents an experimental study carried out to develop a transparent thin-film strain sensor (TFSS) using an unconventional substrate (PET with a pre-applied thin pressure-sensitive adhesive layer) and to investigate its response to static and dynamic strain environments. Insights into the fabrication of high figure of merit transparent thin films at room temperature and the methodology to develop a transparent TFSS, along with its performance evaluation, are described in this chapter. Chapter 16 reports the work done on high-performance radio frequency (RF) magnetron sputtered cerium oxide (CeO_2) thin-film-based oxygen sensors by optimizing the film thickness. Chapter 17 presents the fabrication of a metal oxide (MOX) trace moisture sensor on a flexible substrate. The sensors are parallel-plate capacitors with nanoporous alumina hydrophilic sensing films, deposited on polyimide using the solution method. Chapter 18 discusses the importance of droplet detection and the need for improvements in sensor geometry for precise and accurate detection of microdroplets. A novel type of printable and flexible sensor is introduced for droplet detection, which utilizes the capacitive transduction principle and the detection is contactless, thus increasing the lifetime of the detection system. Chapter 19 focuses on flexible and conformal antennas for wireless communication and sensing applications.

The chapters contributed to this book have been written with the utmost care and detail in order to present the work in a simple and efficient manner. The valuable research ideas imparted by the contributing authors have allowed us to present the high-quality research taking place in the microelectronics industries. Each of the presented research works will help the reader understand the functionality of printed flexible sensing systems at both the basic and advanced levels. The compilation of this interesting and useful book would not have been possible without the priceless contribution of the authors and their willingness to participate in this journey.

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