Mini-Symposia Title:

Mobile Point-of-Care Diagnostic and Health Monitoring Devices

Mini-Symposia Organizer Name & Affiliation:

Professor Benoit Gosselin and Dr. Partha Sarati Das, Université Laval

Mini-Symposia Speaker Name & Affiliation 1:

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Mini-Symposia Speaker Name & Affiliation 2:

Professor Jae Yeong Park, Kwangwoon University

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Theme:

- ○ 01. Biomedical Signal Processing
- ○ 02. Biomedical Imaging and Image Processing
- ○ 03. Micro/ Nano-bioengineering; Cellular/ Tissue Engineering &
- ○ 04. Computational Systems & Synthetic Biology; Multiscale modeling
- ○ 05. Cardiovascular and Respiratory Systems Engineering
- ○ 06. Neural and Rehabilitation Engineering
- ◉ 07. Biomedical Sensors and Wearable Systems
- ○ 08. Biorobotics and Biomechanics
- ○ 09. Therapeutic & Diagnostic Systems and Technologies
- ○ 10. Biomedical & Health Informatics
- ○ 11. Biomedical Engineering Education and Society
- ○ 12. Translational Engineering for Healthcare Innovation and Commercialization

Mini-Symposia Synopsis— Max 2000 Characters

Wearable sensors and devices play a vital role in medical technology. The objective of this Mini-Symposia is to talks and panel discussions on Mobile Point-of-Care Diagnostic and Health Monitoring Devices. The theme of this Mini-Symposia is Biomedical Sensors and Wearable Systems. The topic includes:

1. Wearable electrochemical biosensors and microfluidic devices
2. Wearable physiological sensors
3. Flexible, stretchable, printed, hybrid sensors and electronics
4. Fabrication, packaging, and assembly techniques for wearable devices
5. Smart fabrics based wearable sensors

Flexible, stretchable and healable bioelectronics

Fabio Cicoira, Department of Chemical Engineering, Polytechnique Montréal, Canada

***Abstract*—** Organic electronics, based on semiconducting and conducting polymers, have been extensively investigated in the past decades and have found commercial applications in lighting panels, smartphone and TV screens using OLEDs (organic light emitting diodes) technology. Many other applications are foreseen to reach the commercial maturity in future in areas such as transistors, sensors and photovoltaics.

Organic electronic devices, apart from consumer applications, are paving the path for key applications at the interface between electronics and biology, such as in polymer electrodes for recording and stimulating neural activity in neurological diseases. In such applications, organic polymers are very attractive candidates due to their distinct property of mixed conduction: the ability to transport both electron/holes and ionic species. Additionally, conducting polymers offer the possibility to tune their surface properties (e.g., wettability or chemical reactivity) by changing their oxidation state, thus promoting or hindering the adhesion of biomolecules. This feature can be particularly useful for enhancing the biocompatibility of implantable electrodes.

My talk will deal with processing and characterization of conducting polymer films and devices for flexible, stretchable and healable electronics as well as for implantable electrodes.

Our group fabricated water-stable and flexible organic electrochemical transistors based on poly(3,4-ethylenedioxythiophene) doped with poly(styrenesulfonate) (PEDOT:PSS) on a plastic substrate using a new process based on a fluorinated photoresist. The PEDOT:PSS films, mixed solely with a biocompatible conductivity enhancer, show robust adhesion on plastic substrates, and exhibit unchanged electrical properties under extreme bending. This simplifies the fabrication of high-performance OECTs and places them in a highly competitive position for flexible electronics and healthcare applications.

The fabrication of stretchable electronic devices is presently rather challenging due to both the limited number of materials showing the desired combination of mechanical and electrical properties and the lack of techniques to process and pattern them. My group reported on transfer patterning process to fabricate high-resolution metal microelectrodes on polydimethylsiloxane (PDMS) by using ultrathin Parylene films (2 μm thick). By combining transfer patterning of metal electrodes with orthogonal patterning of PEDOT:PSS on a pre-stretched PDMS substrate and a biocompatible "cut and paste" hydrogel, we demonstrated fully stretchable organic electrochemical transistors, relevant for wearable electronics, biosensors and surface electrodes to monitor body conditions.

Self-healing electronic materials are highly relevant for application in biology and sustainable electronics. We observed mechanical and electrical healability of PEDOT:PSS thin films. Upon reaching a certain thickness (about 1 μm), PEDOT:PSS thin films damaged with a sharp blade can be healed by simply wetting the damaged area with water. The process is rapid, with a response time on the order of 150 ms. Significantly, after being wetted, the films are transformed into autonomic self-healing materials without the need of external stimulation. This reveals a new property of PEDOT:PSS and enables its immediate use in flexible and biocompatible electronics, such as electronic skin and bio-implanted electronics, placing conducting polymers on the front line for healing applications in bioelectronics.

We have recently electropolymerized PEDOT coatings on sharp platinum-iridium recording and stimulating neural electrodes and demonstrated its mechanical and electrochemical stability Electropolymerization of PEDOT:tetrafluoroborate was carried out in three different solvents: propylene carbonate, acetonitrile and water. The stability of the coatings was assessed via ultrasonication, phosphate buffer solution soaking test, autoclave sterilization and electrical pulsing. Coatings prepared with propylene carbonate or acetonitrile possessed excellent electrochemical stability and survived autoclave sterilization, prolonged soaking and electrical stimulation without major changes in electrochemical properties. Stimulating microelectrodes were implanted in for 60 days. The electrochemical properties monitored *in vivo* demonstrated that coated electrodes show lower impedance and higher stability over time.

KEYWORDS

Conducting polymers, bioelectronics, transistors, electrolyte-gating, in vivo measurement.

Thermally reduced graphene oxide-nylon membrane based epidermal sensor for wearable electrophysiological signals and human motion monitoring

Partha Sarati Das, Department of Electrical & Computer Engineering, Université Laval, Canada

Abstract— **In this presentation, I will review a fabricated high-performance paper-based epidermal sensor on biocompatible nylon-membrane without utilizing any harmful chemicals & complicated processes. The proposed epidermal sensor was fabricated using thermally reduced graphene oxide and a nylon-membrane (TRGO/NM). The epidermal sensor (TRGO/NM) has been developed to reduce the usage of Ag/AgCl (sticky sensor). The sensor demonstrates high sensitivity (sheet resistance = 40 Ω/sq.), because skin-contact impedance was ~20KΩ at low frequency. We applied the epidermal sensor for obtaining electrocardiography (ECG), electroencephalography (EEG), and electromyography (EMG) as well as monitoring human motions also. The biocompatibility of the TRGO/NM sensor was confirmed by performing the cytotoxicity test.**

I. Introduction

Thermally reduced graphene oxide (TRGO) is one of the candidates for a cheap and clean sensor material. However, one concern regarding TRGO is the toxicity resulting from the direct contact of the sensor on human epidermis layer, though numerous studies have been accomplished for bioelectric recording, and biocompatibility issues have been recently studied in the literature. Because biocompatibility is particularly essential for lengthy-time measurements, the issue should be thoroughly studied.[1]–[4] Here, we propose a low-cost, biocompatible, reusable, and flexible dry epidermal sensor based on TRGO/NM. It is an excellent candidate for this application with regard to flexibility and reusability characteristics.

II. Methods

We mixed 20 mg of the TRGO platelet with 20 ml of DMF (Dimethylformamide) and DI water (1:1) with the assistance of an ultra-sonicator for 2.5 h. NM (pore size = 0.2 mm and diameter = 4.7 cm) was purchased from the Whatman™ company. The vacuum filtration of the mixture was done by placing the NM paper on top of the filtration beaker, as shown in Fig.1(a). Finally, we dried the NM paper in a hot plate at 60ºC for 1 h.

III. Results

The performance of the TRGO/NM-based flexible dry paper sensor was comparable to that of the typical Ag/AgCl wet sensor. The experimental outcomes indicated that the newly developed dry paper sensor is compatible with a sticky gel-based Ag/AgCl sensor.

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In addition, it showed no cytotoxicity, implying that it can be utilized for a lengthy-time, unlike Ag/AgCl sensors. The developed TRGO/NM-based dry paper sensor can be utilized for various human bioelectric signal observing applications over longer time without irritation problems.

IV. Discussion & Conclusion

The proposed sensor can be used for human motion monitoring under different deformations. This TRGO/NM-based flexible dry paper sensor exhibits good electrical performance, flexibility, reusability, biocompatibility, and wearability. The successful creation and validation of the proposed paper-based epidermal sensor indicate that it is suitable for use in health-care monitoring purposes, and is eco-friendly and economical.

Acknowledgment

This research was supported by the Technology Innovation Program (20000773, Development of nanomultisensors based on wearable patch for nonhaematological monitoring of metabolic syndrome) by the Ministry of Trade, Industry & Energy (MI, Korea), the Bio & Medical Technology Development Program of the NRF grant funded by the Korean government (MSIT) (NRF-2017M3A9F1031270), and by the Research Grant of Kwangwoon University in 2019.

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Flexible electrochemical and physiological nano-biosensors for wearable healthcare monitoring

Jae Yeong Park, Department of Electronic Engineering, Kwangwoon University, South Korea

***Abstract*—High performance electrochemical and physiological nano-biosensors are presented for wearable healthcare monitoring. First, a novel MXene-Ti3C2Tx enabled minimally invasive microneedle biosensor patch is presented for continuous glucose monitoring through ISF. The MXene is utilized due to its unique properties like excellent conductivity, biocompatibility, and hydrophilic surface. Second, MXene-PVDF polymer nanofiber mat based flexible capacitive pressure sensor is presented. The fabricated composite nanofiber mat is a pioneer attempt to fabricate the flexible and highly sensitive pressure sensor with ultra-low detection limit.**

V. Introduction

Recently, intensive investigations have been conducted to develop the microneedle-based wearable glucose biosensors for monitoring glucose levels in interstitial fluid (ISF) [1-2]. 2D MXene-$Ti_3C_2T_x$ has drawn much attention as a biosensing material due to its unique properties like excellent conductivity, biocompatibility, and hydrophilic surface [3]. Herein, we newly develop a novel MXene-$Ti_3C_2T_x$ enabled minimally invasive microneedle biosensor for continuous monitoring glucose levels through ISF. A nano fiber mat of polymer materials has been widely used as a flexible dielectric layer for making capacitive pressure sensors. Recently, Chunhong et al. demonstrated a capacitive sensor with $CaCu_3Ti_4O_{12}$ composite fiber sponge, which showed high sensitivity (1.66 kPa^{-1}) for low pressure range [4]. A carbonized polyacrylonitrile/barium titanate nanofiber was reported for pressure sensor applications which showed excellent stability (>60 000) [5]. In order to overcome the limitations of these sensors such as poor stability, high detection limit, and complex fabrication, we newly develop a highly stable and sensitive pressure sensor and its facile fabrication technique.

VI. Methods

The three-electrode based microneedle was formed on polyimide (PI) film (225 μm) using a microfabrication and laser cutting technologies. After making MXene-$Ti_3C_2T_x$ solution using ultrasonication, MXene was coated by drop-casting on the patterned working electrode of gold. Platinum nanoparticles (PtNPs), glucose oxidase, and nafion were deposited and coated sequentially by electrodeposition and drop-casting techniques, respectively.

The dried MXene powder of different wt % was mixed separately with N, N-dimethylformamide (DMF)/Acetone solution at ratio of 3:2 and then ultrasonicated for 1 h. Subsequently, PVDF-TrFE powder with 21% w/w was dissolved and stirred for another 3 h before loading the solution for electrospinning. Finally, the proposed flexible pressure sensor was fabricated (Figure 1b) by sandwiching the composite fiber mat between PEDOT: PSS flexible electrodes.

VII. Results

Fig. 1 shows images of the fabricated microneedle glucose sensor and flexible pressure sensor. Fig. 1 (c) shows amperometric response to the glucose concentration. The fabricated sensor exhibited sensitivity up to 46.8 μA/mM·cm^2. The detection-limit (S/N=3) was calculated as low as 3.63 μM. Figure 1(d) shows a sensitivity 0.465 kPa^{-1} for low pressure range, 0-1000 Pa and 0.011 kPa^{-1} for high pressure range, 10-100 kPa. The sensor could detect ultralight weight object of 25 mg corresponding to the pressure of ~1.5 Pa .

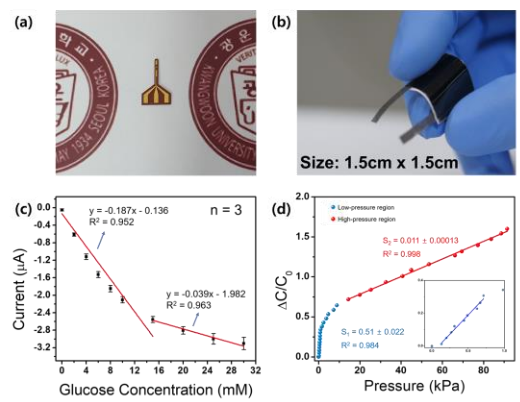

Figure 1. Phtographs and perforamce characterization of fabricated MXene based glucose and pressure montoring nano-biosensors.

Acknowledgment

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Mobile Point-of-Care Diagnostic for Monitoring of Human Metabolism

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Abstract— **Aim of this invited talk is to present innovative concepts for multi-panel, highly integrated, fully implantable, remotely powered and real-time monitoring systems for human metabolism at molecular level. The considered metabolic molecules are glucose, lactate, glutamate, ATP, anticancer and anti-inflammatory, and anesthetic drugs. In case of drugs, the specificity of electrochemical sensors is improved at system level. The proposed nanotechnology is based on carbon or platinum nanotubes or corals to improve the sensors performance. To pursue specific aims of detection, innovative VLSI solutions are also discussed including system remote powering or fluidics. The new approach is demonstrated by showing Systems-In-Package with embedded System-On-Chip that integrate: (i) a sensors array for data acquisition; (ii) remote power and/or data transmission; (iii) nano-sensors; (iv) CMOS ICs; (v) multi-panel metabolites detection. Applications are shown in the field of implantable or Point-of-Care devices, with in-vivo experiments too, while addressing issues related to biocompatibility, or specific monitoring needs required by intensive care or day-hospital treatments.**

VIII. INTRODUCTION

Integrated electrochemical Nano-Bio-Sensors [1] for diagnosis and/or treatment of patients with specific physiological conditions (e.g., heart, cardiovascular, or cancer diseases) is a key factor to provide better, more rationale, effective and ultimately low-cost health care also at home. The ultimate goal of improved health care on those subjects is extension of the patients' autonomy, possibility for auto-monitoring, improvement of their comfort levels, and better integration into everyday life. Some systems for home monitoring are available in the market, e.g., with wearable devices such as accelerometers or heartbeat detection systems. However, all these devices do not allow measurements of human metabolism at molecular level on each single metabolite. The only available real-time and point-of-care systems for monitoring of human metabolism are limited to glucose detection and used for diabetic patients only. On the other hand, electrochemical sensors are much powerful to measure many other molecules, molecules with crucial relevance for metabolic diseases. So far, there are no available integrated nano-bio-systems for multi-metabolites, real-time, point-of-care monitoring of human metabolism in general.

IX. METHODS

Thus, the aim of this talk is to present innovative concepts for multi-panel, highly integrated, fully implantable or point-of-care, and continuous monitoring systems for human metabolism at molecular level. The monitored metabolic molecules will be not limited to glucose, while instead extended to lactate, glutamate, ATP [2], as well as anticancer, anti-inflammatory [3], and anesthetic drugs [4]. In case of drugs, the specificity of electrochemical sensors is sometimes improved at system level [5], while nanostructures based on carbon, gold, or platinum improve the sensors performance [3, 6]. To pursue these detections, innovative VLSI solutions [7] are also discussed, including remote powering and fluidics.

X. RESULTS

This new approach is demonstrated by showing Systems-In-Package with embedded Systems-On-Chip that integrate: nano-sensors and sensors array for data acquisition, remote powering and data transmission [8], with dedicated CMOS IC design to provide multi-panel metabolites detection [7]. Monitoring applications are shown in the field of implantable or point-of-care devices, with in-vivo experiments too [9], while addressing issues related to biocompatible-packaging [9] or monitoring-needs in intensive care units [10].

XI. DISCUSSION & CONCLUSION

Impact in medicine is clearly and highly relevant related to the possibility for remote monitoring of several metabolic diseases.

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Flexible and non-invasive wearable sensors based on multi-material fibers for real time health monitoring

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Abstract— **Recent technological advances in material sciences, microelectronics, and wireless communication brought functionalized textile to a new era of smart connected wearable devices such as smart T-shirt. A new generation sensors based on multi-material metal-polymer-glass hollow core fiber connected to a smart wearable device are proposed for real time monitoring of breath and muscular activity. The high flexibility of the fiber allows their easy integration into stretchable textile without compromising the comfort of the users. In this, talk we will present the design and performance of the new sensors.**

I. Introduction

Continuous monitoring of vital signs of patient using wearable technologies is ubiquitously an important diagnostic method since it opens a new era for medical assistance pushing the healthcare out of hospital. This technology will allow to remotely communicate medical information from home monitored patients to health professionals, which helps them to make a real time evaluation of the patient's physiological condition and make appropriate intervention. Breathing rate and muscular activity (surface EMG) signals are among the important vital signs used to monitor the progress of illness such as for new born infants, or for aging persons. However, the existing equipment in medical facilities used to monitor these two signals faces several lacks such as accuracy, reliability and comfort for long term uses.

We have developed recently a new generation of functionalized optical fiber capable to detect in real time human breathing and EMG signals when connected to appropriate electronic devises and communicate the signals through wireless Bluetooth protocol. The breath detection is based on a fiber antenna with spiral shape sensitive to the deformation of human chest during breath.

II. Fibers Sensors Fabrication

The sensors were fabricated from the functionalization of polyimide-coated hollow-core silica fibers with an inner radius of 100 μm and outer radius of 181 μm. The functionalization consists of plating a thin layer of conductive nanoparticles on either the outer or the inner surface of the fiber using two difference methods: the redox chemical reaction and the MCVD methods.

III. Results

In this section, we present our recent results for breath detection using a single fiber antenna in spiral shape placed on a volunteer chest, and the muscular activity monitoring using fiber electrodes placed in parallel to the trapeze muscles of a volunteer.

*Research supported by CRSNG foundation.

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Breath detection:

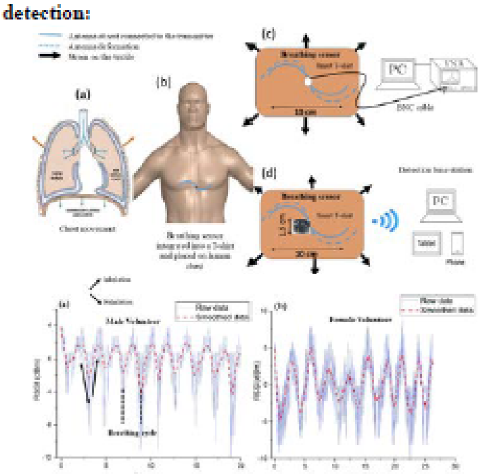

Figure 1: Upper panel: Schematic representation of the working principle for breath detection. Lower panel: Breathing signal patterns obtained from the RSSI measurements (blue) and the corresponding filtered signals (red) for regular breathing of female (a) and male (b) volunteers.

Muscular activity detection

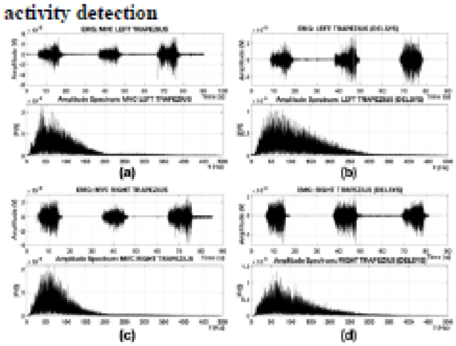

Figure 2: sEMG signals and the corresponding power spectra recorded during MVC of trapezius left and right muscles. (a)-(c) for signals recorded using a 2 cm long fiber electrodes, while (b)-(d) for signal recorded with Trigno Delsys medical system.

IV. Discussion & Conclusion

The accurate measurements obtained with our wearable sensors could make them as potential devices for medical application such as: detecting respiratory arrest that can occur during deep sedation, and to to study workrelated shoulder musculoskeletal disorders, and physiological parameters assessment applications

Acknowledgment

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e-Textiles on Skin: Adhesion and Sensitivity from User's Perspective

Hyun-Joong Chung, Department of Chemical & Materials Engineering, University of Alberta, Canada

Abstract— Wearable healthcare systems require sensing units that are often in contact with skin, as well as embedded circuitry to enable signal processing and transmittance and energy devices to enabling their operations, while mandating the maximal comfort for wearers. Textile-based electronics, known as “e-textiles”, offer a platform technology that allows comfort for patients. In this talk, I will review recent advances in the field of skin-adhesive patches and e-textiles from the perspective of the wearer's comfort, followed by introducing our group's contributions to related technologies.