

Wearable and Implantable  
Sensors and  
Electrochemical Devices

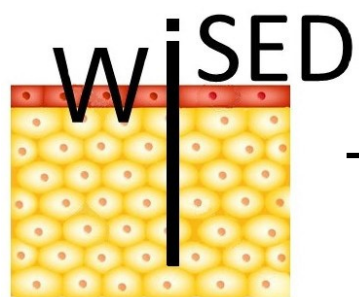
November 27-29, 2024

Lyon, France

<https://wised2024.univ-lyon1.fr>



Abstracts book



# Summary

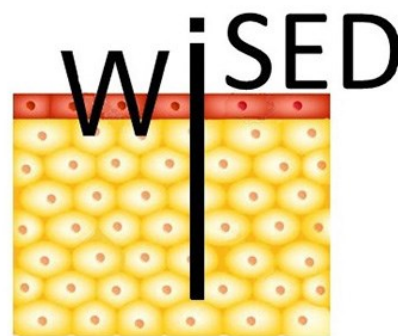
---

Welcome	3
Program	4 - 6
Talks	7 - 46
Posters	47 - 59
Venue	60
Contact	61
Sponsors	62
Partners	62

# Wearable and Implantable Sensors and Electrochemical Devices

27-29 November 2024

Lyon, France



Wearable and implantable sensors enable in vivo monitoring of physiological parameters in animals or humans, whether freely moving or anesthetized. They offer minimally invasive or non-invasive alternatives for the in situ quantification of biochemical markers such as glucose or lactate concentrations, stress biomarkers, inflammatory molecules, etc. They can also monitor the physiological or pathological state of animals or humans, as well as living organs such as the brain or tumors. In recent years, research into wearable and implantable electrochemical devices has expanded rapidly. Thanks to these devices, tomorrow's medicine will be based on continuous, real-time, personalized patient monitoring. Although the scientific community working on these devices is developing rapidly, there are currently no scientific events dedicated to this community. Our aim is therefore to launch the first meeting on this theme. This scientific event will enable exchanges between researchers from the academic and medical worlds, as well as with companies specializing in bio-microtechnologies.

We hope that participants will find here a workshop to meet colleagues sharing the same interest in wearable and implantable devices, and that they will enjoy the beautiful city of Lyon with its cultural, architectural and gastronomic assets.

## *Local Organizing Committee*

Stéphane Marinesco, UCBL/INSERM, Lyon

Abdelkader Zebda, Université de Grenoble alpes (UGA/INSERM)

Errachid Abdelhamid, UCBL, Lyon

Pascal Mailley, CEA/LETI, Grenoble

## *Scientific Committee*

Seiya Tsujimura, University of Tsukuba, Japan

Isao Shitanda, Tokyo university of science, Japan

Aziz Amine, Université de Marrakech, Maroc

Pankaj Vadgama, Université Queen Mary, Angleterre

Mamas Prodromidis, Editeur, Microchimica Acta, University of Ioannina, Greece

Elena E. Ferapontova, Editor manager, Electrochimica acta, Aarhus University, Danemark

Martin Peacock, CEO Zimmer and Peacock, Norvège

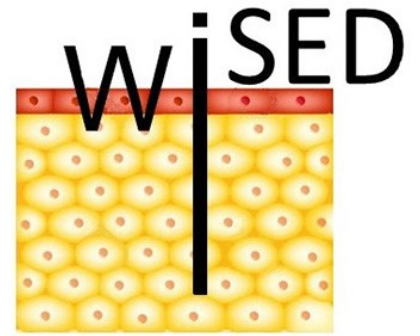
Parastoo Hashemi, Imperial College London (UK)

Minteer Shelly, University of Utah, USA

Wearable and Implantable Sensors  
and Electrochemical Devices

27-29 November 2024

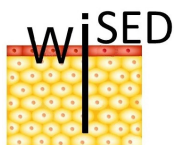
Lyon, France



# Program

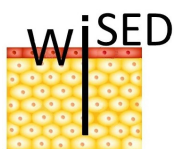
---





November 27<sup>th</sup>

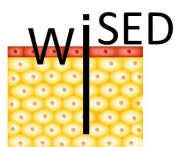
12h35-14h00	<b>Welcome</b>
14h00-14h35	<b>Parastoo Hashemi</b> <i>Ex vivo</i> electrochemical platform for antidepressant screening O01 (Chairperson: S.Marinesco)
14h35-15h35	<b>Session Wearable</b> (chairperson: S.Marinesco) <b>Chloé Aymard</b> Development of a new wearable auto-calibrated electrochemical biosensors for multi-target detection in sweat samples O02 <b>Melissa Hexter</b> The characterization of simple laser-induced carbon electrodes for fast scan cyclic voltammetry O03 <b>Rémy Séquestra</b> A hormonal monitoring device for detection of ovulation in cows O04
15h35-16h00	<b>Coffee Break</b>
16h00-16h35	<b>Martin Peacock</b> Four commercial cgm case studies: an analysis of success and failure O05 (Chairperson: A.Errachid)
16h35-17h35	<b>Session Implantable/ In Vitro Sensors</b> (Chairperson: A.Errachid) <b>Seiya Tsujimura</b> Immobilization of redox mediators for a fungal fad-dependent glucose dehydrogenase electrode O06 <b>Riccarda Antiocha</b> Wearable electrochemical microneedles-based sensor for real-time continuous catecholamine detection O07 <b>Marc Parrilla</b> Wearable 3D-printed microneedle voltammetric sensor for uric acid monitoring in interstitial fluid O08
17h35	<b>Welcome Cocktail</b>



November 28<sup>th</sup>

9h00-9h35	<b>Serge Cosnier</b> Bioelectrocatalytic materials based on carbon nanotubes from design to <i>In vivo</i> applications O09 (Chairperson: S. Tsujimura)
9h35-10h35	<b>Session Implantable Sensors</b> (Chairperson: S. Tsujimura) <b>Adam Milam</b> Investigating glucose oxidation cascades for self-powered glucose biosensors O10 <b>Thomas Lecourt</b> Optimization of implantable glucose biofuel cells (Gbfcs) based on gold nanostructures O11 <b>Nicole Jaffrezic-Renault</b> VOC Biosniffers for food quality control and breath monitoring O12
10h35-11h00	<b>Coffee Break</b>
11h00-11h35	<b>Pierre Yves Benhamou</b> Diabetes and glucose monitoring: medical perspectives O13 (Chairperson: A. Zebda)
11h35-12h35	<b>Session Implantable Sensors</b> (Chairperson: A. Zebda) <b>Niels Erik Olesen</b> Microneedle-based porous gold electrochemical sensor for real-time levodopa monitoring O14 <b>Etienne Le Bourdonnec</b> Microelectrode fiber sensors: advancing chemical sensing for implantable and wearable applications O15 <b>Shuting Chen</b> Brain tissue oxygen pressure monitoring using polyphenylenediamine-polyurethane-coated carbon fiber microelectrodes O16
12h35-14h00	<b>Lunch Break</b>
14h00-14h35	<b>Pankaj Vadgama</b> Challenges of biocompatibility for implantable electrodes O17 (Chairperson: P.Mailley)

14h35-15h35	<b>Session Implantable / In Vitro Sensors</b> ( <i>Chairperson: P. Mailley</i> )
	<b>Onur Parlak</b> Transdermal sensing of disease biomarkers enabled by epidermal microneedle patch O18
	<b>Boudewijn Van Der Sanden</b> In Vivo biocompatibility, stability and immuno-isolation analysis of new matrixes for an artificial pancreas O19
	<b>Sponsor Presentation</b>
15h35-16h00	<b>Coffee Break</b>
16h00-16h35	<b>Shelley Minteer</b> Enzymatic bioelectrodes for a contact lens lactate biofuel cel O20 ( <i>Chairperson: I. Shintanda</i> )
16h35-17h35	<b>Session In Vitro Sensors</b> ( <i>Chairperson: I. Shintanda</i> )
	<b>Gauthier Menassol</b> Electrochemical multisensor platform for bioproduction O21
	<b>Marc Zelsmann</b> Nanostructured electrodes for amino acid detection O22
	<b>Muhammad Iqbal</b> Development of nicu – mof for electrochemical immunosensor applications to detect denv – 3 O23
17h35	<b>Poster Presentation</b>
20h00	<b>Gala Dinner</b>



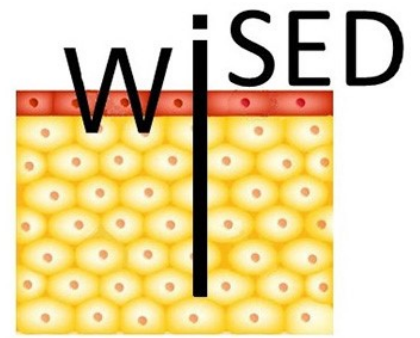
November 29<sup>th</sup>

9h00-9h35	<b>Roger Narayan</b> Electrochemical wearable technology and implementation of ai O24 ( <i>Chairperson: P.Hashemi</i> )
9h35-10h35	<b>Session Wearable</b> ( <i>Chairperson: P.Hashemi</i> )
	<b>Pauline Kiefer</b> Prediction of glucose electrchemical enzymatic biosensor's sensitivity using machine learning O25
	<b>Robert Marks</b> Estimating accrued air toxicity using a wearable luminescent biosensor patch array O26
	<b>Sponsor Presentation</b>
10h35-11h00	<b>Coffee Break</b>
11h00-11h35	<b>Session Implantable Sensors</b> ( <i>Chairperson: P. Vadgama</i> )
	<b>Andrew J. Gross</b> Hydrogel microneedle arrays for transdermal bioelectrochemical monitoring with matrix protection O27
	<b>Samuel Mugo</b> Transdermal wearable sensors for mental health analytics O28
	<b>Laurabelle Gautier</b> Monitoring circulating metabolic markers through microneedle arrays for animal welfare O29
	<b>Award Ceremony</b>
12h35-14h00	<b>Lunch Break</b>
14h00-14h35	<b>Isao Shitanda</b> Applications of screen-printed electrodes to wearable biosensing devices O30 ( <i>Chairperson: S. Cosnier</i> )
14h35-15h35	<b>Session</b> ( <i>Chairperson: S. Cosnier</i> )
	<b>Mohamed Rezki</b> Rational design of redox active metal organic frameworks for improved enzyme electrode performance O31
	<b>Adélèyè Chogolou</b> Towards the development of a wearable biocompatible sensor for dialysis monitoring O32
	<b>Anastasia Berezovska</b> Integration and optimisation of electrical impedance sensors in organ-on-chip for monitoring of organoids viability O33
15h35-16h00	<b>Closing Ceremony</b>

Wearable and Implantable Sensors  
and Electrochemical Devices

27-29 November 2024

Lyon, France



# Talks

---

# EX VIVO ELECTROCHEMICAL PLATFORM FOR ANTIDEPRESSANT SCREENING

O01

**Bettina Bohl,<sup>1</sup> Naima, A.,<sup>1</sup> Parastoo Hashemi<sup>1</sup>**

*<sup>1</sup> Institution, Department, City and Country; <sup>2</sup> Institution, Department, City and Country; <sup>3</sup> Institution, Department, City and Country; <sup>4</sup> Institution, Department, City and Country (corresponding author: email address) (Arial 10 italic)*

**Keywords:** Depression, Serotonin, Cerebral Organoids, FSCV, Microfluidics

Already the leading cause of world-wide disability, the post-COVID era is set to see depression skyrocket. Diagnosis and treatment of depression, based on questionnaires often fail. Selective serotonin reuptake inhibitors (SSRIs) are some of the most prescribed medicines globally but have side effects and type and dosage are often established *via* trial-and-error. A further, and alarming, problem is the lack of reliable pre-clinical screening tools forcing pharmaceutical companies to tone down antidepressant drug discovery. These issues persist because the community has not formed consensus on a pathophysiological basis of depression. This, to more accurately diagnose and treat depression, we must better define the chemical basis of this illness in humans. A critical step towards this goal is to identify and measure depression biomarkers in human models and assess their response to potential antidepressants. In prior *in vivo* work with fast scan cyclic voltammetry (FSCV) we identified serotonin to be a potential biomarker of depression and antidepressant activity in mice and here we take the first steps to translate these findings to humans in *ex vivo* models. We present the first, human-derived, immune-competent cerebral spheroids on a chip to measure serotonin transmission in response to antidepressants. Predictive AI models will be generated to predict individual treatment strategies based on biomarker responses to antidepressants. This work will provide the first prototype of personalised treatment platforms for depression, holding potential for upscaling towards a high throughput drug screening system to fundamentally re-invigorate antidepressant discovery.



# DEVELOPMENT OF A NEW WEARABLE AUTO-CALIBRATED ELECTROCHEMICAL BIOSENSORS FOR MULTI-TARGET DETECTION IN SWEAT SAMPLES

O02

**Chloé Aymard<sup>1</sup>, Pauline Kiefer<sup>1</sup>, Nelle Varoquaux<sup>1</sup>, Abdelkader Zebda<sup>1</sup>**

<sup>1</sup> TIMC (Recherche Translationnelle et Innovation en Médecine et Complexité), équipe SyNaBi (Systèmes Nanobiotechnologiques et Biomimétiques), UMR 5525 CNRS, UGA, VetagroSup, Faculté de Médecine de Grenoble, Pavillon Taillefer, 38706 La Tronche, France  
corresponding author: [chloe.aymard@univ-grenoble-alpes.fr](mailto:chloe.aymard@univ-grenoble-alpes.fr)

Keywords: wearable, autocalibration, electrochemical biosensors, sweat, biomarkers

Monitoring biomarkers raised a great interest for several years and allows to get personalized and preventive medicine. It enables the monitoring of an individual's health and fitness status and alert of potential health problems. Wearable biosensors are compact electronic devices that integrate biosensors located on the skin or within the human body (patches, tattoos, gloves, clothes, implants, etc.). The most popular applications of these devices are monitoring lactate and glucose levels in sweat. These biosensors use an electrochemical method, called amperometry, which is based on the electrochemical measurement of a current generated during the oxidation of the substrate (glucose or lactate) catalyzed by an oxidoreductase-type enzyme immobilized at the surface of a conductive electrode. Although sensitive, these biosensors are limited by a short lifespan, which is strongly related to the stability of the biosensor's sensitivity, leading to signal drift and requiring constant sensor calibration. Our aim is to develop an intelligent patch for the detection and quantification of multiple biomarkers (glucose, lactate, uric acid) in sweat. To increase the biosensor's lifespan and correct signal drift, two strategies have been combined: the first focuses on improving enzyme stability, particularly through its immobilization in organic matrices and the formation of enzyme nanoflowers. The second strategy relies on predicting and correcting signal drift using machine learning techniques. The combination of these two strategies allows us to offer a sensor with a lifespan of 1 year, without the need for calibration.

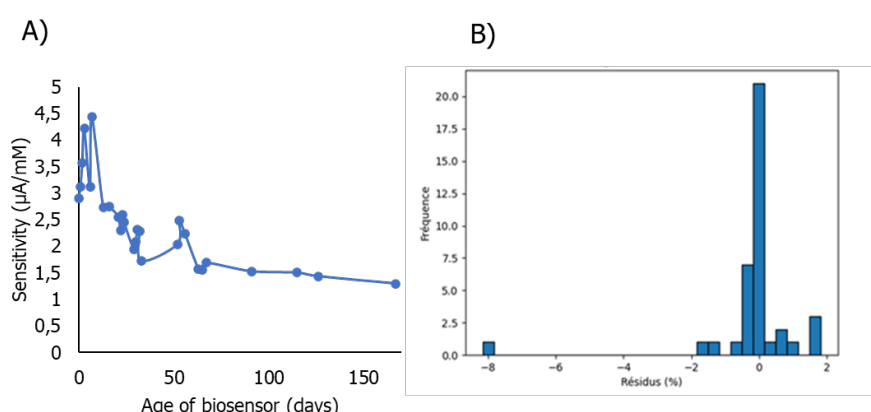


Figure 1. A) Evolution of sensitivity with age of glucose biosensors (dry condition storage) B) Relative difference between modeled and experimentally obtained glucose concentrations

# THE CHARACTERIZATION OF SIMPLE LASER-INDUCED CARBON ELECTRODES FOR FAST SCAN CYCLIC VOLTAMMETRY

O03

**Melissa Hexter<sup>1</sup>, Parastoo Hashemi<sup>2</sup>**

<sup>1</sup> Center For Neuroscience Research Lyon, TIGER, Lyon, France; <sup>2</sup> Imperial College London, Department of Bioengineering, London, UK

Keywords: Electrochemistry, Calibration, Serotonin, FSCV, FIA, Microfluidics,

Quantifying neurotransmission is essential to unravel the complexities of neuropathophysiology. Fast scan cyclic voltammetry (FSCV) distinguishes itself as a powerful tool for the electrochemical detection of neurotransmitters with excellent sensitivity and temporal resolution. However, the accuracy and reliability of FSCV measurements demand troubleshoot-free calibration of electrodes. Typically, calibration involves flow injection analysis (FIA), which replicates the rapid fluctuations of neurotransmitter levels that occur *in vivo*. This is achieved using a flow cell, a component of the FIA system whose design varies significantly between laboratories. Without careful consideration of the mechanics of the system, FIA may encounter issues with reproducibility due to the potential for leaks, electrode damage during manipulation, and flow instabilities that heavily influence the current-injection profile. Additionally, FSCV is evolving for application to *in vitro* measurements, necessitating a calibration system that is as close to the *in vitro* acquisition system as possible. Direct integration of electrodes into the FIA apparatus is an attractive solution to address these requirements. In this work, we developed a protocol to fabricate laser induced carbon electrodes (LINC) encapsulated with PDMS to provide a versatile electrode configuration compatible with PDMS based devices for an optimized FIA platform. Furthermore, we optimized this composite carbon material for FSCV measurements of serotonin and evaluated characteristics such as sensitivity, noise, and capacitance in comparison to other well-performing carbon materials. Thus, we present a novel electrode design suitable for FSCV of neurotransmitters within PDMS based devices, or where flexible carbon sensors may be required.

# A HORMONAL MONITORING DEVICE FOR DETECTION OF OVULATION IN COWS

O04

**Rémy Séquestra<sup>1, 3</sup>, Ilaria Sorrentino<sup>1</sup>, Pascal Mailley<sup>1</sup>,  
Thomas Alava<sup>1</sup>, Fabienne Blanc<sup>2</sup>, Chrystelle Le Danvic<sup>3</sup>**

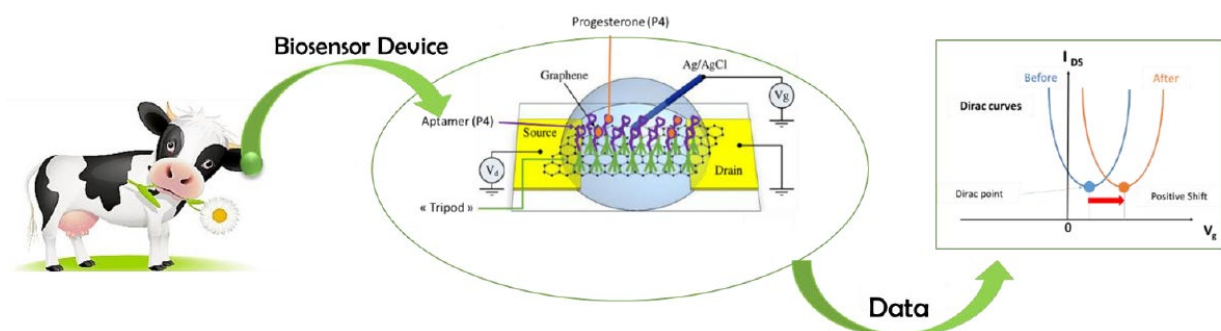
*<sup>1</sup>Univ Grenoble Alpes, CEA Leti, F-38000 Grenoble ; <sup>2</sup>VetAgro Sup-Inrae, UMR Herbivores, F-63370 Lempdes ; <sup>3</sup>ELIANCE, pôle innovation et marchés, F-75595 Paris  
(corresponding author : [remy.sequestra@cea.fr](mailto:remy.sequestra@cea.fr))*

**Keywords :** solution-gated field-effect transistor (SG-FET), graphene, aptamers, ovarian hormones

Animal insemination (AI), compared with natural breeding, allows better genetic control, improved health safety and time saving. AI is widely used on dairy farms in France (+80%) [1] and its success rate depends heavily on the ability to identify the optimal insemination window [2]. In daily practice, breeders have tools to detect oestrus signs that the cow expresses in the 25 to 30 hours preceding ovulation [3]. However, the effectiveness of this detection for estimating the ovulation window is reduced by less expression of specific oestrus behaviours and the variability between the start of oestrus and ovulation itself [4][5].

Therefore, with the goal of improving the insemination strategy, there is a clear need to develop a methodology that allows hormonal monitoring (e.g., progesterone, oestradiol, and LH) and predict ovulation with great accuracy.

This communication deals with the development of a portable, low cost and minimally invasive device that combines a micro-needle patch for interstitial fluid (ISF) extraction with a graphene-based liquid gate field effect transistors (SG-FETs) for the cows hormonal monitoring.



The chosen SG-FETs has great potential for the field of biosensing and from an industrial point of view. The signal amplification of SG-FETs coupled with the high sensitivity of graphene allows the detection of rare and local events with excellent sensitivity. The partner company Grapheal that produces it industrially provides this technology to us. The difficulty lies in mastering relevant and effective surface functionalization in order to demonstrate reproducible and specific detection in a simple medium. Furthermore, in order to claim a specific and dynamic measurement, aptamers are used as biorecognition elements because they have significant advantages compared to antibodies : better manufacturing reproducibility, higher stability, inexpensive and reversible recognition process at body temperature. Finally, the fixation of the aptamers on the graphene is carried out via an organic molecule call “tripod”.

This molecule was designed specifically for probe grafting at a fixed distance while preserving the electrical sensitivity of graphene [6].

This work will then report the first results of electrical measurements including functionalization steps and detection of progesterone in a simple medium.

#### References :

- [1] D. FARADJI and S. DOMINIQUE, "Statistiques des inséminations sur femelles laitières, campagne 2022." [Online]. Available : <https://idele.fr/detail-article/statistiques-generales-des-inseminations-animales-sur-femelles-laitieres-campagne-2022>
- [2] H. Seegers, "Economics of the reproductive performance of dairy herds. XXIV World Buiatrics Congress, Nice France.," 2006.
- [3] J. B. Roelofs, "When to inseminate the cow ? – Insemination, ovulation and fertilization in dairy cattle," no. February, p. 152, 2005.
- [4] E. Cutullic, L. Delaby, D. Causeur, G. Michel, and C. Disenhaus, "Hierarchy of factors affecting behavioural signs used for oestrus detection of Holstein and Normande dairy cows in a seasonal calving system," *Anim. Reprod. Sci.*, vol. 113, pp. 22–37, 2009, doi : 10.1016/j.anireprosci.2008.07.001.
- [5] F. Blanc *et al.*, *Caractérisation de l'oestrus chez la vache allaitante : quantification des manifestations comportementales et facteurs de variation.*
- [6] J. A. Mann, T. Alava, H. G. Craighead, and W. R. Dichtel, "Preservation of antibody selectivity on graphene by conjugation to a tripod monolayer," *Angew. Chemie – Int. Ed.*, vol. 52, no. 11, pp. 3177–3180, 2013, doi : 10.1002/anie.201209149.



# **FOUR COMMERCIAL CGM CASE STUDIES: AN ANALYSIS OF SUCCESS AND FAILURE**

O05

**Martin PEACOCK**

# IMMOBILIZATION OF REDOX MEDIATORS FOR A FUNGAL FAD-DEPENDENT GLUCOSE DEHYDROGENASE ELECTRODE

O06

**Seiya Tsujimura**<sup>1</sup>

<sup>1</sup> University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, Japan, [seiya@ims.tsukuba.ac.jp](mailto:seiya@ims.tsukuba.ac.jp)

**Keywords:** Glucose dehydrogenase, redox mediator, immobilization, biosensor, porous carbon

Enzyme electrodes are used in biofuel cells and biosensors, particularly for medical diagnostics like blood glucose measurements. Fungal flavin adenine dinucleotide-dependent glucose dehydrogenase (FAD-GDH) has emerged as a promising enzyme for enzymatic glucose electrodes. Herein, I will present recent developments in organic redox mediators for FAD-GDH. A new quinoline-5,8-dione (QD) was developed as a diffusional mediator with high water solubility and appropriate redox potential, which showed very high reactivity toward FAD-GDH. A disposable sensor using QD was demonstrated, in which glucose concentration can be determined from the glucose-diffusion-controlled current.

Co-immobilization of FAD-GDH and redox mediators on the electrode surface are required to operate implantable or wearable applications continuously. Co-immobilization technologies involve physical adsorption, (electrochemical) grafting, and cross-linking. Our group had developed a high-performance FAD-GDH hydrogel electrode based on "wiring technology" pioneered by A. Heller. The glucose electrode was fabricated by cross-linking FAD-GDH and Os polymer on the porous carbon electrode surface using poly(ethylene glycol) diglycidyl ether. Instead of Os-based polymer, we recently investigated a variety of co-immobilization technologies using phenothiazines such as thionine, toluidine blue, methylene blue, and azure A as a redox mediator, and FAD-GDH, involving electrochemical grafting of a redox mediator, a redox polymer containing redox mediator, cross-linked redox network, and direct surface grafting, etc.

## References:

Biosens. Bioelectron., 230, 115272 (2023), Chem Comm., 57, 6999-7002 (2021), Biosens. Bioelectron., 189, 113357 (2021), J. Phys. Energy, 3, 024005 (2021), ChemElectroChem, 7, 4543-4549 (2020), Colloids and Surfaces B: Biointerfaces, 192, 111065 (2020), Electrochimica Acta, 343, 136110 (2020).

# WEARABLE ELECTROCHEMICAL MICRONEEDLES-BASED SENSOR FOR REAL-TIME CONTINUOUS CATECHOLAMINE DETECTION

O07

C. Tortolini<sup>1</sup>, A.M. Isidori<sup>1</sup>, A.Lenzi<sup>1</sup>, A.E.G. Cass<sup>2</sup>, R. Antiochia<sup>3</sup>

<sup>1</sup>Department of Experimental Medicine, Sapienza University of Rome, Rome, Italy

<sup>2</sup>Department of Chemistry & Institute of Biomedical Engineering, Imperial College, London, UK

<sup>3</sup>Department of Chemistry and Drug Technologies, Sapienza University of Rome, Rome, Italy

[riccarda.antiochia@uniroma1.it](mailto:riccarda.antiochia@uniroma1.it)

Microneedle arrays for minimally invasive continuous sensing in the dermal interstitial fluid (ISF) have been demonstrated in both amperometric [1,2] and potentiometric [3] modes for detection of several biomarkers of clinical interest [4], however there are no publication where microneedle arrays have been used for direct monitoring of catecholamine in ISF.

Dopamine, epinephrine and norepinephrine are the main catecholamine of clinical interest, as they play crucial roles in the regulation of nervous and cardiovascular systems and are involved in some brain behaviours, such as stress, panic, anxiety and depression. Changes of catecholamines concentrations in organisms have a close connection with some neurological disorders and certain diseases. Therefore, there is an urgent need for a reliable sensing device able to provide their continuous monitoring in a minimally invasive manner [4].

In this work, we present the first highly nanoporous gold (h-nPG) microneedles-based sensor for minimally invasive monitoring of catecholamine in ISF.

The highly nanoporous microneedles-based gold electrode was prepared by a simple electrochemical self-templating method that involves two steps, gold electrodeposition and hydrogen bubbling at the electrode, which were realized by sweeping the potential between +0.8 V and 0 V vs Ag/AgCl for 25 scans in a 10 mM H<sub>2</sub>AuCl<sub>4</sub> solution containing 2.5 M NH<sub>4</sub>Cl, and successively applying a fixed potential of -4 V vs. Ag/AgCl for 60 s [5]. The resulting microneedle-based h-nPG sensor displays an interference-free catecholamine detection without compromising its sensitivity, stability and response time.

The performance of the h-nPG microneedle array sensor for catecholamine detection was successively assessed in a hydrogel skin model at typical physiological concentrations.

## References :

- [1] Cass, A. E. G., & Sharma, S. (2017). Microneedle Enzyme Sensor Arrays for Continuous In Vivo Monitoring. *Meth.Enzymol.*, 589, 413-427. doi:10.1016/bs.mie.2017.02.002
- [2] Ventrelli, L., Strambini L.M., Barillaro, G. (2015). Microneedles for transdermal biosensing: current picture and future direction, *adv. Healthcare Mater.*, 4, 2606-2640. doi:10.1002/adhm.201500450
- [3] Rawson, T. M., Sharma, S., Georgiou, P., Holmes, A., Cass, A., & O'Hare, D. (2017). Towards a minimally invasive device for beta-lactam monitoring in humans. *Electrochemistry Communications*, 82, 1-5. doi:10.1016/j.elecom.2017.07.011
- [4] Ribeiro, J.A.; Fernandez, P.M.V.; Pereira, C. M.; Silva, F. (2016) Electrochemical sensors and biosensors for determination of catecholamine neurotransmitters: A review. *Talanta* , 160, 653-679.679. doi:10.1016/j.talanta.2016.06.066
- [5] Bollella, P.; Sharma, S.; Cass, A.E.G.; Tasca, F.; Antiochia, R. (2019). Minimally Invasive Glucose Monitoring Using a Highly Porous Gold Microneedles-Based Biosensor: Characterization and Application in Artificial Interstitial Fluid. *Catalysts* 9, 580. doi:10.3390/catal9070580.

# WEARABLE 3D-PRINTED MICRONEEDLE VOLTAMMETRIC SENSOR FOR URIC ACID MONITORING IN INTERSTITIAL FLUID

O08

**Marc Parrilla,<sup>1,\*</sup> Annemarijn Steijlen,<sup>1</sup> Phil Clerx,<sup>2</sup> Regan Watts,<sup>2</sup>  
Karolien De Wael<sup>1</sup>**

<sup>1</sup> Antwerp engineering, photoelectrochemistry and sensing (A-PECS), University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium. \* [marc.parrilla@uantwerpen.be](mailto:marc.parrilla@uantwerpen.be)

<sup>2</sup> Product Development Research Group, Faculty of Design Sciences, University of Antwerp, Ambtmanstraat 1, 2000 Antwerp, Belgium.

**Keywords:** *solid microneedles, 3D printing, wearable electrochemical sensor, microneedle voltammetric sensor, health monitoring.*

Wearable microneedle-based devices have been extremely attractive for minimally-invasive diagnostics and health monitoring owing to the ability to provide continuous on-body information [1]. Dermal interstitial fluid has been recently a new analytical matrix with value for health monitoring while being a simpler matrix than blood [2]. On the other hand, 3D printing enables the rapid prototyping of devices, a huge decrease in manufacturing costs, and potential scalability [3]. Herein, 3D-printed microneedle-based voltammetric sensors are developed for the monitoring of uric acid (UA) in interstitial fluid (ISF). First, affordable microneedle arrays (MNA) were manufactured. Subsequently, a metallic layer was sputtered on top of the MNA to create MN electrodes. Gold sputtering was employed for the working and counter electrodes, and silver for the reference electrode. A novel plug-in three-electrode cell design was employed to manufacture the MN UA sensor. The MN UA sensor was analytically characterised exhibiting linear response in the physiological range of interest in ISF (i.e. 100 – 500  $\mu\text{M}$ ) even after several insertions in porcine skin proving its mechanical robustness. The MN UA sensor was analytically characterised in phosphate buffer pH 7.4 with and without bovine serum albumin to evaluate the biofouling at the surface of the electrode. ISF was prepared by using diluted human serum to emulate real conditions, and the MN UA sensor was interrogated under this condition showing linear range and stability to monitor UA. Finally, the MN UA sensor was used to monitor UA in an *ex vivo* setup consisting of piercing the MN patch through porcine skin. This new design brings advances in affordable MN electrochemical sensors allowing the democratization of this type of platform for future diagnostics and health monitoring devices.

## References:

- [1] C. Wei, D. Fu, T. Ma, M. Chen, F. Wang, G. Chen, Z. Wang, Sensing patches for biomarker identification in skin-derived biofluids, *Biosens. Bioelectron.* 258 (2024) 116326. <https://doi.org/10.1016/j.bios.2024.116326>.
- [2] M. Friedel, I.A.P. Thompson, G. Kasting, R. Polsky, D. Cunningham, H.T. Soh, J. Heikenfeld, Opportunities and challenges in the diagnostic utility of dermal interstitial fluid, *Nat. Biomed. Eng.* 7 (2023) 1541–1555. <https://doi.org/10.1038/s41551-022-00998-9>.
- [3] U. Detamornrat, E. McAlister, A.R.J. Hutton, E. Larrañeta, R.F. Donnelly, The Role of 3D Printing Technology in Microengineering of Microneedles, *Small.* 18 (2022) 2106392. <https://doi.org/10.1002/sml.202106392>.



# BIOELECTROCATALYTIC MATERIALS BASED ON CARBON NANOTUBES: FROM DESIGN TO IN VIVO APPLICATIONS

O09

**Serge Cosnier**<sup>1, 2</sup>

<sup>1</sup> CNRS Université Grenoble Alpes, Département de Chimie Moléculaire, Grenoble, France; <sup>2</sup> Silesian University of Technology, Centre for Organic and Nanohybrid Electronics, Gliwice, Poland

Keywords: biofuel cell, carbon nanotube, enzyme wiring, in vivo

For four decades, the functionalization of electrodes by biomaterials based on electrogenerated polymers, carbon nanotubes and / or nano-objects, was widely used in the field of analytical chemistry and energy conversion for the design of biosensors and biofuel cells [1]. Some new approaches for developing nanostructured biomaterials based on functionalized carbon nanotubes, will be briefly described as the compressions of carbon nanotubes, the self-assembly of carbon nanotubes in the form of buckypapers or the creation of hollow electrodes.

These different electrochemical materials combined with enzymes as catalytic element, will be applied to the design of glucose/oxygen enzymatic fuel cells and their performances will be compared. Examples of implantation of these biofuel cells in animals will be presented.

In particular, the concept of hollow bioelectrodes based on the assembly of two buckypapers was developed to generate a microcavity defined by the thickness of the glue linking the two sheets [2]. These buckypapers are permeable only to water and enzyme substrates but not allow the permeation of enzymes. Therefore, the enzyme trapped in powder form is then solubilized inside the microcavity leading to a high density of biocatalyst in solution with an electrical connection with the buckypapers. The electrocatalytic performance of the bilirubin oxidase hollow electrode was described as a function of pH, temperature and the amount of entrapped enzyme. Owing to the complexity of optimizing a multienzyme system, this concept also constitutes an attractive strategy to design and optimize enzyme cascade reactions. Besides the easy modulation of enzyme ratios, we have also demonstrated the possibility of trapping with enzymes a redox mediator ensuring the electrical connection of an enzyme [3].

## References:

1. S. ul Haque, S. Cosnier, M. Yasir. Biosens. Bioelectron., 214 (2022) 114545-114554P.
2. H. M. Buzzetti A. Berezovska, Y. Nedellec, S. Cosnier, Nanomaterials 12 (2022) 2399-2405.
3. I. Jeerapan, Y. Nedellec, S. Cosnier. Nanomaterials 14 (2024) 545.

# INVESTIGATING GLUCOSE OXIDATION CASCADES FOR SELF-POWERED GLUCOSE BIOSENSORS

O10

**Adam Milam<sup>1</sup>, Rokas Gerulskis <sup>1</sup>, Shelley D. Minter<sup>2</sup>**

<sup>1</sup> *University of Utah, Department of Chemistry, Salt Lake City, Utah;*

<sup>2</sup> *Missouri University of Science and Technology, Rolla, Missouri*

*adam.milam@utah.edu*

Keywords: Glucose, Enzyme, Cascade, Stability, Oxidation

Self-powered glucose biosensors benefit from efficient fuel utilization by minimizing the total substrate demand which limits the sensor's impact on critical equilibria in blood or interstitial fluids. Exploring novel glucose cascades is critical for better understanding how to address inefficient fuel utilization as seen in many glucose biofuel cells.<sup>1-4</sup> First, by leveraging the promiscuity of an organic catalyst, we have developed a three-catalyst hybrid glucose cascade capable of facilitating all twelve possible oxidation reactions of glucose. To address long-term instability of 2-keto-3-deoxygluconate aldolase (KDGA), a key member of our cascade, we are investigating solution additives. Current results show that additives causing KDGA to favor its compact form improve its long-term stability. Together, these results provide key insight on how to pursue advancements in glucose bioanode design.

## References:

- 1 Kwon, C. H.; Ko, Y.; Shin, D.; Kwon, M.; Park, J.; Bae, W. K.; Lee, S. W.; Cho, J. High-power hybrid biofuel cells using layer-by-layer assembled glucose oxidase-coated metallic cotton fibers. *Nat. Commun.* **2018**, 9 (1), 1-12. DOI: 10.1038/s41467-018-06994-5
- 2 Atanassov, P.; Appleby, C.; Banta, S.; Brozik, S.; Barton, S.; Cooney, M.; Liaw, Y.; Mukherjee, S.; Minter, S. D. Enzymatic Biofuel Cells. *Electrochem. Soc. Interface*, **2007**, 16 (28), 28–31. DOI: 10.1149/2.F04072IF
- 3 Kulkarni, T.; Slaughter, G. Enzymatic Glucose Biofuel Cell and its Application. *J. Biochips Tiss. Chips*, **2015**, 5 (111), 1-10. DOI: 10.4172/2153-0777.1000110
- Zhu, Z.; Kin Tam, T.; Sun, F.; You, C.; Percival Zhang, Y. H. A high-energy-density sugar biobattery based on a synthetic enzymatic pathway. *Nat. Commun.* **2014**, 5, 1-8. DOI: 10.1038/ncomms4026

# OPTIMIZATION OF IMPLANTABLE GLUCOSE BIOFUEL CELLS (GBFCS) BASED ON GOLD NANOSTRUCTURES

O11

**Thomas Lecourt<sup>1, 2, 3</sup>, Abdelkader Zebda<sup>1</sup>, Seiya Tsujimura<sup>2</sup>, Marc Zelsmann<sup>3</sup>**

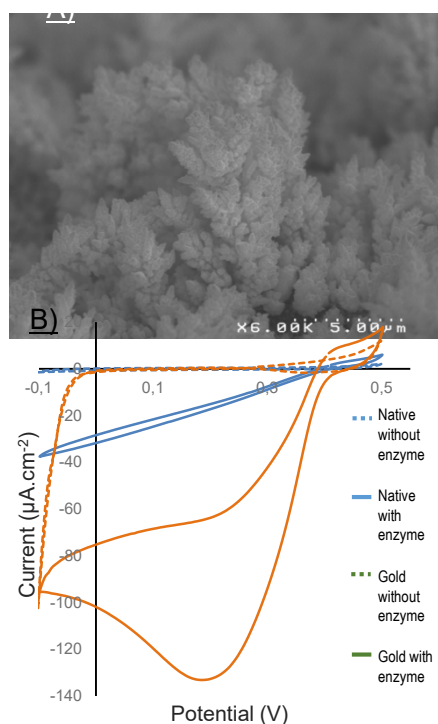
<sup>1</sup> *Timc (Recherche Translationnelle et Innovation en Médecine et Complexité), équipe SyNaBi (Systèmes Nanobiotechnologiques et Biomimétiques), UMR 5525 CNRS, UGA, VetagroSup, Faculté de Médecine de Grenoble, Pavillon Taillefer, 38706 La Tronche*

<sup>2</sup> *Division of Materials Science, Faculty of Pure and Applied Sciences, University of Tsukuba1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8573, Japan*

<sup>3</sup> *University Grenoble Alpes, CNRS, CEA/LETI Minatec, Grenoble INP, LTM, 17 Avenue des Martyrs, Grenoble Cedex 9, 38054 France*

Keywords: Biofuel cell, Gold nanostructures, DET, Bilirubin Oxidase

Today, main source of energy for implantable medical devices is lithium batteries. However, these batteries have two limitations. The first is a problematic volume/power ratio. For a pacemaker, lithium battery delivers a power of a few tens of microwatts for a volume of 10 cm<sup>3</sup>, but for medical devices requiring an electrical power of more than 20mW, volume of lithium battery can reach 1L, which is not sustainable for a patient. The second limitation is the finite lifespan of lithium batteries [1]. This is why new energy sources are being considered. One solution is glucose biofuel cells. Glucose oxidation on anode side of biofuel cell via an enzyme such as Glucose Oxidase and the reduction of dioxygen on cathode side via an enzyme such as Bilirubin Oxidase (BOD) makes it possible to obtain a renewable biofuel with an inexhaustible supply of fuel. However, one of the main limits of those new devices is their low electrical power and current density [2]. To increase the number of direct electron transfer (DET) exchanged between enzymes and electrode surface, we explore the possibility of both increasing the electroactive surface area without increasing the geometric surface area and of a better orientation of the enzymes. To this purpose, deposition of porous gold nanostructures using Dynamic Hydrogen Bubble Template method [3] will be presented, together with the electrical connection results after addition of BOD to modified electrodes. Gold nanostructures morphology, observed using SEM images (Figure 1A), as well as cyclic voltammetry in absence and presence of BOD (Figure1B), allow us to conclude that the gain in specific surface area, as well as the morphology of nanostructures, improves DET method.



**Figure 1:** A) SEM image of gold nanostructures electrodeposited on screen-printed carbon B) Cyclic voltammetry of electrodes before (Native) and after (Gold) gold deposition in the absence or presence of BOD (10mg/ml)

References:

- [1] Zebda A, Alcaraz JP, Vadgama P, et al. *Bioelectrochemistry*. 2018;124:57-72.
- [2] Xiao X, Xia H qi, Wu R, et al. *Chem Rev*. 2019;119(16):9509-9558.
- [3] Plowman BJ, Jones LA, Bhargava SK. *Chem Commun*. 2015;51(21):4331-4346.



# VOC BIOSNIFFERS FOR FOOD QUALITY CONTROL AND BREATH CONTROL

O12

**Nicole Jaffrezic-Renault**

*University of Franche-Comte, UTINAM Institute, 25000 BESANCON, France  
email address: nicole.jaffrezic-renault@univ-fcomte.fr*

Keywords: VOC, biosniffer, electrochemistry, conductometry, fluorimetry

Volatile organic compounds (VOCs) are chemicals with a relatively high vapor pressure at room temperature and atmospheric pressure so they vaporize readily. VOC can be used in breath to indicate health conditions and in packaging for controlling food quality. The techniques for quantifying VOC are GC-MS, PTR-MS, etc; these devices are bulky, expensive, and time-consuming. Semiconducting metal oxide-based gas sensors are cheap, miniaturized, and very sensitive; their main drawbacks are their high working temperature and rather bad specificity. Taking advantage of the enzyme selectivity, enzyme-based sensors were used as “bio-sniffer” for detecting different types of VOC.

## **Detection of ethanol in food**

Analysing the headspace above the liquid sample, instead of the liquid sample itself, offers the advantage that possible non-volatile interfering substances in the liquid sample (e.g. ascorbic acid) cannot impair the measurement. Fruit juice can contain small amounts of ethanol due to the fermentation of the fruits during storage before juice processing; the maximum permitted level of ethanol is 65 mM.

An electrochemical detection of ethanol was carried out, using a 3-electrode configuration with a Pt gas diffusion electrode as the working electrode [1]. The amperometric detection of hydrogen peroxide, produced by the enzymatic reaction of the alcohol oxidase, allowed the detection of ethanol in the gas phase. The response time was 1 min and the detection limit was 10  $\mu$ M. The concentration of ethanol, in different apple juices, was determined, and overestimated, compared to the HPLC result, due to the low sensitivity to methanol of the AOx. A simple conductometric microsensor, based on interdigitated electrodes and alcohol dehydrogenase immobilized in a chitosan film on top of the sensor, will be presented, for the detection of ethanol in the headspace of commercial wine [2].

## **Detection of ethanol in breath**

An acetaldehyde “biosniffer”, based on the reverse reaction of alcohol dehydrogenase, was composed of an UV-LED as an excitation light source, a photomultiplier tube as a fluorescence detector and an optical fiber [3]. This biosniffer shows a response time of less than 2 min and a dynamic range of 0.02 – 10 ppm, and was applied to measure the concentration of acetaldehyde in exhaled breath from healthy subjects after ingestion of alcohol.

## **References:**

- [1] M. Hämmerle, K. Hilgert, M.A. Horn, R. Moos. Sensors and Actuators B 2011, 158, 313-318
- [2] A. Madaci, N. Jaffrezic-Renault et al. J Mater Sci: Mater Electron 2021, 32, 17752–17763
- [3] K. Iitani, P.J. Chien, T. Suzuki, K. Toma, T. Arakawa, Y. Iwasaki, K. Mitsubayshi. ACS Sensors 2018, 3, 425-431

# DIABETES AND GLUCOSE MONITORING: MEDICAL PERSPECTIVES

O13

**Pierre Yves BENHAMOU**

*Department of Endocrinology, University Hospital Grenoble Alpes, CS 10217X,  
38043 Grenoble, France  
e-mail [PYBenhamou@chu-grenoble.fr](mailto:PYBenhamou@chu-grenoble.fr)*

The number of patients living with diabetes has reached 828 millions worldwide in 2022. Among them, patients living with type 1 diabetes are 8.7 millions, with an increase of 4% per year. Continuous glucose monitoring was a major breakthrough in the management of diabetes, and probably one of most important achievement since the discovery of insulin. It allows a better adherence of patients to their treatment, a better understanding of the disease, a better follow-up of the efficacy of therapeutic management, and is the cornerstone for the development of modern treatments such as automated insulin delivery. Current CGM are minimally invasive and achieve an accuracy, measured by MARD (mean absolute relative difference) of 8 to 10%. There is room for the improvement of CGM device, with various approaches: changes in the technological choices for the measurement of glucose, allowing for non invasive devices with increase in accuracy and reliability, reduction in wastes and costs.

# MICRONEEDLE-BASED POROUS GOLD ELECTROCHEMICAL SENSOR FOR REAL-TIME LEVODOPA MONITORING

O14

**Niels Erik Olesen<sup>1</sup>, Maria Dimaki<sup>1</sup>, Winnie E. Svendsen<sup>1</sup>**

*<sup>1</sup>DTU Bioengineering, Technical University of Denmark, Søltofts Plads Building 221, 2800 Kgs Lyngby, Denmark (corresponding author: nieol@dtu.dk)*

Keywords: Microneedles, Parkinson's, Levodopa, Nanoporous

Levodopa can effectively treat Parkinson's symptoms. However, the medication is characterized by a narrow therapeutic window and is therefore an attractive candidate for real-time therapeutic drug monitoring by a wearable microneedle sensor. Here, we present a levodopa sensor based on a microneedle array with demonstrated in-vivo performance (Figure 1). We show that at relatively low potentials the catechol-group of levodopa is oxidized in a 2-electron/2-proton electron transfer process leading to dopaquinone as the reaction product (Figure 2).

The sensor was functionalized with highly nanoporous gold by the dynamic hydrogen bubbling template [1]. Tortolini et al. [2] has previously used this method to functionalize the microneedle array for detecting dopamine, epinephrine and norepinephrine. However, the physiological concentration of these three catecholamines are all below 5 nM, some orders of magnitude below the sensor's limit of detection of 100 nM [2]. On the other hand, the therapeutic window of levodopa is approximately 5–10  $\mu$ M [3] and nanoporous gold therefore seems obvious to investigate for therapeutic drug monitoring of levodopa.

First the porous gold layer was electrochemically characterized by electrochemical impedance spectroscopy (EIS) in ferricyanide on a gold rod electrode. It was noted that the EIS data showed a large difference in electron transfer resistance, between the pristine and the porous electrode, see Figure 3. Subsequently, the electroactive area was investigated by measuring the charge required to reduce the oxide layer formed by cyclic voltammetry in sulfuric acid as shown in Figure 4. The porous gold had an approximately 10-fold increase in electroactive area compared to flat pristine gold on a rod electrode (4.6 mm<sup>2</sup> versus 40.9 mm<sup>2</sup>).

On pristine gold electrodes, the peaks for ascorbic acid and levodopa typically overlap [4], but on porous gold, ascorbic acid was seen to have a more negative peak potential resulting in clearly resolvable peaks. This effect was also observed in [4] and ascribed to nanoconfinement [5]. Finally, the analytical performance of the microneedle sensor with porous gold surface was investigated for levodopa. The sensitivity, limit of detection and selectivity towards ascorbic acid and uric acid will be presented.

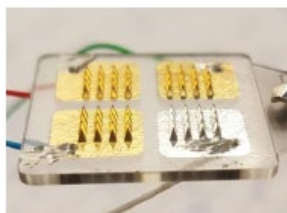


Figure 1: Microneedle array with 1 mm tall needles with geometries of a square-based pyramids. Each electrode has 16 needles and are arranged in to two working electrodes, one counter electrode, and one reference electrode.

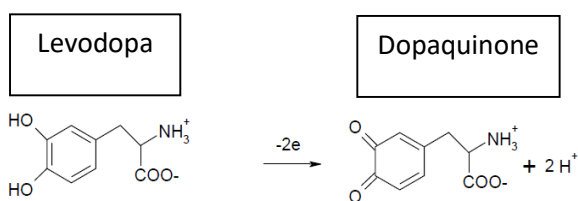


Figure 2: The catechol-group of levodopa is oxidized in a 2-electron/2-proton electron transfer process leading to dopaquinone as the reaction product. Levodopa is zwitterionic at physiological pH with a total net charge of 0 [pKa (strongest acidic) = 1.65, pKa (strongest basic) = 9.06].

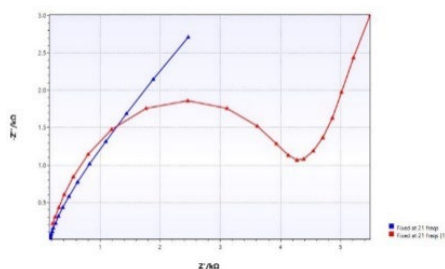


Figure 3: Nyquist plot of electrochemical impedance spectroscopy data, showing a pristine gold electrode (red) and the porous gold electrode (blue) in 5.0 mM  $[\text{Fe}(\text{CN})_6]^{3-/4-}$  and 0.1 M KCl

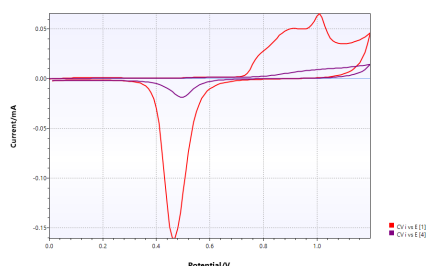


Figure 4: Cyclic voltammetry of 0.5 M  $\text{H}_2\text{SO}_4$  at a scan rate of  $100 \text{ mV s}^{-1}$  on pristine gold electrode and porous gold electrode.

## References:

- [1] P. Bollella *et al.*, 'Highly Sensitive Membraneless Fructose Biosensor Based on Fructose Dehydrogenase Immobilized onto Aryl Thiol Modified Highly Porous Gold Electrode: Characterization and Application in Food Samples', *Anal Chem*, vol. 90, no. 20, pp. 12131–12136, 2018.
- [2] C. Tortolini *et al.*, 'Microneedle-based nanoporous gold electrochemical sensor for real-time catecholamine detection', *Microchimica Acta*, vol. 189, no. 5, 2022.
- [3] C. Hiemke *et al.*, 'Consensus Guidelines for Therapeutic Drug Monitoring in Neuropsychopharmacology: Update 2017', *Pharmacopsychiatry*, vol. 51, no. 1–2. Georg Thieme Verlag, pp. 9–62, 2018.
- [4] T.A. Silva *et al.*, 'Simultaneous electrochemical sensing of ascorbic acid and uric acid under biofouling conditions using nanoporous gold electrodes', *Journal of Electroanalytical Chemistry*, vol. 846, 2019
- [5] S. Park *et al.*, 'Electrochemical analysis based on nanoporous structures', *Analyst*, vol. 137, no. 17. Royal Society of Chemistry, pp. 3891–3903, 2012

# MICROELECTRODE FIBER SENSORS: ADVANCING CHEMICAL SENSING FOR IMPLANTABLE AND WEARABLE APPLICATIONS

O15

**Yuanyuan Guo<sup>1, 2, 3</sup>, Etienne Le Bourdonnec**

*1. Frontier Research Institute for Interdisciplinary Sciences (FRIS), 2. Graduate School of Medicine, 3. Graduate School of Biomedical Engineering, Tohoku University, Sendai 980-8578, Japan  
Email address: [yyuanguo@fris.tohoku.ac.jp](mailto:yyuanguo@fris.tohoku.ac.jp)*

**Keywords:** microelectronic fibers, biochemical sensing, implantable neural probes, wearable fiber and textiles

Globally, millions suffer from brain disorders, highlighting the urgent need for advanced therapeutic interventions. Achieving this requires a comprehensive understanding of neural circuits across molecular, cellular, systemic, and behavioral dimensions. Our research addresses this by leveraging innovative engineering solutions to bridge critical knowledge gaps. Traditional neural technologies have focused primarily on electrical activities, overlooking the potential of intrinsic chemical signals within neural circuits. Our research involves the development of polymer-based microelectronic fibers developed through thermal drawing techniques, which integrate electrical, chemical, optical, and mechanical functionalities within a single thin strand of fiber with its footprint at microscale. These multifunctional fibers serve as advanced bio-interfaces, facilitating both detailed mechanistic studies and therapeutic applications.

One particular focus of our work is the integration of novel bioreceptors, such as aptamers and ionophores, into these fibers to enable high-sensitivity in vivo neurochemical sensing[1]. Additionally, we are pioneering the development of shape-programmable smart fibers that act as multimodal catheters. These fibers dynamically adjust their orientation based on chemical sensing data, enhancing their functionality[2] (PCT/JP2022/17664). By incorporating microfluidics, we enable precise manipulation of biofluids, pioneering lab-in-fiber (LoF) bioanalytical applications.[3] Extending their utility further, we have also developed fiber-based smart textiles for continuous health monitoring[4], capable of measuring diverse physiological parameters including sweat compounds, brain waves, body temperature, and respiration rate.

This innovative approach not only propels forward fundamental neuroscience research but also revolutionizes the study of brain-body interactions. Our ongoing research into these microelectronic fiber-based multimodal bio-interfaces is poised to pioneer new frontiers in in vitro Lab-in-Fiber (LoF) analyses, in vivo neuroscience studies, and the wearable technology domain for health surveillance.

## References:

- [1] T. Saizaki, M. Kubo et al, *Analytical Chemistry*, 2023.
- [2] Y. Sato and Y. Guo\*, *ACS Applied Engineering Materials*, 2023, 1, 2, 822–831.
- [3] S. Kato, D. Carlson, A. Shen\* and Y. Guo\*, *Microsystems and Nanoengineering*, 2024,10,1,14.
- [4] J. Wu, Y. Sato and Y. Guo\*, *Analytical and Bioanalytical Chemistry*, 2023,1-2.

# BRAIN TISSUE OXYGEN PRESSURE MONITORING USING POLYPHENYLENEDIAMINE-POLYURETHANE-COATED CARBON FIBER MICROELECTRODES

O16

**Shuting Chen<sup>1</sup>, Melissa Hexter<sup>1</sup>, Andrei Sabac<sup>2</sup>, and Stephane Marinesco<sup>1</sup>**

1 : Université Claude Bernard Lyon 1, CNRS UMR5292, INSERM, Centre de Recherche en Neurosciences de Lyon CRNL U1028 UMR5292, Team TIGER, F-69500, Bron, France

2 : CNRS UMR5005, Ecole Centrale de Lyon, INSA de Lyon, Ampère Laboratory, Villeurbanne, France

Brain tissue oxygen pressure (PbtO<sub>2</sub>) monitoring is important to understand brain metabolism at rest or during neuronal activation. Electrochemistry provides high spatial and temporal resolution to achieve PbtO<sub>2</sub> monitoring, especially platinum (so-called Clark electrodes) and carbon fiber microelectrodes (CFMEs). However, a major problem with in vivo PbtO<sub>2</sub> recordings is a significant loss of sensitivity due to sensor fouling in the living brain tissue. Here, we tested a polyphenylenediamine-polyurethane (PPD-PU) coating to minimize electrode fouling in vivo and improve the stability of PbtO<sub>2</sub> recordings. PPD and PU coatings were deposited on CFMEs (7 µm diameter, 100 µm long, 4400 µm<sup>2</sup>) and displayed less fouling in vivo than bare CFMEs, or CFMEs coated with PPD only. Oxygen reduction started around -300 mV vs Ag/AgCl and PPD-PU deposition increased microelectrode diameter by 1-2 µm. Carbon fiber microelectrodes coated with PPD-PU were used for 2.5-5 h of PbtO<sub>2</sub> monitoring in anesthetized rats and there was no significant change in O<sub>2</sub> sensitivity before and after in vivo implantation. These results indicate that PbtO<sub>2</sub> monitoring can be achieved reliably using PPD-PU coating on carbon fiber microelectrodes, preventing electrode fouling in vivo, and providing an inexpensive and minimally invasive tool to study brain oxygen metabolism.

# CHALLENGES OF BIOCOMPATIBILITY FOR IMPLANTABLE BIOELECTRODES

O17

**Pankaj Vadgama**

*Queen Mary University of London, School of Engineering and Material Science, London. UK*

Keywords: Tissue implantation, polymer membranes, glucose, lactate, oxygen.

Changes in metabolite intermediates and oxygen can be quite rapid where the patient is metabolically stressed, eg in diabetes, shock and hypoxia. We have focused on classical oxidase based electrochemical sensors for subcutaneous tissue implantation for real time monitoring and compared the effects of physiological perturbation on the 'housekeeping' variables of glucose, oxygen and lactate. *In vivo* use imposes a severe test on biosensor chemistry due mainly to issues of sterilisation, response linearisation in undiluted samples and stabilization in the face of tissue response. The latter is the fundamental challenge for all bio-interfacing foreign materials be they biomaterials or biosensors. In the case of biosensors, the reactivity induces the following artefactual environment: an interstitial fluid that is a distortion of normal blood transudate, a cellular rich space with excess of metabolizing inflammatory cells and ultimately a fibrous capsule that acts as a barrier membrane to efficient solute crosstalk. Underlying all this is a continuously remodelling protein layer due to protein adsorbates on the artificial surface. We have focused on devices protected by low permeability membrane barriers to aid functional biocompatibility by creating low flux responding systems. These have been partially successful for short term monitoring. An early effort improved outcomes through the delivery of fluid over the sensing surface to create a mobile surface interface, more recently we used recessed electrodes to preclude colloid entry to the sensor and finally have tested a thermally addressable N-isopropylacrylamide/N-vinyl pyrrolidone copolymer abled to remodel through temperature change to create a self-cleaning surface. Whilst tissue is a hostile environment, it is preferable to saliva or sweat for any form of metabolite monitoring, since both these fluids are physiologically partitioned compartments, despite recent hopeful reports. The challenge remains but with careful materials design there is a possibility of at least reducing artefactual distortion of implanted biosensors.

## References:

1. S. Anastasova, A.-M. Spehar-Délèze, R. M. Kwasnicki, G.-Z. Yang, P. Vadgama. 2020. "Electrochemical Monitoring of Subcutaneous Tissue pO<sub>2</sub> Fluctuations during Exercise Using a Semi-implantable Needle Electrode" *Electroanalysis* 32, 2393.
2. A.-M. Spehar-Délèze, S. Anastasova, P. Vadgama. 2021. "Monitoring of Lactate in Interstitial Fluid, Saliva and Sweat by Electrochemical Biosensor: The Uncertainties of Biological Interpretation" *Chemosensors* 9, no. 8: 195.
3. L. Yang, I. Campelo Lopes, P. Vadgama. 2023. "Self-cleaning sensors based on thermoresponsive polymeric film modified screen-printed platinum electrode" *Chemical Engineering Journal* 474, 145932



# TRANSDERMAL SENSING OF DISEASE BIOMARKERS ENABLED BY EPIDERMAL MICRONEEDLE PATCH

O18

**Onur Parlak**<sup>1, 2</sup>

<sup>1</sup> Karolinska Institute, Division of Dermatology and Venereology, Stockholm, Sweden; <sup>2</sup> Technical University of Munich, Department of Dermatology and Allergy, Munich, Germany  
(corresponding author: [onur.parlak@ki.se](mailto:onur.parlak@ki.se))

**Keywords:** epidermal sensors, microneedles, skin health, wearable bioelectronics

Wearable bioelectronics represents a significant breakthrough in healthcare settings, particularly in (bio)sensing which offers an alternative way to track individual health for diagnostics and therapy. However, there has been no notable improvement in early diagnosis of dermatological diseases. Here, we established a wearable bioelectronic patch platform for transdermal sensing of the various biomarkers ranging from small molecules to proteins using a microneedle array integrated with a surface-bound chemo-responsive smart probes to enable target-specific electrochemical detection directly from human skin tissue. The results presented herein demonstrate the feasibility of a transdermal microneedle sensor for direct quantification of biomarkers in an ex vivo skin model. Initial performance analysis of the transdermal microneedle sensor proves that the designed methodology can be an alternative for fast and reliable diagnosis and the evaluation of disease progression in human skin. We believe that the innovative approach presented here may revolutionize the landscape of skin monitoring by offering a nondisruptive means for continuous surveillance and timely intervention of skin anomalies, such as inflammatory skin diseases or allergies and can be extended to the screening of multiple responses of complementary biomarkers with simple modification in device design.

## References:

[1] N. Poursharifi, M. Hassanpouramiri, A. Zink, M. Ucuncu, O. Parlak, *Advanced Materials*, 2024, 2403758.

# IN VIVO BIOCOMPATIBILITY, STABILITY AND IMMUNO-ISOLATION ANALYSIS OF NEW MATRIXES FOR AN ARTIFICIAL PANCREAS

O19

**Boudewijn van der Sanden<sup>1</sup>, Ibrahim Shalayel<sup>1</sup>, Ibrahima Doumbouya<sup>1</sup>, Quentin Perrier<sup>2</sup>, Clovis Chabert<sup>2</sup>, Sandrine Lablanche<sup>2,3</sup>, Pierre-Yves Benhamou<sup>2,3</sup>, Laetitia Gredy<sup>4</sup>, Olivier Stephan<sup>4</sup>, Abdelkader Zebda<sup>1</sup>**

<sup>1</sup>TIMC, team SyNaBi, La Tronche, France; <sup>2</sup>Laboratory of Fundamental and Applied Bioenergetics (LBFA), Grenoble Alpes University and INSERM U1055, France, <sup>3</sup>Department of Endocrinology-Diabetology-Nutrition, Grenoble University Hospital, France, <sup>4</sup>MoVe, Laboratoire interdisciplinaire de physique, CNRS UMR 5588, Grenoble Alpes University, St-Martin d'Hères, France ([boudewijn.vandersanden@univ-grenoble-alpes.fr](mailto:boudewijn.vandersanden@univ-grenoble-alpes.fr))

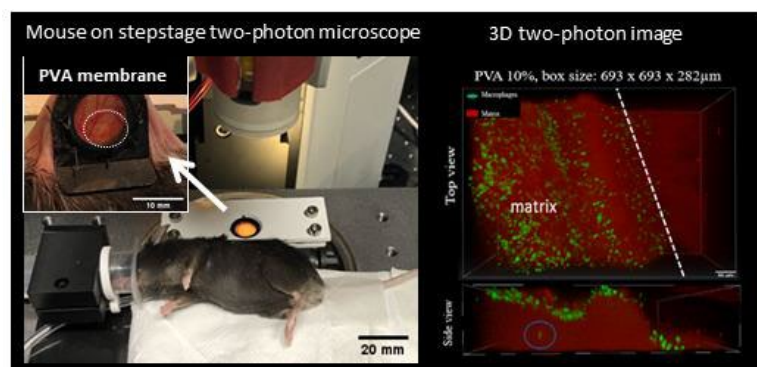
**Keywords :** Artificial pancreas, Inflammation, GelMA matrix, Digital Light Processing, Intravital microscopy

**Introduction.** Macro-encapsulation of pancreatic islets in semi-permeable matrixes is a new treatment for type 1 diabetes, improving the survival and function of pancreatic cells in islets without using an immunosuppressive treatment. These matrixes should allow diffusion of glucose and insulin, while blocking immune cells. Further, they need to be stable *in vivo* and avoiding a chronic inflammation around the device after implantation. **Aim of this study** is to select matrixes that fulfil these requirements.

Two-photon microscopy is a powerful tool to address these analyses on whole mice after implantation of these matrixes in a dorsal skin fold chamber, see figure 1. A transgenic mouse model that expressed eGFP in mononuclear phagocytes (1) permit to monitor the inflammation (macrophage distribution and density) around and in the device and thus analyse their immuno-isolating capacity.

**Results.** In the current study, several matrixes for macro-encapsulation were tested: chemical crosslinked or photopolymerized collagen and Gelatin Methacrylate (GelMA) matrixes (2), as well as, PolyVinyl Alcohol (PVA) membranes for a better immuno-isolation of the islets in the device.

**Figure 1:** CX<sub>3</sub>CR<sub>1</sub><sup>gfp</sup> - C57BL/6 mouse with a dorsal skinfold chamber on the step stage of a two-photon microscope. Scalebars are 20 mm and 10 mm in the insert. The PVA membrane was inserted inside the chamber and covered with quartz coverslip. The 3D two-photon image shows the PVA membrane in red and the macrophages in green at the top. Scale bar = 50  $\mu$ m.



Chemical crosslinked collagen matrixes were instable *in vivo* (crosslinker = genepin) or cytotoxic (crosslinker = glutaraldehyde, Young's modulus = 2.2 kPa) during 3 weeks after implantation. The macrophages densities (n/mm<sup>2</sup>) inside the matrixes were: 929  $\pm$  262 (genepin) and 139  $\pm$  35 (glutaraldehyde). In comparison, photopolymerized GelMA matrixes

(Young's modulus = 8 kPa) using Digital Light Processing were stable for at least 3 weeks with only a mean macrophage density of  $24 \pm 22$  inside the matrixes. No macrophages entered the 10% PVA membrane (Young's modulus = 40 kPa), with less macrophages at their surface than GelMA matrixes.

**Conclusion.** Digital light processed GelMA matrixes are stable *in vivo* with a high immune-isolating capacity, which can be enhanced with an extra thin 10% PVA membrane.

#### References :

- 1) S Jung et al, Analysis of fractalkine receptor CX(3)CR1 function by targeted deletion and green fluorescent protein reporter gene insertion, Mol Cell Biol, 2000 Jun; 20(11):4106-14. doi: 10.1128/MCB.20.11.4106-4114.2000.
- 2) Menassol G et al, Gelatine-collagen photo-crosslinkable 3D matrixes for skin regeneration. Biomater Sci. 2024 Mar 26; 12(7):1738-1749. doi: 10.1039/d3bm01849k

# ENZYMATIC BIOELECTRODES FOR A CONTACT LENS LACTATE BIOFUEL CELL

O20

**Shelley Minter**

Implantable and wearable ocular devices require a compact continuous power source that does not interfere with vision or regular physical activity. An enzymatic biofuel cell fits this description provided it has sufficient power density and stability. Two proof-of-concept contact lens lactate biofuel cell prototypes were designed and fabricated to investigate making enzymatic bioelectrodes that are flexible, have high surface area and conductivity and that could be integrated into a contact lens. The first prototype utilized a bilirubin oxidase biocathode and a lactate dehydrogenase bioanode. When tested in conditions similar to those found on the eye, this prototype produced more power ( $3\ \mu\text{W}$  at  $\sim 0.2\ \text{V}$ ) than the second prototype but it did not sustain appreciable electrical activity for more than 4 hours due to poor cofactor/mediator immobilization. The second prototype used lactate oxidase at the anode and the device was stable for at least 24 hours of continuous operation but had lower power output ( $0.5\ \mu\text{W}$  at  $\sim 0.2\ \text{V}$ ) than the first prototype because of lower electrode surface area (but increased biocompatibility). Both prototypes were limited by the oxygen reduction reaction (ORR) at the air-breathing biocathode. Oxygen concentration and transport are commonly blamed for low cathodic current but it is less understood how carbon nanotube (CNT) networking and CNT surface activity might affect catalytic current. For the second prototype, Monte Carlo and numerical simulations revealed that only 20% of the CNTs were networked to the current collector and, within that fraction, only  $\sim 5\%$  of the CNT surfaces contributed to current output. These results have implications for enzymatic biofuel cells in general through two conclusions: 1) enzymatic electrode films that are thicker or having more CNTs may not be beneficial and 2) there is much opportunity to improve enzyme-CNT electron transfer. This paper will discuss strategies for next generation wearable enzymatic bioelectrodes.

# ELECTROCHEMICAL MULTISENSOR PLATFORM FOR BIOPRODUCTION

O21

**Gauthier Menassol<sup>1</sup>, Ilaria Sorrentino<sup>1</sup>, Stanislas Lhomme<sup>1</sup>, Eric Calvosa<sup>2</sup>  
Amélie Revaux<sup>1</sup>**

<sup>1</sup> Université Grenoble Alpes, CEA, LETI, F-38000 Grenoble, France

<sup>2</sup> Sanofi, 69280 Marcy l'Etoile, France

(corresponding author: [amelie.revaux@cea.fr](mailto:amelie.revaux@cea.fr))

Keywords: bioproduction; monitoring; electrochemical; platform; multi-sensor

In bioproduction, monitoring and regulating physicochemical parameters is essential for optimizing cell culture and achieving high yields in the production of target molecules<sup>1</sup>. The French national funded CALIPSO project aims to address the needs related to the control of biomass production stages by monitoring physicochemical parameters such as pH, conductivity, temperature, pO<sub>2</sub>, and pCO<sub>2</sub> during bacterial (*E. coli*) and mammalian cell (CHO) cultures. Today, these parameters are monitored in industry via individual and bulky sensors, i.e. one sensor per analyte. The ambition of the CALIPSO project is to combine all these sensors into a single, miniature multiparametric platform whose performance matches that of commercially available individual sensors. The CALIPSO multi-sensor platform implements electrochemical measurements such as open circuit potential (OCP), impedance spectroscopy (EIS), and chronoamperometry (CA). This single platform offers flexibility and low cost due to the use of low-tech components, its reusable embedded electronics, and disposable probes. It also allows a decrease of installation, maintenance and calibration time. Single control electronics for all sensors makes it easy to automate bioreactor actions (nutrient addition, pH adjustment, etc.). Today's bioreactors are conventionally monitored using optical sensors. These devices, although efficient, induce a dead volume due to the optical fibers and their protections. Thus, the CALIPSO platform allows for: reducing the volume occupied in the bioreactor and minimizing the risk of contamination by decreasing the number of sensors inserted into the bioreactor. CEA multi-sensor platform integrates nine sensors with 2 pO<sub>2</sub> sensors, 2 pCO<sub>2</sub> sensors, 2 pH sensors, 2 conductivity sensors, as well as 1 temperature sensor located on the back side of the PCB. This platform is already fully functional in a laboratory environment. Tests are currently underway to validate its effectiveness in culture media under conditions representative of bioreactors in operation.

## References:

[1] E. Trummer *et al.*, "Process parameter shifting: Part I. Effect of DOT, pH, and temperature on the performance of Epo-Fc expressing CHO cells cultivated in controlled batch bioreactors," *Biotechnol. Bioeng.*, vol. 94, no. 6, pp. 1033–1044, 2006, doi: 10.1002/bit.21013

# NANOSTRUCTURED ELECTRODES FOR AMINO ACID DETECTION

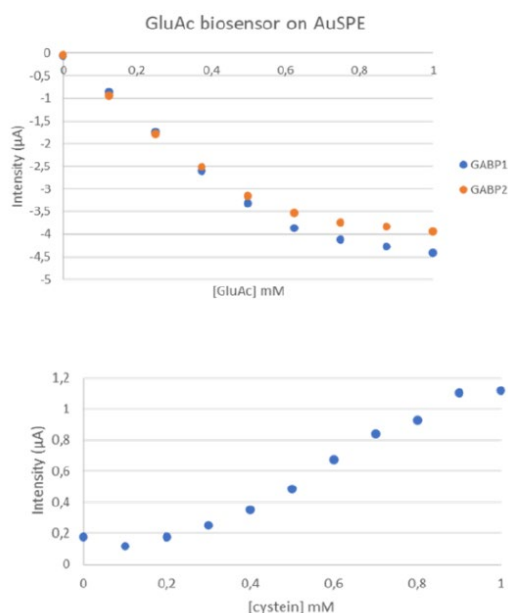
O22

**Marc Zelsmann<sup>1</sup>, Yuki Oguri<sup>2</sup>, Chloé Aymard<sup>2</sup>, Thomas Lecourt<sup>1, 2</sup> and Abdelkader Zebda<sup>2</sup>**

<sup>1</sup> University Grenoble Alpes, CNRS, CEA/LETI Minatec, Grenoble INP, LTM, 17 Avenue des Martyrs, Grenoble Cedex 9, 38054 France; <sup>2</sup>TIMC, UMR 5525 CNRS, UGA, VetagroSup, Faculté de Médecine de Grenoble ([marc.zelsmann@cea.fr](mailto:marc.zelsmann@cea.fr))

Keywords : amino acid, nanostructured electrodes, electrochemistry

Amino acids such as cysteine, glutamic acid and tyrosine are essential to monitor because of their key roles in metabolic processes. Cysteine is a precursor of glutathione, a powerful antioxidant that protects cells from oxidative damage. Glutamic acid is essential for neurotransmission and energy metabolism, acting as a precursor of gamma-aminobutyric acid (GABA), which regulates brain function. Tyrosine serves as a precursor to catecholamines such as dopamine and norepinephrine, which are essential for stress response and cognitive functions [1]. Monitoring these amino acids can prevent metabolic imbalances, improve clinical outcomes and enable personalized treatment strategies [2]. Our study investigated the use of nanostructured metallic electrodes, modified or unmodified with Prussian blue, to detect these amino acids in physiological buffers. We found that Prussian blue-modified gold nanostructured electrodes are highly sensitive to glutamic acid, with a detection limit of 3  $\mu$ M. For cysteine, our electrode detects at a low potential of 100 mV versus Ag/AgCl, showing strong linearity, making gold nanostructured electrodes promising for cysteine detection. Although tyrosine does not undergo direct oxidation, its reaction product exhibited reduction behavior on the nanostructured electrode surface, suggesting potential for indirect detection. These results open up new opportunities for the development of wearable amino acid biosensors for continuous health monitoring.



Example of electrochemical responses of glutamic acid (top) and cysteine (bottom) on nanostructured gold electrodes.

## References :

- [1] Jian Wu et al., *Amino acid metabolism in health and disease*, Signal Transduct Target Ther. 8 (2023) 345
- [2] M. Wang et al., *A wearable electrochemical biosensor for the monitoring of metabolites and nutrients*, Nature Biomedical Engineering 6 (2022) 1225

# DEVELOPMENT OF NICU – MOF FOR ELECTROCHEMICAL IMMUNOSENSOR APPLICATIONS TO DETECT DENV – 3

O23

**Neng Astri Lidiawati<sup>1</sup>, Ni Luh Wulan Septiani<sup>2</sup>, Ahmad Nuruddin<sup>1</sup>, Nugraha<sup>1</sup>  
and Brian Yulianto<sup>1,3</sup>**

<sup>1</sup> Institut Teknologi Bandung, Advanced Functional Materials Research Group, Bandung, Indonesia,

<sup>2</sup> National Research and Innovation Agency (BRIN), Research Center for Chemistry, Indonesia,

<sup>3</sup> Research Center for Nanosciences and Nanotechnology, Bandung, 40132, Indonesia

(corresponding author: [brian@tf.itb.ac.id](mailto:brian@tf.itb.ac.id))

**Keywords:** electrochemical immunosensor, MOF, CuNi-BTC, dengue virus.

Dengue hemorrhagic fever (DHF) is the most common arboviral disease worldwide. The dengue virus causes it and infects humans through the bite of the *Aedes aegypti* mosquito. It is found in tropical and subtropical areas. In Indonesia, the prevalence of this disease is increasing every year. Early detection can reduce the risk.

This study developed an electrochemical immunosensor based on a modified metal-organic framework (MOF) on the working electrode surface to detect dengue virus NS-1 serotype 3. Cu-BTC and CuNi-BTC materials with variations in the Cu:Ni composition ratio of 5:1 (CuNi-BTC-1), 3:1 (CuNi-BTC-2), and 1:1 (CuNi-BTC-3), and the addition of 10 wt% triethanolamine (TEOA) as a modulator have been successfully synthesized. The synthesis was performed by co-precipitation at room temperature and dried at 60°C for  $\pm$  24 hours. The MOF characteristics were comprehensively evaluated using various analytical techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), Brunauer-Emmett-Teller (BET) surface area analysis, and electrochemical assessments. The material's performance as an electrochemical immunosensor was further investigated by employing cyclic voltammetry (CV), differential pulse voltammetry (DPV), and electrochemical impedance spectroscopy (EIS).

The cyclic voltammetry (CV) analysis demonstrated that CuNi-BTC-3 achieved an optimal reduction current of 19.12 A and an oxidation current of 13.17 A. Based on these findings, CuNi-BTC-3 was selected for further electrochemical testing to detect the dengue virus (DENV). The detection was performed using differential pulse voltammetry (DPV) within a linear range of NS-1 protein concentrations from 5 ng/mL to 0.001 ng/mL. The results indicated that CuNi-BTC-3 exhibited a low limit of detection (LoD) of 0.77 pg/mL. Selectivity testing across four DENV serotypes revealed that the CuNi-BTC metal-organic framework (MOF) material possessed excellent selectivity towards NS-1 DENV serotype 3. A serum test for NS-1 DENV serotype – 3 at concentration variations of 0.001, 0.01, 0.1, 1, and 10 ng/mL showed recovery rates of 98%, 94%, 97%, 95%, and 98%, respectively. These results highlight the potential of the CuNi-BTC-3-based electrochemical immunosensor for the detection of NS-1 DENV serotype 3 antigens.

# ELECTROCHEMICAL WEARABLE TECHNOLOGY AND IMPLEMENTATION OF AI

O24

**Roger Narayan**<sup>1</sup>

<sup>1</sup> *North Carolina State University, Department of Biomedical Engineering, Raleigh, USA*

Keywords: ML, biosensor, microneedle

We have recently performed two studies that used machine learning to evaluate data acquired using microneedle sensors. In one study (Kadian S, Kumari P, Sahoo SS, Shukla S, Narayan RJ. Machine learning enabled microneedle-based colorimetric pH sensing patch for wound health monitoring and meat spoilage detection. *Microchemical Journal*. 2024 May 1;200:110350), a machine learning model was utilized to analyze the data that was obtained with a pH-test strip within a microneedle-based colorimetric pH sensing device. In another study (Kadian S, Sahoo SS, Kumari P, Narayan RJ. Machine learning enabled onsite electrochemical detection of lidocaine using a microneedle array integrated screen printed electrode. *Electrochimica Acta*. 2024 Jan 20;475:143664), a machine learning model was created with sensing data and used to predict the lidocaine concentration for a screen-printed electrode-based electrochemical device that contained a microneedle array. These results suggested that machine learning-based approaches may be useful for understanding the data that is obtained using microneedle-based sensors, which are finding greater use for portable and wearable sensing applications.



# PREDICTION OF GLUCOSE ELECTROCHEMICAL ENZYMATIC BIOSENSOR'S SENSITIVITY USING MACHINE LEARNING

O25

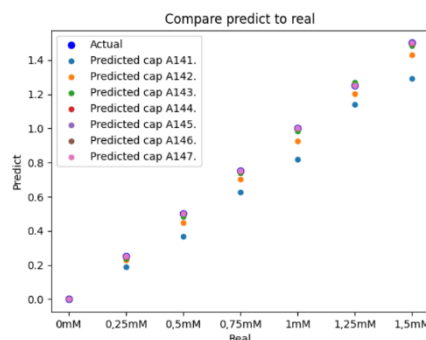
**Pauline Kiefer<sup>1, 2</sup>, Chloé Aymard<sup>1</sup>, Seiya Tsujimura<sup>2</sup>, Nelle Varoquaux<sup>1</sup>, Abdelkader Zebda<sup>1, 2</sup>**

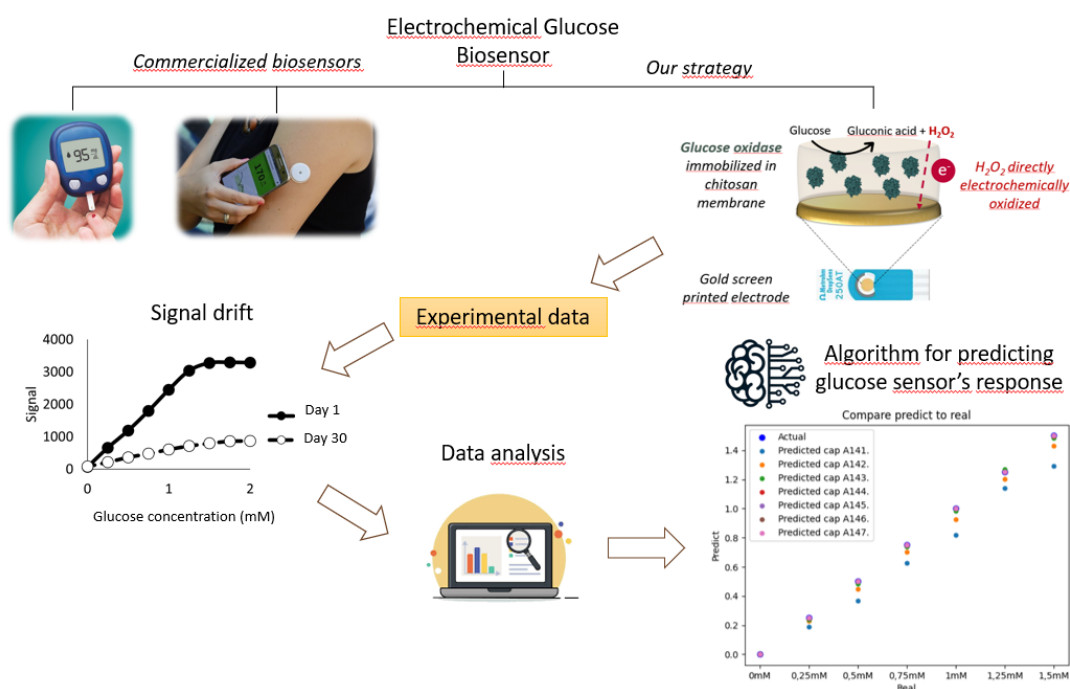
<sup>1</sup>*TIMC (Translational Innovation in Medicine and Complexity), UMR 5525 CNRS, UGA, VetagroSup, Faculté de Médecine de Grenoble, Pavillon Taillefer, 38706 La Tronche*

<sup>2</sup>*Division of Material Science, Faculty of Pure and Applied Science, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki, 305-5358, Japan*

Keywords: glucose, enzyme, electrochemistry, autocalibration, machine learning

Glucose monitoring is essential for effective diabetes management, helping to prevent serious health complications. This monitoring is primarily achieved through Continuous Glucose Monitoring Systems (CGMS), which use enzymatic electrochemical biosensing technology. However, current enzymatic detection methods have limitations. They are invasive, relying on microneedle-based biosensors to detect glucose in interstitial fluid, and they have a short lifespan due to the drift of enzymatic electrochemical sensors over time. Here, we focus on developing a non-invasive glucose detection method using electrochemical enzymatic sensors combined with machine learning algorithms. Specifically, we are coupling a new enzyme immobilization strategy with machine learning methods to predict and correct sensor drift over time. This project utilizes enzymatic methods such as Entrapment and Crosslinking, along with machine learning techniques like Random Forest and neural networks, including Recurrent Neural Networks (RNNs). So far, we have made predictions on first-generation sensors. These predictions were based on several series of three replicates of enzymatic electrochemical sensors. Two series of tests were carried out on each sensor replicate. The first test evaluated the algorithm on the last measurement series of each sensor to observe how the prediction evolves on a known and aging sensor. The second test evaluated a complete sensor (an unknown unit to the program) to assess reproducibility between similar sensors manufactured under the same conditions. Currently, the maximum error is 15% with the first test. In conclusion, this project has already yielded promising results, opening up new possibilities for using machine learning in the field of enzymatic electrochemical biosensors.





## References:

- [1] Investigation of GOx Stability in a Chitosan Matrix: Applications for Enzymatic Electrodes, Ayman Chmayssem, Ibrahim Shalayel, Stéphane Marinesco and Abdelkader Zebda, *Sensors* 2023, 23, 465. <https://doi.org/10.3390/s23010465>
- [2] ReviewnGlucose Biosensors: 40 Years of Advances and Challenges, Joseph Wang, *Electroanalysis* 2001, 13, No. 12, 1040-0397/01/1208–0983
- [3] Electrochemical Glucose Biosensors, Joseph Wang, *Chem. Rev.* 2008, 108, 814-82510.1021/cr068123a
- [4] Advancing Biosensors with Machine Learning, Feiyan Cui, Yun Yue, Yi Zhang, Ziming Zhang, and H. Susan Zhou, <https://dx.doi.org/10.1021/acssensors.0c01424>

# ESTIMATING ACCUMULATED AIR TOXICITY USING A WEARABLE LUMINESCENT BIOSENSOR PATCH ARRAY

O26

**Robert S. Marks**

*Department for Biotechnology Engineering, The Ben Gurion University of the Negev, Beer-Sheva,  
Israel  
[rsmarks@bgu.ac.il](mailto:rsmarks@bgu.ac.il)*

Keywords: biosensor patch array, toxicity, bacterial bioreporter

Canaries do it better in air. Fish do it better in water. They are both very sensitive and will provide rapidly accurate and sensitive reading on the matrix they are present in. Humans can sense volatile organic compounds and toxic chemicals, but they cannot estimate the exposure properly and, if in protected gear, they are then obligated to probe the exposure to their environment independently. In space, we can imagine bacterial bioreporters exposed over time to celestial radiations, whose overall exposure can be measured. On earth, these same bioreporters can probe the surrounding air, and estimate the exposure level. Unfortunately, these measurements, despite being real-time, in the lifecycle of a living cellular organism, it still requires just under an hour to respond. In the case of a long exposure, then this lag time is no longer relevant. Thus, our genetically engineered bacteria can be used in a wearable sensor system setup. We will describe how our whole cell biosensors can be used to monitor exposure to harmful substances in real-time in environmental or occupational air, providing an estimation of toxicity, which no enzymatic sensor can provide, not being 'living'. The reporter system used, here lux, generates a measurable signal (luminescence) but can be easily shifted to an electrochemical one (electrical), when relevant. Our wearable design is that of an array of such bioreporters (we have 5) which is integrated into the users' clothing gear. Reading is done off-line to ensure no contamination of external light and the accumulated data offers insight into exposure and potential health risk. Practically, industrial workers exposed to toxic gases ought to wear such patches, urban end-users in high-level polluted cities would find numerical indication of their exposure, and first responders would be informed of the level of hazardous chemicals they were exposed to. Our system is user friendly, as it the sole requirement would be to connect the patch to an off-line reading device for an immediate answer. Our system immobilizes the bacterial bioreporters inside calcium alginate pads, which, being hydrogels enable to retain a minimum amount of humidity. These are porous entities that enable gases to diffuse in. The bacteria are then exposed to the said toxicant aerosols and they respond accordingly, and semi-quantitatively. One hour from exposure an answer is obtained.

## References:

- Eltzov, E., A. Cohen and R. S. **Marks** (2015) Bioluminescent liquid light guide pad biosensor for indoor air toxicity monitoring. *Analytical Chemistry*. 87 (7) 3655-3661. Axelrod, E.,  
Eltzov, M. Lerman, D. Harpaz, and R. S. **Marks** (2021) Cigarette smoke toxicity modes of action estimated by a bioluminescent bioreporter bacterial panel. *Talanta*. 226: 122076.  
<https://doi.org/10.1016/j.talanta.2020.122076>

Paul, A. A., Y. Schlichter Kadosh, A. Kushmaro, and R. S. **Marks** (2024) Microbead-encapsulated luminescent bioreporter screening of *P. aeruginosa* via its secreted quorum sensing molecules. 10.20944/preprints202406.1169.v1.

# HYDROGEL MICRONEEDLE ARRAYS FOR TRANSDERMAL BIOELECTROCHEMICAL MONITORING WITH MATRIX PROTECTION

O27

**Andrew J. Gross**<sup>1</sup>, Bastien Darmau<sup>1,2</sup>, Martha Sacchi<sup>2</sup>, Isabelle Texier<sup>2</sup>

<sup>1</sup> CNRS-UGA, Dept. of Molecular Chemistry, Université Grenoble Alpes, 38000 Grenoble, France

<sup>2</sup> CEA-LETI, 38054 Grenoble, France

[andrew.gross@univ-grenoble-alpes.fr](mailto:andrew.gross@univ-grenoble-alpes.fr)

**Keywords:** in vivo bioelectrocatalysis; continuous glucose monitoring (CGM); wearable biosensors; biopolymers; dextran

Enzymes are nature's catalysts that are being increasingly exploited at electrodes to drive and control chemical transformations for biosensor and biofuel cell devices [1,2]. State-of-the-art portable and wearable continuous glucose monitors (CGMs) employing oxidoreductase-modified electrodes have revolutionised diabetes management. Nevertheless, such devices are limited by their cost, invasivity, and stability. Further limitations include the widespread use of synthetic polymers and the lack of practical monitors beyond glucose. Microneedle arrays could offer improved comfort compared to invasive implanted or mm-sized needle devices, but such devices are hampered by complex fabrication methods, limited sensor stability and durability, and cytotoxicity concerns.

This talk will explore our recent advances on the development of dextran-derived hydrogels for electrochemical biosensing and monitoring [3]. The aqueous synthesis of dextran methacrylate will be described, a reaction that proceeds with high efficiency and reaction control without toxic solvent and catalysts. The development of a crosslinked transdermal hydrogel microneedle-bioelectroenzymatic sensor that enables glucose extraction and robust longer-term transdermal monitoring will be highlighted. The integrated 2<sup>nd</sup> generation biosensor (WE) exploits FAD-glucose dehydrogenase immobilised at a porous nanostructured carbon buckypaper electrode [4]. The cross-linked hydrogel patch provides strength for skin penetration with swelling properties to enable interstitial fluid extraction to the integrated electrodes. The glucose patch offers promising selectivity, monitoring stability, and cytocompatibility (WST-1 assay) thanks to the hydrogel microenvironment [5].

## References:

- [1] A. Heller, B. Feldman, Chem. Rev., 2008, 108, 2482.
- [2] A. J. Gross, M. Holzinger, S. Cosnier, Energy Environ. Sci, 2018, 11, 1670.
- [3] I. Texier-Nogues, B. Darmau, A. J. Gross, EP4201966A1 (CNRS-CEA Leti)
- [4] A. J. Gross, X. Chen, F. Giroud, C. Abreu, A. Le Goff, M. Holzinger, S. Cosnier, ACS Catal., 2017, 7, 4408.
- [5] B. Darmau, I. Texier-Nogues, A. J. Gross, 1 publication and 2 patents submitted (CNRS-CEA LETI)

# TRANSDERMAL WEARABLE SENSORS FOR MENTAL HEALTH ANALYTICS

O28

**Samuel Mugo<sup>1</sup>, Scott Robertson<sup>1</sup>, Maher Al Rayess<sup>1</sup>,  
Ignacio Ramos de la Torre<sup>1</sup>**

<sup>1</sup> MacEwan University, Physical Sciences Department, Edmonton, Canada. (Samuel Mugo: [mugos@macewan.ca](mailto:mugos@macewan.ca))

**Keywords:** Real-Time Mental health diagnostic technology; Molecular Imprinting; Wearable electrochemical probes, IoT Devices.

In this presentation we will feature our flexible electrochemical probes based on biomimetic responsive composite hydrogels for in-situ multiplex detection of biologically relevant chemical markers, e.g., redox biomarkers, pH, biogenic amines, lactate, cortisol, adrenaline, Interleukin-6, and alpha-amylase. The composite hydrogels in these sensors simultaneously serve as an interface for biological fluid sampling and a medium for electrochemical sensing. In this presentation we will demonstrate results of our e-skin wearable sensors for real-time wireless monitoring of mental health biomarkers (emphasis on cortisol and adrenaline) in human sweat, towards applications in diagnostics in mental health and wellness. An accompanying emotional sensor app will be demonstrated.

## References:

- [1] Mugo et al., *Talanta*, 2023, p.124531. [doi.org/10.1016/j.talanta.2023.124531](https://doi.org/10.1016/j.talanta.2023.124531)
- [2] Mugo et al., *Biosensors*, 12, 2022, p.854. [doi.org/10.3390/bios12100854](https://doi.org/10.3390/bios12100854)
- [3] Mugo et al., *Microchimica Acta*, 189, 2022, 206. [doi.org/10.1007/s00604-022-05307-4](https://doi.org/10.1007/s00604-022-05307-4)

# TABOLIC MARKERS THROUGH MICRONEEDLE ARRAYS FOR ANIMAL WELFARE

O29

**L. Gautier<sup>1</sup>, I. Sorrentino<sup>1</sup>, S. Brulais<sup>1</sup>, F. Gondret<sup>2</sup>, C. Verplanck<sup>1</sup>, I. Texier<sup>1</sup>**

<sup>1</sup>Université Grenoble Alpes, CEA, LETI-DTIS, F-38054 Grenoble, France (corresponding author : [laurabelle.gautier@cea.fr](mailto:laurabelle.gautier@cea.fr)) ; <sup>2</sup>PEGASE, INRAE, Institut Agro, F-35590 Saint-Gilles, France

Keywords: Microneedles, conductivity, skin perforation, animal welfare

The analysis of the dermal interstitial fluid (ISF), which is representative of blood in terms of circulating markers but is more accessible, could provide an interesting alternative to traditional blood sampling tests. Real-time measurements of circulating markers to follow the kinetics of variations in response to nutritional or environmental changes could be very useful to check adaptive physiology in a non-invasive way to assess health and well-being of livestock animals, particularly when facing heat stress due to climate change. Microneedles (MNs) with micropoints of 400-1500  $\mu\text{m}$  height (for human), are able to perforate the skin and can give an easy access to ISF. Integrated with optical or electrochemical sensors to design wearable devices, MN arrays offer a minimally invasive and painless solution for the analysis of circulating metabolites or physiological integrative proxies [1-3]. The ambition of the project is to design MN-based electrochemical wearable sensors to monitor markers of animal well-being in real time. We focused on conductivity measurements that are indicative of variations in electrolytes content in intracellular fluids and monitor the metabolism of water and ions and therefore the animal dehydration.

For that purpose, wearable devices were designed where the microneedles themselves served as the measurement electrodes. A poly(lactic-co-glycolic) microneedles array was prepared by a hot-molding process and used as a template, then coated with different thin metallic layers. Metal-coated MNs were then screened for conductivity measurement performance in pure chemical solutions and in different skin models. Stability and ageing tests were performed to evaluate the robustness of the system to perform long lasting measurements. Finally, a complete packaged system was developed and tested on living pigs subjected to heat stress (32°C) during 7 days.

## Acknowledgements :

The WAIT4 project is funded by Agence Nationale de la Recherche under the France 2030 program with the reference ANR-22-PEAE-0008.

## References:

- [1] J. Li, M. Wei, B. Gao, « A Review of Recent Advances in Microneedle-Based Sensing within the Dermal ISF That Could Transform Medical Testing », *ACS Sens.*, vol. 9, no 3, p. 1149-1161, mars 2024, doi: 10.1021/acssensors.4c00142.
- [2] J. Li et al., « High-Performance Flexible Microneedle Array as a Low-Impedance Surface Biopotential Dry Electrode for Wearable Electrophysiological Recording and Polysomnography », *Nano-Micro Lett.*, vol. 14, no 1, p. 132, juin 2022, doi: 10.1007/s40820-022-00870-0.
- [3] S. A. N. Gowers et al., « Development of a Minimally Invasive Microneedle-Based Sensor for Continuous Monitoring of  $\beta$ -Lactam Antibiotic Concentrations in Vivo », *ACS Sens.*, vol. 4, no 4, p. 1072-1080, avr. 2019, doi: 10.1021/acssensors.9b00288.

# APPLICATIONS OF SCREEN-PRINTED ELECTRODES TO WEARABLE BIOSENSING DEVICES

O30

**Isao Shitanda**

*Department of Pure and Applied Chemistry, Faculty of Science and Technology, Tokyo University of  
Science, 2641 Yamazaki, Noda, Chiba 278-8510, Japan  
shitanda@rs.tus.ac.jp*

Keywords: Lactate, Glucose, Diaper, Sweat analysis, Screen-printing

Recently, wearable biosensors that detect physiological indicators in body fluids such as sweat, saliva, and tears have been developed for early detection and prevention of diseases<sup>1,2)</sup>. These devices can be worn in daily life or during exercise to diagnose exercise efficiency and health status, and are useful for health monitoring. They are also attracting attention in the medical and welfare fields. For example, they can be used in conjunction with drug delivery modules to make health care easier for outpatients.

We have studied biosensors and self-powered biosensors based on porous carbon materials with controlled nano-/mesopores/macropores<sup>3-5)</sup>. In particular, we investigated a biosensing system with improved output and wireless transmission using a carbon material with controlled pore structure (hereafter referred to as “MgOC”), using magnesium oxide (MgO) as a template. This system has been applied to the monitoring of lactate in sweat and continuous monitoring of glucose in urine. In particular, we have focused on the sensing system using screen printing. We would like to present the details of these studies.

## References:

- 1) J. Min et al., Chemical Reviews, 123 (8), pp. 5049-5138 (2023).
- 2) T. R. Ray et al., Chemical Reviews, 119 (8), pp. 5461-5533 (2019).
- 3) I. Shitanda et al., Journal of Physics-Energy, 3 (1), 2021.
- 4) I. Shitanda et al., ACS Sensors, 6 (9), pp. 3409-3415 (2021).
- 5) I. Shitanda al., Acs Sensors, 8 (6), pp. 2368-2374 (2023).



# RATIONAL DESIGN OF REDOX ACTIVE METAL ORGANIC FRAMEWORKS FOR IMPROVED ENZYME ELECTRODE PERFORMANCE

O31

**Muhammad Rezki<sup>1</sup>, Seiya Tsujimura <sup>1\*</sup>**

*<sup>1</sup> Faculty of Pure and Applied Sciences, University of Tsukuba, Ibaraki, Japan*

*(\*Email: [seiya@ims.tsukuba.ac.jp](mailto:seiya@ims.tsukuba.ac.jp))*

**Keywords:** Metal Organic Frameworks, Redox Mediators, Enzyme, Electrode

Metal-Organic Frameworks (MOFs), organic-inorganic hybrid porous crystalline materials, have gained significant attention in recent decades 1–3. MOFs offer various advantages, including extremely large surface areas, permanent porosity, and abundant active sites, making them promising materials for surface modification. We see a great opportunity to utilize MOFs in mediated enzyme electrode platforms, a concept that has not yet been thoroughly investigated. However, challenges such as low conductivity, redox inactivity, and instability in humid conditions limiting their application in electrochemistry 2. To address these issues, we synthesized a stable redox-active MOF capable of mediating electron transfer in enzymes with buried active sites, such as flavin adenine dinucleotide glucose dehydrogenase (FADGH) and lactate oxidase (LOx). High current densities from glucose and lactate oxidation, up to 2.05 mA·cm<sup>2</sup> and 0.5 mA·cm<sup>2</sup> respectively, were successfully achieved. Additionally, we demonstrated excellent continuous operational stability, maintaining approximately 70% of the initial current after five days of continuous operation, surpassing the reported stability of enzyme electrodes based on organic redox mediators. We believe that this stability can be further improved with several optimizations in the future. This work pioneers the utilization of redox-active MOFs in enzyme electrode applications.

## References:

- (1) Wang, Q.; Astruc, D. State of the Art and Prospects in Metal–Organic Framework (MOF)-Based and MOF-Derived Nanocatalysis. *Chem Rev* **2020**, *120* (2), 1438–1511.
- (2) Baumann, A. E.; Burns, D. A.; Liu, B.; Thoi, V. S. Metal-Organic Framework Functionalization and Design Strategies for Advanced Electrochemical Energy Storage Devices. *Commun Chem* **2019**, *2* (1), 86.
- (3) Introduction to Metal–Organic Frameworks. *Chem Rev* **2012**, *112* (2), 673–674.

# TOWARDS THE DEVELOPMENT OF A WEARABLE BIOCOMPATIBLE SENSOR FOR DIALYSIS MONITORING

O32

**Adélèye Chogolou<sup>1\*</sup>, Véronique Mourier<sup>1</sup>, Isabelle Texier<sup>1</sup> and  
Yohann Thomas<sup>1</sup>**

<sup>1</sup> Univ. Grenoble Alpes, CEA, Leti, DTIS, LMCD, F-38000 Grenoble, France  
(corresponding author: [adeleye.chogolou@cea.fr](mailto:adeleye.chogolou@cea.fr))

Keywords: Ion-Selective-Electrode, Biocompatible sensor, Potassium, Urea

Improving patients' monitoring between dialysis treatment sessions is desirable to adjust the therapy and offer a better quality of life for patients suffering from kidney failure. For instance, urea concentration in blood is low post-dialysis, but it does not reflect its concentration in the interstitial fluid (ISF) bathing the tissues [1,2]. The equilibrium between blood and ISF occupying the space between capillary blood vessels and cells could take approximately one hour [3]. After treatment, a significant rebound in urea concentration in blood is often observed, indicating the release of urea from non-purified tissues towards this compartment.

A wearable, biocompatible, electrochemical sensor able to continuously monitor markers in the ISF could therefore present a high interest to enhance dialysis treatment quality by adjusting time between sessions. In particular, devices composed of microneedles able to uptake mini-invasively interstitial fluid and electrochemical sensors for performing in-situ its analysis are of high interest [4]. An Ion-Selective-Electrode (ISE) measures a potential dependent on the selected ion activity according to the Nernst equation and offers high sensitivity and selectivity for the specific detection of ionic species in biological environments thanks to an Ion-Selective Membrane (ISM). Integrated into wearable sensors, ISEs open the way to numerous applications in monitoring, understanding biological processes and assisting in diagnosis, particularly in the field of nephrology. The use of biocompatible ISE sensing materials is however crucial for the development of wearable devices including these sensors in direct contact with biological fluids such as ISF.

We therefore herein explore the development of ISM formulations based on biocompatible materials to prevent undesired immune responses, comply with the regulation and enable mid- to long-term monitoring on the person [5,6]. Different formulations of ISM were screened and characterized for potassium and urea sensing. In the presentation, we will detail their electrochemical performances and the perspectives for their integration in a wearable device.

## References:

- [1] <https://www.francerein.org/vivre-avec-la-maladie/maladies-et-traitements>
- [2] H. Fessi. *Néphrologie & Thérapeutique*, vol. 18, pp. 5S18-5S22, 2022.
- [3] G.S. Metry and al. *Kidney International*, vol. 44, pp. 622–629, 1993.
- [4] H. Lu, and al. *Biotechnol*, vol. 10, pp. 851134, 2022.
- [5] D. Grieshaber and al. *Sensors*, vol. 8, pp. 1400–1458, 2008.
- [6] M.M. Shanbhag, and al. *Chemical Engineering Journal Advances*, pp. 100516, 2023.

# INTEGRATION AND OPTIMISATION OF ELECTRICAL IMPEDANCE SENSORS IN ORGAN-ON-CHIP FOR MONITORING OF ORGANOID VIABILITY

O33

**Anastasiia Berezovska<sup>1</sup>, Joris Kaal<sup>1</sup>, Manuel Alessio<sup>1</sup>, Pascale Pham<sup>2</sup>,  
Marion Gobbo<sup>1</sup>, Emily Tubbs<sup>3</sup>, Yohann Thomas<sup>1</sup>, Marie-Line Cosnier<sup>1</sup>**

*1 Univ. Grenoble Alpes, CEA, LETI, DTIS, F-38000 Grenoble, France; 2 Univ. Grenoble Alpes, CEA, LETI, DOPT, F 38000 Grenoble, France; 3 Univ. Grenoble Alpes, CEA, INSERM, IRIG, Biomics, F-38000, Grenoble, France (corresponding author: [anastasiia.berezovska@cea.fr](mailto:anastasiia.berezovska@cea.fr))*

Keywords: integrated electrochemical sensor, impedance measurements, organ on chips, organoid viability

Organs on a chip (OoCs) are new tools capable of mimicking, even partially, the physiology of the human organ in a way that is more faithful to physiological reality than traditional models (in vitro 2D and animal). Hence, it becomes imperative to perform *in-situ* monitoring of cell viability and evaluate the impact of drugs or applied stresses on them. One promising approach for this purpose is to integrate the impedance sensors into OoC. While real-time monitoring using impedance measurement has been successfully validated for 2D cell cultures in the research world, its adaptation for 3D biological structures is currently in progress. Previously in our team the gold micro-electrodes in OoC microfluidic system, keeping optical access for imaging, were successfully integrated to make measurements on 3D biological structures. This COC (cyclic olefin copolymer) - based device enabled them to study the viability of organoids and detect their two states: dead and alive [1,2]. Our current objective is to enhance this system and carry out the monitoring as close as possible to organoid over time with the new idea of making a cavity between the electrodes, which allows us to have a fixed position of the spheroids and therefore ensure reproducibility of the measurements. Furthermore, this approach can contribute to carry out viability analyses of organoids over time (not just “dead/alive”).

Furthermore, to enhance the study of organoids, a new device design is currently under development based on the extensive experience of CEA in working with silicon-based materials, and the exceptional maturity of nanofabrication technologies for these materials (especially in extreme miniaturization). This approach is currently undergoing the patenting process, underscoring its novelty and potential for proprietary application.

In conclusion, this work focused on optimizing a chip with an integrated impedance sensor, with the purpose of analyzing the functionality and viability of 3D biological objects over time.

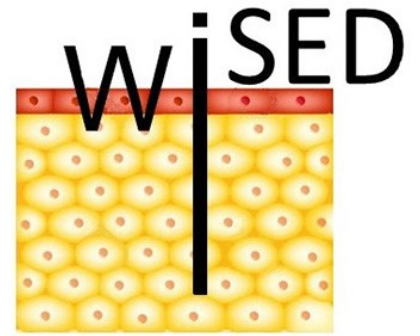
## References:

- [1] A. Bussoo et al., *Biosensors and Bioelectronics*, 11, 100198, 2022
- [2] M.-L. Cosnier et al., US20230085355, 2023

Wearable and Implantable Sensors  
and Electrochemical Devices

27-29 November 2024

Lyon, France



# Posters

---

# PRINTABLE MEDIATED GLUCOSE BIOSENSOR DEVELOPMENT FOR WEARABLE DEVICES COUPLED WITH SKIN ELECTRODERMAL ACTIVITY

P01

**Aoife Newman, Benne Dirk Johannes Reinoud Fennema, Eithne Dempsey\***

*Kathleen Lonsdale Institute of Human Health, Chemistry Department, Maynooth University,  
Maynooth, Co. Kildare. ([aoife.newman.2018@mumail.ie](mailto:aoife.newman.2018@mumail.ie))*

A multiparametric, non-invasive and reagentless sensing strategy for diabetic monitoring is proposed based on a bespoke graphite ink “writable” formulation (including biocompatible binders and modifiers) as conductive layer for glucose oxidase immobilisation within an epidermal patch. This enables encapsulation of the heterocyclic quinoid species 1,10-phenanthroline-5,6-dione<sup>1</sup> via enzymatic polymerisation, acting as a proton and electron acceptor for FADH<sub>2</sub> cofactor regeneration. Surface characterisation of the modified ink was achieved via FTIR, thermal analysis and scanning electron microscopy. Voltammetric and pulse techniques establish analytical performance criteria for the mediated biosensor over physiological glucose levels in sweat (10-200  $\mu\text{M}$  <sup>2</sup>) at neutral pH. The optimum method was transferred to a low-cost carbon cloth transducer, as a proof of principle, with glucose signal monitored via the electrocatalytic cathodic DPV process.



Figure 1: Carbon cloth

The prototype electronic control system (Fig. 2) involves a customisable Arduino based potentiostat<sup>3</sup> using off the shelf electronic components capable of performing the electrochemical measurements, with galvanic skin sensor response (GSR)<sup>4</sup>. The addition of electrodermal activity via a GSR sensor detection module makes for a multiparametric system which responds to electrical activity in the skin due to the variation in moisture level due to sweating. GSR reflects sweat gland activity and changes in the activity of the sweat glands in response to sympathetic nervous stimulation<sup>4</sup>. The system proposed has the goal of small sample volumes (<50  $\mu\text{L}$ ) with rapid time to result <1 min. Integration of allied electronics has the potential for transduction and wireless transmission to be carried out contributing to smart and remote healthcare.

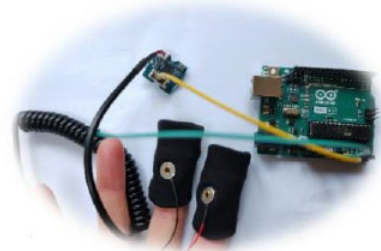


Figure 2: Wearable galvanic skin sensor

## References :

1. G. Halpin, K. Herdman and E. Dempsey, *Sensors and Actuators Reports*, 2021, **3**, 100032.
2. A. Wiorek, M. Parrilla, M. Cuartero and G. A. Crespo, *Anal Chem*, 2020, **92**, 10153-10161.
3. G. N. Meloni, *Journal of Chemical Education*, 2016, **93**, 1320-1322.
4. S. S. Shetgaonkar, A. V. Salkar and P. P. Morajkar, *Chem Asian J*, 2021, **16**, 2871-2895.

# OPTIMIZATION OF PRUSSIAN BLUE LAYERS ON GOLD AND CARBON ELECTRODES FOR LACTATE BIOSENSORE DEVELOPMENT

P02

**Yuki Oguri<sup>1</sup>, Chloe Aymard<sup>1</sup>, S. Tsujimura<sup>2,3</sup>, Abdelkader Zebda<sup>1,3</sup>**

<sup>1</sup> Université Grenoble Alpes, TIMC-IMAG/CNRS/INSERM, UMR 5525, F-38000, Grenoble, France

<sup>2</sup>Department of Materials Science, Institute of Pure and Applied Sciences, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki 305-5358, Japan

<sup>3</sup>Japanese-French Laboratory for Semiconductor Physics and Technology (J-FAST)-CNRS- Université Grenoble Alpes, Grenoble, France  
corresponding author: ogrdenki.yuki@gmail.com

Keywords: electrochemical biosensors, lactate, Prussian blue layer, sweat, wearable

Enzymatic electrochemical biosensors are popular due to their sensitivity, rapid response, cost-effectiveness, and ease of use. Lactate biosensors monitor health by detecting exercise-induced lactate, aiding athletes in optimizing training and recovery by measuring lactate levels in blood or sweat. Lactate oxidase (LOx) produces hydrogen peroxide ( $H_2O_2$ ) while catalyzing oxidation of lactate in presence of oxygen. In first generation biosensors,  $H_2O_2$  can be detected by oxidation but high potential is required, leading to interferences due to oxidation of others electrosensitive molecules (ascorbic acid or uric acid for example). To decrease working potential, some electrochemical mediators, such as Prussian blue (PB) are used. In this case,  $H_2O_2$  is reduced by PB at very low potential avoiding interferences. In this report, PB electrodes were successfully fabricated by electrodeposition of ferricyanide onto gold and carbon electrodes. Electrodeposition conditions were optimized and performances for  $H_2O_2$  detection were characterized by chronoamperometry (CA) at 0V vs. Ag/AgCl. As this results, 1mM ferricyanide at pH 4.0 exhibited highest sensitivity was stable during minimum 4 weeks. Then, lactate biosensor was fabricated by entrapping LOx into chitosan membrane and immobilized at the surface of these PB-modified electrodes.  $H_2O_2$  produced by LOx in the presence of lactate was detected by electrochemical reduction at -0.1V vs. Ag/AgCl. Finally, stability of lactate biosensor was studied by storing them in dry conditions and same activity was measured after 1 month of storage.

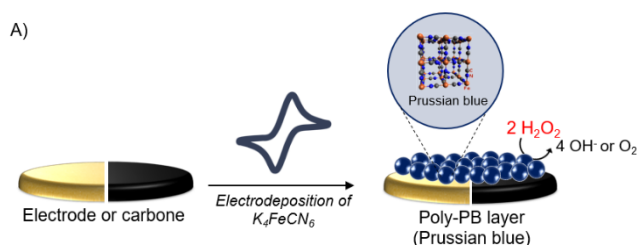


Figure 1.A) Electro deposition of Prussian blue onto gold and carbon electrode

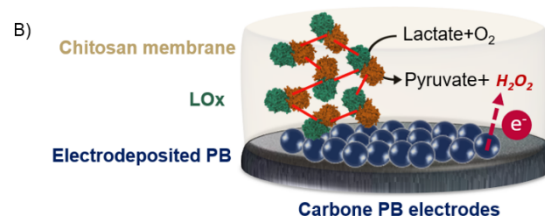


Figure 2.B) Lactate biosensor reaction mechanism

# NANOMATERIAL-BASED ELECTROCHEMICAL SENSORS FOR ASCORBIC ACID DETECTION IN BIOMEDICAL AND FOOD APPLICATIONS

P03

**Sophie Tingry<sup>1</sup>, Ines Santiago<sup>1</sup>, Zakia Adaidi<sup>1</sup>, Abdelkadder Zebda<sup>2</sup>,  
Yaovi Holade<sup>1</sup>**

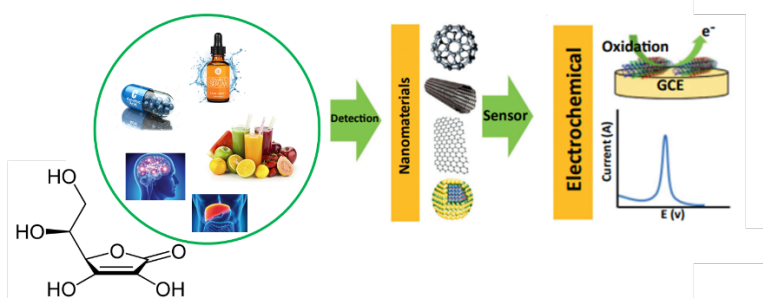
<sup>1</sup> Institut Européen des Membranes, IEM UMR 5635, Université Montpellier, ENSCM, CNRS, Montpellier, France; <sup>2</sup> Univ. Grenoble Alpes, CNRS, UMR 5525, VetAgro Sup, Grenoble INP, INSERM, TIMC, 38000 Grenoble, France;

Corresponding author: [sophie.tingry@umontpellier.fr](mailto:sophie.tingry@umontpellier.fr)

Keywords: ascorbic acid, nanomaterials, electrochemical sensors, sweat, fruit juice

L-ascorbic acid (AA) or vitamin C is a widespread water-soluble organic compound and powerful antioxidant, present in the human body, in fruits, vegetables and as a nutritional supplement in cosmetic formulations, foods and beverages. AA is the main active form of vitamin C, which oxidizes to dehydroascorbic acid (DHA). However, in some cases, variations in its concentration can lead to certain diseases, and inhibit natural processes in foods, contributing to deterioration in taste and aroma. Given the importance of AA for human health and industrial applications (quality control), the precise determination of AA in clinical samples (sweat) and food samples (fruit juices) is one of the most interesting areas of research. This presentation describes recent advances in the field of non-enzymatic electrochemical sensors using various nanomaterials (noble metals, transition metals) for AA detection. This presentation shows both the potential benefits of nanomaterials in biosensing technologies that improve stability and provide a larger electroactive surface for sensing, and the challenges associated with mass-producing low-cost nanomaterial-based catalysts with reliable operation on real samples.

Potential application of electrochemical sensors to detect ascorbic acid



## References:

- [1] Review on nanomaterials-enabled electrochemical sensors for ascorbic acid detection, K. Dhara, R. Mahapatra Debiprosad, Analytical Biochemistry 586 (2019) 113415.
- [2] A Review on Electrochemical Microsensors for Ascorbic Acid Detection: Clinical, Pharmaceutical, and Food Safety Applications, T. Dodevska, D. Hadzhiev, I. Shterev, Micromachines 2023, 14, 41.



# IMPROVING THE PERFORMANCE OF AN OPTICAL SENSOR FOR ADVANCED APPLICATIONS

P04

**Abdelkader Aissat**<sup>1,2</sup>, **Nabil Hafi**<sup>2</sup>, **Mathieu Halbwax**<sup>3</sup>, **Samuel Dupont**<sup>3</sup>,  
**Jean Pierre Vilcot**<sup>3</sup>

*1 University of Ahmed Draya, Adrar, Algeria.*

*2LATSI, Laboratory, University Blida1, Algeria*

*3 Institute of Electronics, Microelectronics and Nanotechnology (IEMN), UMR CNRS 8520.  
University of Sciences and Technologies of Lille 1Avenue Poincare, 60069, 59652 Villeneuve of Ascq,  
France*

*Corresponding author, abdlekader aissat : [sakre23@yahoo.fr](mailto:sakre23@yahoo.fr)*

**Keywords :** optical sensors, responsivity, quantum efficiency, optoelectronic.

Optical sensors based on III-V materials are fast and high-performance components. Optical sensors combine the advantages of group III nitride semiconductors (Al, In)GaN and silicon (Si) to realize high-performance and versatile optoelectronic devices. These sensors typically exhibit a responsivity ranging from 0.10 to 0.50 A/W and high quantum efficiency, making them very effective at converting incident photons into electrical signal. Additionally, they have a cutoff frequency reaching several GHz, ideal for applications requiring fast responses and the dark current remains low, ensuring high sensitivity and low power consumption. These technical characteristics make InGaN/Si optical sensors ideal tools for ambient light detection, optical communication, and medical imaging, offering high performance and great flexibility of use.

## References:

- [1]. A. Aissat, R. Bestam, B. Alshehri, J.P. Vilcot. Modeling of the absorption properties of  $Ga_{1-x}In_xAs_{1-y}N_y$  quantum well structures for photodetection applications, *Superlattices and Microstructures*, 82, 623-629 (2015).
- [2]. R. Suram, N. D. Gupta. Design and Analytical Study of InGaN/GaN Multiple Quantum Wells Based Photodetector for UV Range. 2022 IEEE 19th India Council International Conference (INDICON). IEEE, 1-5 (2022).
- [3]. M. Elbar, B. Alshehri, S. Tobbeche, E. Dogheche. Design and Simulation of InGaN/GaN p-i-n Photodiodes. *physica status solidi (a)*, 215(9), 1700521 (2018).
- [4]. R. Amraoui , A. Aissat , J.P. Vilcot , D. Decoster . Frequency response optimization of P-I-N
- [5]. photodiode based on InGaAsN lattice matched to GaAs for High-Speed photodetection applications. *Optics & Laser Technology*, 145, 107468. (2021).
- [6]. O. Saidani, S. Tobbeche. Numerical study and design of high-efficiency p-In<sub>0.1</sub>Ga<sub>0.9</sub>N/i-GaN/n-GaN heterojunction photodiode. *Micro and Nanostructures*, 175, 207490 (2023).



# TOWARDS AN INTEGRATED MULTIPARAMETRIC ELECTROANALYTICAL PLATFORM FOR ORGAN-ON-CHIP MONITORING

P05

**Marie-Helene Steger-Polt<sup>1</sup>, Nathalie Demoncheaux<sup>1</sup>, Joris Kaal<sup>1</sup>,  
Yohann Thomas<sup>1</sup>, Pascale Pham<sup>2</sup>, Pascal Mailley<sup>1</sup>**

<sup>1</sup> Uni. Grenoble Alpes, CEA, LETI, 38000 Grenoble, DTIS, FRANCE; <sup>2</sup> Uni. Grenoble Alpes, CEA, LETI, 38000 Grenoble, DOPT, FRANCE (corresponding author: marie-helene.polt@cea.fr)

Keywords: Organ-on-chip, electrode optimization, EIS, biocompatible electrodes, COMSOL

Drug testing and drug development are of great general interest to our society. However, they are currently both costly and inefficient, due to a lack of appropriate models [1]. OOC is an aspiring technology that can potentially revolutionize these processes [2]. OOCs are microfluidic devices designed to facilitate the cultivation of biological cells in a 3D manner. This allows for screening close to in vivo conditions, while avoiding the use of animal models. To routinely use this technology in clinical settings, a number of challenges still need to be overcome. One of them is the integration of sensors for live and continuous monitoring of biological cells cultivated in OOC devices [3]. Depending on the demand, different approaches of sensor integration (in-situ/ex-situ, on-chip/off-chip= online/offline) can be considered. The sensors itself are either targeted at detecting specific biomarkers or at the monitoring of cell integrity. Cell integrity is commonly evaluated using Transepithelial/transendothelial electrical resistance (TEER) measurements done in Transwell® configuration [4]. However, measurements that are more accurate can be obtained by using electrochemical impedance spectroscopy (EIS). EIS is a powerful method for assessing the cell viability and formation of tight junctions, which also accounts for the capacitive behavior of cells [5]. Despite this potential, EIS measurements are not yet widely used in OOC, because their biological interpretation remains challenging. To address this we propose the conception of a gut-on-chip (GOC) device with integrated sensing units. The GOC device itself houses integrated biocompatible electrodes for EIS measurements that can simultaneously be followed by microscopic interrogation, thanks to the partial transparent nature of the electrodes.

To achieve this we improved the patented technology for flexible screen-printed electrodes proposed by Chmayssem et al. [6] and modified the design of the microfluidic device to accommodate two separated cell chambers. A porous non-woven membrane separates these two chambers. Rather than working with conventionally used PDMS; we opted for this material, as we hope to address the lack of resemblance of currently used models to the basement membrane found in vivo [7]. The non-woven substrate was further impregnated, to provide an ECM like microenvironment. SEM and fluorescence images were obtained to verify the surface modifications, as well as cell proliferation and differentiation.

With regard to the electrode design, we were able to show that increasing the size of the electrodes and thereby changing the electrode/hole ratio leads to a decrease in difference ( $\Delta$ ) of the current distribution of 30% and thus a more homogeneous current distribution over the area of interest. It is essential to understand these physiochemical properties of the set-up to:

A) Adjust the design regarding the area of interest and

B) Consequently, correctly interpret and correlate impedance data with microscopic images

We hope that our work illustrates the value added by including numerical simulations when working in complex sensing environments as the one we proposed. In our case, this is even truer since the aim is to provide further insight into the understanding of impedance data for biological tissues.

#### References:

- [1] Gail A. Van Norman: Limitations of Animal Studies for Predicting Toxicity in Clinical Trials: Is it Time to Rethink Our Current Approach?, *JACC: Basic to Translational Science*, Volume 4, Issue 7, 2019, Pages 845-854, ISSN 2452-302X, <https://doi.org/10.1016/j.jacbts.2019.10.008>.
- [2] Duxin Sun, Wei Gao, Hongxiang Hu, Simon Zhou, Why 90% of clinical drug development fails and how to improve it?, *Acta Pharmaceutica Sinica B*, Volume 12, Issue 7, 2022, Pages 3049-3062, ISSN 2211-3835, <https://doi.org/10.1016/j.apsb.2022.02.002>.
- [3] Jonathan Sabaté del Río, Jooyoung Ro, Heejeong Yoon, Tae-Eun Park, Yoon-Kyoung Cho, Integrated technologies for continuous monitoring of organs-on-chips: Current challenges and potential solutions, *Biosensors and Bioelectronics*, Volume 224, 2023, 115057, ISSN 0956-5663, <https://doi.org/10.1016/j.bios.2022.115057>.
- [4] Gerasimenko Tatiana, Nikulin Sergey, Zakharova Galina, Poloznikov Andrey, Petrov Vladimir, Baranova Ancha, Tonevitsky Alexander, Impedance Spectroscopy as a Tool for Monitoring Performance in 3D Models of Epithelial Tissues, *Frontiers in Bioengineering and Biotechnology*, Volume 7, 2020, ISSN 2296-4185, <https://www.frontiersin.org/articles/10.3389/fbioe.2019.00474>, DOI 10.3389/fbioe.2019.00474
- [5] Srinivasan B, Kolli AR, Esch MB, Abaci HE, Shuler ML, Hickman JJ. TEER measurement techniques for in vitro barrier model systems. *J Lab Autom.* 2015 Apr;20(2):107-26. doi: 10.1177/2211068214561025. Epub 2015 Jan 13. PMID: 25586998; PMCID: PMC4652793.
- [6] Chmayssem, A.; Tanase, C.E.; Verplanck, N.; Gougis, M.; Mourier, V.; Zebda, A.; Ghaemmaghami, A.M.; Mailley, P. New Microfluidic System for Electrochemical Impedance Spectroscopy Assessment of Cell Culture Performance: Design and Development of New Electrode Material. *Biosensors* 2022, 12, 452. <https://doi.org/10.3390/bios12070452>
- [7] Pasman Thijs, Grijpma Dirk, Stamatialis Dimitrios and Poot Andreas, 2018, Flat and microstructured polymeric membranes in organs-on-chips *J. R. Soc. Interface.* 152018035120180351 <http://doi.org/10.1098/rsif.2018.0351>

# RING RESONATOR FOR GLUCOSE DETERMINATION

P06

**Anthony Biard<sup>1</sup>, Nicolas Corrao<sup>1</sup>, Thierry Lacrevez<sup>1</sup>, Olivier Lavastre<sup>1</sup>,  
Edouard Rochefeuille<sup>1</sup>, Tân-Phu Vuong<sup>1</sup>, Pascal Xavier<sup>1</sup>, Gregory Houzet<sup>1</sup>,  
Valentino Liva<sup>2</sup>**

<sup>1</sup> CROMA, UMR CNRS 5130, Université Savoie Mont-Blanc, Rue du Lac de la Thuile, Bâtiment 21 - 73370 Le Bourget-du-Lac, France; <sup>2</sup> EuramNET LLC, 954 Leonello Avenue - 94024 Los Altos (CA), USA (Contact : [pascal.xavier1@grenoble-inp.fr](mailto:pascal.xavier1@grenoble-inp.fr))

Keywords : Diabetes, non-invasive glucose sensor, ring resonator, permittivity

Diabetes is a chronic condition that affects approximately 10% of the global population<sup>1</sup>. It is characterized by persistently high blood glucose levels. It can lead to serious complications such as nerve damage, cardiovascular and ocular disease, etc. Current treatment involves highly demanding and invasive monitoring of blood glucose levels through regular drop sampling.

The goal of this poster is to show the feasibility of producing a non-invasive blood glucose sensor based on an existing microwave device. It can differentiate glucose levels in a range of values between 30 and 250 mg/dL. The solvent is a saline solution at 0.9%.

Ring resonators are known to be highly sensitive to variations in permittivity, which directly depends on the sample placed on the ring<sup>2</sup>. The glucose concentration in the solution affects the sample's permittivity<sup>3</sup>.

To carry out the tests, a 3D-printed liquid container was fabricated. Its graduation marks allow precise positioning of the container.

By analysing the S21 parameter, it is possible to distinguish between the different glucose solutions. The results show that there is a consistent correlation between the S21 module and glucose concentration for 0 mg/dl, 30 mg/dl, 125 mg/dl, 175 mg/dl and 250 mg/dl.

Unlike many studies, we used test fluids with characteristics close to those of blood: physiological serum with various amounts of glucose added. The sensibility of the sensor is currently low but could be improved by analysing both the module and the phase of the S11 and the S21 parameters. Although the early results on the non-invasive blood glucose sensor are promising, further development is required to make it fully reliable.

## References:

<sup>1</sup> Dianna Magliano and Edward J. Boyko, *IDF Diabetes Atlas*, 10th edition (Brussels: International Diabetes Federation, 2021).

<sup>2</sup> U. Schwerthoeffer, R. Weigel, and D. Kissinger, 'A Highly Sensitive Glucose Biosensor Based on a Microstrip Ring Resonator', in *2013 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO)* (2013 IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO), Singapore, Singapore: IEEE, 2013), 1–3, <https://doi.org/10.1109/IMWS-BIO.2013.6756148>.

<sup>3</sup> Mahdi Srour, 'Etude et réalisation de capteurs hyperfréquences : application à la détermination de la concentration en glucose', n.d.

# ELECTROCHEMICAL DETECTION OF BRAIN DOPAMINE RELEASE EVOKED BY ELECTRICAL OR FOCUSED ULTRASOUND STIMULATION

P07

**Sarvenaz Khodayari**<sup>1,2</sup>, Ivan Suarez-Castellanos<sup>2</sup>, Tom Aubier<sup>2</sup>,  
Magali Perier<sup>2</sup>, Parastoo Hashemi<sup>4</sup>, Alexandre Carpentier<sup>3,5</sup>,  
W. Apoutou N'Djin<sup>2</sup>, Stephane Marinesco<sup>1</sup>

<sup>1</sup> CRNL, INSERM- U1028, Lyon- France

<sup>2</sup> LabTAU, INSERM- U1032, Lyon- France

<sup>3</sup> AP-HP, Neurosurgery Department, Pitié-Salpêtrière Hospital, Paris, France

<sup>4</sup> Department of Bioengineering, Imperial College, London, UK

<sup>5</sup> Sorbonne University, GRC23, Interface Neuro Machine Team, Paris, France

(corresponding author: [sarvenaz.khodayari@inserm.fr](mailto:sarvenaz.khodayari@inserm.fr))

**Keywords:** Focused Ultrasound Stimulation- Fast Scan Cyclic Voltammetry- Carbon Fiber microelectrode- Dopamine

Neurostimulation is a technique that modulates nervous system activity to treat neurological disorders. Non-invasive neurostimulation with low energy Focused Ultrasound (FUS) has sparked significant interest due to its high spatial selectivity for stimulating neurotransmitter release. However, FUS lacks *in-vivo* fundamental scientific understanding, which must be developed.

This project explores low energy FUS neurostimulation to evoke dopamine (DA) release using fast-scan cyclic voltammetry (FSCV) at Carbon Fiber Microelectrodes (CFME) to detect it

The project includes *in-vitro* and *in-vivo* trials. CFMEs were fabricated at CRNL using 7 µm diameter carbon fibers (Goodfellow France), 150 µm long and their sensitivity was tested in a flow cell setup, before being use for *in-vitro* and *in-vivo* neuromonitoring. *In-vitro* tests have then been started at LabTAU on dopaminergic differentiated neural progenitor cell cultures (RenCell VM), with applications of mechanical and single-pulse FUS stimulations, while recording of cell responses were done via calcium monitoring (fluorescence microscopy) and DA monitoring (FSCV). Mechanical stimulations were performed by applying a mechanical disruption on one cell with the CFME tip. In parallel, *in-vivo* tests have been initiated at CRNL on mice, with applications of electrical and FUS stimulations, while implantation of a CFME sensor was done for recording DA release in the brain. Before testing FUS *in-vivo*, a stimulating electrode was also implanted in the medial forebrain bundle to stimulate dopaminergic fibers. for electrical stimulation in order to identify the optimal stimulation position in the striatum. When successful, the FUS transducer would be placed to target the same brain region and to explore the best FUS parameters for DA release.

First, DA concentrations in the order of hundreds nM (comparable to biological levels), were detected in the flow-cell with the home-made CFME biosensor. *In-vitro* mechanical stimulations and subsequent DA detection allowed validating the successful dopaminergic differentiation of the neural progenitor cell line. Successful *in-vitro* FUS stimulation using single pulses of 400µs, and acoustic frequency of 8.23 MHz was confirmed with calcium and DA

detections. *In-vivo*, electrical stimulations (320 $\mu$ A, pulse duration of 5ms, 40 repetitions, 60Hz) evoked detectable DA release

Our *in-vitro* results confirm the FUS capabilities to activate calcium activity in dopaminergic cells which highly regulates dopamine release dynamics. *In-vitro* setup refinements are underway to enhance the integration of the FSCV, fluorescence imaging and FUS systems. *In vivo*, now that detectable DA release can be evoked electrically, the electrical stimulation electrode will be replaced with the FUS transducer to modulate DA release via FUS application. Overall, these preliminary results introduce the potential use of FSCV in vitro and in vivo to understand the efficiency of low energy FUS for modulation of neural activity in dopaminergic circuits.

**Kornelia Bobrowska<sup>1</sup>, Marcin Urbanowicz<sup>1</sup>, Marek Dawgul<sup>1</sup>, Kamila Sadowska<sup>1</sup>**

*<sup>1</sup>Nalecz Institute of Biocybernetics and Biomedical Engineering Polish Academy of Sciences, Ks.  
Trojdena 4, 02–109 Warsaw, Poland  
kbobrowska@ibib.waw.pl*

Keywords: direct printed electrodes, reticulated vitreous carbon (RVC), biofunctionalization

Enzymatic biofuel cells (EBFCs) are electrochemical devices that convert chemical energy into electricity. EBFCs are promising power sources for wearable and implantable medical devices. The main goal of research in this field is to improve the stability and efficiency of biofuel cells by adapting the composition and structure of the bioelectrodes. We intend to improve EBFC performance by an automated method of producing electrodes using microdosing robot for direct printing of different conducting materials. The advantage of this technique is full control of the electrode preparation, starting from the possibility of modifying the composition of the pastes from which the electrode will be made by controlling the dosing process and ending with the possibility of printing electrodes at different surfaces, such as flexible polyester foil. In addition, applying three-dimensional materials for electrode construction increases the electroactive surface area, which is beneficial for EBFCs performance. For this purpose, working electrodes based on highly porous reticulated vitreous carbon (RVC) were designed and fabricated in our laboratory. As RVC is highly hydrophobic, oxygen plasma pre-treatment was applied to make it hydrophilic, resulting in the electroactive surface area increase of approximately 50%. A number of modifications were then applied using various types of linkers and enzymes. Owing to their organized structure, dendrimers have been exploited for enzyme immobilization to increase the number of attached biomolecules and their stability [1]. Biofunctionalization assessment of gold chips modified with linear or/and dendritic linkers was performed by surface plasmon resonance (SPR) for glucose oxidase, glucose dehydrogenase, laccase and bilirubin oxidase, which are enzymes widely used in EBFCs. The SPR results revealed a significant increase in the enzyme loading density of 11-mercaptoundecanoic acid (MUA) and dendrimers (PAMAM 2G, 4G) for glucose oxidase, laccase and bilirubin oxidase. In contrast, glucose dehydrogenase loading decreased with increasing dendrimer generation.

## Acknowledgements:

The study was supported by the Polish National Science Centre, Project number 2021/43/O/ST5/01925.

1. M. Urbanowicz, K. Sadowska, B. Lemieszek, A. Paziewska-Nowak, A. Sołdatowska, M. Dawgul, D. G. Pijanowska, Effect of dendrimer-based interlayers for enzyme immobilization on a model electrochemical sensing system for glutamate. *Bioelectrochemistry* 2023, 152, 1-9.

# WEARABLE PATCH BASED ON 3D-PRINTED SOLID MICRONEEDLE POTENTIOMETRIC pH SENSOR FOR PLANT MONITORING

P09

**Marc Parrilla,<sup>1,\*</sup> Annemarijn Steijlen,<sup>1</sup> Phil Clerx,<sup>2</sup> Regan Watts,<sup>2</sup> Karolien De Wael<sup>1</sup>**

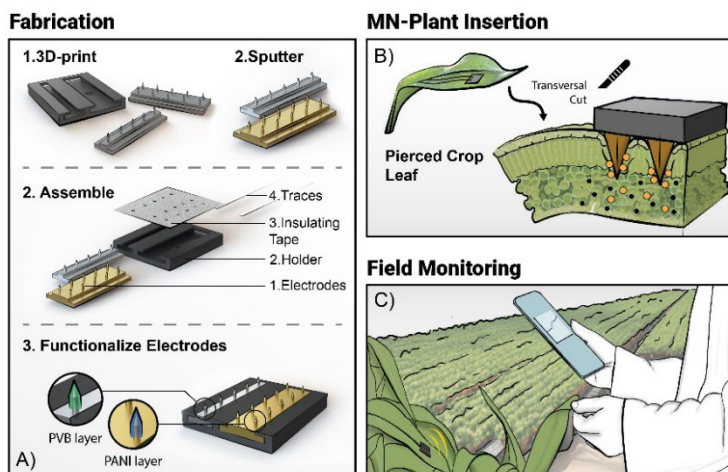
<sup>1</sup> Antwerp engineering, photoelectrochemistry and sensing (A-PECS), University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium. \* [marc.parrilla@uantwerpen.be](mailto:marc.parrilla@uantwerpen.be)

<sup>2</sup> Product Development Research Group, Faculty of Design Sciences, University of Antwerp, Ambtmanstraat 1, 2000 Antwerp, Belgium.

**Keywords:** solid microneedles, 3D printing, wearable electrochemical sensor, microneedle pH sensor, plant health.

The continuous chemical monitoring of plants can provide a better understanding of the plant dynamics which can aid in diagnosing certain plant conditions [1]. pH can be an indicator of plant abiotic stress due to changes in environmental conditions or biotic stress as a result of damage done to the plant by other living organisms [2]. With the increasing climate change, abiotic and biotic stresses are exacerbated. Hence, the engineering of miniaturized

tools to monitor chemical signaling such as pH can be highly valuable as smart sensors for precision agriculture [3]. Herein, 3D-printed microneedle-based electrochemical sensors are presented for in-plant monitoring of pH in plant sap (**Figure 1**). First, affordable microneedles (MNs) of  $868.6 \pm 14.2 \mu\text{m}$  in height,  $287.8 \pm 7.9 \mu\text{m}$  in width, and  $29.9 \pm 2.9 \mu\text{m}$  in tip diameter were manufactured. Subsequently, a metallic layer was sputtered on top of the MN arrays to create MN electrodes. A novel plug-in two-electrode cell design was used to develop the MN pH sensor employing polyaniline as a pH-sensitive layer. The MN pH sensor was analytically characterized exhibiting near-Nernstian response (i.e.,  $-59.9 \pm 1.5 \text{ mV pH}^{-1}$ ) even after several insertions in a leaf proving its mechanical robustness. Ex vivo analysis with plant sap from different species was successfully validated with a standard glass pH electrode. Finally, MN sensing patches were used to monitor pH in two plant species under regular conditions for four days. Interestingly, the MN pH sensor was also able to distinguish shifting pH events in plants under abiotic stress conditions (i.e., drought and watering). This new design brings a leap forward in smart sensors for applications in precision agriculture.



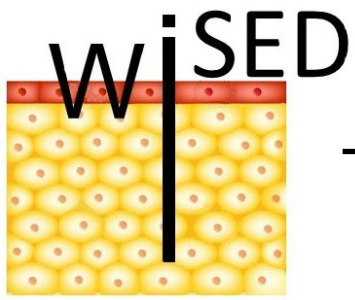
**Figure 1:** From the fabrication of affordable microneedle arrays to the sensing application.

## References:

[1] P. Coatsworth, et al., Continuous monitoring of chemical signals in plants under stress, *Nat. Rev. Chem.* 7 (2022) 7–25.

- [2] D. Lo Presti, et al., Current understanding, challenges and perspective on portable systems applied to plant monitoring and precision agriculture, *Biosens. Bioelectron.* 222 (2023) 115005.
- [3] M. Parrilla, et al., A 3D-printed hollow microneedle-based electrochemical sensing device for in situ plant health monitoring, *Biosens. Bioelectron.* 251 (2024) 116131.





# Venue

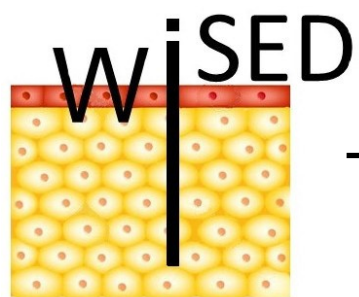
## Centre de Recherche en Neurosciences de LYON - CRNL Centre Hospitalier le Vinatier

95 Bd Pinel, 69500 Bron

Jean Guyotat Amphitheater  
416 Building, 2<sup>nd</sup> floor







# Contact

---

Université Claude Bernard  Lyon 1

Congrès  Lyon 1

Université Claude Bernard Lyon 1

Cellule Congrès - WISED 2024

Bâtiment Géode

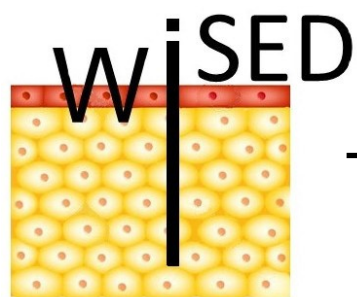
43 bd du 11 novembre 1918

69622 Villeurbanne Cedex, France

wised2024@univ-lyon1.fr

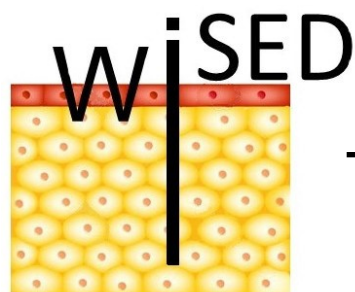
<https://wised2024.univ-lyon1.fr>





# Sponsors

---



# Partners

---

