“Technologies for an Implantable Nano-Bio-Sensing Laboratory”

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This tutorial addresses the development of Integrated electrochemical CMOS-Bio-Sensors [1] for diagnosis and/or treatment of patients with specific physiological conditions (e.g., heart, cardiovascular, cancer diseases) or convalescents is a key factor to provide better, more rationale, effective and ultimately low-cost health care also at home. The ultimate goal of improved health care on those subjects is the extension of the patients’ autonomy, the possibility for auto-monitoring, the improvement of their comfort levels and their integration into everyday life. On-line monitoring is also required in professionals and recreational sportsmen training, as well as in elderly and/or disabled citizen care and/or people involved in public utilities (e.g. the public-transportation drivers). For those, it is a key aspect the maintenance of their safety by through embedded systems to alert emergency services in the event of a potentially dangerous situation. Some systems for on-line monitoring are available in the market. They use wearable devices (accelerometers, heartbeat monitoring system, etc). However, all these systems do not measure the human metabolism at molecular level (metabolites). The only available real-time, implantable/wearable systems for metabolic control are limited to glucose monitoring and used only for diabetic patients. However, electrochemical sensors may address so many other molecules, which have crucial relevance in human metabolism of chronic patients. So far, there are no available integrated nano-bio-systems for multi-metabolites, real-time, remote monitoring of the human metabolism. Thus, the aim of this tutorial is to present to students and young scientists innovative concepts for multi-panel, highly integrated, fully implantable, remotely powered and real-time monitoring systems for human metabolism at molecular level. The core of the presented system is an extremely integrated implantable chip that can be seen as a tiny molecular laboratory located under the patient’s skin for providing molecular telemetry. The considered metabolic molecules are glucose, lactate, glutamate, ATP [2], and anticancer drugs as well as anti-inflammatory ones [3]. In case of drugs, the specificity of electrochemical sensors is improved at system level [4]. The proposed nanotechnology is based on carbon nanotubes to improve the sensors performance [3, 5]. To pursue the molecular detection, innovative VLSI solutions [6] are discussed including new ideas on the remote powering [7]. The new approach is obtained by integrating nano/bio/micro/CMOS/SW/RF systems in three devices: (i) a fully implantable sensors array for data acquisition (the tiny laboratory!); (ii) an on-skin intelligent-patch for remote powering and Bluetooth® connections; (iii) a mobile phone for data collection, elaboration, storage, and retransmission.

[1] Sandro Carrara (Au), Bio/CMOS interfaces and co-design, Springer, New York, 2012
[2] Sandro Carrara, Léandre Bolomey, Cristina Boero, Andrea Cavallini, Eric Meurville, Giovanni De Micheli, Fabio Grassi, Tanja Rezzonico, Remote System for Monitoring Animal Models with Single-Metabolite Bio-Nano-Sensors, IEEE Sensors, 13(2013) 1018-1024
[3] Sandro Carrara, Andrea Cavallini, Victor Erokhin, Giovanni De Micheli, Multi-panel drugs detection in human serum for personalized therapy, Biosensors and Bioelectronics, 26 (2011) 3914–3919

[4] Camilla Baj-Rossi, Giovanni De Micheli, Sandro Carrara, Electrochemical Detection of Anti-Breast-Cancer Agents in Human Serum by Cytochrome P450-Coated Carbon Nanotubes, Sensors 12 (2012) 6520-6537
[5] Cristina Boero, Sandro Carrara, Giovanna Del Vecchio, Laura Calzà, Giovanni De Micheli, Highly-Sensitive Carbon Nanotubes-Based Sensing for Glucose and Lactate Monitoring in Cell Culture, IEEE Transaction on Nanobiology, 10(2011) 59-67
[6] S. Sara Ghoreishizadeh, Irene Taurino, Sandro Carrara, and Giovanni De Micheli, A Current-Mode Potentiostat for Multi-Target Detection Tested with Different Lactate Biosensors, IEEE International Conference BioCAS 2012, 28-30 November 2012, Hsinchu, Taiwan, pp. 128 – 131
[7] Jacopo Olivo, Sandro Carrara, and Giovanni De Micheli, A study of Multi-Layer Spiral Inductors for Remote Powering of Implantable Sensors, IEEE Transaction of Biomedical Circuits and Systems, 2013, in press

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