31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Parylene-Based Encapsulated Fluid MEMS Sensors

Ellis Meng, *Member, IEEE* and Christian Gutierrez

Abstract—**A new class of transducers based on a Parylene C encapsulated fluid element are introduced. These versatile units have thus far been explored as impedance-based contact sensors and electrolysis-based actuators for fine positioning of neural recording electrodes. These sensors may be fabricated on thin, flexible substrates which permits application on non-planar or three dimensional surfaces. Another interesting modality is the coupling of individual mechanically-responsive, impedance-based sensing elements distributed over a surface but interconnected through microfluidic channel networks in a manner that emulates mechanotransduction in natural biological systems. These fluidic elements offer interesting new possibilities in neural prosthetics.**

I. INTRODUCTION

BIOELECTRIC neural prostheses currently operate in a single modality (electrical) and omit other information-rich interaction modalities (e.g. mechanical and chemical). This is in part due to the lack of suitable integration technologies that allow production of sensor elements in reasonable density and co-location with recording or stimulating electrode arrays. In some applications, this is further complicated by the requirement of flexible substrates. Here, technologies enabling the integration of mechanical modalities with existing microelectrode array technology for application in neural interfaces are discussed.

The success of microelectronic retinal prostheses is in large part dependent on the electromechanical interaction occurring at the device-tissue interface [1]. These factors may include but are not limited to electrode-to-tissue distance, local temperature, shear and normal forces, and micromotion. Static implanted microelectrode arrays are unable to adjust electrode-to-tissue spacing nor detect and respond to forces resulting from contact between the tissue and device. A biomimetic approach is taken towards addressing these deficits by building mechanically-responsive and mechanically-active fluid-filled cell-like units on polymer substrates [2].

Each unit is constructed by trapping fluid in a Parylene C microchamber. Contained within the microchamber is a pair of interdigitated electrodes. This electrode pair may function as an impedance-based sensor or an electrochemical actuator. A third electrode may be patterned on top of the chamber for stimulation of or recording from cells.

II. PARYLENE FOR FLUID ENCAPSULATION

Fluidic encapsulation in microfabricated Parylene C chambers is accomplished by taking advantage of stiction. The chamber is attached to at least one stiction valve through a short microchannel. Stiction valves consist of a partially exposed chamber; an annular stiction valve, for example, is constructed from a circular compartment with a central opening. The opening results in a large free-standing structure anchored at the compartment periphery. Once the chamber, microchannel, and compartment are filled with liquid by submersion, the device is removed from the water bath and exposed to air. Evaporative drying through the valve opening induces collapse of the free-standing walls of the compartment due to stiction. This phenomena is normally undesirable in microelectromechanical devices (MEMS) but is crucial in this application as it seals off any remaining fluid inside the attached chamber.

Stiction valve design parameters depend on a number of factors detailed in [3], [4]. Both sensor configurations rely on the creation of stiction-valve gated fluid-filled chambers. In all cases, structures were fabricated by Parylene surface micromachining technology and deionized water was used for filling microchambers.

III. TRANSDUCER CONFIGURATIONS

The basic sensor unit consists of a Parylene C microchamber encapsulating a pair of electrodes and fluid (Fig. 1). As is, this unit may function as an impedance-based sensor. An alternative configuration includes an external electrode patterned on top of the microchamber. Here, the microchamber may be actuated via electrolysis to allow fine out-of-plane positioning of an electrode located on top of the compliant portion of the microchamber.

A. *Impedance-Based Tactile Sensing*

Many transduction methods have been explored for contact sensors including piezoresistive, capacitive, conductive polymers, optical, and ultrasound [5]. However, these sensors typically occupy large footprints precluding their use in electromechanical tissue interfaces. Impedance-based sensors are in their infancy in development but offer a potential solution. Large format sensors already demonstrated detection of multiple parameters including

---

Manuscript received April 6, 2009. This work was supported in part by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC-0310723 (Biomimetic MicroElectronic Systems) and the Bill and Melinda Gates Foundation (CG).

E. Meng is with the Departments of Biomedical and Electrical Engineering, Viterbi School of Engineering, University of Southern California, Los Angeles, CA 90089-1111 USA (phone: 213-740-6952; fax: 213-821-3897; e-mail: ellis.meng@ usc.edu).

C. Gutierrez, is with the Department of Biomedical Engineering, Viterbi School of Engineering, University of Southern California, Los Angeles, CA 90089-1111 USA. (e-mail: cagutier@usc.edu).

978-1-4244-3296-7/09/$25.00 ©2009 IEEE

point contact, force, direction, object shape, and texture [6], [7]. Miniaturization of these sensors may enable µN-mN force sensors for detection of mechanical interactions between implanted prosthetics and tissue.

These sensors consist of an electrode pair (Pt) surrounded by fluid contained within a soft contact surface (Parylene C). External forces deform the compliant fluid-filled structure and redistributed the contained fluid. This redistribution also alters the volume conductive path which registers as a change in solution impedance. Single sensors achieved impedance sensitivity of 1.7%/µm and detection of forces up to 6 mN (square or circular chambers with sides or diameters of 300-500 µm).

Multiple distributed sensors interconnected by microfluidic channels were also fabricated. Electrofluidic coupling of forces applied on distant elements were sensed and offer a new bio-inspired sensing modality.

B. *Electrolysis-Actuated Electrodes*

For the aforementioned reasons, it is desirable to explore dynamically positionable electrodes over conventional static implementations in neuroengineering applications. Many actuation methods are amenable to miniaturization to achieve fine positioning including electrostatic, pneumatic, electrolysis, and shape memory alloys. In terms of performance, power consumption, and heat generation, electrolysis is the preferred method for neural prosthetics [8]. For example, a wide range of force (up to 200 MPa pressure) and deflections are possible while maintaining low power consumption, low heat generation, and small footprint [9].

In addition to the electrode pair encapsulated in fluid, an additional external electrode fabricated on top of the actuation chamber is required here. Wiring to the external electrode must be carefully routed avoid fracture due to tethering during electrolysis-induced deflection. Electrolytic generation of hydrogen and oxygen proceeds upon application of current through the electrode pair. The pressure-volume change subsequently induces deflection of the compliant Parylene diaphragm and thus positioning of the attached electrode. For the devices fabricated, a 5 µA current applied for only a few seconds is sufficient to initiate electrolysis. The flat Parylene diaphragms are operated in the elastic range and have limited travel range (up to 8 µm for 500 µm square chambers). Larger deflections (10's of µm) are necessary for practical positioning of electrodes, for example, in epiretinal prostheses and require investigation of alternative diaphragm geometries.

IV. CONCLUSION

This novel Parylene-based sensor/actuator element provides a practical means by which to integrate electromechanical functionality with conventional multi electrode arrays. Further miniaturization is pursued towards the precise determination of proximity and pressure interactions at cellular resolutions between neural implants and tissue. Future work includes integration with Parylene-based flexible neural prosthetics for *in vitro* and *in vivo* experiments in neural tissue [10].

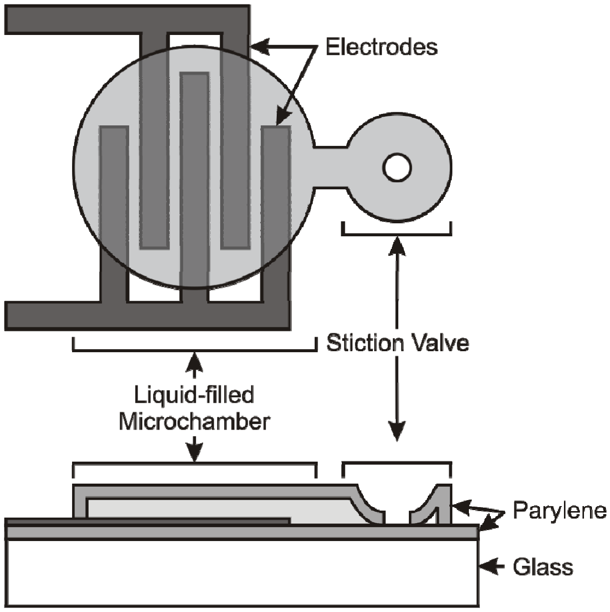

Fig. 1. Schematic showing basic transducer unit. The stiction valve traps fluid inside the Parylene microchamber. This configuration shows a pair of interdigitated electrodes in a circular chamber. Other chamber geometries were also explored. An additional electrode may also be integrated on the top exterior of the microchamber. While the device above is drawn attached to a glass substrate, the Parylene film may be peeled from the supporting rigid substrate if a flexible substrate is desired.

ACKNOWLEDGMENT

The authors would like to thank the following for their contributions to this work: Dr. Donghai Zhu, Dr. Jim Weiland, Dr. Tuan Hoang, Mr. Man Nguyen, and Mr. Lawrence Yu.

REFERENCES

[1] J. D. Weiland, W. Liu, and M. S. Humayun, "Retinal prosthesis," *Annual Review of Biomedical Engineering*, vol. 7, pp. 361-401, 2005.
[2] C. Gutierrez and E. Meng, "A dual function parylene-based biomimetic tactile sensor and actuator for next generation mechanically responsive multielectrode arrays," in *Transducers 2009*, Denver, Colorado, 2009, to be published.
[3] H. Zhang, S. Wang, and Y. Xu, "Study and applications of a parylene self-sealing structure," in *Mems 2006*. Istanbul, Turkey, 2006, pp. 282-285.
[4] Z. Wang and Y. Xu, "Theoretical and experimental study of annular-plate self-sealing structures," *Journal of Microelectromechanical Systems*, vol. 17, pp. 185-192, 2008.
[5] J. Tegin and J. Wikander, "Tactile sensing in intelligent robotic manipulation - a review," *Industrial Robot*, vol. 32, pp. 64-70, 2005.
[6] M. Helsel, J. N. Zemel, and V. Dominko, "An impedance tomographic tactile sensor," *Sensors and Actuators*, vol. 14, pp. 93-98, 1988.
[7] N. Wettels, V. J. Santos, R. S. Johansson, and G. E. Loeb, "Biomimetic tactile sensor array," *Advanced Robotics*, vol. 22, pp. 829-849, 2008.
[8] C. Pang, Y. C. Tai, J. W. Burdick, and R. A. Andersen, "Electrolysis-based parylene balloon actuators for movable neural probes," in *IEEE*

International Conference on Nano/Micro Engineered and Molecular Systems, Bangkok, Thailand, 2007, pp. 913-906.

[9] C. G. Cameron and M. S. Freund, "Electrolytic actuators: Alternative, high-performance, material-based devices," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 99, pp. 7827-7831, 2002.

[10] D. C. Rodger, A. J. Fong, L. Wen, H. Ameri, A. K. Ahuja, C. Gutierrez, I. Lavrov, Z. Hui, P. R. Menon, E. Meng, J. W. Burdick, R. R. Roy, V. R. Edgerton, J. D. Weiland, M. S. Humayun, and Y. C. Tai, "Flexible parylene-based multielectrode array technology for high-density neural stimulation and recording," *Sensors and Actuators B-Chemical*, vol. 132, pp. 449-460, 2008.