MEMS
Room 309 - Session MM+BI-ThM

Bio-MEMS and Microfluidics
Moderator: P.G. Datskos, Oak Ridge National Laboratory

8:20am **MM+BI-ThM1 Microfabrication Technologies for Biomedical Applications**, ***M. Ferrari,*** The Ohio State University **INVITED**
PLEASE SEND US AN ABSTRACT. Thank you.

9:00am **MM+BI-ThM3 Suppression of Blood Serum Adhesion on Quartz Inner Wall of Microcapillary Coated by Bio-compatible MPC Polymer**, *H. Ogawa, A. Oki,* ***Y. Takamura****, S. Adachi,* The University of Tokyo, Japan*; T. Ichiki,* Toyo University, Japan*; K. Ishihara, Y. Horiike,* The University of Tokyo, Japan

We are developing the healthcare device which enables us to detect various health markers from trace amount of the blood. To suppress adhesion of proteins in a blood injected into a quartz made microcapillary, the 2-methacryloyloxyethylphosphorylcholine (MPC) polymer which is now utilized to artificial blood tube, contact lens, in-vivo sensors, etc. has been coated on the inner wall, thus leading to bio-compatibility of the quartz surface. A microcapillary with a 30 x 30 µm cross-section and 10 mm in length was fabricated in a 2cm x 2cm quartz chip by dry-etching and subsequent press-bonding of a cover quartz plate in 1% HF solution. A pH=7.4 phosphate buffered solution (PBS) was filled in the capillary and the serum was injected from one end by electroosmosis pumping. The concentrations of proteins, which were monitored by 220nm UV absorption at the point of 4mm apart from the injection, rose up rapidly when the serum arrived at this point and then were kept at a constant value in the 3 wt% MPC coated capillary, while those in uncoated capillary were decreased gradually by adhesion of proteins on the inner wall after showed maximum. To investigate the interaction of proteins with the MPC polymer coated surface, FTIR-ATR spectra for MPC coated and uncoated wall surfaces exposed by a blood serum were measured. The adsorption peaks by NH@sub x@ and C=O of proteins in the uncoated surface increased with exposure time, while the proteins did not absorb on the coated surface. These results clearly demonstrate the excellent bio-compatiblity of the MPC polymer for a blood handling capillary chip.

9:20am **MM+BI-ThM4 Biologically-Compatible Polymeric MEMS Devices Fabricated using Holographic Two-Photon Induced Photopolymerization**, ***L.L. Brott,*** Technical Management Concepts, Inc.*; S.M. Kirkpatrick,* Science Applications International Corporation*; M.O. Stone,* Wright-Patterson Air Force Base

Research in the bio-MEMS field has been driven by the desire to reduce the time, complexity and equipment needed to carry out clinical diagnostic procedures. Current bio-MEMS strategies rely extensively upon externally added reagents and conventional photolithography in the fabrication of these systems. In an effort to simplify these devices even further, research has begun incorporating the reagents, i.e. enzymes, directly into the walls of the microfluidic channels. Consequently, a new polymeric material based on poly(ethylene glycol) which maintains the biological activity of the reagents and is not sensitive to aqueous environments, yet whose monomeric form accepts aqueous solutions, was developed. The microfluidic channels were patterned by photocuring the monomer using a two-photon initiated photopolymerization process at 800 nm. A rose bengal/triethanol amine initiator system was used. By using a laser as the light source, holograms were patterned onto the device resulting in well defined and complex patterns.

9:40am **MM+BI-ThM5 Patch Clamping with Microfabricated Planar Electrodes**, ***K.G. Klemic,*** *J.F. Klemic, M.A. Reed, F.J. Sigworth,* Yale University

The patch clamp technique is the most sensitive way to record the small ionic currents carried by ion channels and transporters in cell membranes. To make a typical recording, the ~1 micron tip of a glass or fused-quartz micropipette, filled with saline solution, is sealed over a patch of cell membrane, electrically isolating it with a very large electrical "seal resistance" of 10-100 G@ohm@. Here we describe the first use of new materials and a new configuration for patch-clamp electrodes. We have microfabricated planar electrodes that mimic the shape of the tip of the micropipette by aniostropic etching of single crystal quartz or by micromolding the silicone elastomer, poly(dimethylsiloxane) (PDMS). The planar geometry has several advantages over the standard glass micropipette currently used for patch clamp recording. First, it permits direct integration of the first stage of amplification electronics into the electrode. Second one electrode can be easily scaled to an array of electrodes for simultaneous patch-clamp recordings from many cells, greatly expanding the discovery of new ion channel genes and new pharmacological agents directed to ion channel targets. Third, microfluidic channels can be integrated to permit fast solution exchange on both sides of the membrane, something that is not presently possible. Lastly, the electrode is designed to have a small solution volume that reduces the capacitance and thereby reduces by an order of magnitude the contribution of the electrode to the background noise. The design and fabrication of these novel patch electrodes as well as membrane current recordings using these devices will be presented.

10:00am **MM+BI-ThM6 High Sensitivity Resonant Biosensor**, ***B. Ilic,*** *D. Czaplewski, H.G. Craighead,* Cornell University*; P. Neuzil,* Institute of Microelectronics, Singapore*; C. Campagnolo, C. Batt,* Cornell University

There is a growing demand to produce highly selective biological sensors for the detection of small quantities of biological microorganisms using micromachining. In this work, the detection of bacteria using a resonant frequency based mass detection biological sensor has been accomplished. The biological sensor under development consists of an array of resonating cantilever beams fabricated, using bulk silicon micromachining techniques, from both low pressure chemical deposition (LPCVD) and plasma enhanced chemical vapor deposition (PECVD) low stress silicon nitride. For this experiment an array of cantilevers with dimensions of varying length from 15µm to 500µm, varying width of 2µm to 20µm, thickness of 320nm for the LPCVD, and t=600nm for the PECVD nitride, were used. Escherichia coli O157:H7 antibodies were immobilized on the surface of the resonators. Devices were subsequently exposed to varying concentrations of E. Coli cells in solution and any loosely bound cells were removed. In order to determine the mass bound to the cantilever, a frequency spectra was taken before and after the binding of the cells to the cantilever. Signal transduction of the micromechanical oscillators has been accomplished by measuring the out of plane vibrational resonant mode with an optical deflection system. The measured vibrational mode was entirely due to thermal noise and ambient vibrations in air. The measured resonant frequency shift as a function of the binding of additional cells was observed and correlated to the mass of the specifically bound E. Coli O157:H7 cells. Our results indicate good agreement with the predicted theory of linear elasticity. Under ambient conditions where considerable damping occurs, we were able to detect single E. Coli cells. Methods, utilizing vacuum encapsulation and tailoring of the cantilever dimensions, for single molecule detection will be discussed.

10:20am **MM+BI-ThM7 Nanofluidic Entropic Trap Array device for DNA Separation**, ***J Han,*** *H.G. Craighead,* Cornell University

A nanofluidic entropic trap array device@footnote 1@ for separation and analysis of long DNA molecules was constructed and tested. The device contains many constrictions (entropic traps) with dimensions smaller than the radius of gyration for the DNA molecules. The length dependent trapping of DNA and resulting electrophoretic mobility difference enables efficient separation of DNA in the range of 5kb ~ 200kb, typically within 30 minutes, in a channel as short as 15 mm without using a gel.@footnote 2@ We fabricated devices with multiple channels with the same structural parameters, for a parallel analysis of samples. Multiple DNA samples were separately introduced into the device and collected into narrow bands for launching. The amount of DNA in the launching band could be electrically controlled. Simultaneous separation of multiple samples enables one to compare electrophoregrams for calibration or direct comparison for applications such as DNA fingerprinting. A range of device parameters were tried, and the optimization of the device will be discussed. @FootnoteText@ @footnote 1@ J. Han and H. G. Craighead, J. Vac. Sci. Tech. A, 17, 2142 (1999) @footnote 2@ J. Han and H. G. Craighead, Science, in publication (2000)

10:40am **MM+BI-ThM8 Integration of Microcapillary Electroporesis and Inductively Coupled Plasma Spectrometry for Rapid Biological/Chemical Analysis**, ***T. Ichiki,*** *T. Koidezawa, R. Taura, T. Ujiie,* Toyo University, Japan*; Y. Horiike,* The University of Tokyo, Japan

Rapid and sensitive elemental specification of trace amounts of samples are important for chemical, biological, environmental and clinical applications. For the goal of integration of microcapillary electrophoresis (µCE) and inductively coupled plasma (ICP) optical emission spectrometry (OES) on a chip, we have fabricated µmCE chips with a nebulizer, and have investigated conditions for generating microscale ICPs. Microcapillary and

nebulizer patterns were etched onto the quartz plate in C@sub 4@F@sub 8@/SF@sub 6@ plasmas using Cr masks. The etched quartz plate was dipped in 1% diluted HF solution and then bonded together with the other quartz plate with drilled holes. These two plates were press-bonded under the load of 1.3 MPa at room temperature for 24 hours. Samples separated via electroosmotic and electrophoresis phenomena were nebulized by controlling the carrier gas flow around the nozzle located at the capillary end to achieve the injection of pico-liter droplets in the gas. Subsequently, generation of microscale VHF-ICPs was investigated. Discharge chambers of 500µm-5 mm depth and/or width were fabricated on 20 mm@super 2@ quartz plates, which was attached under the 70-mm-@phi@ circular quartz plate set on a small vacuum chamber. A 5-mm-@phi@ antenna was set on the circular quartz plate so as to locate just above the discharge chamber. The power for Ar plasma ignition and mode jump from E- to H-discharge was examined by means of spectroscopy. In the case of discharge chamber dimension of 5 mm width and more than 2 mm depth, the power for ignition was only 5 W at pressures of 0.01-1 Torr, while no mode changes were observed even at 100 W. When reducing the discharge chamber depth to 1-1.5 mm, mode change occurred around 10 W and emission intensity drastically increased by 100 times. Thus high density VHF-ICP was found to be easily attained when the characteristic length of the discharge space is around 1 mm and the pressure is 1-10 Torr.

11:00am **MM+BI-ThM9 Silicone Elastomer Microwell Arrays for High Throughput Protein Biochemical Assays**, ***J.F. Klemic***, *H. Zhu, M.A. Reed, M. Snyder,* Yale University

The identification of the function of large numbers of gene products is an important challenge in post-genomic research. Inexpensive, disposable microwell arrays have been developed for high throughput screening of protein biochemical activity. The microwell arrays are cast in silicone elastomer sheets and placed on top of microscope slides for compatibility with commonly available sample handling and recording equipment. Arrays consist of high density (hundreds per slide), small volume (~300nl) wells which permit high throughput batch processing and simultaneous analysis of many individual samples using only small amounts of protein. Device utility has been demonstrated through the simultaneous analysis of 120 protein kinases from Saccharomyces cerevisiae assayed for phosphorylation of 17 different protein substrates. These microwell arrays, as tested, permit the simultaneous measurement of hundreds of protein samples, however, the use of micromolded silicone elastomer allows array densities to be readily increased by several orders of magnitude. With the further development of appropriate sample handling and measurement techniques, these arrays may be adapted for the simultaneous assay of several thousand to millions of samples.

11:20am **MM+BI-ThM10 Development of a Micro Capillary Pumped Loop System for Microelectronic Device Cooling**, ***H. Yun***, *H. Lee, K. Cho, I. Song,* Samsung Advanced Institute of Technology, South Korea

Increasing demand for processing data leads to faster clock speeds and large integration. As a result, the heat generation of microelectronic devices is increasing at rapid rate. Current PCs generate 20~30 Watts/cm@super 2@ of heat. If this trend continues, 100 Watts/cm@super 2@ of heat generation are expected within few years. Since conventional phonon diffusion based metal heat sinks can handle only up to 10 Watts/cm@super 2@, an alternative cooling technology is desired. In this paper, a micro capillary pumped loop (CPL), which is a microfabricated, capillary pressure driven fluid cycle is proposed as an alternative means of cooling microelectronic devices with large heat generation. The heat is absorbed at the evaporator by vaporizing the circulating fluid, and released out of the system at the condenser. The capillary forces of the microfabricated wick structure at the evaporator drives the fluid. Since the fluid particle directly carries the heat out of the system, the micro CPL is expected to be more effective than the conventional diffusion-based heat sinks. A prototype of 30 Watts/cm@super 2@ cooling capacity has been built and tested. Microchannels have been etched on a silicon wafer to form the evaporator and the condenser. The prototype operated successfully under 30 Watts/cm@super 2@ heat flux while keeping the junction temperature below 400K. The maximum heat flux was 50 Watts/cm@super 2@ before the dryout at the evaporator occurred. A nonlinear dynamic model has been developed to simulate the interaction between various components of the micro CPL. The simulation model successfully captured the overall trends of the experimental data. Further research on the underlying physics are desired for better understanding of this device.

11:40am **MM+BI-ThM11 Design, Fabrication, and Testing of Cross Flow Micro Heat Exchanger**, ***C.R. Harris***, *M. Despa, K.W. Kelly,* Louisiana State University

A cross flow micro heat exchanger was designed and fabricated to maximize heat transfer from a liquid to a gas (air) for a given frontal area and pressure drop of each fluid. To accomplish the goal of high heat transfer, micro channels with scales ranging from 200 µm to 500 µm were utilized. By constraining the flow to narrow channels, heat transfer is enhanced since the convective resistance at the solid/fluid interfaces is reduced. To minimize the pressure drop associated with micro channels, air passes through the plane of the heat exchanger via thousands of parallel short channels. Heat is transferred to the air from liquid that passes in cross flow through tens of parallel channels. Predicted design performance for plastic, ceramic, and aluminum micro heat exchangers are compared to one another and to current innovative car radiators. The micro heat exchangers can transfer greater heat per mass or volume than existing heat exchangers within the context of the design constraints specified. Important applications of this technology include automotive, home heating, and aerospace fields. The heat exchanger designed for plastic was fabricated by aligning and bonding two identical polymer (PMMA) parts that had been embossed using the LIGA process. After heat exchanger assembly, liquid was pumped through the heat exchanger with no leaks. Heat transfer and pressure drop tests were performed on the fabricated polymer heat exchanger. The experimental data is compared to the design calculations and to other heat exchangers.

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