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SPECIAL SESSION VI B3L-A Force Sensing Applications **Chairs:** B. Pruitt, *Stanford University, USA* D. Sun, *Xiamen University, CHINA*	SESSION B3L-B Bio Sensing Systems and Applications **Chairs:** M. Atashbar, *Western Michigan University, USA* Z. Wang, *Tsinghua University, CHINA*	SESSION B3L-C Resonators **Chairs:** J. Miao, *Nanyang Technological University, SINGAPORE* M. Ziaei-Moayyed, *Sandia National Laboratory, USA*
MONARCHY	**KING'S GRAND**	**QUEEN'S GRAND**
	13:15	
B3L-A1 ***INVITED*** **OPTIMIZATION WITH PROCESS LIMITS AND APPLICATION REQUIREMENTS FOR FORCE SENSORS** S.-J. Park, J.C. Doll, N. Harjee, and **B.L. Pruitt** *Stanford University, USA*	**B3L-B1** **MULTI-POINT ATP SENSING FOR RAPID PRECISE FISH FRESHNESS CHECK** D. Itoh[1], T. Nishi[2], S. Murata[3], and H. Suzuki[1] [1]*University of Tsukuba, JAPAN,* [2]*Fujidenolo Co., Ltd., JAPAN, and* [3]*National Research Institute of Fisheries Science, JAPAN*	**B3L-C1** **A MICROMECHANICAL RESONATOR TO REACH THE QUANTUM REGIME** M. Bahriz[1], O. Ducloux[1], S. Masson[1], D. Janiaud[1], O. Le Traon[1], A. Kuhn[2], A. Heidmann[2], C. Molinelli[2], T. Briant[2], P.-F. Cohadon[2], C. Michel[3], L. Pinard[3], and R. Flaminio[3] [1]*ONERA, FRANCE,* [2]*University Paris et M. Curie, FRANCE, and* [3]*CNRS, FRANCE*
	13:30	
	B3L-B2 **DIGITAL MICROFLUIDIC CHIP FOR RAPID PORTABLE DETECTION OF MERCURY (II)** X. Liu, A. Gao, T. Li, Q. Yang, L. Wang, C. Fan, P. Zhou, and Y. Wang [1]*Chinese Academy of Science, CHINA*	**B3L-C2** **GEOMETRICAL OPTIMIZATION OF RESONANT CANTILEVERS VIBRATING IN IN-PLANE FLEXURAL MODES** L.A. Beardslee[1], A.M. Addous[1], K.S. Demirci[1], S.M. Heinrich[2], F. Josse[2], and O. Brand[1] *1Georgia Institute of Technology, USA and 2Marquette University, USA*
	13:45	
B3L-A3 **NONLINEAR PIEZORESISTANCE OF SILICON** B. Lemke[1], M.E. Schmidt[1], J. Gutmann[1], P. Gieschke[1], P. Alpuim[2], J. Gaspar[1], and O. Paul[1] [1]*University of Freiburg - IMTEK, GERMANY and* [2]*University of Minho, PORTUGAL*	**B3L-B3** **WIRELESS TRANSMISSION OF SENSOR SIGNALS FOR PHONOCARDIOLOGY APPLICATIONS** A. Sa-Ngasoongsong and S.T.S. Bukkapatnam *Oklahoma State University, USA*	**B3L-C3** **DETECTION AND MASS MEASUREMENT OF INDIVIDUAL AIR-BORNE PARTICLES USING HIGH FREQUENCY MICROMECHANICAL RESONATORS** A. Hajjam, J.C. Wilson, A. Rahafrooz, and S. Pourkamali *University of Denver, USA*
	14:00	
B3L-A4 **FABRICATION OF POLYMER CANTILEVER INTEGRATED FULL-BRIDGE AS A PIEZORESISTIVE SENSOR** J.H. Ahn and D.-W. Lee *Chonnam National University, SOUTH KOREA*	**B3L-B4** **CYLINDRICAL MULTIPHASE INTERFACES IN MICROFLUIDIC CHANNELS FOR LAB-ON-A-CHIP** D. Cheng and H. Jiang *University of Wisconsin, USA*	**B3L-C4** **DYNAMICS OF IMMERSED CLAMPED-CLAMPED MICRORESONATORS** W.J. Venstra, H.J.R. Westra, and H.S.J. van der Zant *Delft University of Technology, THE NETHERLANDS*
	14:15	
B3L-A5 **PIEZORESISTIVE RESONANT CANTILEVER SELF-ASSEMBLED WITH SPECIFIC-GROUP-MODIFIED CNTs FOR DETECTION OF TRACE-LEVEL VOC VAPORS** P. Xu, H. Yu, and X. Li *Chinese Academy of Science, CHINA*	**B3L-B5** **NOVEL PDMS LEAKY WAVEGUIDE WITH SELF-ASSEMBLED GOLD NANO-PARTICLES FOR ssDNA DETECTION** C.-H. Lin[1], Y.-C. Chen[1], C.-H. Tsai[2], and W.-L. Tseng[1] [1]*National Sun Yat-sen University, TAIWAN and* [2]*National Ping-Tung University, TAIWAN*	**B3L-C5** **GaN-BASED LAMB-WAVE MASS-SENSORS ON SILICON SUBSTRATES** C.M. Lee, K.M. Wong, P. Chen and K.M. Lau *Hong Kong University of Science and Technology, HONG KONG*
	14:30	
B3L-A6 **COAXIAL TIP PIEZORESISTIVE SCANNING PROBES WITH SUB-NANOMETER VERTICAL DISPLACEMENT RESOLUTION** N. Harjee, A. Haemmerli, D. Goldhaber-Gordon, and B.L. Pruitt *Stanford University, USA*	**B3L-B6** **NOVEL FLOW CYTOMETRER UTILIZING WAVELENGTH-RESOLVED DETECTION UNDER A DIASCOPIC ILLUMINATION CONFIGURATION** S.-W. Lin[1], C.-H. Chang[1], C.-Y. Lee[2], L.-M. Fu[2], and C.-H. Lin[3] [1]*National Cheng Kung University, TAIWAN,* [2]*National Pingtung University of Science and Technology, TAIWAN, and* [3]*National Sun Yat-sen University, TAIWAN*	**B3L-C6** **PULSE ACTUATION-READOUT SCHEME FOR BULK DISK RESONATOR BASED MASS SENSOR** A. Cagliani, M. Tang, and Z.J. Davis *Technical University of Denmark, DENMARK*

14:45 - 15:15	**Break and Exhibit Inspection**

Fabrication of Polymer Cantilever Integrated Full-bridge as a Piezoresistive Sensor

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***Abstract*— In this study, we describe the design and fabrication of polymer (SU-8) cantilever with integrated Full-bridge strain sensor. Changes in the surface stress on the SU-8 cantilever are detected by integrated Au strain sensors. Results showed that the full-bridge integrated SU-8 cantilever provides much higher sensitivity than those of conventional type cantilever. The fabricated SU-8 cantilever having the spring constant os 0.2N/m showed a maximum resonance frequency value 5KHZ.**

I. INTRODUCTION

The use of cantilever in micro technology became popular in conjunction with the atomic force microscope (AFM) since 1986 [1-2]. Over the past decade, cantilever based AFM has been proved as a reliable tool for taking high-resolition surface imaging. The surface of conductive and non-conductive materials, can be characterized by using cantilever based AFM which utilizes the van der Waals force [3]. The visualization of high-resolution surface images is a key feature of AFM application. Recently, the micro cantilever has been further applied in various fields of studies, such as mass detection with resonating devices [4] and magnetic force microscope. In bio-sensing, changes of surface stress [5-6] or the selective attachment of magnetic beads were used to induce the static bending of the cantilever. A low spring constant of the cantilever has been known to produce the high lateral resolution feature, whereas the flexibility of the cantilever is associated with the vertical resolution. Most cantilever for AFM (atomic force microscope) applications are fabricated with single crystal silicon or one of its compounds, such as silicon dioxide and silicon nitride. The spring constant of the materials, which decide the sensitivity of fabricated cantilever is affected by the dimensions and the young's modulus of material. Both Si (E_{Si}=160GPa) and Si_3N_4(E_{Si3N4}=304GPa) have known to have relatively high young's modulus than polymers. The thickness of cantilever also known to be related with the generation of enhanced vertical resolution. The cantilever fabricated with SU-8 (E_{SU-8}=4.2GPa) photoresist have the thickness smaller than 1 μm known to yield high vertical resolution [7-9]. The SU-8 is known to have good mechanical properties, water insolubility, bio-compatibility, and chemical durability following the polymerization. SU-8 cantilevers for AFM applications have already been demonstrated by several groups; however, the integrated deflection sensor into the SU-8 cantilever for AFM application has not been reported. The SU-8 cantilever with a built-in full-bridge could reduce the noise effect by virtue of the obviation of external circuit. Moreover, the SU-8 based cantilever which possess relatively low spring constant than that on Si-based cantilever achieves high sensitivity. Full-bridge integrated SU-8 cantilever provides about 4 times higher sensitivity than that of the cantilevers fabricated with conventional configuration. In addition, SU-8 cantilevers are able to be handled with biological sample and be applied under aqueous environments [10]. In this paper, we primarily focus on the fabrication of SU-8 cantilever with an integrated Full-bridge configuration. Feasibility of the polymer cantilever were successfully demonstrated by using a hand-made AFM system.

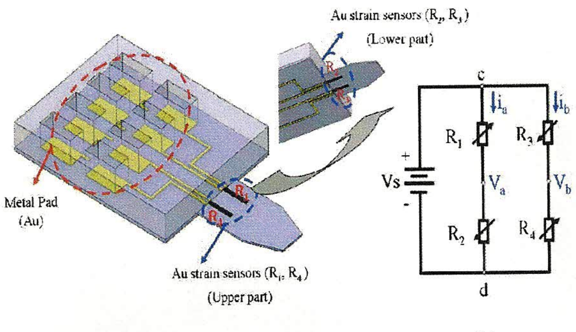

Fig. 1 (a) A schematic diagram of the polymer cantilever integrated full-bridge device and (b) thea full-bridge configuration used to measure the deflection of cantilever.

II. DESIGN AND FABRICATION OF SU-8 CANTILEVER

Fig. 1 (a) and (b) show a schematic diagram which depict the structure of SU-8 cantilever and a Full-bridge configuration used to measure the cantilever deflection. Four strain gauges are employed in this experimental condition, of which two are bonded to the upper surface of the cantilever at a distance from the point where the external force is applied and two are bonded on the lower surface. SU-8 has soft material property compared with other material used in micro electro mechanical system (MEMS) technology. The young's modulus of SU-8 is about 4.2GPa, which is approximately 40 times lower than that of silicon. The parameters used for the fabrication of SU-8 cantilever in this study are listed as

Table 1. Parameter of polymer cantilever design

Cantilever length (μm)	600
Cantilever width (μm)	220
Cantilever thickness (μm)	5
Spring constant (N/m)	0.2
Resonance frequency (KHz)	5

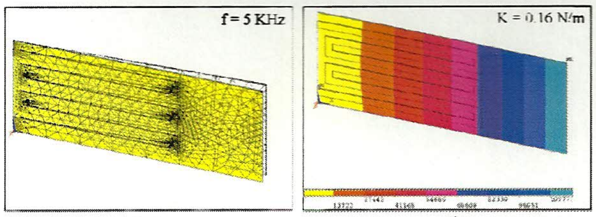

Fig. 2 FEM simulation results of (a) resonance frequency at a 1st mode (b) displacement of SU-8 cantilever used to obtain the spring constant.

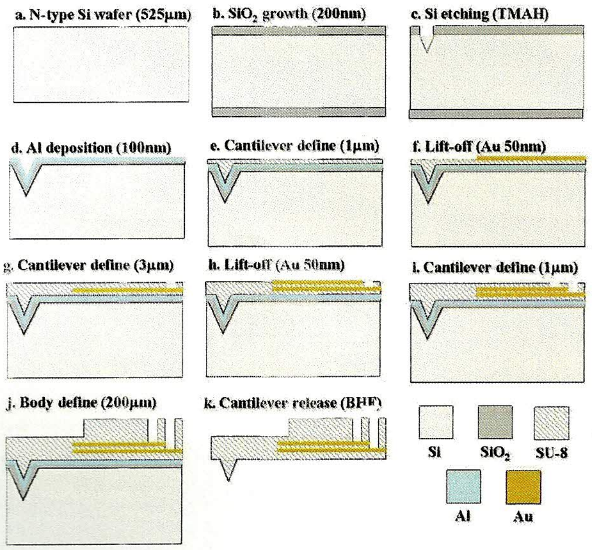

Fig. 3 Fabrication process of the Full-bridge, integrated SU-8 cantilever.

shown in table 1. The integrated Au inside the cantilever which functions as piezoresistor forms full-bridge configuration. Result showed that, the Au resistors having the width of 6 μm and the length of 510 μm and the thickness 0.05 μm have the resistance value of 10Ω. Finite element analysis (FEM) results for obtaining the spring constant and resonance frequency of the cantilever are shown in Fig. 2 (a) and (b), respectively. According to the FEM results, the spring constant of fabricated SU-8 cantilever was 0.2N/m when the resonance frequency was 5KHz at a 1st mode. Three different types of wheastone-Bridge, half-bridge and full-bridge configurations were designed by using single Si wafer.

Fig. 3 shows a main fabrication process for fabrication of SU-8 cantilever with integrated full-bridge configuration.

The fabrication of cantilever followed a standard surface micro machining technique. Total of seven masks was used as following: tip (1 mask), cantilever (3 masks), metal (2 masks), and body (1 mask). The (100) oriented n-type silicon wafer was chosen as the starting material. The orientation of the silicon wafer is important for fabricating the SU-8 cantilever since the micro-mold for tip fabrication is defined through anisotropic wet-etching (TMAH). The initial cleaning steps were processed by placing the Si wafer in the Piranha, RCA-1, and RCA-2 solution in sequence [Fig.3(a)] As following the wet method the 200nm thickness silicon dioxide was thermally grown at 1000℃ for 25min on both sides of the silicon wafer [Fig. 3 (b)]. Then the top oxide film grown on the wafer was tip-patterned by photolithography. Following the oxide was wet etched by using tip-patterened photolithography in buffered hydrofluoric acid (BHF) to form the mask for the micro-molds. Pyramidal holes are then formed by adopting the wet etching method using the tetra methyl armmonium hydroxide (TMAH) as an anisotropic etchant as shown in [Fig. 3 (c)]. To fabricate the V-shaped tip having 15 μm of depth, Si wafer was placed in TMAH (20wt%) at 80℃ until desired structure was achieved. Following the confirmation of V-shaped tip configuration the residual oxide layer was removed by using BHF solution. Before the second oxidation process foe rip sharpening, the wafer was rinsed by adopting a standard Piranha cleaning. To release the cantilever from the Si substrate more convenient, deposition of 100nm of seed Al layer on Si wafer was achieved by using thermal evaporator as shown in [Fig, 3(d)]. Employing Al as a seed layer provide the cost-effective and simple fabrication than the process conducted by using Cr/Au/Cr layer. Next, the cantilever pattern was fabricatied on top of Al seed layer by using SU-8 (2002) negative photoresistor and the thickness of the cantilever layer was 1 μm. In order to generate the piezoresistor, a half of Full-bridge configuration, the 50nm of Au was deposited on Su-8 cantilever layer and subsequent lift-off process was followed, as shown [Fig. 3(f)]. An electron beam evaporator which enables the precise control of the desired film thickness was employed for the Au deposition on SU-8 layer. The lift-off process was conducted to prevent permanent shrinkage of the SU-8 surface from thermal stress which generated during the metal deposition process. By depositing additional 3 μm thick SU-8 layer, the Au layer would be completely encapsulated by SU-8 layers as seen on [Fig. 3(g)]. Following the deposition of 50nm thick Al layer was performed as same procedure to generate piezoresistors, another half of Full-bridge configuration [Fig.3(h)]. To encapsulate the Au layer, additional SU-8 layer was deposited with 1 μm thickness as upper SU-8 cantilever layer [(Fig. 3 (i)). In order to fabricate the body of cantilever, he forth SU-8 (2050) layer with a thickness 0f 200nm is spin-coated and patterned by photolithography, as shown in [Fig. 3 (j)]. Lastly, the Al seed layer which exhibit relatively low affinity with SU-8 layer than that of Ct/Au/Cr, was easily removed by wet-etching in

BHF solution and the SU-8 cantilevers with built-in Full-bridge structure were released from the substrate, as shown [Fig. 3(k)]. Following the fabricated SU-8 Full-bridge cantilever were rinsed in DI water.

III. EXPERIMENTAL RESULTS

Optical microscope images of the fabricated SU-8 cantilever and the integrated Au strain sensor are shown in Fig. 4. The fabricated SU-8 cantilever consists of the tip and an integrated Au strain sensors which is a component of the Full-bridge configuration. The V-shaped tip produced from the Si etch-pits showed high degree of uniformity and the radius of its curvature was smaller than 100nm. In principle, sharper tips having the enhanced lateral resolution could generate high resolved surface topology. The optical diction method is employed to confirm the resonance characteristics of the SU-8 cantilever, as shown in Fig. 5. The resonance frequency of the cantilever was measured and the value was 4.5kHz. The deflection sensitivity of the SU-8 cantilever has been measured by inducing the. varied degree of bending with cantilever. To detect the any changes in resistance value, the stress, strain, force and temperature are used as a driving source of cantilever actuation. One of the simplest applications of strain gauges is in the measurement of the force applied to a cantilever beam as seen on Fig. 6. In this study, integrated Au strain gauges which bonded to the surface of SU-8 cantilever detect surface topology by using altered resistance values when the force was applied, illustrated in Fig. 6. Appling force induced the downward movement of SU-8 cantilever, as consequence the strain sensors sense either tensile or compressive stress depending on their location of upper or lower region of cantilever. As a result, the electrical resistance of the upper strain sensors becomes increase, and that of the lower strain sensors are decreased. The decreased and increased net electrical resistance value is equal. As the result, the Full-bridge integrated SU-8 cantilever provides much higher sensitivity than those of conventional configuration. Fabricated SU-8 cantilever was applied to a custom-built AFM system for line-scan imaging. The cantilever deflection caused by the change in the interactional force between the sample and the tip is measured through the AFM system. Fig.7. shows preliminary result, of the surface image obtained by using custom-built AFM which generated based on the fabricated SU-8 cantilever.

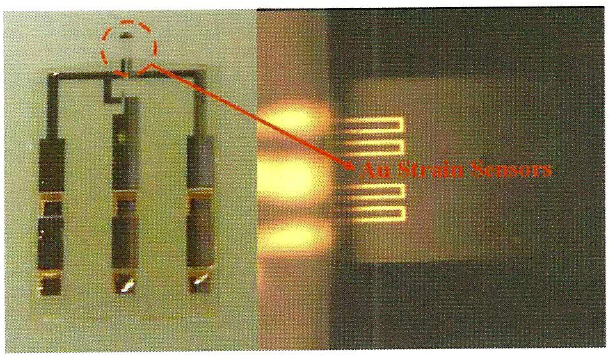

Fig. 4 Optical microscopic images of the fabricated SU-8 cantilever showing, a Full-bridge configuration.

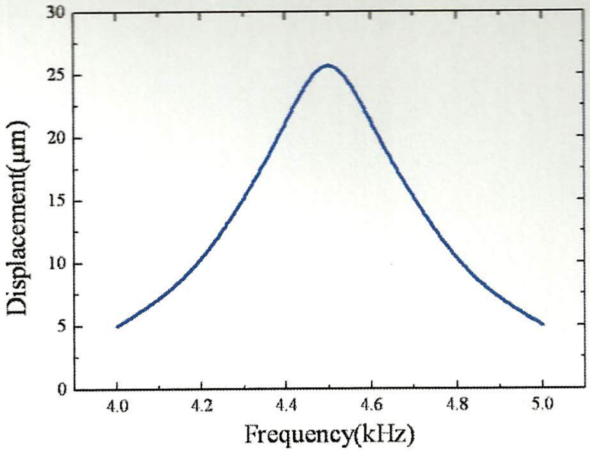

Fig. 5 Resonance frequency of SU-8 cantilever folloeing voltage (V_{pp}140V) was applied.

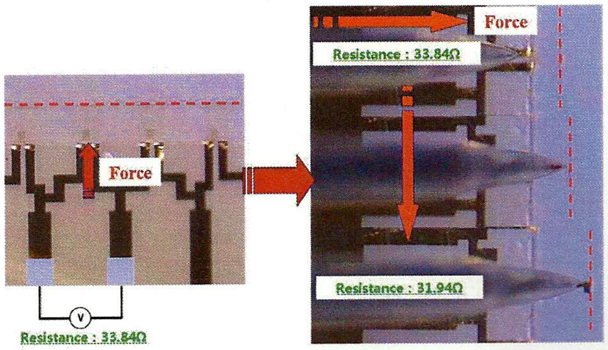

Fig. 6 Measurement of resistance value by loading the probe on SU-8 cantilever.

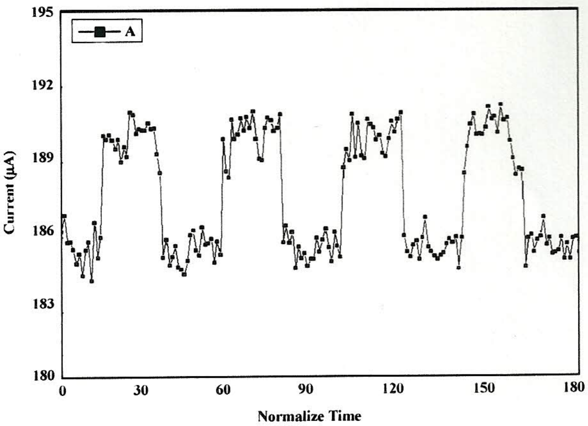

Fig. 7 Line scan images obtained using a custom-bulit AFM system.

By scanning the surface of object material with Lab. View software, the surface structure was displayed as altered current value (Fig. 7). There was a little discrepancy between real structure and scanned value due to the incomplete software operation. We expect that, the resolution and accuracy can be increased by increased by further optimization of AFM system and by replacing highly sensitive strain sensor materials.

IV. CONCLUSIONS

Micro-fabrication processes have been successfully demonstrated the generation of SU-8 cantilever with integrated Au strain sensor. The fabricated SU-8 cantilever with a built-in Full-bridge has a resonance frequency of 4.5kHz at the 1^{st} mode and the spring constant value was approximately 0.2N/m. The SU-8 cantilever exhibited about 30μm deflection at resonance mode (V_{pp}:140V, PZT). Further study need to be focused on the optimization of fabricated tips to improve the sharpness of tips.

Acknowledgment

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