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Session M4C

Microphones & Other Physical Sensors

ROOM 304A

16:00 - 17:30

Y. Fuji, M. Hara, Y. Higashi, S. Kaji, K. Masunishi, T. Nagata, A. Yuzawa, K. Otsu, K. Okamoto, S. Baba, T. Ono, A. Hori, and H. Fukuzawa
Toshiba Corporation, JAPAN

We report on the first spintronic strain-gauge sensor (Spin-SGS) based on a magnetic tunnel junction with a high gauge factor exceeding 5000. We also demonstrate a novel ''Spin-MEMS microphone,'' in which Spin-SGSs are integrated on a diaphragm. The Spin-MEMS microphone exhibits a signal-to-noise ratio (SNR) of 57 dB(A) due to high strain sensitivity of the Spin-SGSs. Furthermore a Spin-MEMS microphone with a first resonance frequency of 74 kHz is also fabricated and exhibits an SNR of 45 dB(A).

J. Manz[1], G. Bosetti[1], A. Dehé[2], and G. Schrag[1]
[1]*Technical University of Munich, GERMANY and* [2]*Infineon Technologies AG, GERMANY*

A novel comb-structure-based, capacitive MEMS microphone concept is proposed, which is supposed to significantly reduce viscous damping losses and, hence, offers the potential to enhance the signal-to-noise-ratio beyond those of up-to-date silicon condenser microphones. The concept is verified by virtual prototyping methods applying a fully energy-coupled and properly calibrated system-level model. Measurements of first prototypes show promising results and agree very well with simulations.

Y. Kusano, J. Segovia-Fernandez, S. Sonmezoglu, R. Amirtharajah, and D.A. Horsley
University of California, Davis, USA

We present a frequency-selective MEMS microphone achieved by utilizing spiral-shaped acoustic resonators inspired by the spiral-shaped structures found in the human ear. The resonators were fabricated by 3D-printing and easily integrated with our test circuit board. Here, we demonstrate simulation and experimental results investigating the effect of aperture locations, and achieving a 2.7x increase in linear sensitivity response at the resonance frequency of 430 Hz.

T. Okatani, A. Nakai, T. Takahata, and I. Shimoyama
University of Tokyo, JAPAN

We report on a MEMS slip sensor that estimates triaxial force as well as coefficient of static friction for prediction of a slip. The sensor was composed of the outer and inner elastomers separated by a hard substrate, which enable to measure triaxial force independently of coefficient of static friction. We fabricated a prototype of the sensor and evaluated it by pressing and sliding it on various conditions of coefficient of static friction.

D.-S. Kim[1], Y.W. Choi[2], T. Lee[2], G. Lee[2], D. Kang[3], M. Choi[2], and D.-W. Lee[1]
[1]*Chonnam National University, KOREA,* [2]*Seoul National University, KOREA, and* [3]*Ajou University, KOREA*

We describes the fabrication and characterization of ultra-sensitive polymeric cantilever sensor to precisely measure the change in contraction force of cardiomyocytes. In spite of all these interesting characteristics, the mechanical crack–based sensor inspired from the spider sensor has not yet been used for biological applications i.e. for detecting cardiomyocyte movements. Herein, we have successfully developed a novel sensing technique for measuring the contraction force of cardiomyocytes.

L. Zhu[1,2], Y.H. Xing[1,2], B. Xie[1,2], C. Xiang[1,2], Y.L. Lu[1,2], D.Y. Chen[1], J.B. Wang[1], and J. Chen[1]
[1]*Chinese Academy of Sciences, CHINA and* [2]*University of Chinese Academy of Sciences, CHINA*

This paper reports a high-Q resonant pressure micro sensor with through-silicon-via electrical interconnections. In order to avoid the failure of vacuum packaging, a through-silicon-via technology was developed to achieve the wire interconnections. Experimental results showed that the Q-factor of the resonator was higher than 27000, and the differential sensitivity was quantified as 84.36 Hz/kPa.

PHOTOCURABLE PUA (POLY URETHANEACRYLAT) CANTILEVER INTEGRATED WITH ULTRA-HIGH SENSITIVE CRACK-BASED SENSOR

Dong-Su Kim[1], Yong Whan Choi[2], Taemin Lee[2, 4], Gunhee Lee[2, 4], Daeshik Kang[3], Mansoo Choi[2], and Dong-Weon Lee[5]

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and
[5]School of Mechanical Engineering, Chonnam National University, Republic of Korea

ABSTRACT

This paper describes the fabrication and characterization of ultra-high sensitive polymer cantilever to precisely monitor the change in contraction force of cardiomyocytes. The mechanical crack-based sensor inspired from a spider showed enhanced sensitivity towards strain and vibration in nature. In spite of all these interesting characteristics, the crack-based sensor has not yet been used for biomedical applications such as detecting a small force generated from cells. Herein we made successful attempt to develop a novel sensing technique for measuring the contraction force of cardiomyocytes. This idea can be applied for the development of cantilever-based cardiac toxicity screening systems.

KEYWORDS

Polymeric cantilever, Crack-based sensor, Cardiomyocytes, Contraction force

INTRODUCTION

A research on flexible artificial electronics-skin for wearable health care is being actively progressed. The researches on high sensitivity sensors that can measure external stimuli and body reactions have attracted great attention. Typically, various sensor systems using nanowire [1], silicon rubber [2], piezoelectric [3], organic thin-film transistors [4] have been developed. Recently, mechanical crack-based sensor inspired by the spider sensory system having high sensitivity to strain and vibration is also reported [5]. On the leg of a spider , there is an institution called as a slit organ, which has a structure in which stress is mechanically concentrated, and it effects an amplifying external stimulus. The crack sensor using cracks which occur between thin and rigid metal membrane and relatively soft polymer was inspired by spider's slit organ. When the crack sensor receives a tensile force, the stress is concentrated at the crack tip and this causes a change in electrical resistance. This causes a change of a gap distance on the crack areas and influences to the electrical resistance. With the increase of a tensile force, the number of electrical contact on the metal membrane decreases and the resistance of the whole crack sensor increases. This enables sensors to measure deformation and vibration with ultra-sensitivity. Despite excellent sensitivity, repeatability and reproducibility, the mechanical crack based sensors have not yet been used in biomedical applications.

In this paper, we present an ultra-high sensitive crack sensor integrated with a PUA (Poly Urethaneacrylate) cantilever for biomedical applications. A thin Pt layer employed as the crack sensor material is patterned on a polymer surface and cracks are then generated by a tensile strain. Micro-patterns are also formed on the PUA cantilever to enhance the contraction force of cardiomyocytes. After ceding the cells on the PUA cantilever, the bending displacement is precisely monitored using the integrated strain sensor, which eliminates the use of any optical systems. The proposed crack-based biosensor is expected to be usable in a system that measures the contractile force of cardiomyocytes responding to very little drugs accurately.

MATERIAL AND METHOD

Design and fabrication of PUA cantilevers

In order to measure the contractile force of cardiomyocytes effectively, a sensor device with a cantilever type was proposed. Stress and displacement of the cantilever against to the contraction force of cardiomyocytes were analyzed using a FEM simulation method. According to Fig. 1, deformation can occur when the cantilever was exposed to a constant force in the vertical direction. The tensile force was maximized at the fixed end of the cantilever where the stress was concentrated. The cracks made by a thin metal layer was placed at the position.

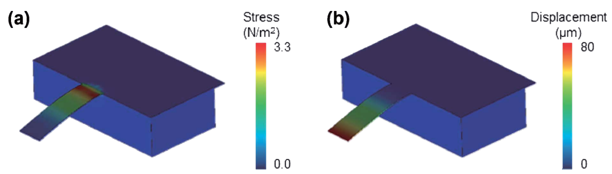

Figure 1: FEM simulation results of (a) stress distribution and (b) cantilever displacement as a function of contraction force of cardiomyocytes.

Detailed driving theory of the crack sensor is shown in Fig. 2. Here, the crack generated in the metal membrane was visualized. When the crack sensor receives a tensile force, stress of the small square metal membrane is concentrated at the surface, and the gap of the metal membrane is expanded. As the crack of the metal membrane is increased, the number of contact points between the crack and the crack decreases and the electrical resistance rapidly increases due to the decreasing of the electrical pathway.

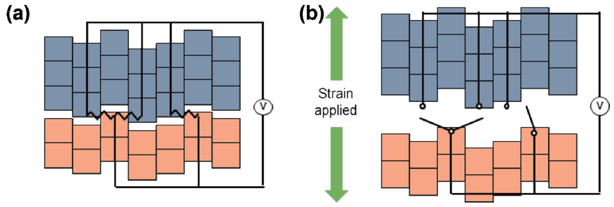

Figure 2: Operation principle of crack-based sensor under different strain conditions.

The fabrication of the cantilever-type crack sensor is a relatively simple as shown in Figure 3. After making a SU-8 mold using a conventional photolithography process, a small quantity of PUA was blade-casted into the SU-8 mold. After that, the PUA was UV-cured through a glass cover. Next, 20 nm thick Pt pattern was formed using a shadow mask as show in Fig. 3 c. In order to increase the reliability of electrical wires and pads, a glass substrate with metal patterns were employed. The prepared glass part was chemically bonded to the cantilever part after the surface treatment with an oxygen plasma.

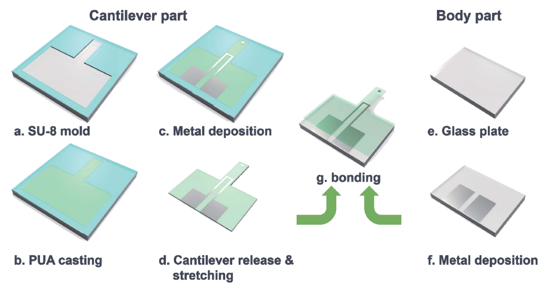

Figure 3: Fabrication process flow of the PUA cantilever integrated with the crack-based sensor.

Cell culture and isolation of neonatal rat ventricular myocyte (NRVM)

Cardiomyocytes were isolated from 1-3 day old neonatal rat heart, which was approved by the Animal Ethics Committee of Chonnam National University. In brief, neonatal rats were decapitated, and then blood was transfused from a decapitated area. A tiny heart was quickly isolated, washed in an enzyme solution, cut into small pieces and dissolved in an enzyme substance until the tissue was fully disintegrated. The cell suspension solution was incubated at 37°C with 5% CO_2. The used culture medium was a plating medium supplemented with 10% fetal bovine serum (FBS). When the cardiomyocytes were seeded on the cantilever surface, fibronectin was used as an extra cellular matrix (ECM). The cardiac cells were seeded on the cantilever with a density of 1000 cell/mm^2. The factors that influence cell culturing are the composition and formation of the media, the CO_2 supply, the culture temperature, etc. These factors were well controlled via the incubator system. The culture fluid was made from DMEM 67% (Dulbecco's modified Eagle's medium, LONZA), M199 17% (heparin sodium salt from porcine intestinal mucosa, Sigma-Aldrich), horse serum 10% (Sigma-Aldrich), FBS 5% (supplemented with 5% fetal bovine serum, Sigma-Aldrich), and penicillin-streptomycin 1% (Sigma-Aldrich). In the culture fluid (DMEM), in addition to the carbon source, energy source, nitrogen source, inorganic salt, and trace elements, there is a buffering agent included. FBS includes an element for promoting cell growth and activity. Additionally, 1% penicillin-streptomycin was used as an antibiotic agent [6].

Immunocytochemical staining

The cardiomyocytes were placed in 3.7% formalin solution for 10 min at room temperature and washed three times with phosphate-buffered saline (PBS Takara). Permeabilization was accomplished with 0.2% Triton-X (Sigma-Aldrich) in PBS for 15 min at room temperature. To prevent nonspecific binding, the antibodies were incubated at room temperature for 40 min using 1% bovine serum albumin (1% BSA, Sigma-Aldrich). The primary antibody, monoclonal anti-actin (α-sarcomeric) was diluted at 1:200 with 1% BSA and incubated at room temperature for 1.5 h. The secondary antibody (Alexa-Flour 488 goat anti-mouse IgG conjugate) was diluted at 1:500 in the same blocking solution and incubated for 1 h at room temperature. Finally, the prepared samples were incubated with 4′,6-Diamidine-2′-phenylindole dihydrochloride (DAPI) at 37°C for 15 min for immunofluorescence of F-actin and nucleus [6].

EXPERIMENT AND RESULTS

Fig. 4 (a) shows an optical image of the fabricated PUA cantilever integrated with an ultra-high sensitive crack-based sensor. The formation of cracks on the integrated crack sensor was clearly confirmed using a SEM as shown in Fig. 4b-c. As shown in Fig. 2, the cantilever tension generated by the contraction of cardiomyocytes expands the crack gap of the metal membrane. The gap formed by the cracks is increased and this cause the increase of the electrical resistance infinitely, thereby realizing a high sensitivity sensor.

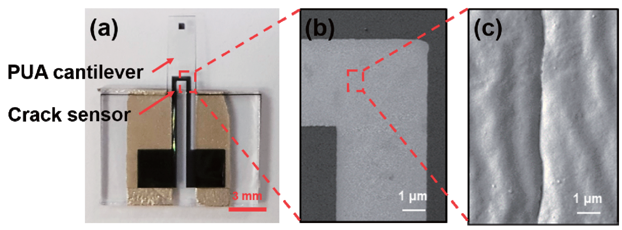

Figure 4: (a) Optical images of PUA cantilever and (b-c) SEM images of crack-based sensor.

Characteristic analysis was carried out according to repeated tension and compression of the PUA cantilever integrated with the crack sensor. Figure 5 (a) shows an experimental setup. The resistance change of the crack sensor by tension is described in the Fig. 5 (a). It can be confirmed that the electric resistance of the crack sensor increases by about 100 times when applying 0-1% strain. This sensitivity is high enough to measure a tiny cantilever displacement caused by the contraction of cardiomyocytes.

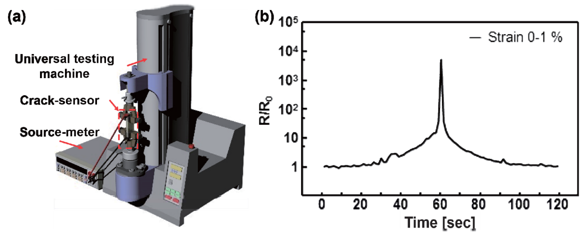

Figure 5: (a) Schematic illustration of experimental setup and (b) change of electrical resistance in response to the strain.

Schematic of the sensor setup and techniques used for sensing characteristics measurements are shown in Fig. 6 (a). The resistance changes of the crack sensor and the Au strain sensor was measured as a function of applied force. After fixing the PUA cantilever to the upper side of the Z-axis motorized stage, a certain displacement is applied to the cantilever via the contact to the free end of the cantilever using a holder. Figure 6 (b-c) shows the change of the electrical resistance for both sensors. Experimental results show that the conventional strain sensor made by metals showed very small resistance change of about 15 mΩ when applying a maximum displacement of 1 mm to the cantilever. However, the resistance changes of the PUA cantilever integrated with the crack sensor was about 25 kΩ with the same displacement. As shown in the inset of Fig. 6c, the resistance change of the crack sensor was about 17 Ω even though the cantilever displacement was about 50 µm. It was experimentally confirmed that the force sensitivity of the crack-sensor was greatly improved compared to the conventional sensing principles.

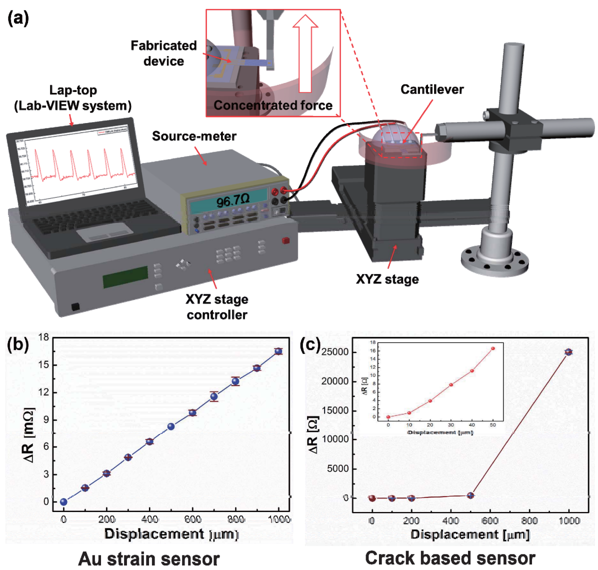

Figure 6: (a) Schematic diagram of measurement system. Comparison of sensitivity for (b) Au strain sensor and (c) crack-based cantilever sensor.

Cardiomyocytes cultured on the PUA cantilever were observed using a fluorescence microscope after the immunocyto-chemical staining process. As shown in Figure 7, cardiomyocytes cultured on a flat surface of the PUA cantilever grew isotropically without any directionality. However, depending on the surface morphology, the cardiomyocytes can be aligned in a certain direction on the upper part of the cantilever using the characteristics of the cardiomyocytes having the directionality. In the case of cardiomyocytes grown along the micro-grooves formed in the longitudinal direction of the PUA cantilever, a large contractile force can be generated, thereby increasing the displacement of the PUA cantilever. In addition, the PUA material is optically transparent and can be equipped with an invert microscope for the purpose of live-cell imaging, making it suitable for in vitro experiments.