MUSCLE-ACTUATED POWER GENERATOR USING CULTURED CARDIOMYOCYTES AND PZT FIBER

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***Abstract*— A novel bio hybrid micro power generator using cardiomyocytes on a polymer wire is proposed. Cultured cardiomyocytes convert chemical energy into kinetic energy efficiently and beat themselves autonomously. PZT fiber was utilized for cell immobilized substrate and electro-machanical coupling material. In this paper, two preliminary experimental results were shown to prove this principle.**

I. Introduction

Natural cellular activities are increasingly exploited for micro analytical systems, biochemical reactors. We have proposed novel use of pulsating heart cells as mechanical micro actuators [1-3]. In this study, we propose a novel bio hybrid micro power generator using cardiomyocytes on a polymer wire. Cultured cardiomyocytes convert chemical energy into kinetic energy efficiently and beat themselves autonomously.

II. Principle of Bio Hybrid Micro Power Generator

The principle of the bio hybrid micro power generator is that heart muscle cells are immobilized on a nylon wire, let it expand and contract, and this heartbeating force converts to a PZT fiber [4,5] mechanically, and then the electrical energy is generated by piezoelectric effect, as shown in Figure 1. PZT fiber was utilized for cell immobilized substrate and electro-machanical coupling material. Figure 2(b) shows a cross sectional view of SEM image of PZT fiber.

III. PZT Fiber With Pt Core

The PZT fiber used in this paper consists of a PZT with a platinum wire and electro-plated with nickel, as shown in Figure 2. Generally, piezoelectric materials need to add electrode applied to both ends of the material. In contrast,

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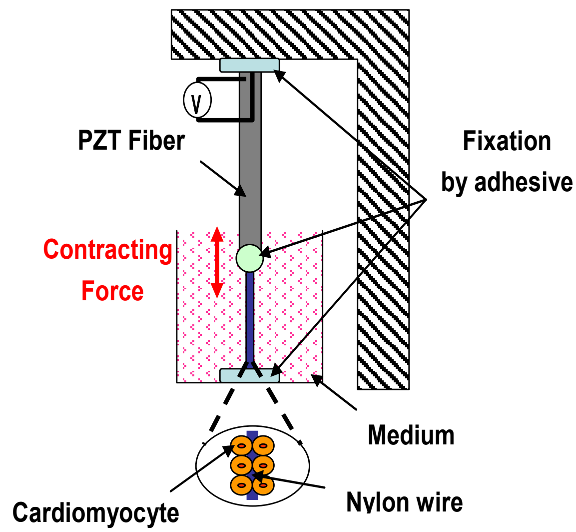

Fig. 1. Principle of bio hybrid micro power generator with heart muscle cells and PZT fiber

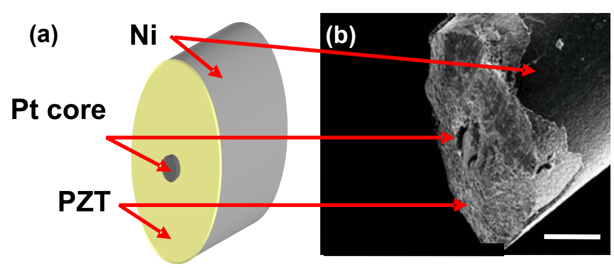

Fig. 2. (a) Schematic view of PZT fiber, (b) Cross sectional view of SEM picture of PZT fiber, scale= 100µm

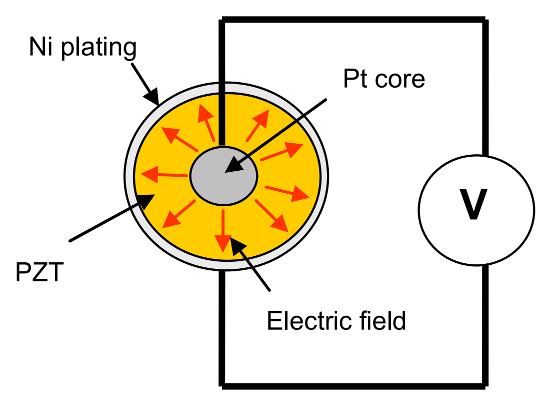

Fig. 3. Principle of electric gereration of PZT fiber

PZT fiber needs not to add electrode, because Pt core and nickel work as the electrodes. In the above system, the electrical energy is generated by piezoelectric effect when the PZT fiber expanded, as shown in Figure 3.

IV. Method of PZT Fiber Wiring

Ni plating and Pt core parts of the PZT fiber has to be connected. However, it is difficult to wire Pt core because the diameter of Pt core is only 50 μm. Thus, Ni plating and Pt core are wired using a SUS board and a shielded wire, as shown in Figure 4. First, the Pt core and center cable of shield wire are connected with silver paste to make contact the Pt core with center cable. Second, the nickel, SUS board and shield part are made contact with by silver paste. This wiring method simply enables a polarization of the PZT fiber and voltage measurement described below. In addition, noise can be reduced by connecting shield part with ground.

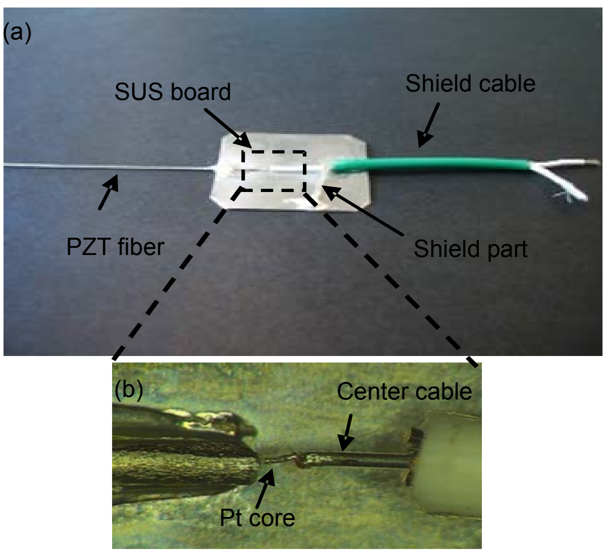

Fig. 4. PZT fiber on SUS board

V. Polarization Process of PZT Fiber

Piezoelectric materials have direction of polarization at the crystal level. Each direction of crystal polarization needs to be common direction to occur piezoelectric effect. Thus, it is necessary for piezoelectric materials to apply a voltage. In this experiment, the applied voltage between Pt core and nickel was 300V for 30minutes by a high voltage power supply.

VI. Pulling Experiment of a Nylon Wire

A. *Outline of the Experiment*

Before the experiment using cardiomyocytes, the fundamental experiment is done to investigate the characteristics of the PZT fiber using a conventional bimorph actuator as a model of the cardiomyocytes. The nylon wire which fixed the bimorph actuator pulls the PZT fiber, and then the output voltage of the PZT fiber is measured. In this experiment, the pulling force of nylon wire is measured by a tension tester.

B. *Experimental Method*

First, the nylon wire and the edge of the bimorph actuator are glued together and the bimorph actuator is fixed to a XYZ stage. Second, the edge of the nylon wire is clamped with the tension tester and then theXYZ-stage is slid up to the position that nylon wire is straight, as shown to Figure 5. Then, the bimorph actuator is driven by the function generator and the applied tension on the nylon wire is measured. In this experiment, the applied voltage of the bimorph actuator is 1V, 2V and 3V, and a frequency is 3Hz.

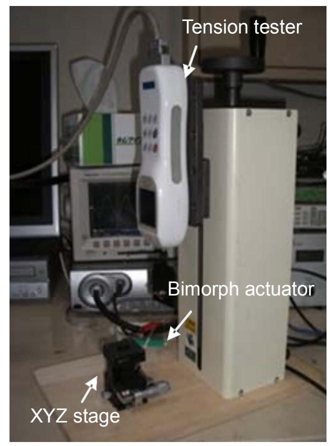

Fig. 5. Photo of Pulling experiment setup

C. *Result*

The output data of tension tester is read at 100datas per second. Figure 6 shows one of the data (at the time input amplitude is 1V). The other results of this experiment also show sine waves which frequency is 3Hz. The amplitudes of the tension of the nylon wire at 1V, 2V and 3V are 4mN, 8mN and 11mN.

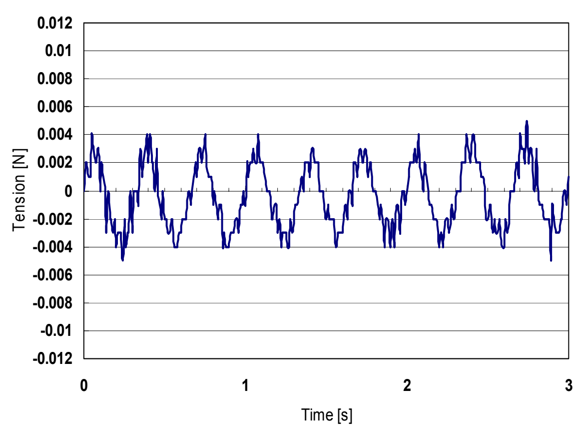

Fig. 6. Tension of bimorph actuator diagram

VII. PZT FIBER RESPONSE TO EXPANSION AND CONTRACTION FORCE

A. Outline of the Experiment

To investigate the characteristics of the PZT fiber about frequency of expansion and contraction force, the pulling experiment of the PZT fiber using the bimorph actuator and the nylon wire described above is performed. The bimorph actuator pulls the nylon wire and then, the PZT fiber is pulled by nylon wire. Output voltage of the PZT fiber is measured by oscilloscope. In this experiment, a severity of the nylon pulling force uses the above results.

B. Experimental method

Figure 7 shows the schematic view of this experiment. In the similar way above experiment, the edge of the bimorph actuator and nylon wire are glued together, and the bimorph actuator fixed a XYZ stage. Next, the PZT fiber and nylon wire is connected and another edge of the PZT fiber is fixed. To contract and expand the PZT fiber, bimorph actuator is driven by a function generator. Then, output voltage of the PZT fiber is measured by oscilloscope. In this experiment, pulling force is 4mN, 8mN and 11mN, and pulling frequency is 1~10Hz. The length of PZT fiber is 20mm and 35mm.

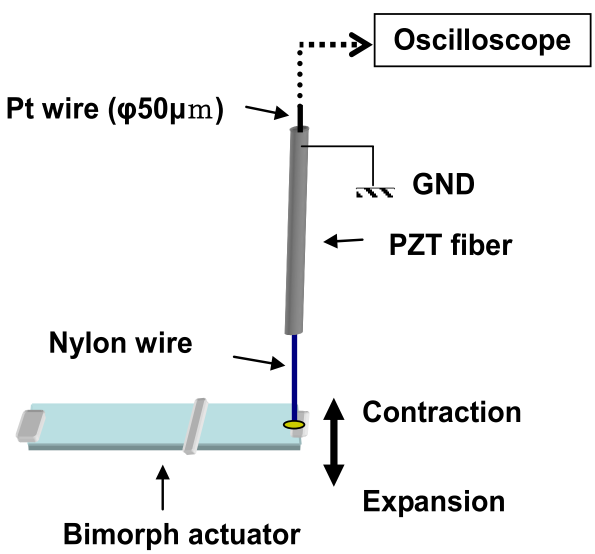

Fig. 7. Schematic view of pulling experiment of the PZT fiber using bimorph actuator

C. Result and discussion

All results of output voltage of PZT fiber measured by oscilloscope show sine waves that have same frequency as each input force have. Figure 8 shows one of the results measured by oscilloscope. (the length of the PZT fiber is 20mm, input frequency is 2Hz) Figure 9 shows comparison of the output voltage with length of the PZT fiber. Figure 8 shows important results about frequency response to contraction and expansion force of the PZT fiber. The results of this experiment indicate that low frequency force as a heartbeating force (1~2Hz) can generate a voltage if cardiomyocytes generate enough force. The results also show length of the PZT fiber effect the output voltage larger than force at low frequency.

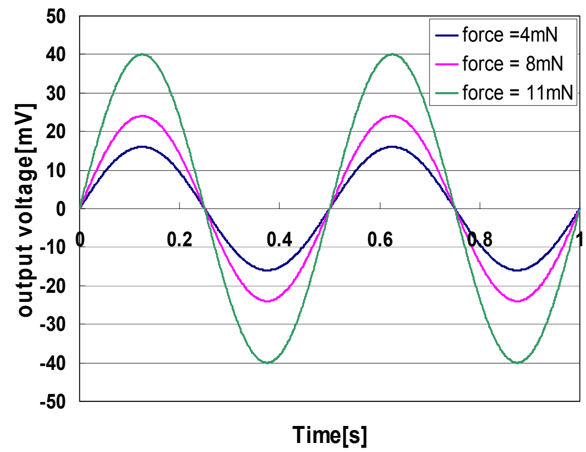

Fig. 8. Output voltage of the PZT fiber, frequency = 2Hz

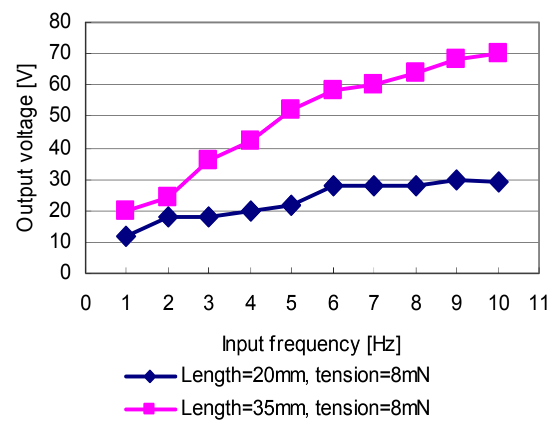

Fig. 9. Output voltage of the PZT fiber dependent on the its length

VIII. CARDIOMYOCYTES CULTURE EXPERIMENT ON THE SILK SUTURE

A. Outline of the Experiment

In this culture experiment, cardiomyocytes are immobilized on the silk suture. A silk suture is often used for medical operation and has biocompatibility. The silk suture is fixed on the polydimethylsiloxane (PDMS) groove. On the silk suture, cardiomyocytes are immobilized, and then immobilization of the cardiomyocytes is observed by inverted microscope.

B. Method of culture experiment

To fix a silk suture, The PDMS structure with groove (The breath and depth is 1mm) is made. A silk suture is sewn on the PDMS groove by a needle.

First, to sterilize the PDMS structure and a silk suture described above, they are immersed in ethanol in 15 minutes, and then they are under UV lamp in 15minutes.Second, to increase a capability of cell attachment of a silk suture, its surface is coated with fibronectin (50μg/ml) and takes an hour at 37 degrees, CO_2 5%.

Third, primary neonatal rat cardiomyocytes were prepared. The cardiomyocytes (about 1×10^6 cells/ml) seed on the silk suture. An hour later we supply the culture medium, and incubate at 37 degrees, CO_2 5%. Figure 10 shows schematic view of culture using a silk suture and Figure 11 shows photo image of cardiomyocytes culturing.

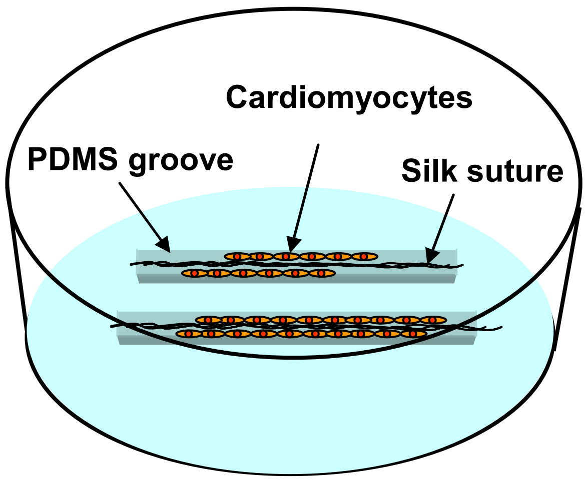

Fig. 10. Schematic view of cultured cardiomyocytes on the silk suture

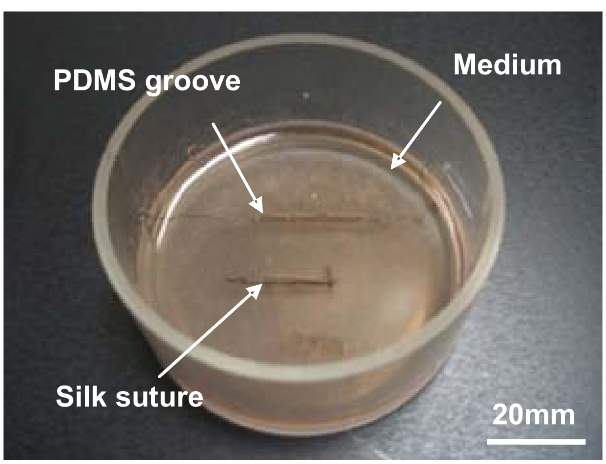

Fig. 11. Picture of culture of cardiomyocytes

C. *Result of culture experiment*

Figure 12 shows the microscopic image of cultured cardiomyocytes on the silk suture (after 3day in culture). The cardiomyocytes on the silk suture start heartbeating after 2day in culture. After 3day in culture, cardiomyocytes that are immobilized on the silk suture are widely observed. In addition, cardiomyocytes start to contract a silk suture.

The result indicates cardiomyocytes can be cultured on the silk suture and contract the silk suture. However, it is not enough force to generate the electrical energy using the PZT fiber at this moment. This reason would be that PDMS groove is not proper size.

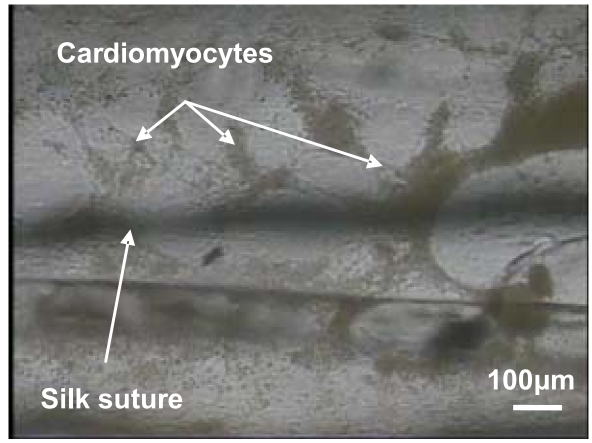

Fig. 12. Microscopic image of cultured cardiomyocytes on the silk suture

IX. Conclusion

In this paper, we propose a novel bio hybrid micro power generator using cardiomyocytes on a polymer wire. PZT fiber was utilized for cell immobilized substrate and electro-machanical coupling material. Two preliminary experimental results were done to prove this principle. We measured a frequency response of the PZT fiber, the nylon wire glued with PZT fiber was pulled at heartbeat frequency (1 ~ 2Hz) using a bimorph actuator and do the cardiomyocytes culture experiment on the silk suture. These results indicate that the PZT fiber can generate a voltage at the low frequency as heartbeat and that the method of cardiomyocytes culture needs to improve to generate the electrical energy.

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