# **Biochemical compatibility of PZT piezoelectric ceramics** covered with titanium thin film

T. SAKAI<sup>\*</sup>, S. HOSHIAI<sup>a</sup>, E. NAKAMACHI<sup>b</sup>

Department of Mechanical Engineering, Takamatsu National College of Technology, 355 Chokushi, Takamatsu, Kagawa 761-8058 Japan

<sup>a</sup>Graduate Student of Medical, Tottori University, 86 Nishi, Yonago, Tottori 683-8503 Japan

<sup>b</sup>Department of Mechanical Engineering, Osaka Institute of Technology, 5-16-1 Omiya, Asahi-ku, Osaka 535-8585 Japan

To discover a piezoelectric-device material with excellent biocompatibility, the biocompatibilities of several materials such as pure PZT, titanium+PZT and ZnO are examined. The proliferation rate of cells in the presence of each material was observed with a phase-contrast microscope. The main conclusions from this study are as follows: (1) the proliferation rate with the as-received PZT hardly changes compared with the control group. However, the survival time of a cell becomes extremely short. (2) As-received PZT with cells in a confluent condition shows very good biocompatibility compared with ZnO.

(Received June 20, 2006; accepted July 20, 2006)

*Keywords*: Biomaterials, Ceramics, Material design, Material testing, Biochemical compatibility, Piezoelectric material, Titanium, Thin film, L929 cells, Proliferation rate

### 1. Introduction

The development of a microactuator which provides fast response and large displacement is indispensable to realize a drug delivery system (DDS) or health monitoring system (HMS) for use in a living body. Piezoelectric materials are candidates for actuator materials; in particular, it is known that zircon acid lead titanium (PZT: Pb(Zr, Ti)O<sub>3</sub>) provides fast response to applied voltage. Thus, this material is a likely candidate to be very effective in the realization of such systems. Biocompatibility is essential for the application of biomimetic micro-electro-mechanical system (bio-MEMS) actuators in vivo or in vitro. Biocompatibility must be investigated, especially since PZT contains lead. Lead is known to adversely influence organisms [1, 2].

Accordingly, this study examines biocompatibility using the following materials: pure PZT; titanium+PZT, which is biocompatible titanium deposited on a PZT surface by RF magnetron sputtering; and the semiconductor oxide ZnO, which is used for comparison. Titanium is a material with very high biocompatibility which has lately been frequently used as a metallic biomaterial in orthopedics [3]. We attempted to synthesize a piezoelectric ceramic material which has excellent biocompatibility; to avoid spoiling its piezoelectric properties, we coated the PZT surface with titanium.

## 2. Evaluation of biocompatibility

Many studies of metal cytotoxicity have been performed [2, 4-6], the results of which have been summarized in a review by Kawahara et al [7]. In his own experiments, Kawahara compared relative cell fertility and the cell growth coefficient for mouse fibroblast tissue origin L929 cells with glass as a contrast material. The biocompatibility of each metal-forming PZT based on this result proves that titanium and zirconium are highly biocompatible elements. On the other hand, although lead is generally believed to have high toxicity, it was not discussed in his report. Consequently, judging PZT biocompatibility from previous reports was inferred to be difficult. Hence, the following experiment was carried out.

The test specimen employed in this experiment was a PZT piezoelectric ceramic in the form of a 0.3mm-thick square plate (Fuji Ceramics Co. Ltd., type C-82). As for the titanium coating on the surface of the PZT, two thin films,  $1.0\mu$ m and  $2.0 \mu$ m thick, were coated on the surface using an RF magnetron sputtering system after removing the silver electrode by chemical polishing [8].

The cells employed in this experiment were mouse fibrous-tissue origin L929 fibroblasts of passage number 25; they were cultivated at 37  $^{\circ}$ C in 100% humidity in a 5% CO2-95% air atmosphere. The culture medium used was Eagle's MEM culture medium to which 10% FCS was added; it was placed in several laboratory dishes to achieve a concentration of 100 cells per 1mm<sup>2</sup>. Then, specimens which had been washed and sterilized with hot air were supplied in a laboratory dish into which the cells were placed. The proliferation rate of the cells was observed with a phase-contrast microscope. In addition, a laboratory dish cultivated with no test specimen was the control.

Simultaneously with these investigations, specimens of PZT and ZnO were supplied to cells proliferated just before passage to confluence, (i.e., point at which a laboratory dish is filled with proliferated cells and no more proliferation is possible); changes in the cells were observed.



Fig. 1. Confocal micrographs of cells subjected to PZT specimen.

#### 3. Results and discussion

The biocompatibility of pure PZT was evaluated; cell proliferation at 96 hours was photographed. The result is shown in Figs. 1(a) and 1(b); the figure shows results for the control group and for cells treated with PZT, respectively. The figure shows that PZT has little effect on the proliferation rate of cells compared with the control group. However, the number of dead white cells increased with time, and the survival time of a cell was shortened extremely by the PZT treatment. This trend also holds when titanium-coated PZT was used. Proliferated cells in the photos were counted; that number was divided by the initial number of cells. These values are shown in Fig. 2 with error bars showing standard deviation. The result in the case of PZT-treated specimens coated with titanium thin films at two thicknesses is shown in the same figure. The results of including 1×10-5#g of ZnO per 1ml of culture media and cultivating a comparison specimen are also shown. From the analysis of variance, no significant difference was observed in the proliferation rate of cells with time after cultivation was initiated. The results are similar for the PZT specimens coated with titanium thin film

On the other hand, our test confirmed that the proliferation rate in the ZnO-treated culture medium, the comparison specimen, was suppressed markedly. The culture appears to be confluent in 72 hours in Fig. 2.



Fig. 2. Proliferation rates of cells subjected to PZT.

The result in the case of as-received PZT and ZnO in the fibroblasts proliferated to confluence is shown in Fig. 3. Dead cells were floating on the salt medium surface with their shape transformed to circular in the ZnO case; no marked difference was observed in the PZT case. The photograph shows that the biocompatibility of the PZT specimen in this test is better than that of ZnO.



*(a)* PZ1 (as received) (b) ZhO *Fig. 3. Confocal micrographs of cells subjected to PZT or ZnO specimen.* 

However, comparison with the control group indicates that, although the proliferation rate of titanium-coated PZT is good, when biocompatibility is judged from cell survival time, it is not necessarily good. Future development of this as a potentially biocompatible material is necessary. Moreover, when a metal enters or is introduced into a living body, it tends to bond with biogenic substances in many cases [1]. Therefore, a different approach is required, such as dipping a metal into blood as well as using a culture medium for cell proliferation containing only the protein component of a biogenic substance. The reason why the proliferation rate obtained in this study is good may reflect the following: titanium and zirconium, highly corrosion resistant components of PZT, block the elution of lead irons, the toxicity of a metal (oxidation and reduction potential) is related to corrosion resistance [5].

## 4. Conclusions

In this study, PZT biocompatibility is examined by targeting a piezoelectric-device material with good biocompatibility as the final goal. Investigations were carried out in the same fashion for samples of PZT with titanium sputtered on the surface. RF magnetron sputtering was used to prepare them. The following results were obtained:

(1) Although the proliferation rate in the case of as-received PZT barely changes compared with the control group, the survival time of a cell becomes extremely short. This trend also holds in the case of titanium-coated PZT.

(2) As-received PZT exposed to cells in a confluent condition shows very good biocompatibility compared with ZnO. However, it is necessary to continue investigations of the relationship to blood conformity and corrosion in the future.

# Acknowledgement

Finally, this study was conducted as part of the "development of synthesis technology of base materials for Bio-MEM", Ministry of Education, Culture, Sports, Science and Technology, a private university biotechnology venture for the research and development base in fiscal year 2000. Discussions with the participants in this venture are deeply appreciated.

# References

- [1] Research Group on Macromolecular Complexes Ed., "An organism and metallic ions", 169 (1991).
- [2] A. Yamamoto, J. Biomed. Mater. Res. 39, 331 (1998).
- [3] I. Kobayashi, Light Metal 52, 7, 330 (2002).
- [4] R. Yamamoto, Materia Japan 40, 1040 (2001).
- [5] S. G. Steinemann, John Wiley & Sons Ltd., 1 (1980).
- [6] H. Kawahara, Monthly Reports of the Japan Institute of Metals **31**,1033 (1992).
- [7] H. Kawahara, Dental-Engineering Magazine 4, 65 (1963).
- [8] T. Sakai, S. Hoshiai and E. Nakamachi, 76th Regular General Meeting of the Japan Society of Mechanical Engineers Kansai Branch 014-1, 4-41-42 (2001).

<sup>\*</sup>Corresponding author: sakai@takamatsu-nct.ac.jp