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Microfabrication Process Using Synchrotron Radiation– LIGA Process

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Recently, micromachining technology has attracted much attention because many practical applications are expected. The LIGA process, which consists of deep X-ray lithography by synchrotron radiation (SR), electroforming and molding, is a highly promising technology. We developed the LIGA process using a compact SR source and a ceramics microfabrication process. These processes enabled us to realize an array of lead zirconate titanate (PZT) rods with a cross section of 25 μm, which were used to manufacture a piezoelectric composite for high resolution ultrasonic diagnosis for the first time. In another case, we applied microdischarge machining with the LIGA process to form a three dimensional structure, and fabricated microconnector. The diameter of this connector is 2.5 mm, and there are 24 cantilever terminals on it. The size of the cantilever terminal is 7 μm thick, and the 80 μm height. These connectors have an automatic connection/disconnection mechanism, the thickness of which is 2mm.
Key words: LIGA, SR, lithography, piezoelectric composite, microconnector

1. Introduction

Nowadays, micromachining technology has attracted the attention because many applications are expected. The LIGA process, which is composed of deep x-ray lithography (DXL), electroforming and molding, is one of the most promising technology. We recognize the future of this process and have studied it using our own SR source, called "NIJI-III", since 1994.
In this paper, we present our unique DXL system [1] and some applications developed by us.

2. DXL

We perform lithography using "NIJI-III" as the SR source. This is a superconducting compact SR source and the circumference is only 19 m. NIJI-III was designed for ULSI fabrication and its peak wavelength is 5 Å. In general, SR with a wavelength between 2 and 3 Å is said to be suitable for DXL. However, the intensity of SR under 3 Å from NIJI-III is about 1% of that from the SR sources normally used for the LIGA process. Therefore, a sensitive resist must be developed.

The developed resist is made of a copolymer of methyl methacrylate (MMA) and methacrylic acid (MAA) and its sensitivity is 10 times higher than that of PMMA, which is conventionally used in the LIGA process. The accuracy is worse than that of PMMA, but 0.16 μm per 100 μm height. This is sufficient for many applications. As a result, the exposure time using a compact SR source is on the same order as that of PMMA with a conventionally used SR source.

The mask is composed of a 2 μm thick SiN membrane and a 5 μm thick WN absorber, which is patterned by ECR etching. The substrate is cooled to −30℃, and side etching is suppressed to less than 0.2 μm.

3. Piezocomposite transducer for medical diagnosis

Medical ultrasonic diagnosis has been widely used because of its weak influence on patients, and abilities of blood flow and realtime measurements [2-4]. Since the improvement of the resolution is an ongoing requirement, many techniques are being studied. To achieve this, in particular, the replacement of the transducer material from piezoelectric ceramics such as PZT to 1-3 piezoelectric composites, as shown in Fig. 1, is a promising idea. However, by the conventional dice-and-fill method, it is impossible to fabricate PZT rods which are small enough to cause the composites to behave like homogeneous materials.

We applied the LIGA process and developed a mass-production process (see Fig. 2), and made piezoelectric

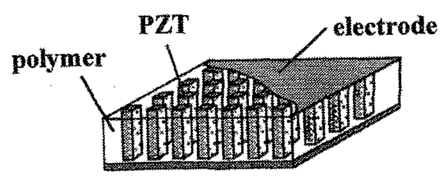


Fig.1 Schematic view of piezoelectric composite.

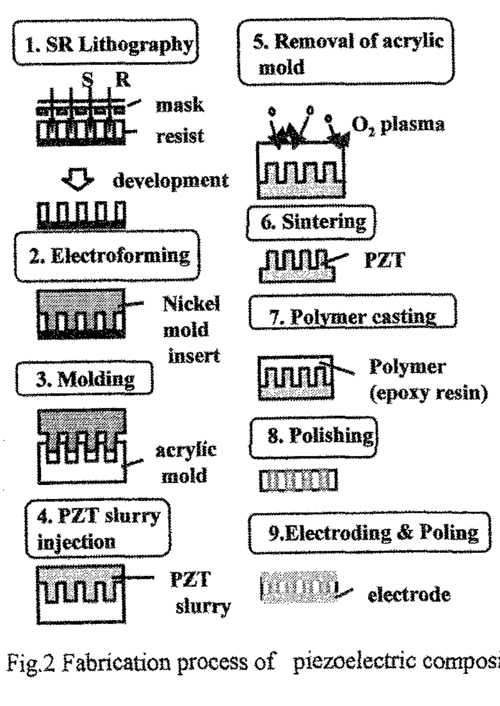
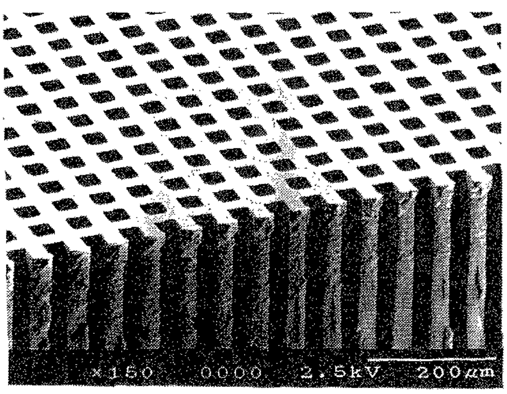
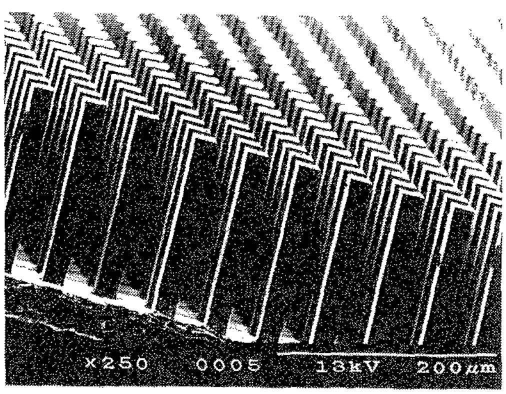


Fig.2 Fabrication process of piezoelectric composite.

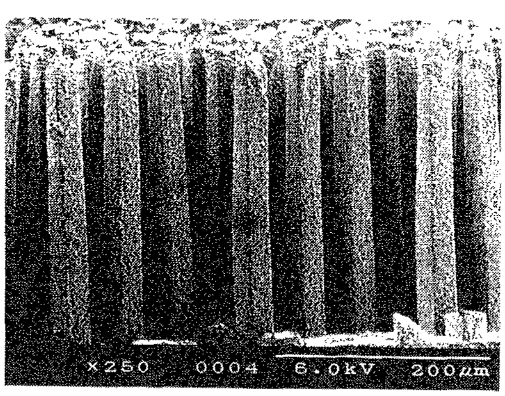
composites for high frequency applications industrially available for the first time. The PZT rod size of 25 μ m was realized. This is one-fifth of the size realized by conventional methods. The characteristic feature is the method of removing the acrylic mold. In the conventional "lost wax" method, a burn-out process is usually adopted to remove the plastic mold. However, the fine PZT rods with a high aspect ratio topple during this process. Therefore, we adopted plasma etching.



(a) Resist structure.



(b) Nickel mold insert.



(c) As-sintered PZT rod array.

(25 μ m square, 250 μ m height)

Fig.3 SEM photographs.

A test probe for 10 MHz was made to measure the properties. The pulse width was recognized to be one-third shorter and the sensitivity was 3 times higher than those of PZT probe. The developed piezocomposite is thought to contribute to the improvement of the resolution.

4. Microconnector

Micromachines must operate as a group because the power of an individual micromachine is low and its functions are limited by its size. One example is the chain-type micromachine system shown in Fig. 4, one of MITI's micromachine projects. To realize this chain-type micromachine system, small connectors having a large positioning margin and an automatic connection/disconnection function are necessary [5,6]. The requirements for the microconnector are summarized in Table I.

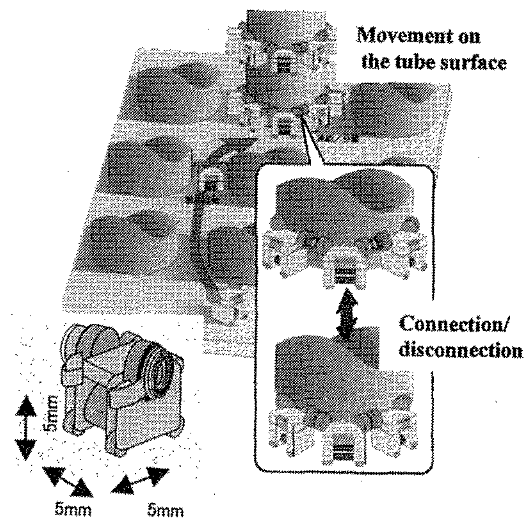


Fig.4 Schematic view of the system for inspecting the outer surface of tubes.

Table I Requirements of the microconnector

Connection /Disconnection	**Automatic (remote control)**
Connectable Distance	**> 500 μ m**
Thickness	**< 2mm**
Diameter	**< 2.5mm**
Electric line	**7**
Current	**500mA (max. 150mA/line)**

4-1. Concept and design

The schematic configuration of the microconnector is shown in Fig. 5. In order to achieve automatic connection/disconnection, a large positioning margin is required. Thus, we arranged the terminals and tapered guides cylindrically. Furthermore, to generate rectification force, the guides of one side of the connector are concentric double rings, and the permanent magnet is installed in the center of the connector. To decrease the load of the actuator, the terminals were coated with Au, and the contact force of the terminals was designed to be 0.5 mN, which is the minimum value required to maintain stable electrical contact between Au and Au. Young's modulus of our electroformed micro nickel structure was measured as 250 GPa. This value is higher than that of conventional nickel bulk (200 GPa). This resulted from the tiny size of crystals of about 50 nm.

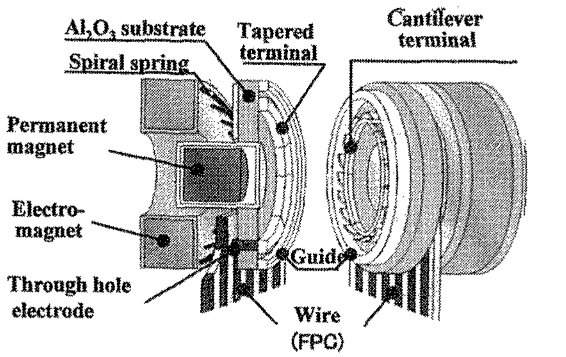


Fig.5 Schematic view of the microconnector.

4-2. Fabrication process of electrical terminals and guides

We fabricated the terminals and guides using DXL and electroforming to achieve high accuracy and a high aspect ratio.

The cantilever terminals were fabricated using a one-layer sacrificial process, as shown in Fig. 6. The 3-μm-thick sputtered titanium (Ti) on the Al_2O_3 substrate is the electroforming electrode and the sacrificial layer. The width of the cantilever terminal is 7 μm, and its height and length are 80 μm and 250 μm, respectively. Therefore, when the Ti layer under the cantilever is removed by wet etching, that under the anchor area remains. Figure 7 shows the cantilever terminals and guides. A fabrication accuracy of less than ± 0.5 μm was achieved.

Tapered terminals and guides for smooth connection with the microconnectors were fabricated by microelectrodischarge machining (μ-EDM) combined with a LIGA-like process. Figure 8 shows the fabricated structures of tapered terminals and guides.

For stable electrical contact under a weak contact force, the terminals are coated with 0.1 ~ 0.5– μm-thick electroplated or electroless-plated Au. The roughness of the Au surface is less than 30 nm (Ra).

4-3. Electric properties of microconnector

An electrical contact was achieved at each terminal of the microconnector. The connection resistance of the micro connector through the FPC is approximately 3.6 Ω/line. The breakdown voltage is 370 V(DC) at atmospheric pressure in air. This is sufficient to drive the device mounted on the micromachine.

We demonstrated the automatic connection/disconnection of the microconnectors, for gap between 300 μm and 800 μm. A ± 5 degree margin of the alignment angle during automatic connection/disconnection was achieved when the initial gap was 500 μm.

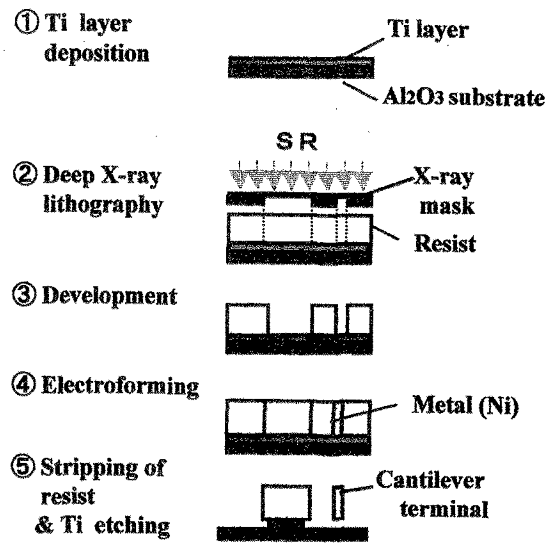


Fig.6 One-layer sacrificial process for cantilever terminals.

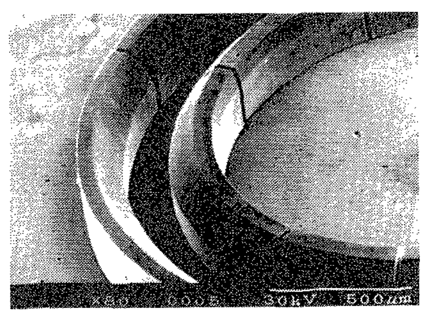


Fig.7 SEM image of the cantilever terminals.

Fig.8 SEM image of the tapered terminals.

5. Conclusions

We developed DXL for a compact SR source and applied it for the commercialization of piezoelectric composite ultrasonic transducers and development of microconnectors. We also developed a microarray electron multiplier and microactuator for hard-disk drives.

We consider that one of the most important point to realize the industrialization of LIGA applications is the reduction of the process cost, especially for manufacturing metallic parts. We are making efforts to solve that problem in order to make many LIGA applications industrially available.

Acknowledgement

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References

[1] T. Numazawa, Y. Hirata and H. Takada, "The copolymer of methylmethacrylate and methacrylic acid as a sensitive resist for deep-etch x-ray lithography", Microsystem Technologies, Vol. 2, No. 2, pp. 46-49, 1996

[2] Y. Hirata, H. Okuyama, S. Ogino, T. Numazawa and H. Takada: Proc. IEEE MEMS'95 pp. 191-196,1995.

[3] Y. Hirata, H. Nakaishi, T. Numazawa and H. Takada, "Piezocomposite of fine PZT rods Realized with Synchrotron Radiation Lithography", Proc. IEEE Ultrason. Symp., pp. 877-881, 1997.

[4] Y. Takeuchi, M. Nozaki, Y. Hirata, H. Takada and L.S. Smith, "Novel 1-3 piezocomposites using synchrotron radiation lithography and its application for high frequency medical imaging arrays", Proc. IEEE Ultrason. Symp., pp. 919-922, 1997

[5] H. Okuyama, T. Haga, K. Emura and H. Takada, "Development of microconnector with automatic connecting/disconnecting mechanism", Proc. IEEE MEMS'99, pp. 257-262 ,1999

[6] T. Haga, H. Okuyama and H. Takada, "Development of microconnector with automatic connecting/disconnectiong mechanism", Microsystem technologies, Vol. 6, pp. 157-160, 2000

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