PLANER FABRICATION OF MULTILAYER PIEZOELECTRIC ACTUATOR BY GROOVE CUTTING AND ELECTROPLATING

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ABSTRACT

This paper reports a new planer fabrication method of multilayer piezoelectric actuator. In this method, three techniques, dicing, electroplating and laser assisted etching (LAE), were used for constructing the multilayer structure. Prototype actuators with 23–120 active layers were fabricated in this method. The measured displacement was 2.5μm (23 layers) and 7.3μm (120 layers) at 100V, respectively. These values agree with the calculated values from the piezoelectric properties of the material.

INTRODUCTION

The multilayer (stacked) piezoelectric actuators have many advantages, for example, large generative force, low drive voltage and quick response[1]. These actuators are generally made by sintering a stacked green sheet and silver paste structure. This method is called 'the tape casting method'. A typical product has 100 active layers of which thickness is 100μm. This expands about 10μm when applied voltage is 100V. In order to fabricate the stacked actuators with very thin layer for the low drive voltage, novel batch fabrication method using Si lost mold technique and hot isostatic pressing (HIP) was proposed[2].

The tape casting method is suitable for the mass production. However, the extra processes are required for fabricating actuator arrays because the monolithic fabrication of an array structure is difficult in this method. If the actuator arrays that constructed by the multilayer piezoelectric actuators can be produced in the simple and monolithic method, it is considerable to apply the various devices that require the small size and large generative force actuator arrays, for example, active flow controller, tactile display for blind people and electric switch of low contact resistance.

In this paper, we take another approach that is suitable for fabricating small actuator arrays and mechanism integrated actuators. We used commercially available high-performance PZT plate. The structure of the multilayer piezoelectric actuator was constructed on this plate by three techniques, dicing, electroplating and laser assisted etching (LAE). This planer fabrication method is simple and low-cost.

Deep and narrow grooves can be made at high speed by dicing saw. Then metal layer is formed into the grooves by electroplating. Parallel electrodes and cross-angled interconnections are constructed in fine pitch. However, the grooves processed by dicing saw are crossing from end to end of the PZT plate, so all electrodes are shorted. To use this as a multilayer piezoelectric actuator, alternate interconnection of parallel electrodes were made by removing the PZT and metal locally. LAE is applicable for this process. LAE was developed for the processing of ceramics, for example, Al_2O_3/TiC[3]. In the case of PZT, LAE can be done using various laser as previously reported[4][5][6].

First, the outline of proposed fabrication process is indicated, then problems of the process and its solutions are discussed. Next, the displacement characteristics of prototype actuators are evaluated. Finally, the advantages of our method and plans for practical applications are discussed.

PROCESS

Fabrication method

The planer fabrication method of multilayer piezoelectric actuators is shown in Fig. 1. We used commercially available high-performance PZT ceramic plates (Tokin Co. N–10), 500μm in thickness, for the material of the active layers.

In the first step, Narrow grooves with 130μm pitch were cut on the top side of the PZT plates (Fig. 1(2)). We used a dicing saw (DISCO Co. Ltd. DAD522) for this process. Grooves with 30μm width were obtained by using a 25μm thick blade. The thickness of the parallel electrodes is determined by the width of these grooves, so it is desirable to use a blade as thin as possible.

Conductive metal, for example, Au/Cr, was deposited by sputtering on the grooved surface, and was polished

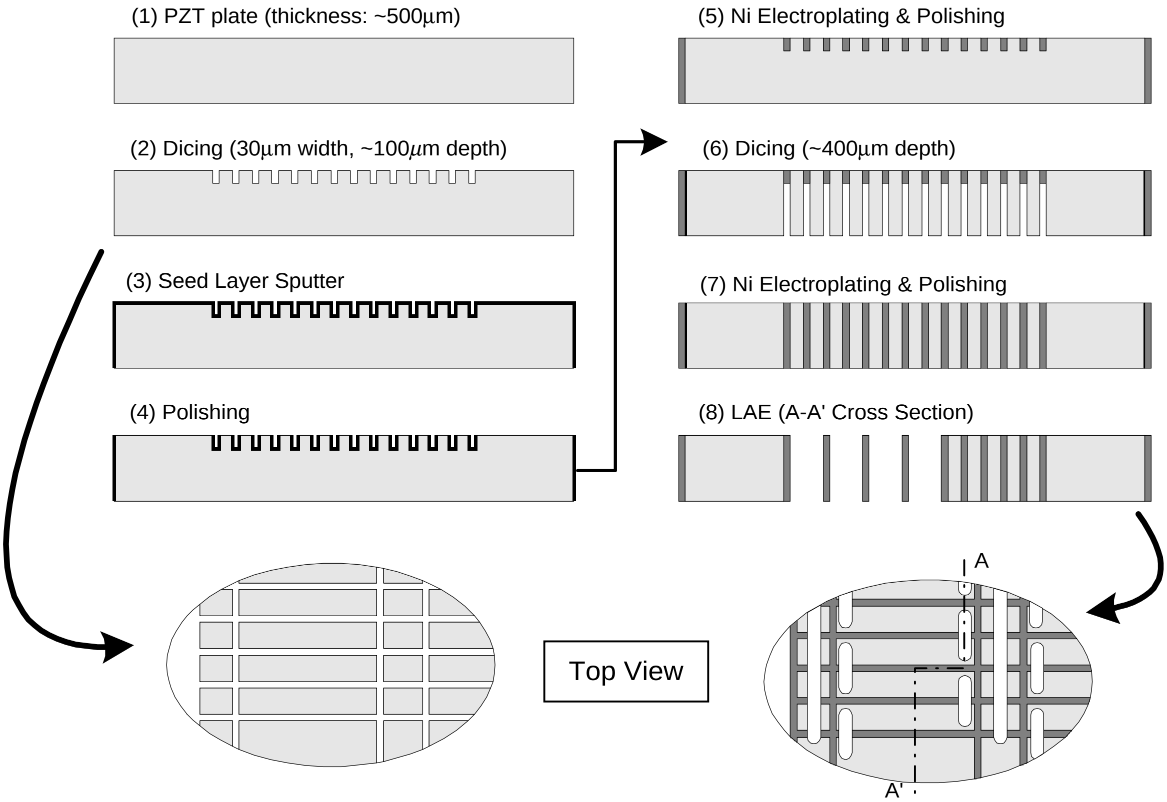


Figure 1: Fabrication processes of multilayer piezoelectric actuator by dicing, electroplating and LAE

Table 1: The electrolyte composition for Ni electroplating

component	
$Ni(OSO_2NH_2)_2 \cdot 6H_2O$	225 g
$NiCl_2$	15 g
H_3BO_3	15 g
DI water	500 ml

away except in the grooves (Fig. 1(3)∼(4)). Then first Ni electroplating was carried out (Fig. 1 (5)). Nickel sulfamate solution was used as an electrolyte in order to reduce the residual stress and to increase the deposition rate. The used electrolyte composition for Ni electroplating are shown in Table 1.

In the next step, as shown in Fig. 1(6), grooves were cut 400μm depth from the bottom side of the PZT plate. This value was determined from the thickness of the PZT plate and the groove depth of first dicing. This bottom grooves should be aligned with the top grooves. Second Ni electroplating process was carried out (Fig. 1(7)) using the first metalized Ni as a cathode. The PZT plate after this process is shown in Fig. 2. The electrodes that penetrate the PZT plate were formed in this process, but these were still shorted in this stage.

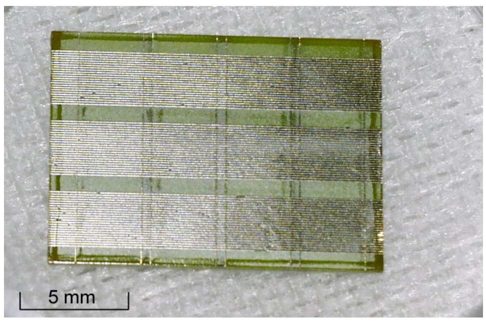


Figure 2: Sample photograph after Fig. 1(7)

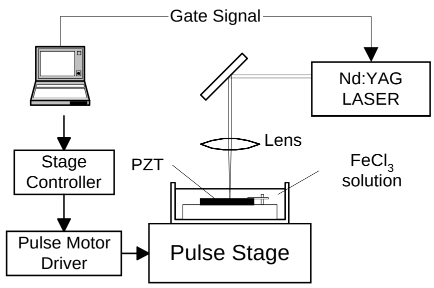


Figure 3: Schematic diagram of LAE system

Finally, LAE was used for cutting out the unnecessary part. The schematic diagram of used LAE system is shown in Fig. 3. These are shown in Fig. 1(8). Alternate interconnection of inner electrode was made by locally removing the PZT and Ni. Each actuator element was separated simultaneously in this process. Fig. 4 shows the SEM photograph after the LAE process.

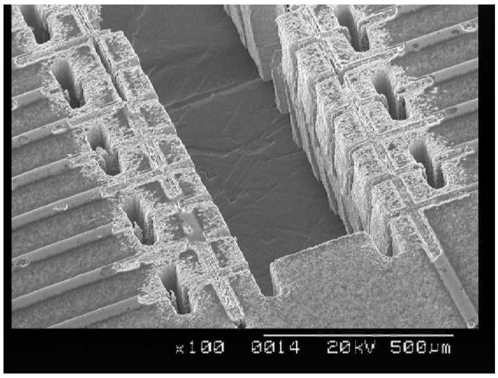


Figure 4: SEM photograph after LAE Process

The problems of process

Electroplating in deep grooves

If the deep grooves were cut in Fig. 1 (2) stage, large cavities, as shown in Fig. 5, were unexpectedly formed in Ni electrode. This means that the groove opening was blocked by the deposited nickel the inner part deposition was not finished.

To avoid this problem, dicing and electroplating processes are repeated twice. The first electroplated Ni layer is shallow in order to avoid the cavity formation. This layer is used for the seed layer of second electroplating process. In the second process, Ni seed layer exists at the bottom of the groove, so Ni deposition also occurs only at the bottom of groove, and progresses toward the opening. As a result, deep grooves are filled completely as shown in Fig. 6.

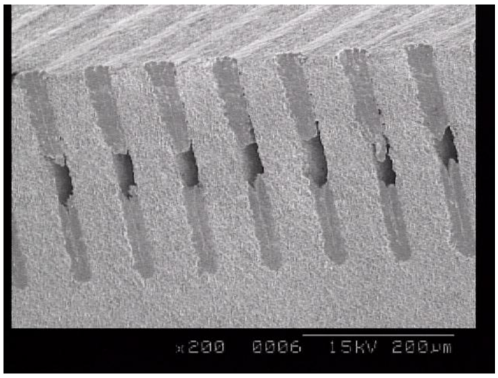


Figure 5: An example of cavity formation during electroplating

LAE of PZT/Ni structure

In the case of PZT etching, LAE can be done in KOH solution[4][5][6]. However, because Ni has etch resistance for KOH, complete cutoff of the Ni electrode by LAE was difficult in KOH solution as shown in Fig. 7(a).

In this study, $FeCl_3$ solution was used to etch PZT and Ni, instead of general KOH solution. The $FeCl_3$ solution is one of the etchant for Ni, so good result is achieved as shown in Fig. 7(b). But if the $FeCl_3$ concentration is too high, non-assisted part will be etched away. So 2–5 wt% $FeCl_3$ solutions were used for this reason. The etching reaction of Ni is thermally assisted by the laser light.

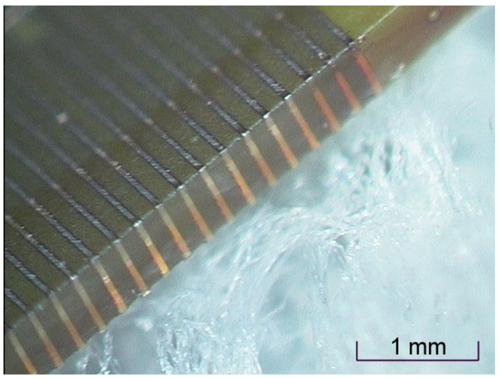


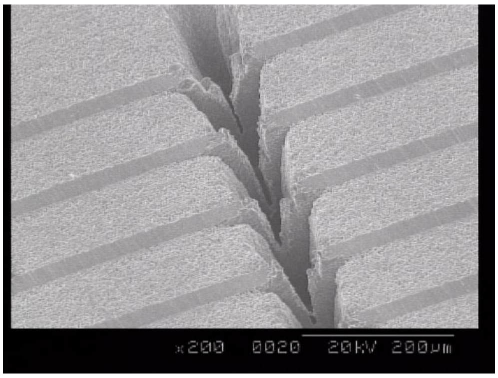
Figure 6: Sample photograph without cavity by this method

RESULT AND DISCUSSION

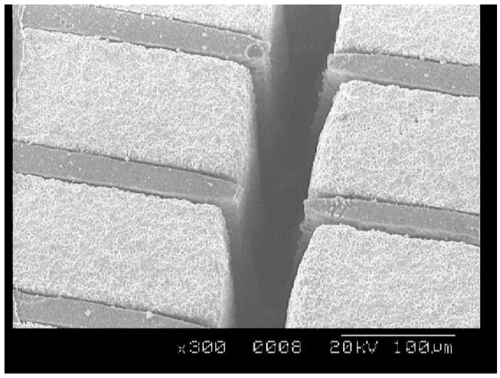
Displacement characteristic

The fabricated actuators are shown in Fig. 8. These actuators have a multilayer structure in which 100μm thick PZT layers and 30μm thick Ni layers are stacked. The height of all actuators is 500μm. Each actuator shown in Fig. 8 has (a) 23 PZT layers, 3mm width, 3mm length, (b) 60 PZT layers, 2mm width, 8mm length, and (c) 120 PZT layers, 2mm width, 16mm length, respectively.

These actuators were polarized by applying DC 200V at

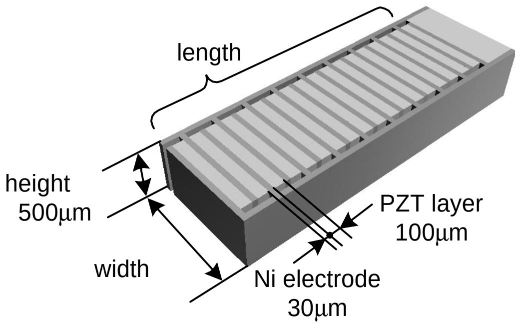


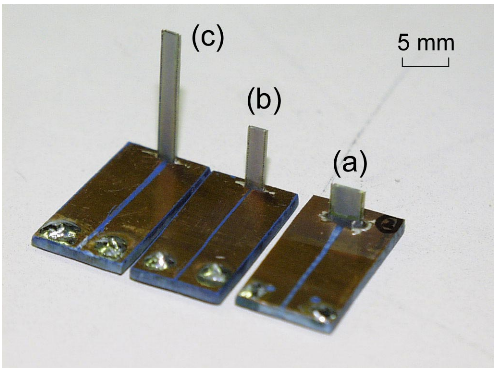
(a) KOH 30wt%



(b) $FeCl_3$ 2wt%

Figure 7: LAE results of PZT/Ni structure in KOH and $FeCl_3$ solutions





(a) 23 layers, width=3mm, length=3mm
(b) 60 Layers, width=2mm, length=8mm
(c) 120 Layers, width=2mm, length=16mm

Figure 8: Multilayer piezoelectric actuator fabricated by planer processes

100 ℃, for 30min., then expand displacement characteristics versus DC drive voltage were measured using the focus point detection mode of the scanning laser microscope. The result is shown in Fig. 9. The displacement at 100 V was about 2.5μm (23 layers) and 7.3μm (120 layers), respectively. These values agree with the calculated values from the piezoelectric properties of the material. This means that piezoelectric properties of the used material are preserved in the fabrication processes.

Bending displacement problem

When DC drive voltage was applied for the displacement measurement, undesirable bending displacement was also observed. Such displacement was especially large in the long actuator. The displacement of Fig. 8(c) actuator tip was about 50μm at 200 V. This value was 4 times larger than the expand displacement.

It is assumed that a non-uniform force distribution in thickness causes the bending displacement. For example,

- The wedge shape profile of the LAE grooves causes restriction force non-uniformity.
- The slight inclination of inner electrode induced by the dicing process causes expand force non-uniformity.

This problem is not resolved yet, so there is room for further investigation.

Discussions for practical use

In our method, a long, narrow actuator that has a large number of active layers can be easily fabricated. Furthermore, because each actuator element is separated by the

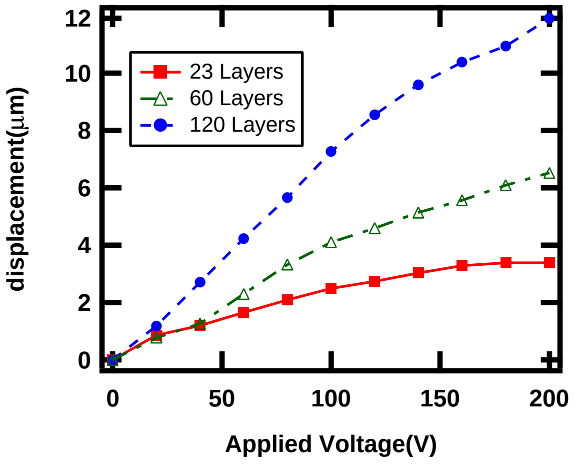


Figure 9: Displacement characteristics of the fabricated actuators

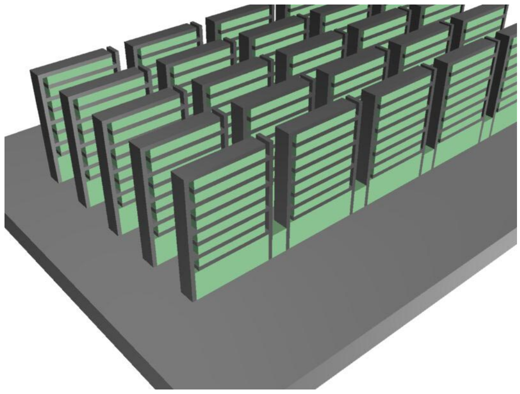


Figure 10: Schematic view of the actuator array for tactile display

local LAE cutting, it is possible to cut only the part between adjacent active elements and keep the connection at non-active edge part. This means that the monolithic linear actuator array can be fabricated without adding processes. It is one of the great advantage of our method.

Therefore, various applications, for example, the tactile display for blind peoples as shown in Fig. 10, would be considered. Because multilayer piezoelectric actuators generate large force, our method is suitable for such purpose.

However, expand displacement of our actuators was about 10μm. This value is too small to use for tactile display. Most simple method to obtain a large displacement is to increase a number of active layer. But this method makes actuator longer, depending on the circumstances,

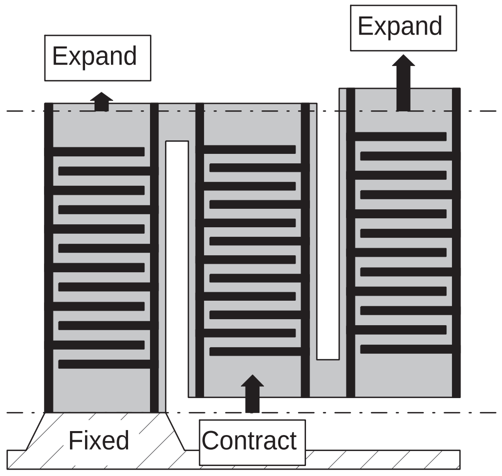


Figure 11: An example of planer actuator structure with large displacement capability

it is not desirable. To avoid this problem, the structure as shown in Fig. 11 is under consideration. On this structure, two adjacent element displace in the opposite direction, expansion and contraction, respectively. As a result, the displacement of each element is added one after another, then large displacement could be obtained.

On the other hand, it is considerable to integrate the flextensional motion structure for obtaining large displacement, for example, like 'moonie'[7] and 'cymbal'[8], or those arrays[9]. Local area cutting by LAE is used at the last stage of fabrication, so it is possible to fabricate monolithic structure as shown in Fig. 12. Processes for the monolithic fabrication will be investigated.

CONCLUSION

In this paper, we propose a new planer fabrication method of multilayer piezoelectric actuator. Three techniques, dicing, electroplating and LAE, were used in this method. Dicing and electroplating were repeated twice in order to avoid the formation of large cavity in Ni electrode. $FeCl_3$ solution was used as a etchant in LAE process, instead of KOH solution. The fabrication of a multilayer structure was realized by these techniques.

The prototype actuators were fabricated in this method, then the displacement characteristics are evaluated. The measured displacement was 2.5μm (23 layers) and 7.3μm (120 layers) at 100V, respectively. These values agree with the calculated values from the piezoelectric properties of the material. However, large bending displacement was also observed. This problem should be solved in the future.

It is one of the great advantage of our method that the

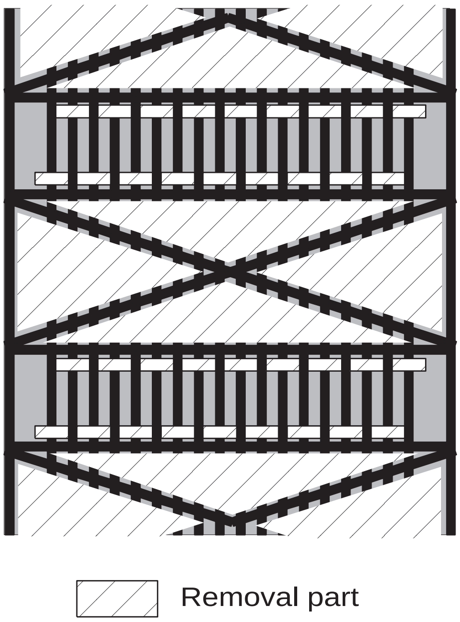


Figure 12: The structure of 'cymbal' like actuator array for obtaining large displacement

monolithic linea actuator array can be fabricated easily. Therefore, various applications, for example, the tactile display for blind peoples would be considered. But the obtained displacement is too small to use for such purpose, so any structure for displacement enlargement should be integrated for the practical use. This is a present subject to be solved.

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