Paper

Micro Connector for High Packaging Density Fabricated by Using UV Thick Photoresist

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ABSTRACT

A fork - type micro connector with high aspect ratio and high packaging density was fabricated using UV thick photoresist and Ni electroforming. A negative photoresist (THB - 130N) was used as a mold for Ni electroforming. The tips of the plug terminal of the micro connector were formed as movable portions using Cu sacrificial layer etching. In order to make firm contact of the micro connector, a two-step guidance was adopted. The size of the terminal of the fabricated micro connector was 50 μm-thickness and 15 μm-width (minimum). The maximum aspect ratio of the fabricated micro connector was 3.3 and the terminal pitch 80 μm. A contact resistance of 50 mΩ, a contact force of 2.08 mN, Young's modulus of 80 GPa and a permissible current were obtained for practical use for the micro connector.

Keywords: *micro connector, thick photoresist, high packaging density, contact resistance.*

1 INTRODUCTION

Recently, miniature, light and high functional electronic devices have been developed using high functional LSIs called SOC (system on chip) [1]. Miniature connectors with smaller pitches have been required in order to satisfy specifications of these electronic devices. At present, the minimum pitch of commercial connectors is 300 μm, and the manufacturing method is pressing and injection molding [1]. It is difficult to make connectors with pitch smaller than 300 μm by using the pressing and injection molding. The pressing and injection molding are not compatible with high-density packaging, which is required in the advanced IT (Information Technology) market [1] - [4]. This study focuses on fabrication of micro connectors by combining UV thick resist photolithography and Ni electroforming. This fabrication method is expected to realize high precision micro connectors and high - density packaging in mass production.

2 DESIGN OF MICRO CONNECTOR

2.1 Design Concept

Fig. 1 shows conventional connectors of fork and cantilever - type [1]. The most suitable structure must be chosen, in order to fabricate the micro connectors using micro fabrication by photolithography and electroforming. To fabricate the cantilever type, many layers of photoresist should be stacked. On the other hand, since the fork-type shape is planar, it can be fabricated using a single layer structure. The number of photomasks required for fork - type connectors is less than that of the cantilever - type, therefore the fork - type has been adopted.

Stable electrical signal can be transmitted only when the plug and socket are completely connected. If contact force between them is not firm enough or gaps between them occur, then variation in contact resistance leads to unstable electrical signal transmission. For this reason, it is important to secure the contact force in the design.

Determining the contact force necessitates an investigation of material quality, dimensions of the terminals, and displacement at contact points when the socket and plug terminals are connected. Moreover, the gaps between the adjacent socket terminals should be taken into account.

2.2 Design of Socket and Plug Terminals

Fig. 2 shows the shape and dimensions of the socket and plug terminals. The minimum width (15μm) and the maximum thickness (50μm) of the plug and socket terminals were determined from the minimum space (15μm) and the maximum aspect ratio (3.3) of the mold for electroforming, which can be achieved by using the UV thick photoresist (THB - 130N) [6]. Once these two dimensions were fixed, the length can be determined to satisfy the specified contact force and the displacement of the socket terminal taking into account the mechanical properties of Ni.

Based on the FEM analysis for load – deflection relation of a single cantilever of the socket terminal, the dimensions are determined to satisfy the specified contact force. Fig. 3 shows the finite element modeling. Ni is selected for structural material. Young's modulus E = 200GPa and Poisson's ratio ν = 0.3 are used for the analysis [4]. The contact force of 4.5 mN is obtained when the displacement of the socket terminal is 5 μm. The maximum Mieses stress is 190 MPa and lower than typical yield stress of electroformed Ni [5]. In order to assure a socket terminal displacement of 5 μm, the dimensions of the socket gap and plug should be 10 μm and 20 μm, respectively (see Fig. 2).

To avoid contact between the adjacent socket terminals when the plug terminals are connected to the socket terminals, the gap between the socket terminals should be set at 20 μm. Consequently, a connector pitch of 80 μm can be realized (Fig. 2). The micro connector can be fabricated, based on these parameters. Table 1 shows the comparison between specifications of the commercial connector and that of the present micro connector [1].

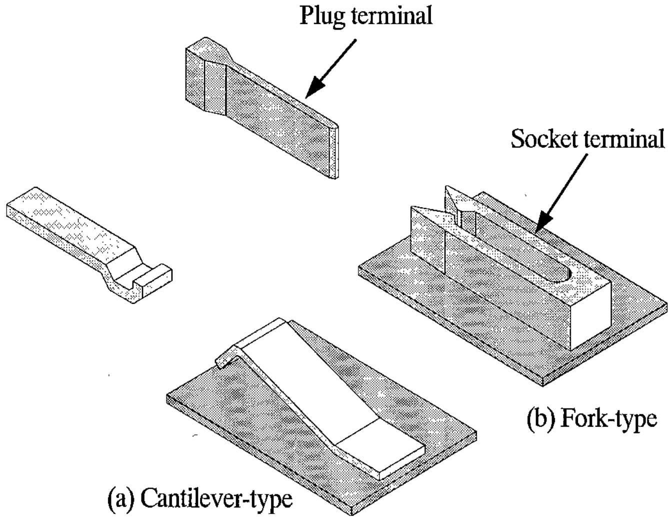


Figure 1. Schematic of conventional connectors.

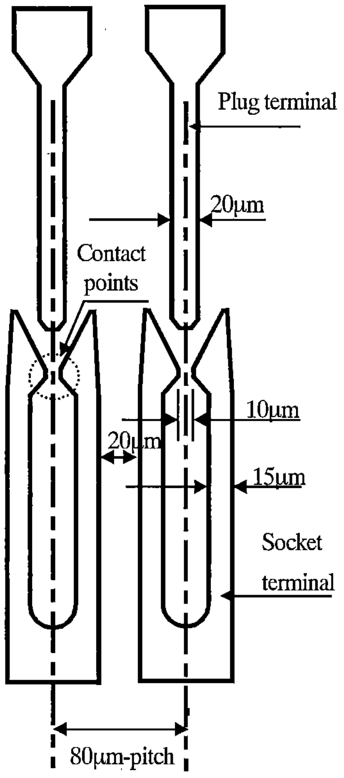


Figure 2. Schematic of socket and plug terminals.

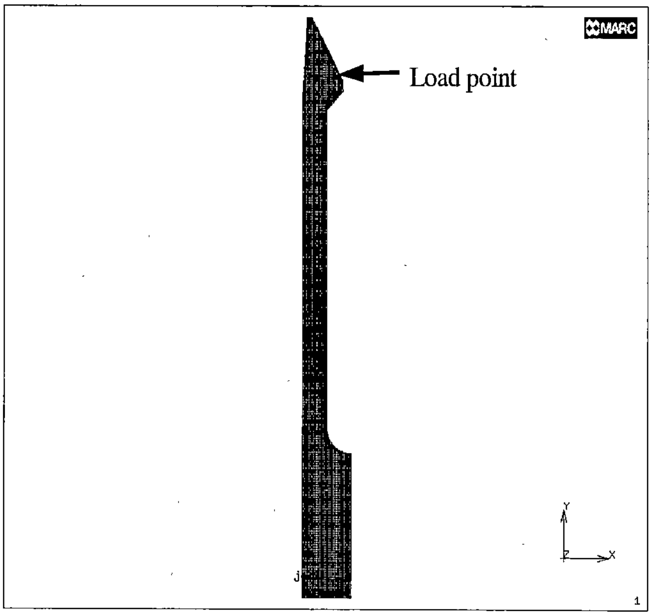


Figure 3. Analytical

2.3 Design of Housing

The structure of the micro connector is shown in Fig. 4. Although the terminals of the micro connector are in micro scale, manual insertion and withdrawal are necessary. In order to make firm contact between the plug and socket, two-step guidance is adopted as shown in Fig. 4. The guides are designed to always contact prior to the terminals. The first guide is of millimeter order, to allow guidance of the socket to the plug before the second guide makes contact. The second guide is of micrometer order, and can be used to connect the terminals precisely.

The structure of the housing is shown in Fig 4. The housing and first guide is made of alumina. The structure of the plug and the socket are shown in Fig. 5. The plug and socket terminals are arranged on an insulation layer on a silicon substrate, and the second guides are arranged on both sides of the terminals. Fig. 6 shows the assembly of the plug, the socket and the housing. As shown in the Fig. 6, the plug and the socket are connected by turning the planes upside down.

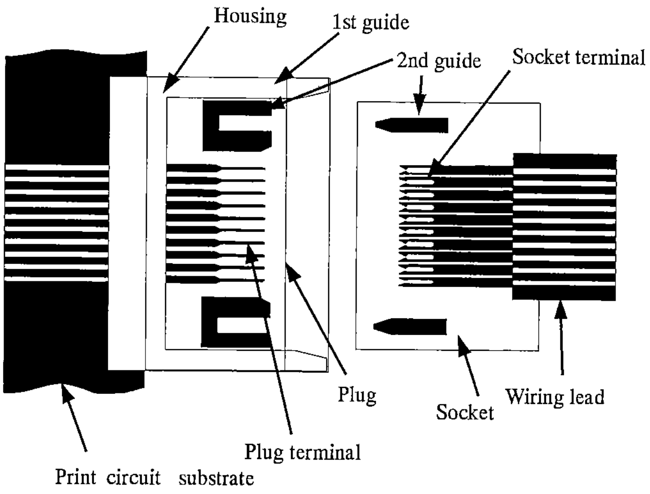


Figure 4. Schematic view of micro connector.

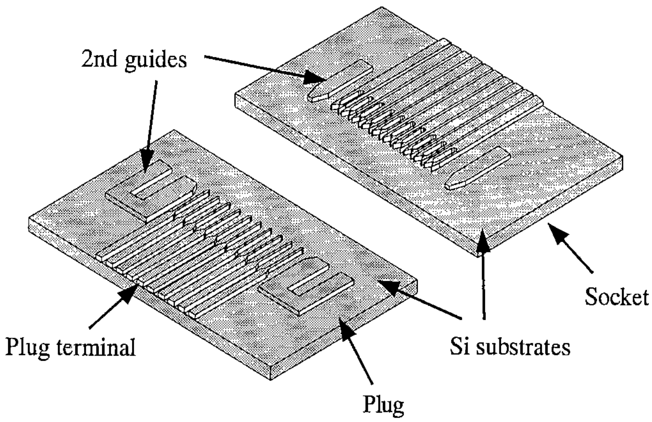


Figure 5. Schematic view of plug and socket.

Table 1. Comparison of the micro connector with commercial connector having minimum pitch.

	Commercial connector	**Micro connector (Target value)**
Application	Mobile device	Wearable device
Classification	Board to Board	Board to Board
Structure	Fork-type / Cantilever-type	Fork type
Pitch	300 μm	80 μm
Number of Pins	20 ～100	100
Permissible current	Less than 500 mA	Less than 10 mA
Contact resistance	Less than 5 mΩ	Less than 50 mΩ
Temperature	Operating temperature: -20～85°C (Including the temperature rise 30°C) Storage temperature: -40～85°C	Operating temperature: -20～85°C (Including the temperature rise 30°C) Storage temperature: -40～85°C
Contact force	More than 290mN /pin	More than 4.5mN / pin
Packaging density	3pin/ mm	12 pin/ mm
Fabrication technology	Pressing and Injection molding	Photolithography Micromachining Technology

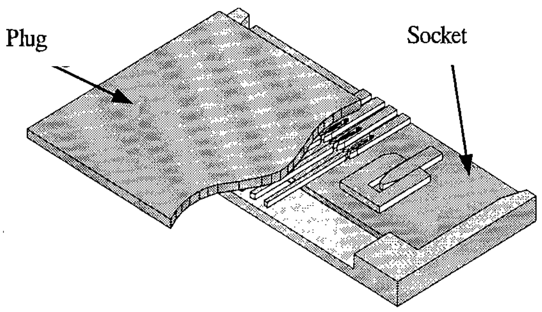


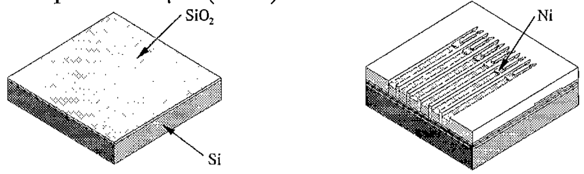
Figure 6. Schematic view of inserted micro connector.

3 FABRICATION PROCESS

The high aspect ratio micro connector increases the contact area of plug and socket terminals, while it decreases contact resistance. Consequently, it improves the reliability of electrical signal transmission. In order to make the terminals thicker, UV thick resist photolithography is necessary. A fabrication process of the micro connector combining UV thick resist photolithography and Ni electroforming was adopted to satisfy the above-mentioned specifications.

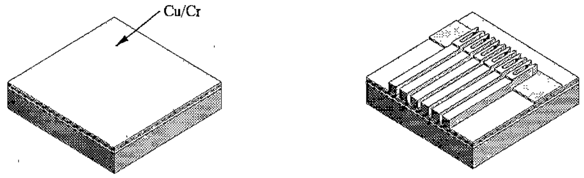
The fabrication process of the micro connector is shown in Fig. 7. First, a SiO_2 layer is deposited on the silicon substrate by pyrogenic oxidation (a). Next, Cu/Cr is deposited on the SiO_2 by vacuum evaporation (b). Then, positive photoresist is patterned for the sacrificial layer. Based on the etching selectivity of the sacrificial layer to Ni with the specified etchant (nitric acid), Cu is chosen for the material of the sacrificial layer. Cu electroforming forms the sacrificial layer. The measurements of the thickness for the Cu sacrificial layer and the Ni microstructure at the center and the 4 peripheral points on the wafers reveal that the in-plane variations of the thickness were within 4%, respectively (c). UV thick photoresist (THB - 130N) [6] is formed as a mold for the terminals The photoresist was spun on the Si substrate having Cu/Cr seed layers. The measurement of the thickness at the center and the 4 peripheral points on the wafer reveals that the in-plane variation of the thickness was within 4% and the average value was 55 μm. The taper angle of cross section of the photoresist as a mold for the terminals was investigated. The upper side space width was 15 μm and the lower side space width was 18.7 μm, when the thickness was 55 μm. Therefore, the shape of cross section was a trapezoid, and the taper angle was 91 degree. The taper angle was defined as a reentrant angle between sidewall of the photoresist and the Si substrate having Cu/Cr seed layers (d). Based on the investigation of ease of electroforming, and mechanical properties to satisfy the specified contact force, Ni is chosen for the material of the terminals. Ni is electroformed in the mold (e). Next, the photoresist, the sacrificial layer, and the Cu/Cr layer are removed in order (f)(g). To avoid corrosion and secure the electrical conductivity at contact points, Au is electroplated on the surface of the Ni terminals (h). Finally, dicing separates the sockets and plugs.

Fig. 8 shows SEM photographs of the plug and socket terminals which were formed by the Ni electroforming. Fig. 9 shows the comparison between a commercial connector with a pitch of 500 μm (upper), and the present micro connector with the pitch of 80 μm (lower).



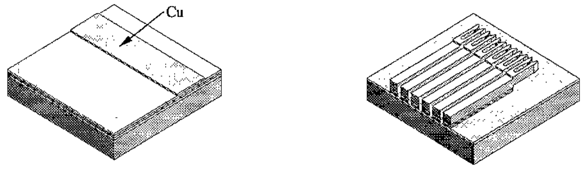
(a) Pyrogenic oxidation

(e) Ni electroforming



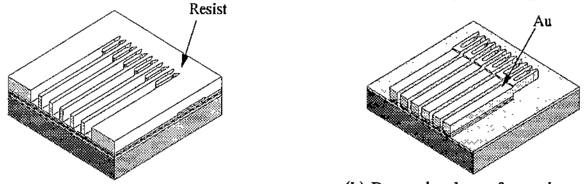
(b) Seed layer vacuum evaporation

(f) Resist removal



(c) Sacrificial layer formation

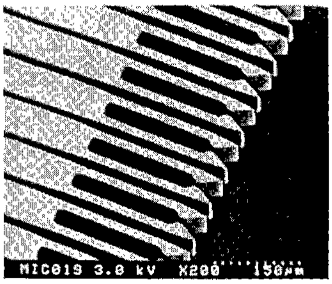
(g) Sacrificial layer and seed layer etching



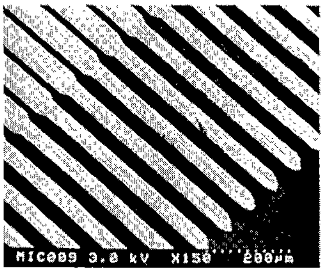
(d) Mold formation

(h) Protection layer formation

Figure 7. Fabrication process of micro connector.



Socket terminals.



Plug terminals.

Figure 8. SEM photographs of socket and plug terminals by Ni electroforming.

4 EXPERIMENTAL RESULTS

4.1 Contact Resistance

Insert connection was confirmed for single pair of the plug and socket terminals on a fabricated connector. The plug terminal was separated from the substrate and was inserted in the socket terminal manually under microscope observation. Contact resistance between the single plug and single socket was measured by the four-point probe method (see Figure10). 10 of 100 pins were chosen arbitrarily in order to investigate the variations in the contact resistance and the contact force. The variation in contact resistance was 37.3 to 50.2 mΩ, and the average value was 43.8 mΩ. Electrical current of 20mA was used for the measurement. In Fig. 10, the values of the conductor resistance of socket and plug terminals were subtracted from experimental value to determine the value of the contact resistance.

4.2 Contact Force

Contact force is a crucial factor to control the contact resistance. In order to obtain the contact force F against the tip of socket terminal u, the load-deflection relation in the cantilever beam was measured by using a nano indentation instrument. Fig. 11 shows the experimental set up where the socket terminal is used as the cantilever beam. Fig. 12 shows the measurement results. The load was kept constant at the maximum value for a few seconds prior to unloading process, in order to check and remove the creep effect on the measurement. This is the reason why the short saturation regime was observed [7]. The loading curve is well approximated by linear relation. Therefore, it is valid to use the loading slope to obtain the contact force at the specified displacement. In contrast, the unloading curve is slightly nonlinear due to the stress relaxation effect [7], and not suitable to use this purpose. As can be seen from Figure.12, the value of F was 2.08 mN where u was 5μm. The design value of F was 4.5 mN. The variation in contact force was 2.08 mN to 3.76 mN, and the average value was 3.11 mN.

As one possible way to interpret the difference in these values, relatively lower Young's modulus of the fabricated Ni microstructure was expected. In the following section, Young's modulus of the Ni microstructure was investigated.

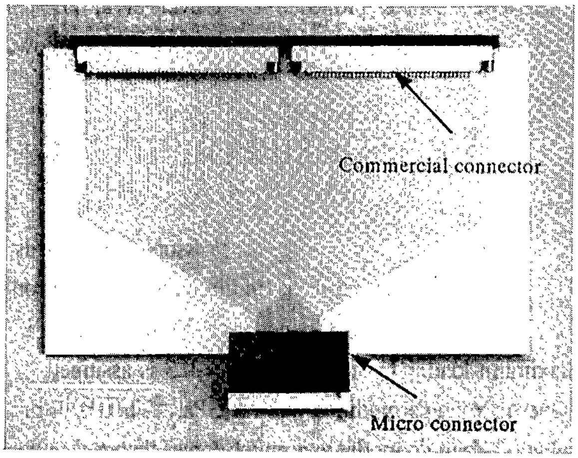


Figure 9. Comparison of packaging density between commercial and micro connector.

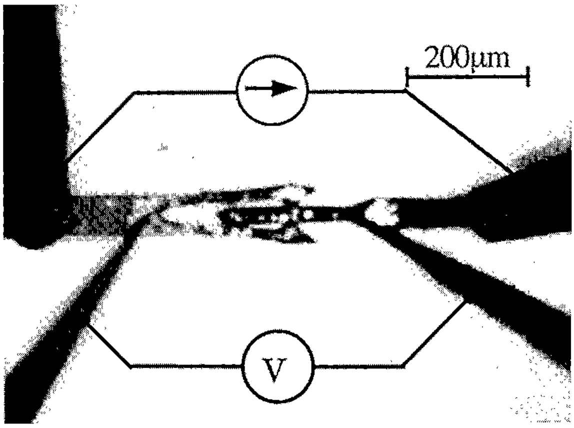


Figure10. Measurement of contact resistance by four-point probe method.

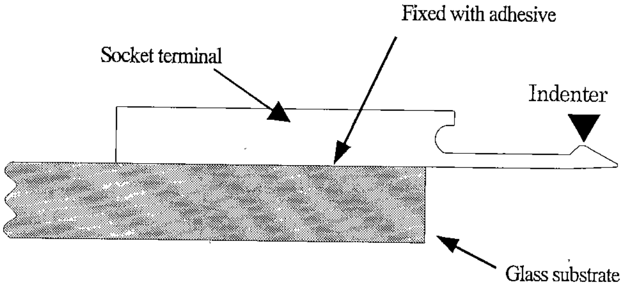


Figure 11. Measurement of contact force.

4.3 Young's modulus

Young's modulus was measured based on the nano indentation method proposed by Oliver et al [7]. The equations to determine the Young's modulus are as follows:

$$E = \frac{1-\nu^2}{2} S \sqrt{\frac{\pi}{A}} \qquad (1)$$

$$A = 24.5\left(h - 0.75\frac{P_{\max}}{S}\right) \qquad (2)$$

where E is Young's modulus, ν is Poisson's ratio, S is the slope of unloading curve at maximum load, A is the contact area of the indenter, h is penetration depth and P_{max} is the maximum load. In equation (1), $\nu = 0.3$ is assumed. The value of Young's modulus was 80 GPa. The experimental value of Young's modulus is much lower than bulk Ni (200 GPa) [5][8]. This might to be due to the porous structure of the electroformed Ni. Optimization of Ni electroforming condition should be performed to obtain a higher Young's modulus.

4.4 Permissible current

A value of permissible current was obtained by measuring temperature rise when a current was applied through the terminal. The terminal was set up on a thermocouple. The temperature rise was 30℃ when the current was 400mA. This result satisfies the specification shown in Table 1.

5 CONCLUSIONS

Specification, basic structure, and fabrication process and characteristics of a micro connector were investigated. The prototype micro connector of 80 μm pitches was fabricated by combining UV thick resist photolithography and Ni electroforming. The size of the terminal of the fabricated micro connector was 50 μm - thickness, 15 μm - width (minimum). The maximum aspect ratio of the fabricated micro connector was 3.3 and the terminal pitch is 80 μm. A contact resistance of 50 mΩ was obtained by using four - point probe method. A contact force of 2.08 mN and Young's modulus of 80 GPa were obtained by using the nano-indentation method. These results show one prospect for development of a micro connector with high - package density, which can be used in next generation of products for the IT market. As future problems, the change in contact force and contact resistance during repeated insertion and withdrawal, and environment reliability still remain to be tested.

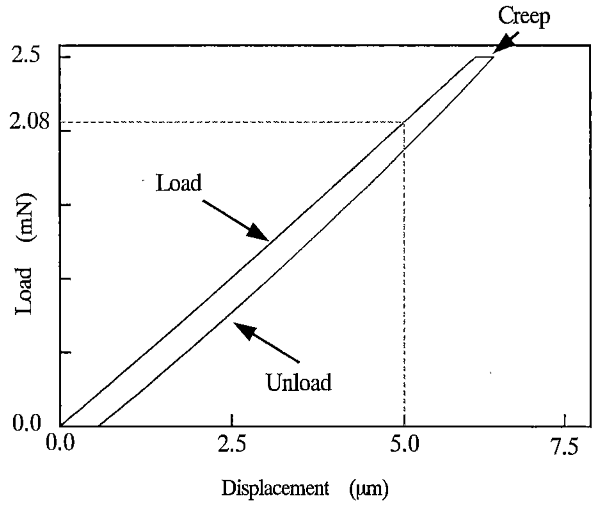


Figure 12. Displacement — Load Characteristic

ACKNOWLEDGEMENTS

This work was partly supported by the Japan Small and Medium Enterprise Corporation (Project No.11-12). The authors would like to thank Mr. S. Uchida at Tokyo Metropolitan Jonan (southern) District Small and Medium-sized Business Promotion for helping measurement of the contact force.

(Manuscript received June 6, 2001, revised Dec. 3, 2001)

REFERENCES

[1] M.Ishii et al.: "Connector Advanced Technology'99", Japan Advanced Technology 1999 (in Japanese).

[2] F. Michel and W.Ehrfeld: "Mechatronic Micro Devices", Proceedings of the 1999 International Symposium on Micromechatronics and Human Science, pp. 27-32,1999.

[3] D. C.Miller, W.Zhang and V.M.Bright: " Microrelay Packaging Technology Using Flip-Chip Assembly", Proceedings of MEMS 2000, pp. 265-270,2000.

[4] H. Okuyama, T.Haga, K.Emura, and H.Takada, "Development of Microconnector with Automatic Connecting /Disconnecting Mechanism", Proceeding of MEMS 1999, pp. 257-262,1999.

[5] W. N. Sharpe Jr., D.A.Lavan and Richard L. Edwards, "Mechanical Properties of LIGA-Deposited Nichel for MEMS Transducers", Digest of Technical Paper ofTRANSDUCERS'97,Vol.1,pp.607-610,1997.

[6] JSR Photoresist Product for Thick Layer Process, JSR Corporation (1999).

[7] W.C.Oliver and G.M.Pharr, "An Improved Technique for Determing Hardness and Elastic Modulus Using Load and Displacement Sensing Indentation Experiments", J.Mater. Res., Vol.,No.6,pp.1564-1583,1992.

[8] Larry L.Chu, Long Que and Yogesh B.Gianchanani, "Temperature Coefficient of Material Properties for Electro-Deposited MEMS", Proceedings of MEMS 2001,pp.68-71,2001.

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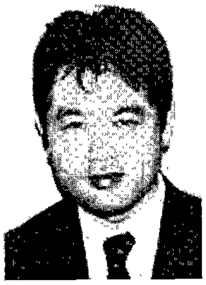

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