Direct drawing method for microfabrication based on selective metal plating technology

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Abstract
This paper describes a direct drawing method for a microfabrication based on a selective metal plating technology. The selective metal plating technology allows metal plating where a seed material is drawn. It becomes possible to combine various materials, so that the proposed method may cover a classical micromachining at the rather large scale.

The direct drawing method can be applied to various surfaces where it is not suitable for a conventional micromachining based on a photolithography technology. A specific drawing system has been constructed in order to apply the proposed method to three-dimensional structures in this study. A fabrication of a multi-layer circuit will be reported as the first example of applications. Next, plating metal patterns on various three-dimensional structures will be demonstrated. Furthermore, plating metal patterns on a ball will be reported. This result promises a possibility that the direct selective metal plating technology can also be applied to the so-called ball semiconductor technology at the rather large scale.

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1. Introduction
Generally, microstructures by micromachining based on a photolithography technology have been planar structures. This feature has both advantages and limitations of MEMS for a long time. In terms to overcome limitations, challenges to develop three-dimensional microstructures have been continued in MEMS field. LIGA technologies have been considered as a key technology for this purpose. Recently, DRIE technologies have come to the fore as an important technology to provide high aspect ratio microstructures, especially silicon structures. As a result of these efforts, it becomes possible to provide various structures with uneven surfaces. Once uneven surfaces are fabricated, conventional methods based on a photolithography technology can not be applied, except a few special lithography methods [1–3].

We can often meet with non-flat structures in the latter steps of a microfabrication process. An effective post-fabrication process technology could contribute to improve such process steps as wiring for a packaging.

From a different angle, a micromachining technology without a photolithography has been expected as a rapid prototyping technology or an on-demand production technology. The conventional micromachining technology with a photolithography is still not suitable for wide use as a rapid prototyping technology because it requires expensive facilities and photo masks. We can find several approaches without a photolithography [4–7], however, these methods require special equipment and materials.

Based on the above backgrounds, we have proposed to draw microstructure patterns like an inkjet printing method [8]. Our key idea is to draw materials of microstructures on surfaces. The direct drawing method makes it possible not only to draw patterns on non-flat surfaces but also to save process steps and costs.

Furthermore, it can be expected to utilize a good combination between printers and computers based on network systems. It becomes possible to choose a place to produce micromachines, so that designers can realize micromachines by their own printers or printing systems equipped at remote...
2. Direct selective metal plating technology

2.1. Principle

A principle of the proposed selective metal plating technology is shown in Fig. 1 [8]. An electroless plating technique is employed because it does not need electrodes for a current supply. Ni and Cu are often used as materials of the electroless plating and our study employs Ni [10]. The selective metal plating progresses as follows:

1. Drawing of a kind of amino silane coupler as a seed material (see Fig. 1a): KBE903(γ-aminopropyl-trimethoxysilane) (Shin-Etsu Chemical Co, Ltd.) is used in our experiments. The amino silane coupler is dried up.

2. Activation by catalyzing and accelerating (see Fig. 1b): CG-535A (Nikko Metal Plating Co, Ltd.) is used in our experiments. After a rinse by water, an acceleration step by H2SO4 is applied.

3. Electroless metal plating (see Fig. 1c): Nicom N (Nikko Metal Plating Co, Ltd.) is used in our experiments under 75 °C for several minutes to grow a few micrometers thick structure, for example.

The minimum size of patterns depends on a drawing resolution at a drawing step (Fig. 1a). Chemical reactions shown in Fig. 2 are considered to progress in this process [11].

In the activation process, coating of catalysts is followed by a surface treatment by a kind of acids (Fig. 1b). A metal structure grows where the seed material is drawn because Ni ion and the seed material can be connected together with the aid of the catalyst as explained in Fig. 1.

![Fig. 1. Principle of selective metal plating technology.](image1)

![Fig. 2. Chemical reaction.](image2)
2.2. Preliminary experiments and estimations

In order to verify our proposed method, drawing the seed material on a flat glass plate through a thin glass pipette was tried. Fig. 3a and b show results. The seed material was drawn in dots and lines. Fig. 3a-1 and a-2 show droplets of the seed material pattern and plated Ni pattern, respectively. Fig. 3b-1 and b-2 show lines of the seed material pattern and plated Ni pattern, respectively. The Ni structure grew only on the part where the seed material existed. The diameter of the circular structure measures 200 μm and the width of the line measures 66 μm. Thus, we can see that it is possible to plate selectively without masking.

The peeling test (JIS C 5012 8.1) was applied to the growth patterns in order to evaluate adhesion. An estimation result of adhesion between the grown patterns and substrates was around 0.1 kgf/cm. The obtained value was not so bad but was still lower than required adhesion for commercialized printed circuits (for example, 0.8 kgf/cm) [12]. As the thickness of plated structure increases, stress of the plated structure cannot be ignored, so that it becomes important to improve this adhesion characteristic.

3. Variety of material

3.1. Other materials for direct drawing method for microfabrication

Various materials are selected and used in MEMS application. Popular MEMS materials are categorized as follows: Si and silicon compounds, metals, organic materials, dopants, and so on. Si is mainly used as a substrate for MEMS. A deposition of Si and silicon compound is not easy by the direct drawing method because it requires liquid materials. It is, however, possible to draw SiO2 using a spin-on-glass (SOG).

Regarding with metals, various metals can be plated on a base metal. We could obtain Cu layer on a base Ni pattern. In MEMS field, a photoresist and a polyimide are often used as organic materials. A polyimide is often used as a passivation layer or a flexible material. A photoresist is used as an etching mask and a mold for electroplating, and a flexible material. It is possible to draw these organic materials by the direct drawing method.

A modification of electrical characteristics by doping is one of important technologies in MEMS. It is possible to draw a liquid dopant by the direct drawing method. Moreover, a high doped Si can endure against such an alkaline etchant as KOH, so that it is expected to form etching mask by drawing liquid dopant. In our study, a liquid dopant including B was tentatively drawn on the n type Si substrate. We could obtain a doped line based on this method. Fig. 4 shows a doped trace in line. The width measures 490 μm. Spin-on diffusion source, PBF3M-31 (Tokyo Ohka Kogyo Co. Ltd. was used as the liquid dopant here. Characteristics of this p+ doped line can be considered as similar to those obtained in usual way with spin-on diffusion source (about several tens Ω/□).

3.2. Combination of materials for multi-layer structure

A fabrication of multi-layer structures is demonstrated through process shown in Fig. 5. The selective metal plating
application of direct drawing method to a fabrication of multi-layer circuits will be reported.

4. Multi-layer circuit

4.1. Preliminary experiments

A commercialized inkjet printer with a resolution of 720 dots/in. was used to draw a seed pattern. A multi-layer printed circuit was taken up as the first target because a pattern of a printed circuit required the similar resolution as a proposed method by an ink jet printer provided.

Fig. 6 shows a plain view of a crossing of two metal lines plated on different layers. An intermediate insulator is polyimide. The thickness of metal lines and polyimide layer are 2 and 4 μm, respectively. The width of metal lines is 50 μm.

4.2. Two layer circuit

A fabrication of the two layer circuits with interconnections is demonstrated. A process flow of multi-layer circuits is explained in Fig. 7. It is not efficient to apply the direct drawing method to form insulating layers because insulating layers have only distributed patterns of via holes. In order to
as insulating materials. Photomasks patterned by the direct drawing method were used to form via holes in the photosensitive insulator for an interconnection between different circuit layers.

Fig. 8 shows a plain view of fabricated two-layer circuits with interconnections. Cu was grown on Ni pattern to improve a conductivity. A cross-sectional view of the structure is shown in Fig. 9. Fig. 9b shows a magnified view of a successfully fabricated interconnection. An average width and a thickness of circuit lines are about 55 and 2 μm, respectively. The thickness of epoxy as the insulator is 20 μm. Electrical interconnections between different layers could be confirmed. For example, an electrical resistance through a single via hole measured 0.7 Ω.

5. Application to three-dimensional structures

5.1. Drawing system construction

A drawing system specialized for our purpose became necessary for the direct drawing method on three-dimensional structures. Fig. 10a shows a constructed drawing system composed of XYZ precise manipulator of a drawing head, θφ precise positioning system of a target, and a
microscope for observations and alignments. An Al₂O₃ ball was set in Fig. 10a and b. Fig. 10b shows a close-up view of a nozzle and a target. A resolution of seed material patterns ejected by an equipped dispenser is several hundreds micrometers. It is possible to improve a resolution up to several tens μm by employing a higher performance injector.

5.2. Diced pole-grid array as three-dimensional structure

Plating a metal dot-grid array on a diced pole-grid array was demonstrated. A 525 μm thick Si substrate was diced into pole-grid array to form a high aspect ratio three-dimensional structure. A top surface of a pole was 850 μm × 850 μm. A gap of a trench was 50 μm. Fig. 11 shows a formed dot-grid array on a diced pole-grid array. A top view of a single dot is shown in Fig. 11b. An average diameter of a dot is 500 μm. An improved drawing system allows increasing the resolution and the uniformity.

5.3. Anisotropically etched pits as three-dimensional structures

We can often meet with anisotropically etched pits of Si such as diaphragm structures or through-holes for
interconnection. Patterning microstructures on the anisotropically etched pits will expand possibilities from the point of view of post-fabrication process. Our proposed method can be applied to this purpose. Fig. 12 shows examples of our trials. The pit is $4.3 \text{ mm} \times 4.3 \text{ mm}$ at the top and $4.0 \text{ mm} \times 4.0 \text{ mm}$ at the bottom, respectively. The depth of the pit is about $200 \mu\text{m}$. An average diameter of a dot is $500 \mu\text{m}$. We could succeed in growing dots at both top and bottom of the pit.

Fig. 12. Metal dot-grid array on anisotropically etched pit.

5.4. Ball as three-dimensional structures with curved surface

The selective metal plating on a sphere was demonstrated as a typical example of curved surfaces. Metal dot-grid arrays were successfully formed on various spheres as shown in Fig. 13. Three kinds of materials were estimated: (1) $\text{Al}_2\text{O}_3$ sphere ($\Phi 10 \text{ mm}$, see Fig. 13a); (2) nylon sphere ($\Phi 9.5 \text{ mm}$, see Fig. 13b); (3) glass sphere ($\Phi 12 \text{ mm}$, see Fig. 13c). A magnified view of dot patterns on an $\text{Al}_2\text{O}_3$ sphere is shown in Fig. 13a–2. An average diameter of a dot is $500 \mu\text{m}$.

Fig. 14 shows metal lines on an $\text{Al}_2\text{O}_3$ sphere ($\Phi 10 \text{ mm}$). These results promise a possibility that a proposed method

Fig. 14. Metal lines on $\text{Al}_2\text{O}_3$ sphere ($\Phi 10 \text{ mm}$).

Fig. 13. Metal dot-grid array on various spheres. (a-1) Metal dot-grid array on $\text{Al}_2\text{O}_3$ sphere ($\Phi 10 \text{ mm}$); (a-2) magnified view of (a-1); (b) metal dot-grid array on nylon sphere ($\Phi 9.5 \text{ mm}$); (c) metal dot-grid array on glass sphere ($\Phi 12 \text{ mm}$).
can also be applied to the so-called ball semiconductor technology at the rather large scale.

6. Conclusions

The direct drawing method based on the selective metal plating technology has been proposed. It becomes possible to combine metal with various other materials by the direct drawing method. Several attractive features of the direct drawing method based on the selective metal plating technology allow applying this method to a microfabrication and covering a classical micromachining at the rather large scale.

Furthermore, the proposed method can provide effective post-fabrication process technology because it can be applied to various surfaces where it is not suitable for a conventional method based on a photolithography technology.

In this paper, several applications of the direct drawing method have been reported. A fabrication of multi-layer circuits has been demonstrated as an example of application for commercial products. The selective metal plating by a developed drawing system has been also applied to various surfaces where it used be difficult. Above all, plating a metal pattern on a ball suggests a possibility that the direct drawing method can also be applied to the so-called ball semiconductor technology at the rather large scale. Further applications of the direct drawing method with improved resolution and uniformity are our current interests.

References


Biographies

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