Electrochemical Microfabrication for High-Aspect Ratio 3-D Microstructures

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The conventional or silicon-based MEMS (MicroElectroMechanical Systems) fabrication techniques, which are derived directly from microelectronics or lC technologies, are not only planar (2-D) processes with low-aspect-ratios, but also material-limited. MEMS are intrinsically different from ICs in requiring 3-D microstructures which make MEMS quite different from microelectronics or ICs. 3-D microstructures allows the fabrication of totally new, complex devices, improved device functionality and performance and much simpler design. This paper reviews emerging 3-D electrochemical microfabrication techniques and discusses their advantages, limitations and potential future development directions.

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Introduction

MEMS (Microelectromechanical Systems) or MST (Microsystem Technology) have been widely recognized as the next technology revolution that will remarkably change human society as, or much greater than, the semiconductor revolution has done. MEMS technology integrates electrical, mechanical, optical and other functional micro-components into a whole system and enable the system to sense, decide and react.[1] Therefore MEMS applications are more diverse and versatile than purely semiconductor integrated circuit (IC) applications.

As the importance of semiconductor fabrication processes to the IC technology, manufacturing techniques for micro-devices are the cornerstone of MEMS or MST. This paper will review the emerging electrochemical microfabrication techniques for three-dimensional microstructures and discuss their advantages, limitations and potential future development directions.

Overview of Fabrication Techniques for Microstructures

Currently, fabrication techniques for microstructures mainly fall into three categories: additive, subtractive and hybrid (combination of additive and subtractive). An additive technique forms microstructures by deposition of materials, e.g., LIGA[1] and LIGA-like processes. In contrast, a subtractive technique involves etching of materials to form microstructures. Silicon bulk micromarching is a typical subtractive process example. A hybrid process uses both additive and subtractive techniques. For instance, in surface micromachining, microstructures are formed by successive deposition and etching of sacrificial and structural thin films on the surface of a silicon wafer.

The microstructure fabrication techniques derived directly from the IC technology are called conventional or silicon-based manufacturing in which most of the currently used manufacturing processes such as photolithography, thin film deposition, and chemical and plasma etching originate from the IC technology. The other fabrication methods developed specifically for MEMS such as LIGA are called non-conventional techniques.

MEMS have three major fundamental distinctions from ICs.

1. A need of true 3-D (three-dimensional) microstructures

MEMS are intrinsically different from ICs in requiring 3-D microstructures. 3-D fabrication techniques are expected to realize totally new and complex devices, improved device functionality and performance, and much easier design of microdevices. For example, 3-D microstructures offer structural rigidity in actuation systems and the possibility of compact production of high torque and/or actuation force.[2]

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[1] *LIGA is a German acronym for LIthographie, Galvanoformung, Abformung (in English, lithograph, electroforming, molding).*

2. A broader selection of materials required for various MEMS applications

The applications of ICs are only for electronics. The materials used for ICs are limited to semiconductor materials and few metals. MEMS, however, have broader applications such as in electronics, automotive, telecommunications, biotechnology, aerospace, military and information technology, which calls for use of different materials to realize different device functions and performance, e.g., electrical conductivity, optical reflectivity, thermal stability, ductility, biocompatibility, magnetic properties. For radio frequency (RF) applications, thick metal layers are preferred over other materials because of their higher conductivity.

3. A greater diversity of the interaction of devices with environment[3]

MEMS require a greater diversity of models, simulations and packaging approaches than ICs.

These distinctions are the major challenges for MEMS fabrication. Indeed, the dominant conventional or silicon-based fabrication techniques not only produce virtually 2-D microstructures with low-aspect-ratios (feature height to width), but also employ very limited materials (silicon, etc.). The limitations of present MEMS fabrication techniques and the need of high-aspect-ratio, true 3-D manufacturing have been stimulating development of new fabrication approaches.

Electrochemical Microfabrication

Electrochemical fabrication utilizes electrochemical principles to manufacture materials or devices. The basic fabrication principle lies in Faraday's law of electrolysis (invented in 1834) which states the quantitative relationship of the amount of current (electrons) passed through an electrochemical cell and the quantity of materials deposited or dissolved at electrodes. The unique characteristic of electrochemical fabrication is that precise amounts of materials can be deposited (additive) or removed (subtractive) by a controlled current applied to an electrochemical cell with suitable electrolytes. This flexible and controllable electrochemical transformation between liquid and solid materials is the basis of electrochemical fabrication for microstructures. Alfred Smee[4] coined a very appropriate term, electro-metallurgy, for this electrochemical material transformation in 1841.

The combination of micro patterning technology and electrodeposition developed by the IBM T.J. Watson Research Center in the late 1960s for thin film heads first brought the electrochemical microfabrication concept into microelectronics[5-7], which resulted in the well-known through-mask plating technology for making high-resolution microstructures. Electrochemical microfabrication is now widely used to make circuit boards, contacts, interconnects, packaging modules, magnetic recording media and heads, etc.[8]

The detailed development of electrochemical microfabrication for 3-D microstructures will be described in the next session.

Development of Electrochemical Microfabrication for 3-D Microstructures

1. Through-Mask Plating - The Cornerstone of 3-D Microfabrication

The up-to-date achievements in 3-D microfabrication truly base on a great IBM invention developed in the late 1960s for fabrication of magnetic storage devices (thin film magnetic heads).[5-7] This fabrication technique is so-called through-mask plating or, more precisely, plating-through-lithographic-masks. It involves electrodeposition of a metal into the precisely patterned voids (having vertical walls and parallelism of two adjacent walls) in a photoresist to form well-defined metal microstructures that accurately replicate the photoresist pattern. This process was also called as "a room temperature metal injection molding process",[5] which vividly describes this process.

The through-mask plating technique was developed to achieve thin film metal devices in which individual metal layers have a thickness usually less than 10 µm (2-5 µm typically) and metal features are embedded in permanent insulating materials (hard baked photoresists). Although the thicknesses of metal features in thin film devices are much greater than those of semiconductor features in semiconductor devices, thin film devices are still considered as planar (2-D) devices.

Other important fruits from the development of the through-mask plating technique, which are tightly related to current MEMS 3-D electrochemical microfabrication, are that 1). plating tools such as the unique paddle plating cell[9-12] and plating methods were developed to achieve uniform thickness and deposit composition distribution, and 2). the fundamental understanding of the through-mask plating process, plating bath chemistry and current distribution[13-17] by mathematical analysis was achieved.

It is also worth mentioning that the through-mask plating technique can be used repeatedly to form a multi-layer microstructure by sequentially building required layers (very thin though) until the structure is completed. If necessary, a previous layer can be planarized to facilitate to build a next layer.[5, 18]

As Romankiw and O'Sullivan[5] pointed out, "it (through-mask plating) has had a profound influence on the direction in which electronics has evolved." Furthermore, the current progresses in MEMS electrochemical 3-D microfabrication has proved that through-mask plating is an indispensable technique for making 3-D microstructures.

2. LIGA and LIGA-like techniques - Extension of 2-D structures into The Third Dimension

LIGA was initially developed at the Institute for Microstructure Technology in Karlsruhe, Germany, in the early 1980s to make diffusion nozzles for uranium enrichment.[1, 19] Now it has become an important MEMS microfabrication technology.

The LIGA process uses a thick resist (X-ray resist, usually PMMA) which is exposed to X-ray synchrotron radiation through a mask to form a pattern (mold) in the resist. The mold is then used to make metal or alloy microstructures by through-mask plating. The formed metal or alloy microstructures may be used as the end-products or as the new molds for molding plastic or ceramic microstructures. LIGA can produce precise microstructures with structure heights more than 1 mm (typically, several tens to several hundred micrometers), lateral feature size as small as 0.2 µm and aspect ratios above 100:1.[1, 20] Fig. 1 shows a LIGA microstructure made of nickel.

Fig. 1. Precision nickel gears (150 µm thick) fabricated by LIGA.[21]

With the development of the LIGA process, one important technique was adopted to produce movable components by using sacrificial layers.[5, 19] Sacrificial layers such as aluminum, copper or titanium are built with fabrication of a structural material such as nickel. After the sacrificial layers has been removed, either a whole microstructure or part of a microstructure is separated from a substrate on which the microstructure was built. Movable components in microdevices are a clear sign of MEMS devices, a significant distinction from ICs.

The LIGA technique realizes the leap from thin microstructures (few micrometers) to very tall microstructures which have a third dimension, the height (z-axis), as well as the length and width (x- and y-axis). However, microstructures fabricated by LIGA are real high-aspect-ratio structures, but not real 3-D structures as the microstructures just extend their 2-D geometry in the xy plane along the z-axis. LIGA devices may be called 2.5-D or quasi 3-D structures. Fig. 1 clearly shows this characteristic of LIGA microstructures.

The biggest obstacle for LIGA commercialization is that it requires a high energy deep X-ray synchrotron radiation source. Access to such a X-ray source is very limited and the cost is high for using the source. Thus, LIGA is not widely available outside a few research organizations. This restriction has stimulated the development of alternatives such as LIGA-like processes.

There are currently two main alternative techniques to make molds. The both techniques use standard cleanroom processes and equipment at low fabrication cost which make them possible to compete with LIGA.

The first approach (called UV-LIGA) is to use thick or ultra-thick UV-photoresists to make molds with a height from 20 µm to several hundred micrometers. SU-8, an ultra-thick photoresist appearing in 1997[22], was developed specially for MEMS use. SU-8 is a negative, epoxy-type, near-UV photoresist that was originally developed and patented by IBM.[23-24] This photoresist can be thicker than 500 µm in a single coating and could be more than 1 mm by multiple coatings with an aspect ratio of more than 18 and resolution in the range of microns to tens of microns. SU-8 itself has good mechanical properties. It can function either as a stable photo-plastic micromechanical material or as stable molds for subsequent electroplating and injection molding for polymers. Fig. 2 shows an SU-8 mold on a silicon wafer.[25] In addition, other thick photoresist such as AZ 4620[25], polyimide[26-27], SJR 5740 and NR9-8000 have also been used to make thick molds.

The second approach is to make molds directly in silicon wafers by using deep dry etching equipment. DRIE (Deep Silicon Reactive Ion Etching) is an advanced dry etch technology patented in 1994[28] and commercial DRIE machines appeared in the late 1990s. DRIE can reach aspect ratios up to 20, etch rates up to 6 µm/min, etch depth up to 1 mm for feature sizes down to 5 µm. It has been used to make silicon molds[29-30] for electroplating and molding or hot embossing. As an alternative of LIGA, this technique is called SIGA (Silicon Galvanic and Abformung (molding)) or Silicon-LIGA.[30] Fig. 3 shows a silicon mold with a depth of 50 µm made by DRIE.[31]

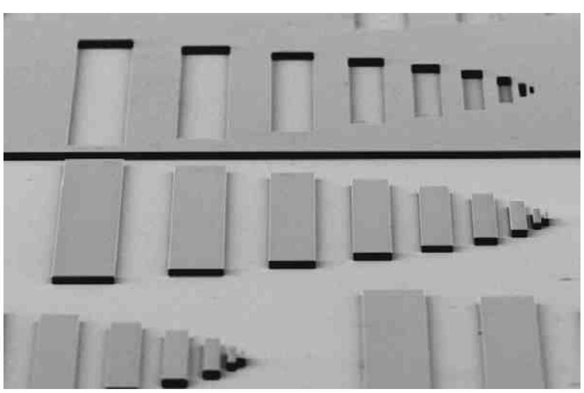

Fig. 2. An SU-8 mold on a silicon wafer.[25]

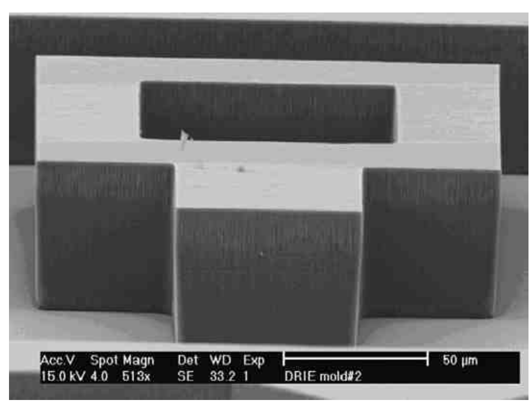

Fig. 3. A silicon mold made by DRIE.[25]

Like the LIGA technique, the LIGA-like processes can only build 2.5-D microstructures with lower high-aspect-ratios than LIGA microstructures.

3. Fabrication of True 3-D Microstructures -The Final Frontier

As true 3-D microstructures are essential elements of MEMS devices for many applications, the MEMS people have been struggling to find solutions to make them. Various concepts and approaches have been proposed, investigated and developed.

Let's take an example. RF MEMS devices (filters, switches, capacitors, inductors, etc.) are expected to be one of the biggest MEMS applications for wireless communication. Fig. 4a shows a CAD illustration of an air core solenoid inductor. This type of inductor is really three-dimensional though it is a quite simple 3-D structure. Several methods were developed to build this type of inductor. Chomnawang et al.[31] used a method in which a temporary photoresist core (bell-shape) was made first. A conductive material (copper or nickel) was then selectively deposited on the top of the core to form the inductor winding. After removing the temporary core, they obtained an inductor (Fig. 4b). Zou et al.[32] developed another approach. They first deposited the inductor winding structures (permalloy) in a horizontal form in a patterned photoresist. Then the winding structures were lifted up to form a 3-D inductor (Fig. 4c and 4d). Yoon et al.[33] made their inductors based on the fact that in many RF MEMS applications, currents are confined to the outermost portions of conductors due to the skin effect. They used SU-8 (epoxy-type photoresist) to build a backbone winding structure. They then metalized the backbone and deposited copper/gold layers to form a metal-on-top-of-epoxy inductor (Fig. 4e).

The above examples reveal the first strategy for fabrication of 3-D microstructures, i.e., custom or specific fabrication. This kind of fabrication is very specific (often one process only for one product and only work for very simple 3-D structures). If end products need to make a change, sometimes the processes will have to be changed greatly or even can not allow this change. Even for very simple 3-D structures, this type of fabrication usually involves many processing steps and has to sacrifice some product features to compensate process limitations.

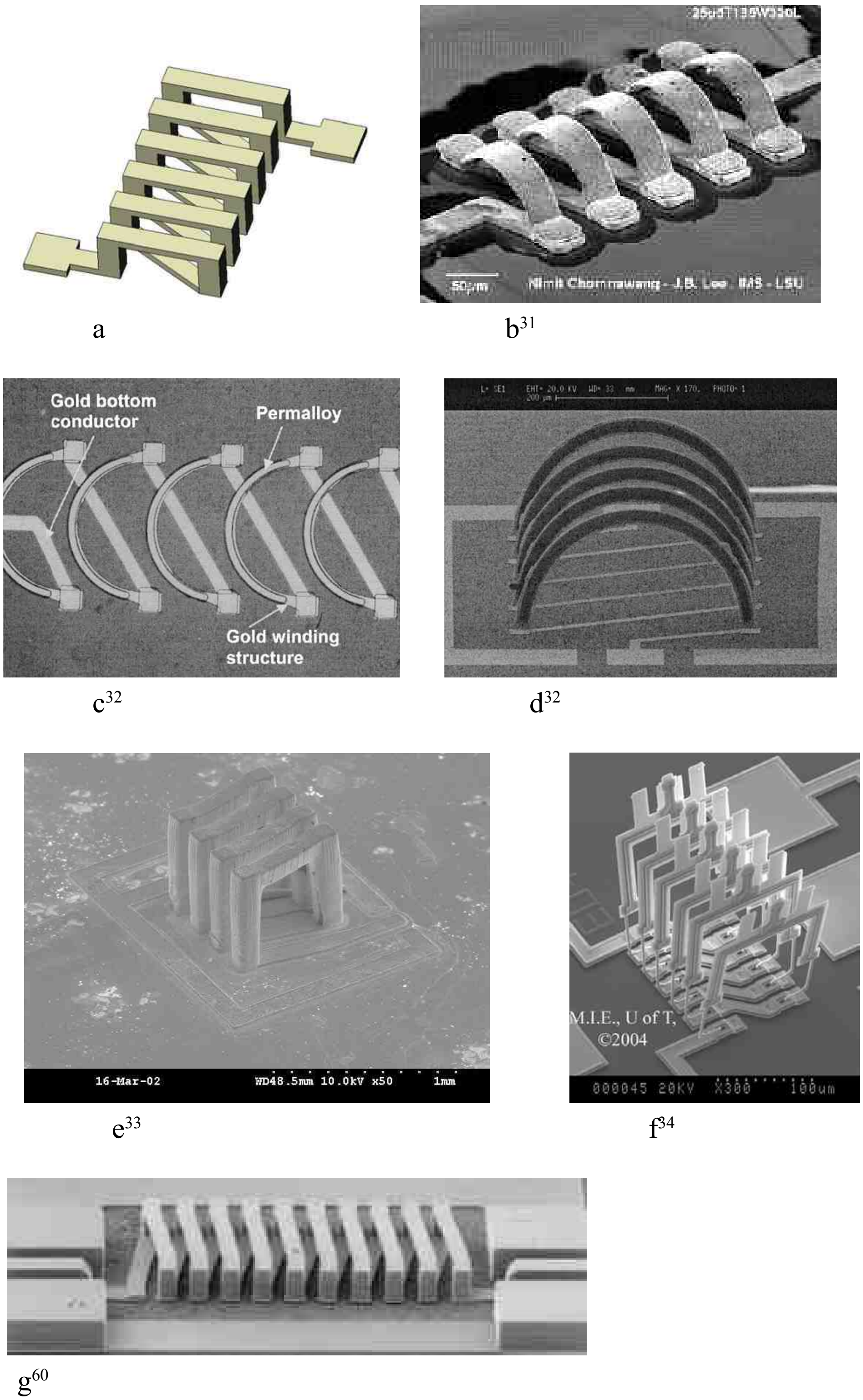

Fig. 4. Air core solenoid inductors fabricated by various approaches.

The second strategy for making 3-D microstructures is to assemble the individual components of a microstructure to form a 3-D structure. This approach is first to fabricate all required components and then assemble or join them together via mechanical means or bonding techniques. Fig. 4f shows a air core solenoid inductor made with a microassembly approach.[34] An escapement mechanism[35] assembled with the LIGA components is shown in Fig. 5. Another approach is to bond individual components together via diffusion bonding. Fig. 6 shows one example in which two LIGA gears are diffusion bonded.[36]

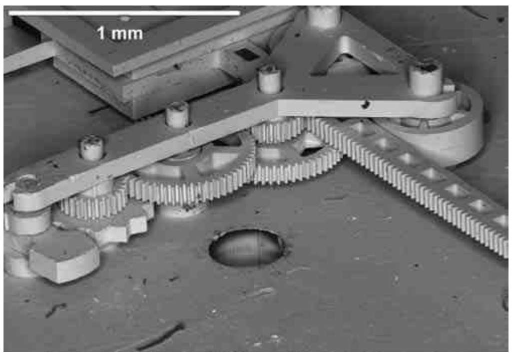

Fig. 5. A LIGA escapement mechanism via a rack-and-pinion assembly.[35]

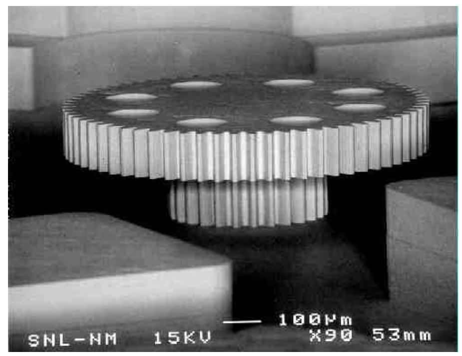

Fig. 6. Two-level batch diffusion bonded nickel LIGA components, large gear on small gear.[36]

This assembly fabrication involves making individual microstructures, handling and manipulating them via tools. Assembly processes often range difficult to virtually impossible. So this fabrication faces serious challenges.

The third strategy is to use the multi-layer fabrication. This technique is so far the most promising and versatile method for fabricating true 3-D microstructures with high-aspect-ratios.

The basic idea of this fabrication is to define or "slice" a 3-D microstructure along its z-axis into thin (2-D) layers, i.e., horizontal cross-sections. These layers are built sequentially (layer by layer) until the microstructure is formed. Each layer contains one sacrificial material and at least one structural material. The sacrificial material is finally removed to reveal the 3-D structure. The sacrificial material serves both as a mechanical support of the structural material and as an "adhesive" which combines isolated structural features together on the layers. It is the use of the sacrificial material that eliminates nearly all geometrical restrictions, which allows the structural features on a layer to overhang and even be disconnected from the structural features on the previous layer. The only type of shapes this technique is unable to produce is that in which the sacrificial material cannot be removed (e.g., a hollow sphere with no etching access hole). The importance of this fabrication technique is that it provides a generic manufacturing platform for making virtually any complex arbitrary 3-D microstructures without a need of developing a specific process for a specific product. It also makes it possible to monolithically fabricated "assemblies" of discrete, interconnected parts.

Among the emerging techniques of this type of fabrication, multi-layer electrochemical fabrication[37-39] has been developed to make 3-D metal or alloy microstructures while microsterelighgrapy[40-41] has been employed to build polymer 3-D microstructures.

In the next section, two strategies of the multi-layer electrochemical fabrication technique will be discussed in details.

Multi-layer Electrochemical Fabrication for 3-D microstructures

The first approach is actually to repeatedly use through-mask plating and blanket plating to make the all layers of a microstructures. H. Guckel[37] invented and patented (1992) this approach. The process flow of this technique is shown in Fig. 7 from Step A-1, A-2, 3, 4, 5, 6, to 7. A brief description of the process is as follows.

In the first step (A-1), a layer of resist (either UV or X-ray resist) is applied and patterned on a plating base on a substrate. In Step A-2, a first material (
sacrificial metal in this case) is selectively deposited into the resist mold via through-mask plating. Step 3 shows the 1st material pattern on the substrate after removal of the resist. A second material (structural metal in this case) is electroplated over the 1st material and the substrate in Step 4. In the 5th step, the entire two-metal layer is then planarized to achieve precise thickness, smoothness and flatness. The same process is repeated until all of the required layers have been constructed (Step 6). Finally, in the last step, a release etchant removes the sacrificial material, leaving behind the free-standing 3-D microstructure.

Although the process flow looks straightforward, the real manufacturing is complicated and involves intensive labor and long processing time due to difficulties of the automation process. For example, it takes up to nine steps to make a plating mold on a substrate, in which different equipment and chemicals are involved. It makes the use of this technique very difficult or impossible to produce hundreds or thousands of layers.

To overcome the drawbacks of the Guckel's method, A. Cohen[38] invented a new approach called EFAB (Electrochemical Fabrication) in 1996 and led a team of engineers to develop this technique (funded by the Defense Sciences Office under the Mesoscale Machines program) at the University of Southern California.[42-48]

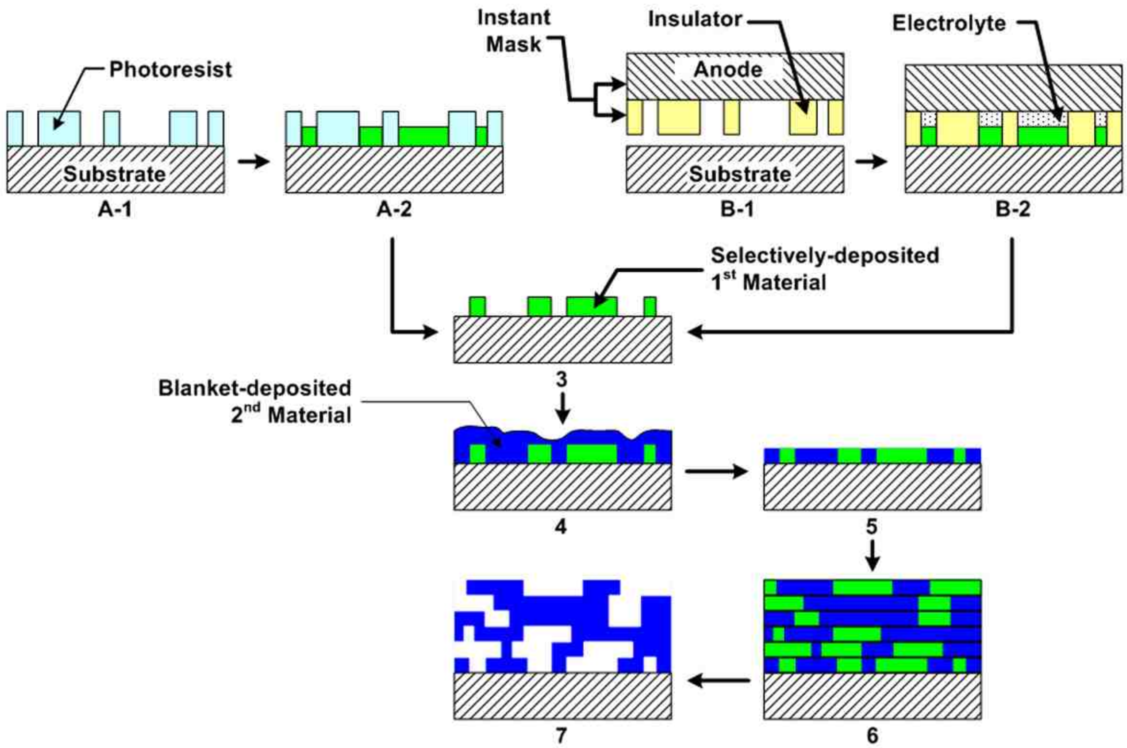

Fig. 7. Two process flows of multi-layer electrochemical microfabrication.

The EFAB concept was stimulated by solid freeform fabrication (SFF) and multilayer electrochemical fabrication.[42] SFF or rapid prototyping (RP), also a multi-layer based manufacturing technology, is a powerful tool for quickly generating complex models and prototypes on the macroscale. It offers 1). virtually arbitrary 3-D geometry; 2). short lead times; 3). fully-automated and unattended processing; 4). a single, self-contained machine that produces an enormous variety of products; 5). device costs that are largely independent of complexity; 6). high repeatability (few process variables) and 7). easy device design (few manufacturing constraints). EFAB was targeted to provide an automated, fast, but yet cost-effective manufacturing technique for 3-D fabrication in a self-contained machine for all fabrication steps including selective plating, blanket plating and planarization.

It is the instant-mask plating of EFAB that makes possible to combine the advantages of SFF and multi-layer electrochemical fabrication. In Guckel's approach, a plating mask (photoresist) is applied on a surface on which a material will be through-mask plated. EFAB, however, uses an instant mask to in-situ pattern a substrate and then perform an instant-mask plating. The EFAB process flow and one type of instant masks are shown in Fig. 7 from Step B-1, B-2, 3, 4, 5, 6, to 7.

The Instant Mask consists of a conformable insulator patterned on the anode (Fig. 7, B-1), instead of on the substrate as Guckel's method does. The anode has two functions. One function is as a supporting material for the insulator layer to maintain its integrity as the pattern may be topologically complex (e.g., involving isolated "islands" of insulator). The other function is as an anode during electroplating. Instant-mask plating is operated by pressing the instant mask against the substrate in a plating bath (Fig. 7, B-2). The plating bath (electrolyte) is trapped in the openings of the insulator layer. The first material is then selectively deposited via instant-mask plating. The instant-mask can be instantly removed after instant-mask plating. The instant mask may be reused, which is a great benefit over through-mask plating. The following steps are the same as the Guckel's method.

Unlike through-mask plating, instant-mask plating allows the process for making instant masks to be performed completely separate from device fabrication as the plating mask is now not on the substrate. All masks can be generated simultaneously, prior to device fabrication rather than during it. This separation makes possible an automated, self-contained machine that can be installed almost anywhere to fabricate devices, leaving the photolithography required for mask-making to be performed by service bureaus using traditional cleanrooms. Fig. 8 illustrates from product CAD design, use of instant mask to final product.

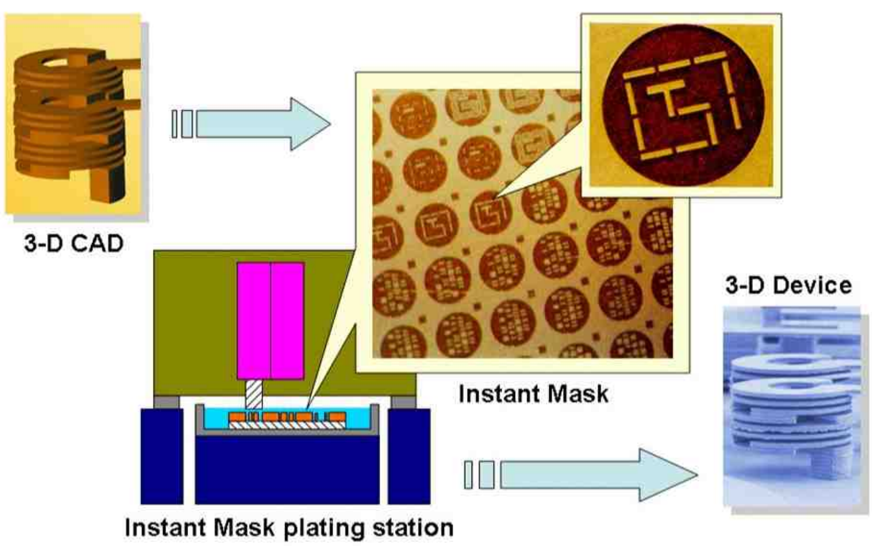

Fig. 8. Instant masks used for EFAB products.

EFAB is an interdisciplinary technology which involves microdevice CAD design and 2-D layer generation, fabrication of instant masks (photolithography, micromolding and RIE)[25], electrochemical deposition and etching, planarization such as diamond lapping[25], and EFAB equipment mechanical and electrical design. Many fabrication steps in EFAB are unique and had to be invented and adapted. All processing steps need to be integrated into a self-contained, automated EFAB machine. Some developed electrochemical technique-related fabrication processes will be briefly described as follows.

Instant-mask plating is a new selective electrochemical deposition method which is not quite the same as through-mask plating. Instant-mask plating has its own characteristics. For instant-mask plating using the insulator-on-anode instant masks, a simplified model of instant-mask plating shown in Fig. 9 is used to demonstrate the unique characteristics of instant-mask plating:[49]

- Sealed micro plating cell
- Microbath plating with bath volumes between sub-nanoliter and microliter.
- Thin electrolyte film plating (large area : volume ratio)
- Diffusion-controlled plating with no agitation
- Higher limiting current density due to thinner diffusion layer (50-70 μm)
- Anode : cathode area ≈ 1 : 1
- Uniform current distribution
- Interaction between the anode reaction and the cathode reaction
- Degradation of bath quality with plating time

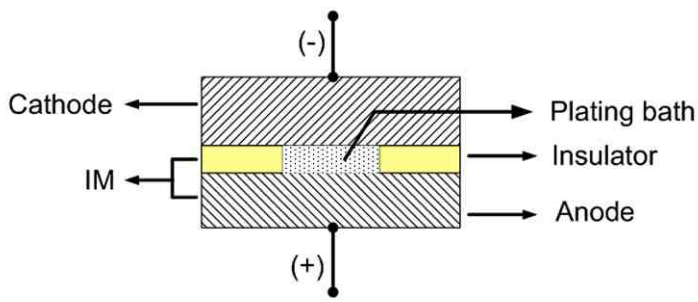

Fig. 9. Simplified model of instant-mask plating.[49]

To make the instant-mask plating process reliable so that a uniform deposit with a certain thickness is obtained, some critical issues have to addressed such as:

- Bath design, selection and formulation
- Optimization of plating parameters
- Deposit uniformity
- Instant-mask plating process monitoring

Intensive efforts were made to prevent from shorting during instant-mask plating (due to very tiny separation between anode and cathode)[50], promote nearly the same deposit thickness distribution in different isolated micro-
plating cells[25, 51], and optimize and monitor the instant-mask plating[25, 52]. Fig. 10 show two patterned copper layer (16 μm thick) made by instant-mask plating.[49, 53]

For multi-layer microstructures, the adhesion between layers is crucial to the integrity of microstructures. An in-situ electrochemical activation prior to plating and a heat treatment method after microdevices are fabricated were

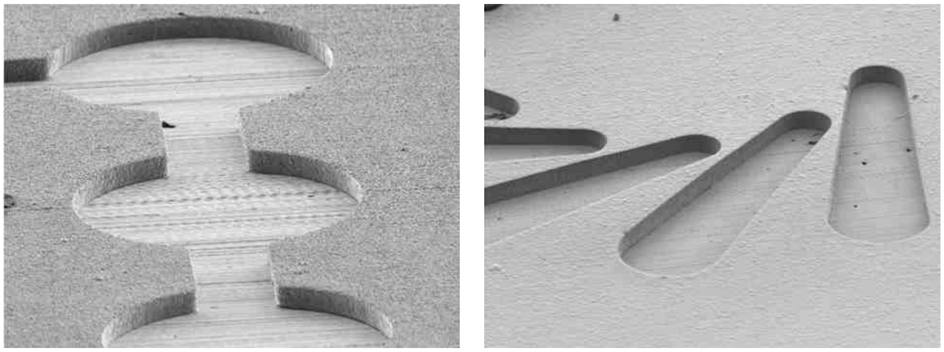

Fig. 10. Patterned copper layers (16 µm thick) made by instant-mask plating.[49,53]

developed to enhance the adhesion between nickel layers.[25, 54-56] Etchants and etching processes for removing a sacrificial material from a structure material must assure not to damage the structure material. Such precise etching can be achieved by using proper etching solutions containing effective corrosion inhibitors.[25, 57-58] To prolong the use life of an insulator-on-copper instant mask in real service environment, a copper surface treatment was implemented in fabrication of instant masks.[25, 51] Stress control in the nickel deposits is also critical in EAFB. A nickel plating bath was optimized to obtain high deposition rate, near zero stress, and good apperance.[25]

The first successful EFAB demo part was made with a manual EFAB machine in the early 1999. It was a 12-layer nickel micro-chain shown in Fig. 11, which has 14 independently-movable links (290 µm wide and 500 µm long) and a total thickness of ~ 100 µm. A household ant lying over the chain is for size comparison. The first self-contained, automated EFAB machine appeared in the early 2000s, which was developed by Microfabrica (an EFAB technology developer) shown in Fig. 12.[53] With the development of EFAB, more complex and more accurate devices have been fabricated. Fig. 13 shows a 24-layer rotary varactor[59] made with the automated EFAB machine. An air core solenoid inductor is shown in Fig. 4g[60], which is the best inductor made so far among the all available fabrication techniques. Very recently, Microfabrica announced that complex three-dimensional microdevices over a millimeter tall were fabricated, bridging the gap between micro and macro worlds.[61] Fig. 14 shows one of the microdevices.[62]

Applications and Future Directions of Multi-layer Electrochemical Fabrication

Multi-layer electrochemical fabrication can manufacture virtually any complex arbitrary 3-D metal microdevices which can not be done with other microfabrication techniques. This makes it become a state of the art technique for building devices for RF applications[60, 63], biotechnology, automotive, aerospace, military and information technology, etc.

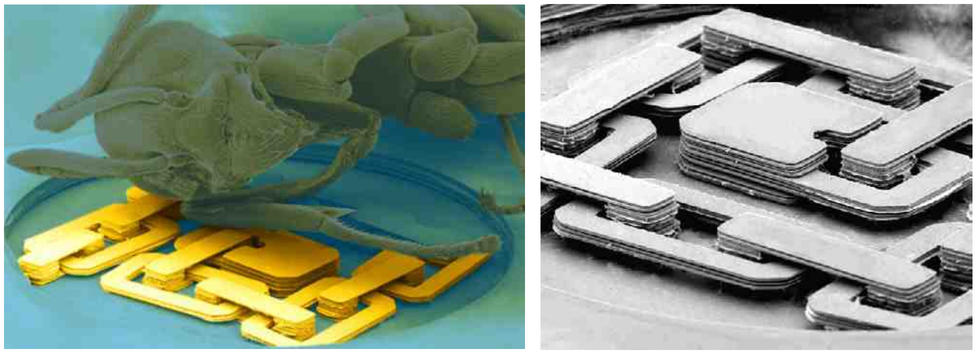

Fig. 11. 12-layer nickel micro-chain made using the EFAB technology.[25]

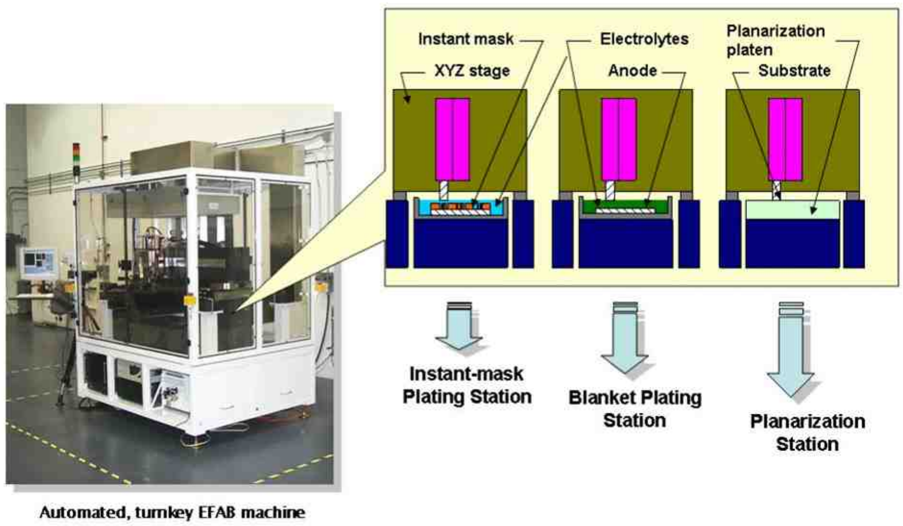

Fig. 12. Automated, turnkey EFAB machine integrating three key process steps.[53]

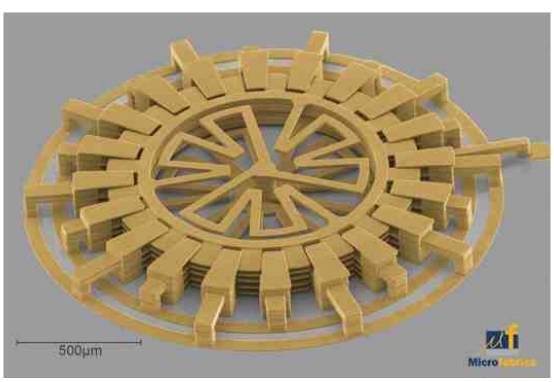

Fig. 13. 24-layer rotary varactor.[59]

Fig. 14. Fluid-driven impeller with reduction gearing (1 mm tall).[62]

Although this multilayer technique is practical to build real three-dimensional microstructures, there are some limitations inherently associated with this approach.

1. Throughput

Production throughput would be low if microdevices require many layers. This is because the multilayer approach is a consecutive process. A layer can only be built until its pervious layer is completed. For example, during fabrication, when one layer meets problems, the whole fabrication process has to be suspended until the problems are solved. If a build has to be discarded due to various reasons during fabrication, all previously fabricated layers have to be wasted.

2. Yield

In reality, each layer inevitably contains some defects. These defects may distribute at different locations on each layer. Therefore, the yield of final good structures would be not very high.

3. Limited material selection

Electrochemical deposition can only be used to fabricate metals and alloys. In addition, although electrodeposition can be used to make many metals and alloys, only a small portion of them can be made practically and economically for mass production. Even the metals and alloys can be made by electrodeposition, in some cases their material properties are not as good as the ones of their corresponding bulk materials.

4. Layer thickness

The maximum metal layer thickness is restricted by mask thickness (e.g., photoresist). Layer thickness that can be freely selected is crucial to the multilayer approach. For example, in some cases, several same thin layers have to be built if a thick layer can not be built.

These existing limitations are expected to drive MEMS research and manufacturing organizations to further optimize the currently available multi-layer fabrication techniques or to develop new fabrication methods. For example, a new manufacturing method is being developed by echemics to overcome these limitations.

Summary

The development of microfabrication techniques for manufacturing true 3-D MEMS microdevices is reviewed in this paper. The multi-layer electrochemical microfabrication has stood out of the current available techniques and become a state of the art technique for manufacturing virtually any complex arbitrary 3-D metal microdevices. The applications, limitations and future development directions of this technique are also discussed.

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Modern Trends & Developments in Plating with Platinum Group Metals

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This paper will show the trends and current developments in the plating of the Platinum Group Metals. Specifically metals such as Palladium (and Palladium Nickel), Rhodium, Platinum and Ruthenium will be covered showing how the development of modern formulations has led to applications in electronics, automotive, aerospace and medical industries as well as developments in the more traditional decorative market. The need to develop environmentally friendly products and how this has been approached will also be covered.

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