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MICROELECTROPLATING OF NICKEL FOR MEMS APPLICATIONS

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Microelectroplating of nickel was proposed as a new approach for MEMS applications. A technique is developed to carry the solution to the exact substrate area, where electrodeposition should take place. It is shown that microelectroplating can be implemented without immersing the entire device in the solution. A microtube brings the solution to the required zone. On contact, electroplating takes place at the substrate in a region bounded by the liquid capillary forces. During the process, the tube is moved over the substrate while surface tension impedes the liquid from spreading. Several effects have an impact on microelectroplating, especially surface tension and formation of bubbles.

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1. Introduction

The development of microelectromechanical systems (MEMS) has focused on integration of electronic and mechanical elements [1]. Materials such as silicon, due to its mechanical properties [2], and techniques used in microelectronics [3], had been found appropriate for MEMS applications. However, it is believed that future development of MEMS will be strongly influenced by the ability to use a variety of materials and fabrication techniques [4].

Most existing techniques are at most suitable for creating generalized two-dimensional (2D) microobjects. Large aspect ratio high quality elements can be fabricated by LIGA (acronym in German) [5, 6]. This method involves molding and electroplating. It relies on high energy X-rays to pattern high aspect ratio features with improved surface quality. Alternative molding and electroplating methods using UV patterning was showed [7]. Recently, a sharp electrode placed in a plating solution has been shown to localize the electroplating, producing 3D elements [8].

Low cost production methods are needed for micromechanical elements, and in particular techniques that are integrable with microelectronic fabrication lines. Electroplating is a suitable choice for microfabrication, being a very flexible and relatively inexpensive method. The solutions used and the appropriate working conditions are well-known and different substances and alloys can be deposited [9, 10]. However, implementation of electroplating for microelectromechanical applications requires special considerations and adjustments. Micromechanical elements are commonly produced by covering a substrate with a proper photoresist. In order to use the electroplating method the photoresist should not be attacked by the plating bath. Exposition to appropriate radiation (X-ray, UV) through a suitable mask, and development of the photoresist, lead to a mould of the desired device. The substrate should be conductive or must be properly coated with a conductive seed layer. The substrate, together with the mould, is immersed into the plating bath. The substrate is used as a cathode. Partial or fully free elements, can be formed by selective etching.

Electroplating solutions, in general, might not be compatible with requirements imposed by the application and in particular by microelectronics. Micromachined elements usually occupy only a reduced area of the chip while electroplating needs the immersion of the entire substrate into the plating bath.

Therefore, it is advisable to develop techniques to eliminate the need for full wetting of the substrate and to restrict the process to the selected area of the required elements.

This work's intention was to develop a method, where electrodeposition takes place at a small zone of the substrate using capillary tubes to carry the solution to aprecise area. This can be implemented, for correcting or adding features on small areas of a device, without immersing the entire device in the solution.

2. Experimental technique

A microelectroplating method has been developed. The principal components of the system are schematically shown in Fig. 1. They include a conductive substrate, a power source, a solution container, an anode, a capillary tube, and a moving stage connected to a controller. The substrate was properly connected as a cathode. The substrate was attached to an X-Y moving stage. A controller was added to allow proper position and speed control of the moving stage. The plating solution was brought to a limited substrate zone by a capillary tube.

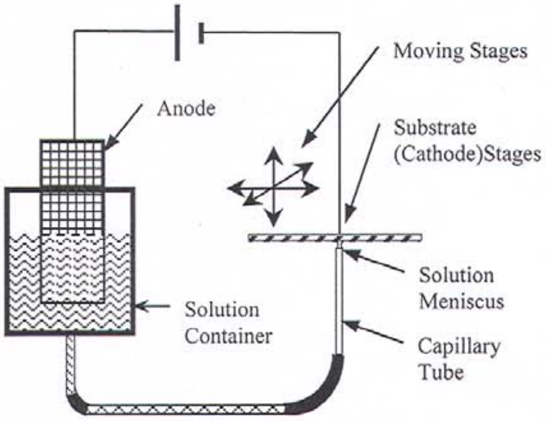

Fig. 1 Schematic presentation of the microelectroplating technique.

Several capillary tubes of different size and materials were tested including metal, glass, ceramics and polymer tubes. Capillary tubes can be obtained with a diameter starting from less than a micron [11]. To manufacture glass tubes a pulling machine was used. In some instances the tip was ground with a delicate grinding paper to diameters ranging from 30 μm to 200 μm. Glass capillaries were found to be very sensitive to handling and special care had to be taken to prevent them from breaking. Metal tubes as well as glass tubes were tried. Metal tubes were prepared from stainless steel syringe needles. These tubes had an 800 μm diameter. Ceramics tubes were also applied and were ground to the appropriated diameter using a grinding machine. Due to their inner diameter it was difficult to obtain diameters smaller than 48 μm using ceramics. However, plastic capillary tips were found to be most useful due to their flexibility and ease of handling. Plastic tubes with diameter of 180 μm were used in the experiments. The length of the tube depends on the material it was constructed from. The actual length of the tubes was a few centimeters long, however, the holding mechanism generally allowed only to a few millimeters to hang free. The free length of the tubes was set so the imaging system was unblocked. The capillary tube was attached to a vertical stage (Z- motion) in order to control and maintain a constant distance (H) to the substrate.

The solution container was connected to the capillary tube by a flexible conduit. The container was kept at a steady working temperature using a heat exchanger that was submerged into the solution (not shown in Fig. 1). The heat exchanger is based on pumped hot water in a closed circuit. The anode, made of the plating material, was immersed in the container. The electrodes were connected to a power supply. The capillary tube manipulations were done under a microscope attached to a CCD camera and a monitor. A personal computer with a frame grabber was used to record and analyse the results.

Nickel (Ni) was selected to be the plated metal. This material was selected since its operating parameters and environment, are well known. It produces flexible coatings, having good adhesion. The deposits also have magnetic properties. The solutions are not poisonous and therefore easy to handle. A standard sulfamate plating bath was used with the following components [12]:

$Ni(SO_3NH_2)_2 \cdot 4H_2O$	400	g/litre
$NiCl_2 \cdot 6H_2O$	8	g/litre
H_3BO_3	25	g/litre
Sodium Dodecyl Sulfate	250	mg/litre.

A nickel dissolving anode was used in order to maintain the solution composition as constant as possible.

Controlling the shape of the solution meniscus, created between the tip of the tube and the substrate, is most significant for an effective operation of the system. For the production of microelements it is desired to confine the solution to the narrowest possible area. The meniscus configurations shown in Fig. 1, have been observed depending on the surface tension by the Young's formula [13]. The first shape is that of an inner meniscus (Fig. 2a).

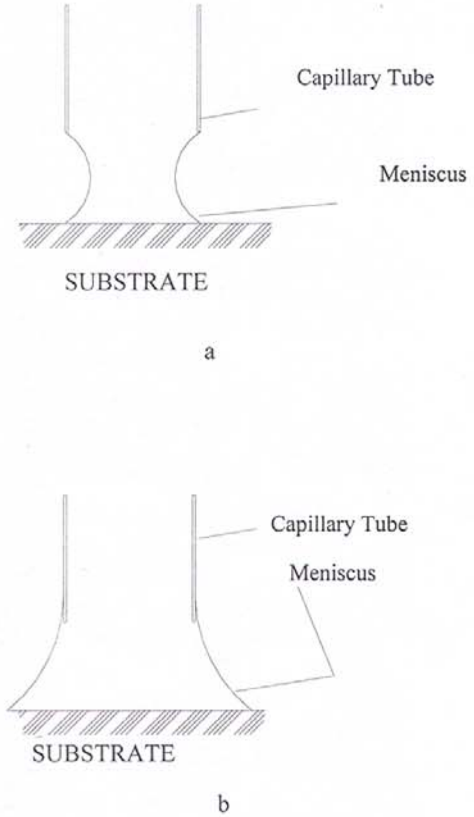

Fig. 2 Observed configurations: (a) "inner meniscus", (b) "outer meniscus".

In this case the solution is confined within the tube diameter. In the second case the liquid is spread beyond the tube diameter creating an external meniscus (Fig. 2b). These configurations constitute two possible modes of operation for the system. The inner meniscus provides the best resolution by confining the solution to the tube diameter. In contrast to common electroplating, microelectroplating requires pressure control due to surface tension effects. In order to obtain the desired inner meniscus the influence of the pressure should be considered. Pressure calibration can be achieved by changing the height position of the container and by measuring the varying free meniscus.

The system described above allows moving the capillary tube over the substrate. Confining the electroplating within the meniscus, and scanning, allow the creation of different features. The mass released during the process can be calculated from Faraday's equation [14]. The actual value of the current is also influenced by hydrogen release.

The experimental system was calibrated and tested. Several microelectroplating experiments were conducted and their results are presented in the following section.

3. Results and discussion

Nickel sulfamat plating solution and ethanol, with densities of 1230 kg/m^3 and 798 kg/m^3, respectively, were mixed.

Preliminary electroplating tests were conducted, on polished (0.05 μm finish) copper substrates. These tests were done to tune platting parameters. Adding at least 25 vol. % ethanol to the nickel electroplating solution improved the platting quality by reducing bubble effects. It also improves the brittleness of the film by reducing its hydrogen contents. The addition of ethanol decreases surface tension therefore affecting the meniscus formation. Current density of 8.5 A/m^2 was found to give smooth platting. The capillary tube and the inner meniscus configuration are shown in Fig. 3.

The above current density resulted in slow deposition rate of nickel, and therefore higher values were applied for the microelectroplating tests. Finally 16.6 A/m^2 was used. Higher current densities were also tested in order to increase plating speed. However, bubble formation became noticeable.

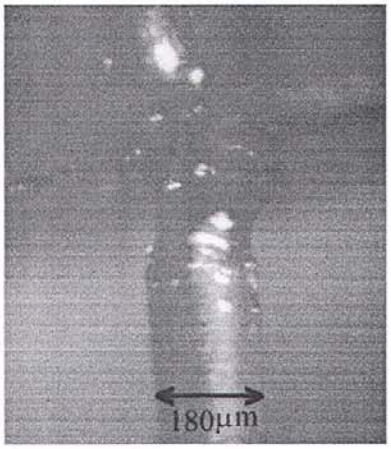

Fig. 3 Capillary tube with an inner meniscus.

To overcome the bubble formation, ethanol was added as mentioned above, and two orientations of the capillary tube end were considered. In the first configuration the tube end pointed downward and in the second one it pointed upwards. Using the first orientation, small bubbles started to form at the surface. Once they had grown to a fraction of the tube diameter, the bubbles released from the substrate and floated through the tube. In the case of a small release of hydrogen, they moved up through the tube without interfering with the plating. However, when hydrogen release became significant, the bubbles tended to stay near the tip. They accumulated, and caused the process to stumble. The bubble expansion decreased the active cross section of the liquid, reducing the conductivity of the solution, and stopping the plating process. A voltage increase was attempted in order to overcome the reduced conductance. However, the increase of the voltage was followed by the formation of dendrite webs at the vicinity of the bubble. This blocked completely the tube, and stopped the process. Attempts to overcome the problem of the bubble formation were tried. A small over pressure, to eject the bubble, was tested. Also, a momentary separation of the tip from the substrate surface was tried. In both cases, spillage of the solution over the substrate was observed. It was therefore concluded that a downward tip should not be preferred.

In an upward tip configuration the bubbles formed at the substrate, and tended to remain and grow near it. Reducing the pressure in the upward configuration created bubble inflow to the tube. This method improved the process by the removal of the bubbles from the substrate.

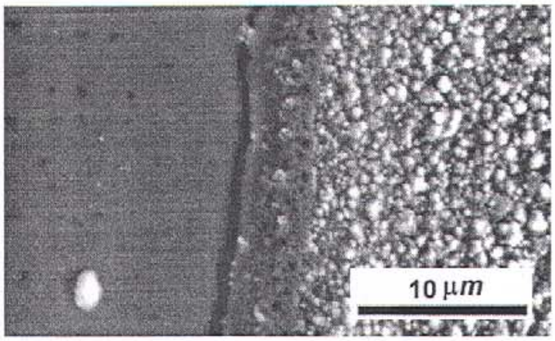

Fig. 4 Microelectroplated nickel on a copper substrate.

An average scan speed of 0.17 μm/sec resulted with approximately 3 μm thick lines, using current density of 16.6 A/m$_2$. The results of microelectroplating are depicted in Fig. 4. It shows both the surface and the thickness of the produced layer of nickel. Experiments with a stationary tube resulted with the formation of 3-D features. A typical profile is shown in Fig. 5, which was obtained using a profilometer. Microelectrodeposition yield of 35%, and more, has been found. Similar yield value is reported elsewhere [15]. This low yield may be a result of the micro effects at the tube end. EDS analysis of all the experiments' outcomes showed the presence of nickel.

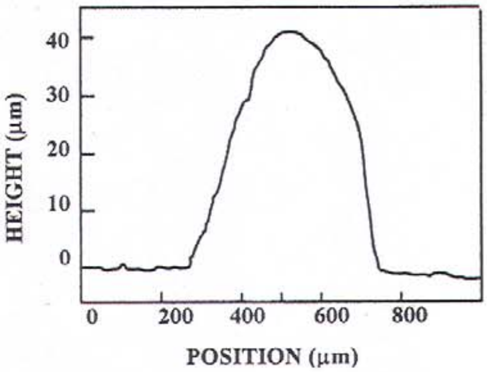

Fig. 5 Profile of a feature microelectroplated by a stationary tube.

4. Conclusions

The possibility to restrictive electroplating in small areas of a substrate is introduced. Microelectroplating is achieved using a capillary tube.

Several factors have an impact on microelectroplating. During electroplating surface tension impedes the liquid from spreading over the substrate beyond an area defined by the capillary tube. Another important factor is bubble formation. Since the diameter of a bubble is of the same order of magnitude as the capillary inner diameter, effects such as stopping the electroplating or sudden spillage of the solution could occur. The mentioned problems might be partially resolved by using adequate tip orientation or low current densities. The control of the plating quality could be enhanced, by lowering the current at the expense of scanning speed.

The results show the feasibility of the method. Microelectroplating can be applied, with or without masking steps, to add features or make corrections in specific locations of a substrate. Furthermore, the substrate may include electronic devices.

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