MODELING CAPILLARY EFFECTS IN ELECTROCHEMICAL PROCESSES

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The unique features of the LIGA processes are increasingly gaining more attention in microelectronics and micromechanics. Complex micro-structures for implementing contact systems, conductive layers and variety of microelectronic elements can be obtained by photolithographic forming of protective mask, followed by electrochemical selective deposition. However, the continuous tendency toward miniaturization has led to some undesirable effects during the galvanic process.

In the present work have been examined the problems related to the micro-capillary effects in the electrolytic cell. When the mask topology for the electrochemical deposition contains microstructures with commensurable dimensions of the diameter and the depth (100 μm and less), the result of the plating process is not always sufficient. This is observed during the manufacturing of microcontact elements "stud" and "ring" with application in the flip-chip technology. The irregular growth in height of the elements is the most encountered problem due to insufficient wetting. In addition, defects may appear like unequal surface or dendrites. Sometimes the microelements do not grow at all. This effect leads to the cathode current density redistribution and changes the predefined parameters of the process.

The analysis of some experimental results demonstrated that the electrolyte wetting of the structures is impeded by capillary effects. Moreover, the wettability depends on the temperature of the electrolyte, as well as on its physical properties – viscosity, density and the metal ions' concentration.

With regard to this, mathematical model of the microcapillary cell was established. The model describes the influence of the electrolyte parameters over the electrolyte wetting angle. The object is to find the most favorable parameters' values for obtaining smooth and uniform galvanic layers. The electrolyte wetting properties where simulated with variable concentration of the metal salt. Furthermore, the influence of the temperature over the solution's viscosity and density is also observed.

With regard to this, mathematical model of the microcapillary cell was established and the influence of the electrolyte parameters over the wettability was simulated. In order to verify the theoretical model, a comparison with experimental data was made under the same conditions. This comparison indicated reasonable correlation between the analytical model and experimental results. As a result, the analysis provides a better understanding of the electrolyte wetting capability in the MEMS conception.

Keywords: capillary effects, microstructure, photolithographic forming, wettability

1. INTRODUCTION

The microcontacts are fabricated by electrodeposition of copper into the topology of the cathode, patterned by photomask. The controllability of the electrodeposited microcontacts is important for obtaining proper interconnection reliability. However, some experimental results demonstrated that the electrolyte penetration in the photomask structures is impeded by the capillary effects. The forming of air pockets in the topology of the photomask (around 100 μm) during the process of electrodepositing prevents complete capillary filling, because air cannot escape out of the photomask electrolytic cell. This causes irregular growth in height of the microcontacts (Fig. 1).

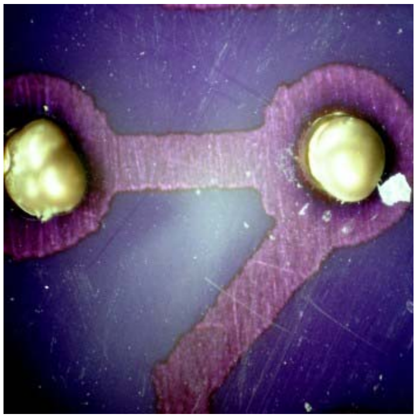

Fig. 1 Irregular growth of the surface of the microcontacts

2. OBJECT

The object of the present investigation is to explain the influence of the physical parameters of the electrolytes, related to the process of electrolyte penetration in small apertures in the photoresist during electrodepositing. The presence of air bubbles that impede the complete wetting is discussed.

3. LITERATURE OVERVIEW

Capillary filling is commonly encountered in Micro-Electrical-Mechanical-Systems (MEMS). For example, in BioChip designs lengthy micro channels are often used to deliver liquid solution from one place to another. Understanding the capillary filling process is important as different geometry of liquid flow pathways may result in different capillary filling behavior including the possibility of entrapping air bubbles, which is the subject of the present research.

3.1 Critical diameter

The problem with the electrodeposition into the topology of the photomask, caused by the capillary effects, could be explained through classical studies of bubbles trapping in isothermal static fluids [1]. A bubble rises through the denser liquid because of its buoyancy. The velocity with which a single bubble rises through stagnant liquid in a duct is governed by interaction between buoyancy and the other forces acting on the bubble because of its shape and motion. If the viscosity of the gas in the bubble is neglected, the forces besides buoyancy, which are important, are those from liquid inertia, liquid viscosity and surface tension.

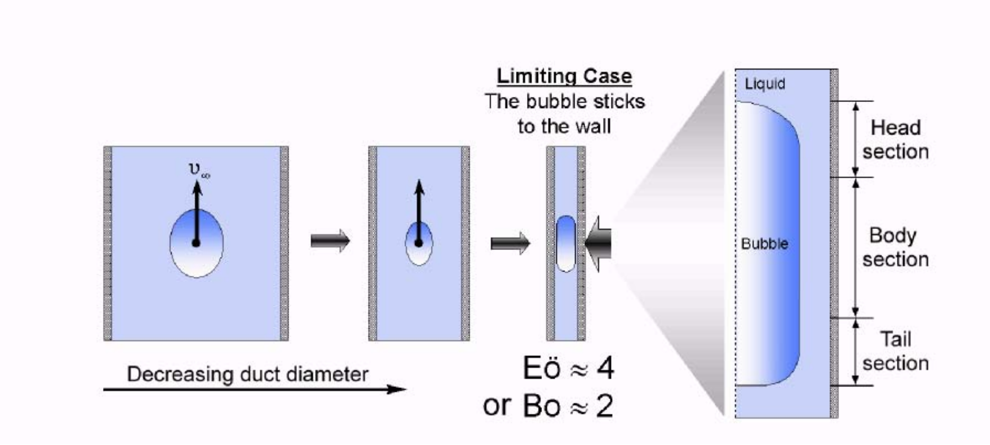

Fig. 2 Critical conditions for zero velocity of a bubble rising through stagnant liquid contained in a channel [2].

Experimental observations of Bretherton P. [1] have shown that while decreasing the diameter of the circular apertures, there is a critical value, below which an air bubble will not rise up by buoyancy. The relation between the critical diameter and the surface tension and the density is defined by the following equation:

$$D_{crit} \approx 2\sqrt{\frac{\sigma}{g(\rho_{liquid} - \rho_{air})}} \qquad \text{Equation (1)}$$

3.2Impact of the photomask topology shape and the temperature on the penetration performance

The interest of the present study is to find a solution to remove the bubbles in a short time. Bico J. and Quéré [3] have proved that the simplest way consists of making thicker the film around the air bubbles. If the topology of the photomask contains angular cavities (Fig. 3), they will trap "fingers" in their corners and thus the electrolyte will attain easily the ends of such cavities.

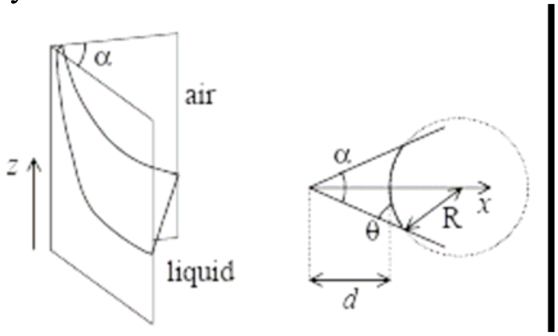

Fig. 3 Electrolyte "finger" trapped in the corner of angular cavity

The electrolyte temperature increase results in a decrease of the surface tension, as well as on the density and the viscosity.

4. EXPERIMENTS

4.1 Physical properties

To demonstrate the influence of the electrolyte parameters (density, viscosity) over the electrolyte wetting properties, microcontact elements (studs) were manufactured using two electrolytes with different physical properties. The first (BCU) finds applications in the industry for manufacturing decorative sparkling cooper layers. BCU belongs to the group of the acid electrolytes and has comparatively high cooper sulphate content – 200 g/l and 40 ml/l – sulphuric acid. The second electrolyte – MCCU – has been developed specially for the needs of the PCB technology for apertures wiring in the dielectric of the multilayered PCBs. For that purpose, the MCCU electrolyte has been chosen in the experiments. MCCU is also representative of the acid electrolytes, with the following contents – 70 g/l and 120 ml/l – sulphuric acid.

The experimental measurements of the viscosity and the density in both cases have shown similar results (viscosity – 0.0013 kg/ms, density – 1012.21 kg/m^3).

In deep apertures [4] (h ≥ D, h – height, D – diameter) the electrolytes are impeded to reach the bottom, because their pressure is not sufficient to remove the trapped air (Fig. 4, Fig. 5). Improvement of the wetting is possible if the electrolyte is injected in the resistive mask.

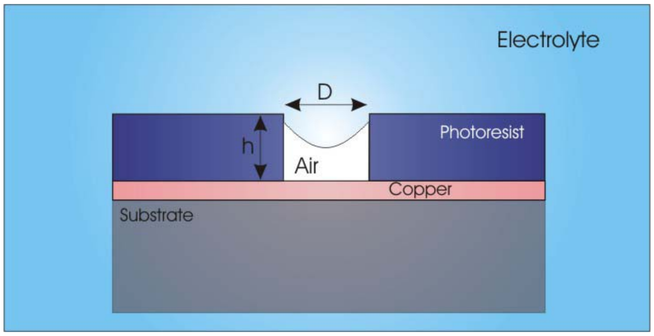

Fig. 4 Wetting in deep apertures (h ≥ D)

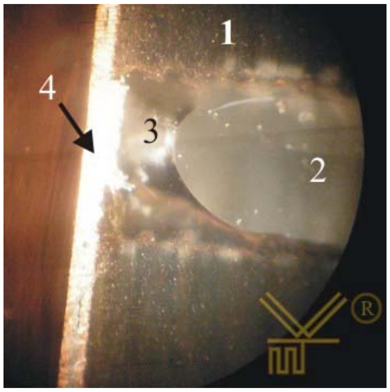

Fig. 5 Microscope photo of wetting in deep apertures (1 – photoresist, 2 – electrolyte, 3 – air, 4 – copper surface)

However, if h ≤ D/2, the electrolytes penetrate to the bottom of the elements and cooper deposition occurs. Observations on the microcontacts' surface have detected defects in the case of BCU, which means that some sections of the substrate have not been wetted (Fig. 6). Furthermore, electrolyte MCCU has demonstrated better results in obtaining smooth and uniform surface of the microcontacts (Fig. 7). This fact can be explained with the different wetting angle of the electrolytes, due to the different sulphurous acid content.

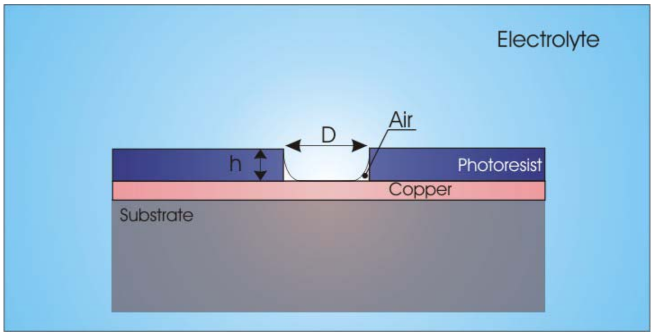

Fig. 6 Wetting for h ≤ d/2

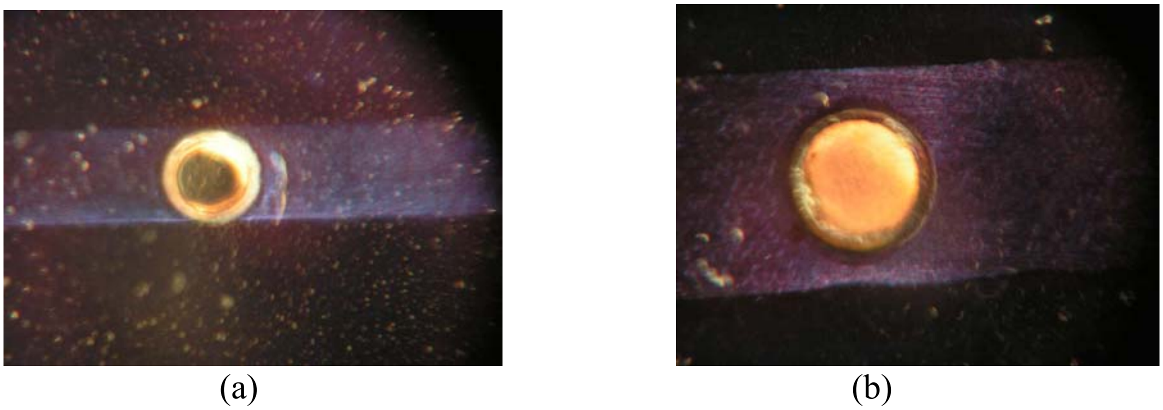
(a)
(b)

Fig. 7 Studs made with, (a) BCU (D=200 μm), (b) MCCU (D=200 μm).

The wetting agents, supplementary used with the electrolytes, are out of the scope of the present investigation.

4.2Angle-shaped microchannels

To verify the statement of Bico J. and Quéré [3], experimental tests were conducted for obtaining triangular-shaped studs. The process of electrochemical deposition was observed with both of the electrolytes and the results are presented on Fig. 8. It can be clearly seen that the surface of the studs is uniform, which proves that the process is well controlled, due to the improvement of the wetting in angle-shaped apertures.

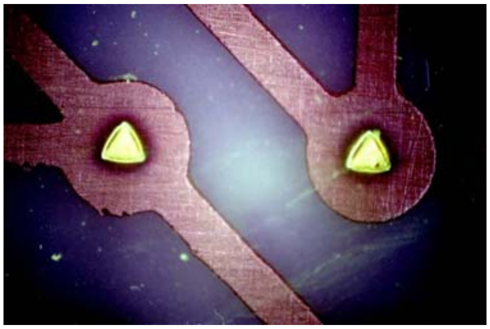

Fig. 8 Triangular-shaped studs

5. CONCLUSIONS

1. The mathematical model of the critical diameter for h ≥ d has shown that to attain good wetting, high electrolyte density is needed. Such density can not be achieved with the acid electrolytes, which are object of further research.

2. In deep apertures (h ≥ D) in the micro scale range, the pressure of the electrolytes is not sufficient to remove the trapped air.

3. If h ≤ D/2, the growth of the micro-studs using the electrolyte MCCU is better that in the case of BCU. We suppose that this result is due to the higher sulphurous acid content in the MCCU, which is an object of a new investigation.

4. Experimental tests for obtaining triangular-shaped studs have proved that the removal of air bubbles improves in the case of angle-shaped topology of the photomask, because the electrolyte easily attains the cavities' ends.

6. REFERENCES

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