Next Generation Tooling Concept for Pattern Electroplating

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A dynamically software controlled electroplating tooling concept (Intellitool®) has been developed for compensating the pattern or seed layer dependence of the deposited layer thickness on printed circuit boards and semiconductor wafers. In this paper, the tooling concept is presented, together with its embodiment in a prototype laboratory scale plating cell. Experimental layer thickness results obtained from a sulfuric acid copper bath are analyzed for determining the spatial resolution that can be obtained. The experimental results are also compared to computer simulation results. The performance of the tooling concept is further demonstrated by computer simulation results showing the improvement of the deposit thickness uniformity for a printed circuit board pattern.

Keywords: *printed circuit boards, pattern plating, acid copper plating, computer simulation*

Introduction

The plating layer thickness distribution on patterned wafers and panels (*e.g.*, copper plating on printed circuit boards (PCBs), silver plating on solar cells) is at least partially determined by the pattern layout. Another complicating factor here is the common absence of a well conductive substrate at the start of the plating process. Often only a very thin conducting seed layer (0.1 μm or even less) is present. This creates a so-called "terminal" effect, whereby initially the zones near the contact points on the substrate will get much more current, due to the internal resistivity of the substrate. This effect will gradually decline in time as the plated layer renders the substrate more conductive. Of course, this reduction in resistivity depends strongly on the pattern and can vary from point to point on the wafer or panel. In case the deposited metal layer remains very thin (a few micrometers), the terminal effect will manifest itself throughout the entire plating time.

For PCBs, typical problems include overgrowth of the photoresist by the copper deposit at spots with excessive current density, thereby creating a mushroom shape. On the other hand, spots with a current density that is too low will create for example tracks that are not up to specifications (due to the resistance of the resulting interconnects).

Tooling concept

The basic tooling concept relies on a structured matrix of dimensionally-stable anode pens that are directed perpendicular to the substrate to be plated. The spacing between the pens is typically in the order of one inch or less, with the tip of the pen being active over a short distance and the remainder of the pen being insulated. Figure 1 depicts a pen matrix tooling device for a wafer plating application.

In order to apply a fixed pen matrix hardware configuration for different pattern layouts, the pens need to be steered individually with electrical current or potential. In addition, this current or potential should be adjustable in time in order to cope with varying conductive seed layer conditions of the substrate. In Fig. 1, the pen holder consists of a multilayered PCB for electrically connecting each pen individually. The copper tracks run out to a connector pin array that is situated outside the plating bath.

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The current to each pen is delivered by a dedicated steering unit. This steering unit comprises a CPU unit for steering the individual digital analog converters (DACs). If the required current per pen is significant (*e.g.*, > 20 mA) the signal from each DAC is amplified before sending to the pen.

The steering unit is connected with a computer through a serial or parallel bus system (Fig. 2). The main principle is that the set of optimal pen current values is determined by computer and then these settings are imposed through a steering unit to the individual pens. The bus system also allows retrieving feedback information on distortions, read-back from set values, etc. This is of particular interest for monitoring the condition of the pens. A pen with deteriorated platinum or iridium coating, or a pen with poor contact can be easily identified online by the fact that the read-back electrode potential will be significantly higher than the normally observed values.

The pen matrix can either be used as the principle anode system, or in combination with a main anode system that in most cases will consist of anode baskets filled with metal pellets or balls. In the latter (hybrid) case, the pen matrix is considered an auxiliary anode system and the pen holder is open to a grid of perforations to allow the current from the main anodes to reach the cathode substrate.

The use of a hybrid system might be advantageous for plating baths that require high maintenance when being used in combination with dimensionally-stable anodes (*e.g.*, due to anodic break down of additives), thereby strongly reducing the current that is to be delivered by the pens. It is not possible to rule out the use of dimensionally stable anodes completely unless the pens would consist of a soluble metal (*e.g.*, copper, nickel). This would however compromise the performance of the pen matrix and require a very frequent replacement of the pens. One possible solution is to surround the pens with a plastic tube, thereby ensuring that the mouth of the tube (in essence, the "virtual" anode) remains always at the same position with respect to the cathode substrate. Since each pen is individually current controlled, the performance of the pen matrix will not suffer from a partial dissolution of the pens. In addition, a read-back of the electrode potential of each individual pen will allow one to determine its dissolution state.

Lab scale embodiment

The prototype laboratory plating cell is of modular design (Fig. 3), allowing operation with or without a main anode basket system. The pen matrix consists of an 8 × 8 matrix of anode pens (Figs. 3 and 4). The pens consist of 1/8-inch diameter platinized titanium rods, with the tip exposed over a length of 1/4 in. Spacing between the pens (center-to-center) is 5/8 in. The steering unit allows imposing individual pen currents up to 100 mA. The pen matrix is connected to the steering unit by means of one single flex connector.

The plating cell operates under forced flow conditions.

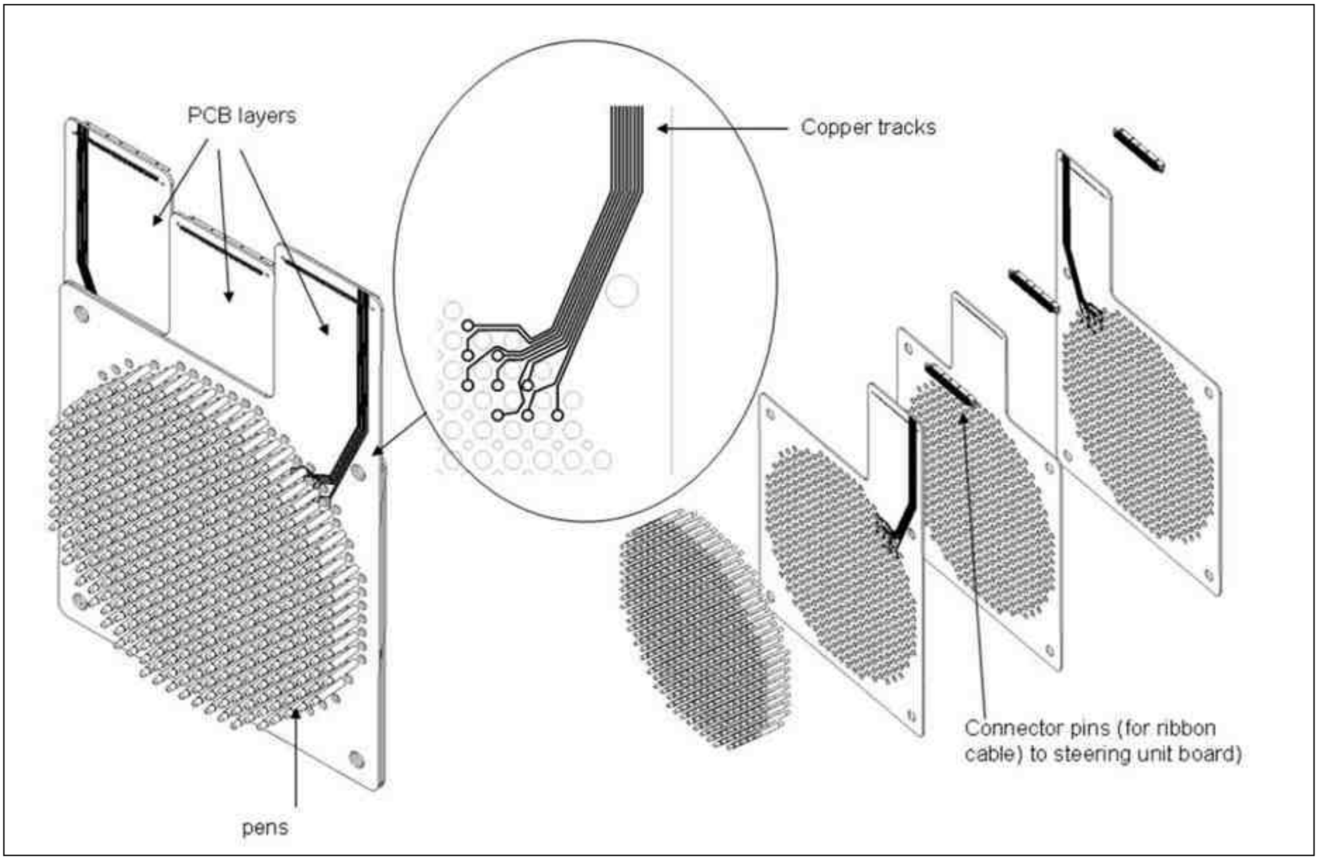

Figure 1 - *Pen matrix structure and holder.*

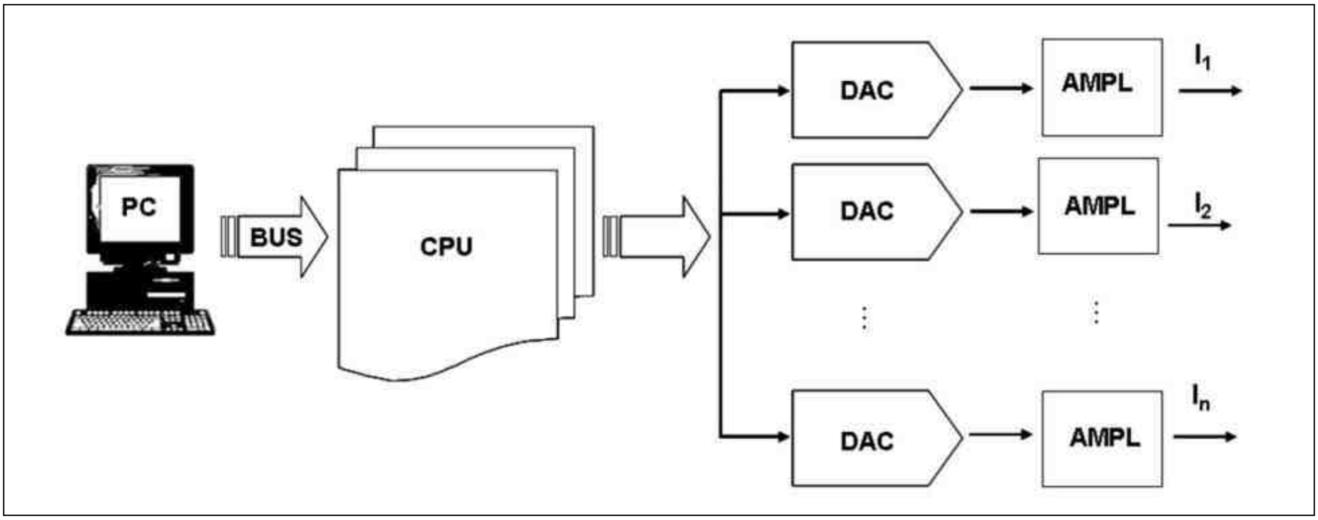

Figure 2 - *Schematic overview of steering unit for imposing pen current values.*

The electrolyte is pumped in the bottom area and by means of a diffuser system injected in the space between the cathode substrate and the pen matrix. The electrolyte exits this compartment by an overflow system and the outlets in the side compartments of the cell.

Plating bath

A proprietary high throw acid copper electrolyte** was used in these tests. For the computer simulations, as reported later, the bath characteristics were determined by means of rotating disc electrode (RDE) polarization measurements. The conductivity was measured to be 53.2 S/m at room temperature.

Evaluation of the pen matrix performance

** *Copper Gleam 125 T-2, Dow Chemical Company, Midland, MI.*

The pen matrix performance was tested by plating copper on a steel substrate. By imposing a constant current through a selection of the pens, while the remainder of the pen set is given zero current, one can analyze to what extent the "photographic image" of the pens is obtained in the copper deposit thickness distribution. Three different cases were considered:

- Case A: pen current = 50 mA for a plating time of 60 min;
- Case B: pen current = 75 mA for a plating time of 40 min;
- Case C: pen current = 100 mA for a plating time of 30 min.

The plating time was adjusted to achieve the same average plating thickness and the end of the plating time for each of

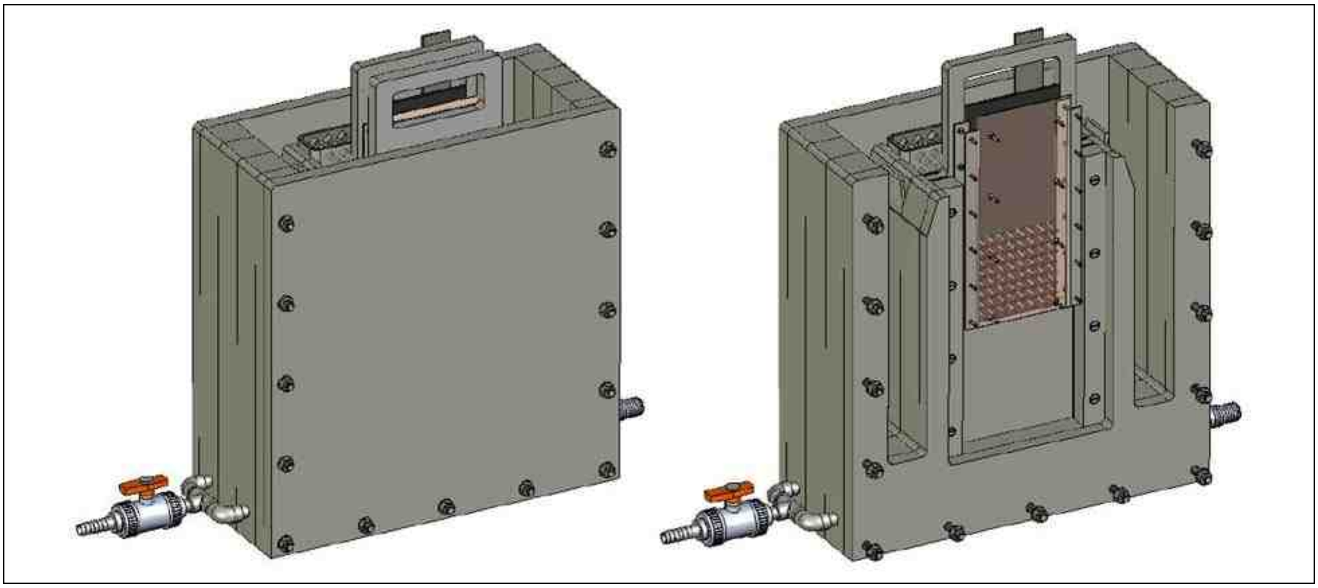

Figure 3 - *Laboratory plating cell with steel plate substrate (transparent view, right) in front of the pens.*

Figure 4 - *Prototype laboratory plating cell (L) and pen matrix holder (R).*

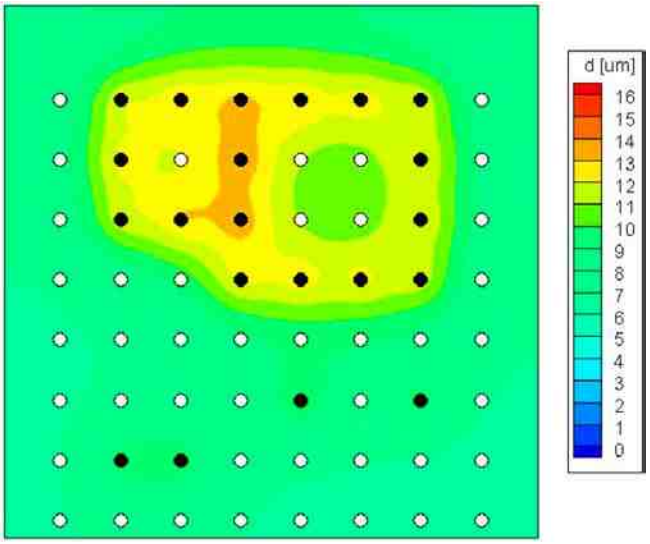

Figure 5 - *Simulated deposition thickness distribution for Case A.*

the cases.

Simulation results

Simulations using the Elsyca PlatingMaster software platform were performed to calculate the distribution of the copper deposition over the steel substrate. Results for Cases A, B and C are presented in Figs. 5, 6 and 7 respectively. The black dots indicate pens with imposed current while the white dots represent inactive anode pens.

The effect of the activated pen pattern on the deposit thickness distribution is very clear. Opposite the active anode pens, the deposition is much higher than under the sections with inactive anodes. Although the electrolyte is deliberately designed to achieve homogeneous deposits, regardless of the active pattern over the cathode substrate (high throwing power), the pen matrix can achieve a significant gradient in the deposit thickness. Furthermore the effect of the current density on the spread of the deposition can be noticed by comparing Cases A, B and C. At lower current density values (Case A), the electrolyte has a higher throwing power resulting in a more uniform deposit. For the higher current density values (Cases B and C), the gradients are much higher and the pattern on the anode is much better reflected in the deposit.

When considering the gradients in the deposit thickness for Cases B and C, it can be concluded that the spatial resolution that can be obtained with the given pen matrix structure for the acid copper bath is of the order of one inch.

In order to study the effect of the conductivity of the electrolyte on the performance of the Intellitool® concept, simulations were performed with an electrolyte conductivity of 26.6 S/m, half of the original value. This corresponds to a practical situation where the sulfuric acid concentration in the electrolyte is drastically reduced. The simulation was performed for the process conditions from Case B (Fig. 8).

When comparing the simulation results to those for the original electrolyte (Figs. 6 and 8), it becomes clear that the

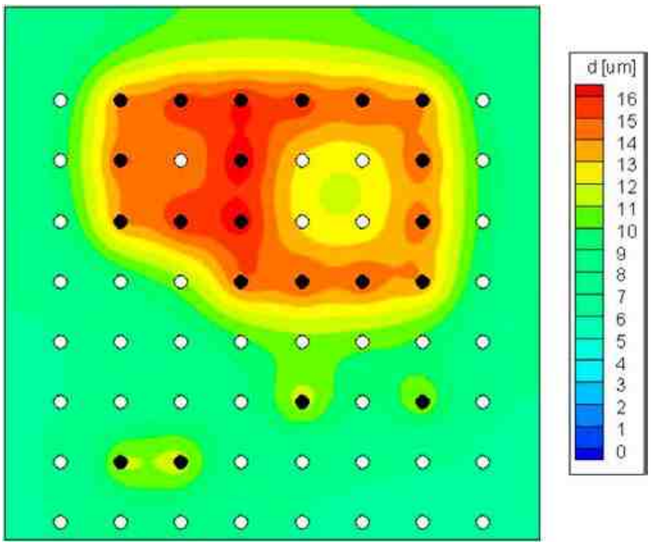

Figure 6 - *Simulated deposition thickness distribution for Case B.*

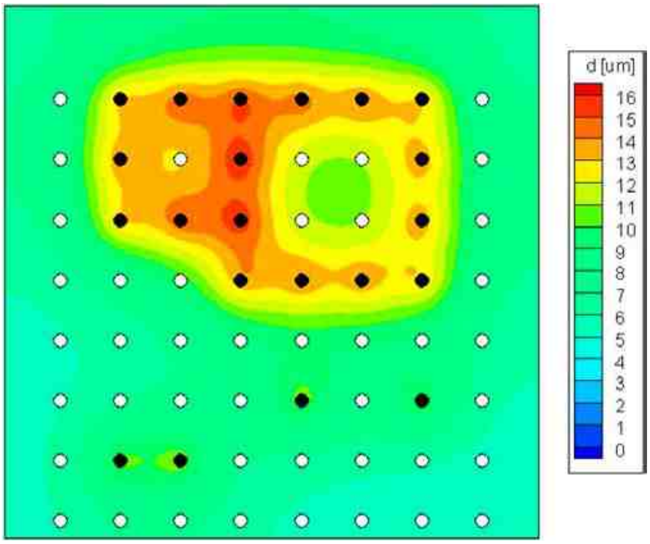

Figure 7 - *Simulated deposition thickness for Case C; 100 mA on each anode, 1800 sec plating time.*

reduced conductivity of the electrolyte enhances the performance (or spatial resolution) of the pen matrix. This implies that the pen matrix structure performs better for plating baths with a low throwing power.

Experimental results

Lab scale tests have been performed for Cases A, B and C. The steel substrate was cleaned with diluted HCl prior to plating. The thickness of the deposited copper was measured using an Oxford Instruments XRF using a 10 × 20 point measurement grid. Results are presented in Figs. 9, 10 and 11. The agreement with the simulated results is good to very good, proving that the computer simulations are a valuable tool for predicting the performance of a pen matrix system for a given set of process conditions.

Application to a printed circuit board pattern

One of the most powerful applications of the segmented anode is to compensate for the deposit thickness distribution on the active pattern of a printed circuit board (PCB). Simulations were performed for a limited size PCB, using a pen matrix configuration similar to the one that is integrated in the prototype lab cell. First, a simulation was performed using only the main anodes while imposing an average current density over the pattern of 25 A/ft^2 for a plating time of 60 min. These process conditions allow achieving a minimum deposit of 25 μm everywhere on the pattern (Fig. 12). Next, a simulation was performed using a pen matrix with optimized individual pen current values. Figure 13 illustrates that a very uniform deposit thickness can be achieved, thereby attaining the minimum specification of 25 μm over the entire PCB pattern with only very limited excess plating at most locations.

In addition the plating time can be reduced to 45 min. Comparison of Figs. 12 and 13 shows a dramatic increase in the uniformity of the deposit.

Conclusions

It has been demonstrated both from computer simulations and laboratory tests that the Intellitool® concept is able to exert strong control of the deposit thickness distribution over a flat substrate. The spatial resolution that could be obtained for an industrial acid copper plating bath was of the order of one inch.

The steerable pen matrix structure enables one to counteract nearly completely the non-uniformity of the deposit as created by the layout of an active pattern on a PCB. It was also demonstrated that an even better spatial resolution can be achieved when an electrolyte with lower throwing power is used. Also the combination of pens with anodic imposed current with pens that are given a cathodic current can further improve the spatial resolution.

About the authors

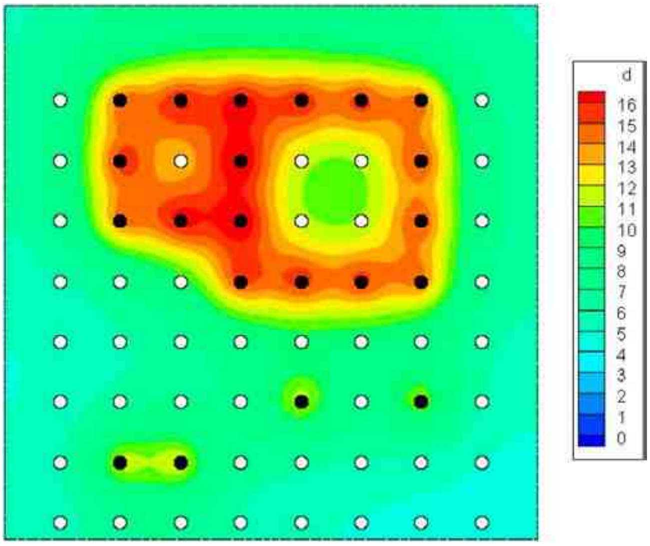

Figure 8 - *Simulated deposition thickness for Case B; reduced electrolyte conductivity.*

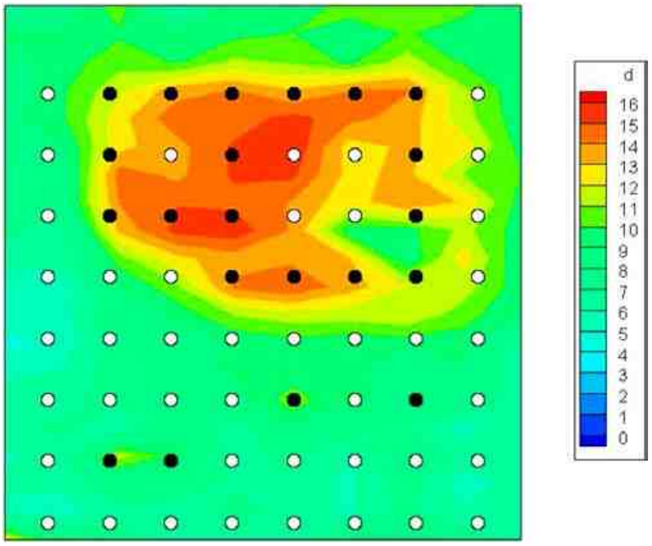

Figure 9 - *Measured deposition thickness values for Case A.*

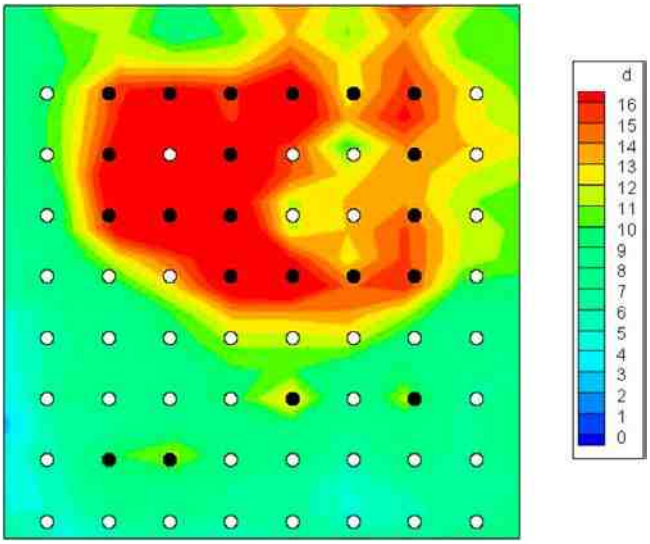

Figure 10 - *Measured deposition thickness values for Case B.*

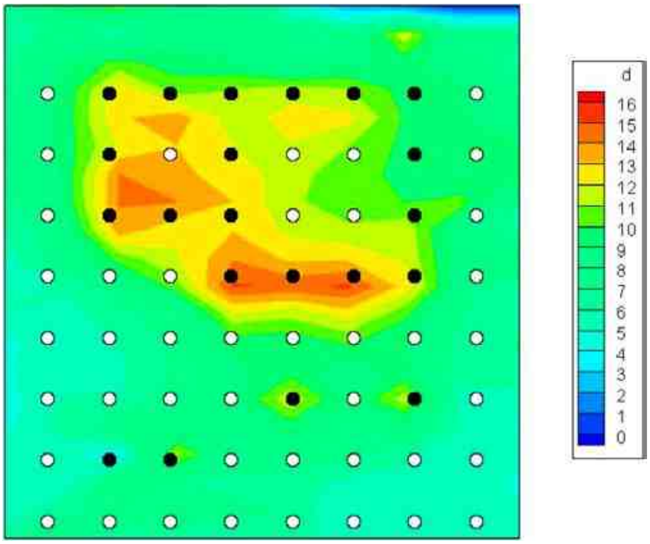

Figure 11 - *Measured deposition thickness values for Case C.*

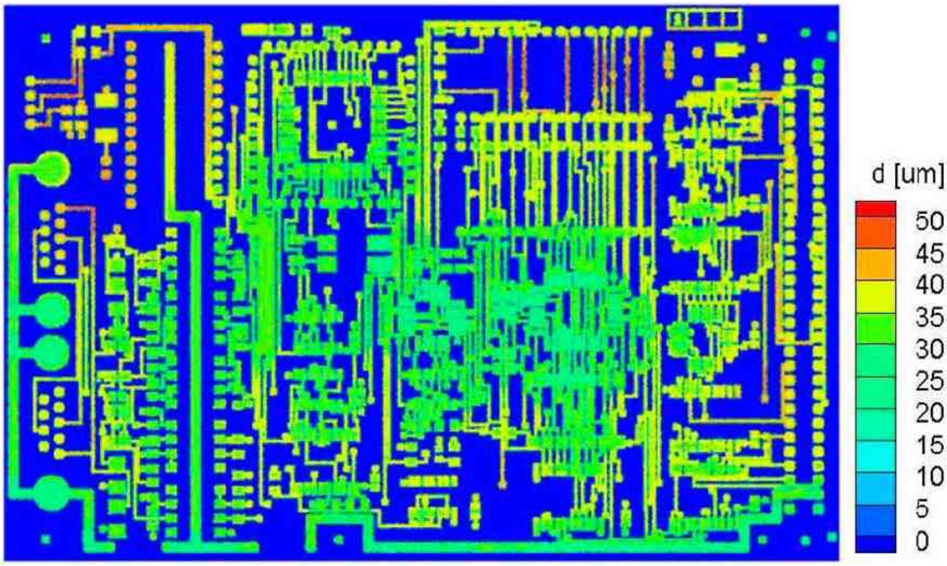

Figure 12 - *Simulated layer thickness distribution over a PCB pattern – main anodes.*

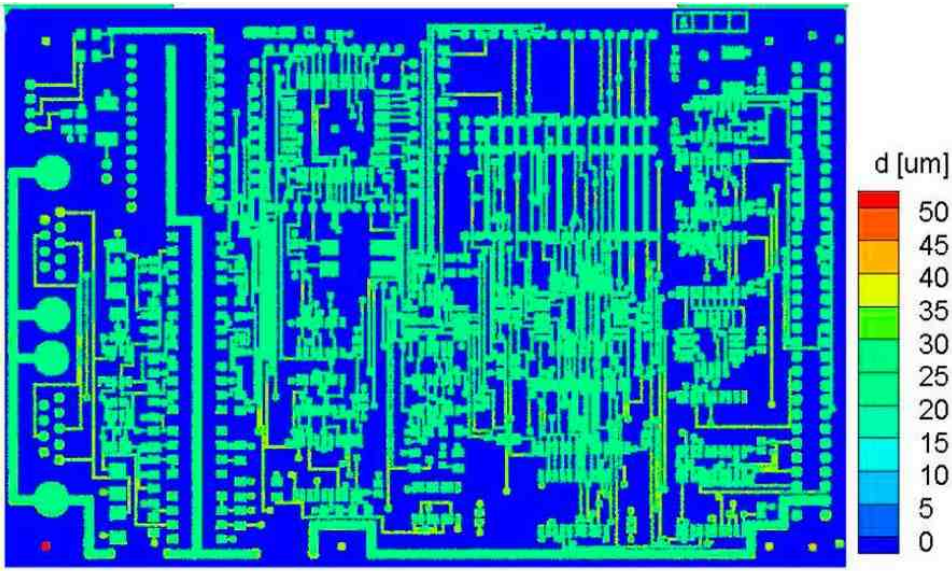

Figure 13 - *Simulated layer thickness distribution over a PCB pattern – pen matrix.*

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Dr. Bart Van den Bossche *graduated from the Vrije Universiteit Brussel (VUB, Belgium) with a M.Sc. degree in Metallurgical Engineering in 1991. He received a Ph.D. in Electrochemical Engineering in 1998. Bart is Elsyca's Engineering Manager for Surface Finishing projects. Bart has been active in electrochemical process computer modeling for over 15 years, as reflected in a series of peer reviewed papers. In addition, Bart has a long track record as a consultant for electrochemical cell and tooling design in the plating, electroforming and electrochemical machining industry. As Elsyca co-founder, Bart is in charge of several Elsyca consulting projects.*

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Dr. Alan Rose *is an elected fellow of the Institute of Mechanical Engineers in the U.K., with a B.Sc. in Aeronautical Engineering and a Ph.D. in Chemical and Process Engineering. He currently holds Research Fellow positions at Manchester University and Liverpool University, where he has been involved in flow-related research and training of graduates and post-graduates in computational fluid dynamics. Dr. Rose is a long-time advocate of engineering simulation tools and has been involved in verification, validation, implementation and simulation programs with the U.S. Air Force, Rolls-Royce, DuPont and Johnson Matthey, to mention a few. For the past five years, he has been instrumental in the adoption and application of software simulation tools in electrochemical process industries, such as plating, machining and even corrosion. Dr. Rose is currently based in Atlanta and is responsible for Elsyca's North American business.*

Paulo Vieira *graduated from the Universidade de Coimbra (Portugal) with a licentiate degree in Industrial Chemistry in 2005. Paulo then joined Electrofer IV, a leading automotive electroplating company in Portugal where he first held responsibilities in production. Paulo became responsible for Development in 2007, ensuring process optimization, testing and approval of prototype parts. In 2008, Paulo joined Elsyca´s engineering team where he currently works on consulting projects as a project engineer. Paulo has been active mainly in functional plating but also in decorative plating, electropolishing and electrocoating.*

Answers to I.Q. Quiz #464
From page 57.

1. Anomalous codeposition is the case where the less noble metal (i.e., more active) is preferentially deposited over the more noble one.
2. Normal codeposition.
3. The coating system corrodes more slowly.
4. False.
5. d) All of the above.

Q&A