Optimization of a Nickel rack plating process using Elsyca PlatingMaster

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One of the main problems encountered in rack plating is ensuring plating uniformity over the entire rack. Traditionally, this is solved in several expensive and time consuming trial and error steps by changing the rack design, masking, fixtures etc. Using Elsyca PlatingMaster, a fully CAD (SolidWorks) integrated simulation software, this trial and error process can be reduced significantly. The software allows calculating the current density and deposit thickness distribution in arbitrary shaped three dimensional electrochemical plating configurations. As a case study, the optimization of a rack plating process for selective deposition of nickel on complex parts will be presented.

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1. Introduction

Although advanced numerical methods exist and have been applied with great success in a broad range of engineering domains (hydrodynamics, aerodynamics, structural mechanics, heat transfer, etc…), the use of these methods for electrochemical plating applications remains rather limited. One of the main reasons is the complexity of the physical, chemical and electrical phenomena governing electrochemical reactor behavior. In general, a complex interplay of the following phenomena takes place: electrochemical electrode kinetics, electrolyte hydrodynamics, ionic mass transport, gas evolution, and heat generation in the bulk and at the electrode-electrolyte interfaces.

From an engineering point of view however, the main focus is on the current density and layer thickness distribution, which principally depend upon the following phenomena:

- ohmic drop in the electrolyte solution;
- cathodic polarisation and plating efficiency;
- anodic polarisation;
- reactor configuration including anode positioning, screens and current thieves;
- workpiece shape and dimensions;
- selective insulation of workpiece surfaces;
- number and position of workpieces on a rack;
- total current injected and anode + workpiece contacting method.

The modeling approach that takes into account these phenomena is commonly denoted as the 'potential model'[1]. In order to produce reliable simulation results, the physico-chemical input parameters (polarisation behavior, plating efficiency and electrolyte conductivity) need to be defined carefully for the electrolyte bath being used, at a given operating temperature.

The Elsyca PlatingMaster tool is entirely integrated in the SolidWorks® CAD environment hence enabling a very fast adaptation of the reactor design at each step. The unique combination of a user-friendly and performant CAD tool with a fast and accurate current density and layer thickness distribution simulation tool allows to design and optimize the entire reactor within a couple of hours. The Elsyca PlatingMaster tool can also be used for the evaluation of current density and layer thickness distributions on electrodes with high internal resistivity e.g. wafers[3], or for electrochemical machining applications [4,5].

2. Mathematical model

A brief overview of the mathematical model behind the current density and layer thickness distribution simulations is given below.

Although cathodic deposition reaction mechanisms can become very complex, the polarisation behaviour for single metal deposition processes $M^{z+} + ze^{-} \rightarrow M$ is often quite accurately described by a Butler-Volmer type relation:

$$j_n = j_0 \cdot \left(e^{\alpha_a F/RT\ (V-U)} - e^{-\alpha_c F/RT\ (V-U)}\right) \tag{1}$$

where j_n is the amplitude of current density normal to the electrode surface, j_o is the exchange current density, R the gas constant, T the temperature, α_a and α_c the anodic and cathodic charge transfer coefficients, and E_{01} the equilibrium potential for the deposition reaction. V and U hold for the electrode respectively electrolyte potential.

The main reaction occurring at inert impressed current anodes is oxygen evolution. Due to the thin passivation layer that is often present on the surface of this type of electrodes, a linear relation approaches the polarisation behavior:

$$j_n = A(V - U) + B, \tag{2}$$

with *A and B* polarisation constants.
The ohmic drop effects in the electrolyte are described by the Laplace equation for the electrolyte potential U:

$$\overline{\nabla}(\overline{j}) = 0 \qquad \overline{j} = -\sigma \overline{\nabla} U \quad . \tag{3}$$

On insulating boundaries, the current density perpendicular to the surface should be zero, which results in the following boundary condition:

$$\overline{j}.\overline{1}_n = j_n = -\sigma \overline{\nabla} U.\overline{1}_n = 0. \tag{4}$$

On electrodes, j_n is given by equations of type (1) or (2).

The local metal thickness d on the cathode is simply computed from Faraday's law:

$$\Delta d = \theta \frac{M \Delta t\, j_n}{\text{ñ}\ z\ F}, \tag{6}$$

where θ is the efficiency for the deposition process (depending on the current density j). M holds for the atomic weight of the metal, ρ for the density, z is the number of electrons exchanged in the metal deposition reaction, and F is Faraday's constant.

The physico-chemical input data (polarisation behavior, plating efficiency and electrolyte conductivity) as used in this paper are those for a typical industrial bright nickel plating bath.

3. Numerical solution method

Different numerical methods exist to solve the equations presented above. One of the most well known and commonly used is the Finite Element Method. Using a discretization (subdivision) of the domain and a predefined test function on each of the elements, equation (3) is transformed into a system of algebraic equations. When this system is solved, the electrical potential in all points of the domain is obtained. From this, the current density can then be computed using equation (3). In the latest version of Elsyca PlatingMaster, an advanced Finite Element Method is used. A more detailed description of this method is beyond the scope of this paper.

Figure 1: A single door handle as designed with the SolidWorks CAD environment

4. CAD based rack design

The application under consideration here is bright nickel plating on door handles. Different rack configurations are studied as well as the influence of a current thieve on the current density distribution on each individual door handle and on the overall behavior.

The basic part is shown in figure 1. Although this door handle does not appear very complex, the design contains 134 edges and 60 faces. The surface area of the handle is 0.01277 m^2 (19.8 square inches). The target average current density on the handle is about 3 A/dm^2, leading to a total current of 3.8 A per work piece.

In order to efficiently plate this door handles with nickel they are placed on a rack. A first design of such a rack, containing 50 pieces (5 by 10) and requiring a total current of 90 A, is shown in figure 2. Remark that the entire rack is included in the simulations. The anodes are positioned far away so that the geometric details are not important in this case.

Using the built-in mesh generator a surface and volume mesh is generated in order to perform the finite element calculations. The mesh used on each handle is shown in figure 3. It contains 10,091 points and 16,670 triangles. The resulting volume mesh contains 2,046,490 points and 11,263,696 tetrahedrons.

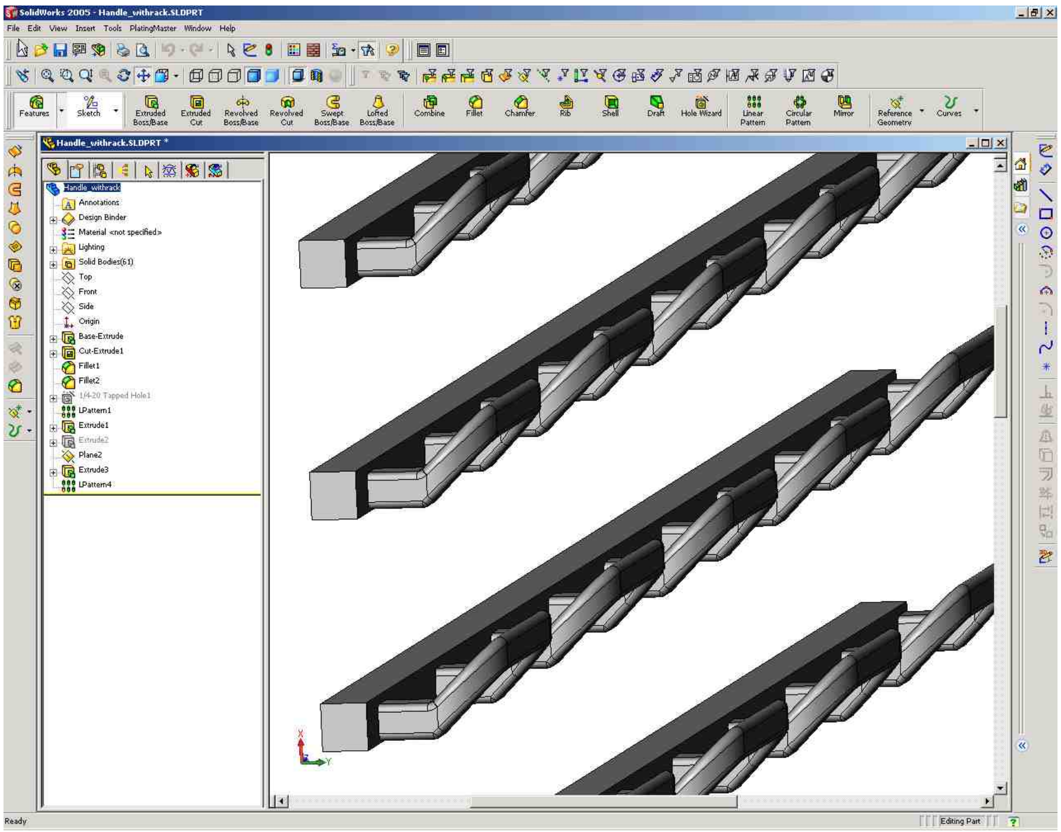

Figure 2: Basic rack design in the Elsyca PlatingMaster environment

Figure 3: Grid the handles

The calculated deposit thickness distribution on the original rack configuration is shown in figure 4. The darker (more green/blue) the lower the deposit thickness, the more red the higher the deposit thickness. From figure 5 it becomes clear that the handles located on the outer edges of the rack attract more current compared to the handles on the inner parts of the rack. The software predicts a spread of more than 29 % in the total current (and thus of the deposition) over the rack, compared to the average value.

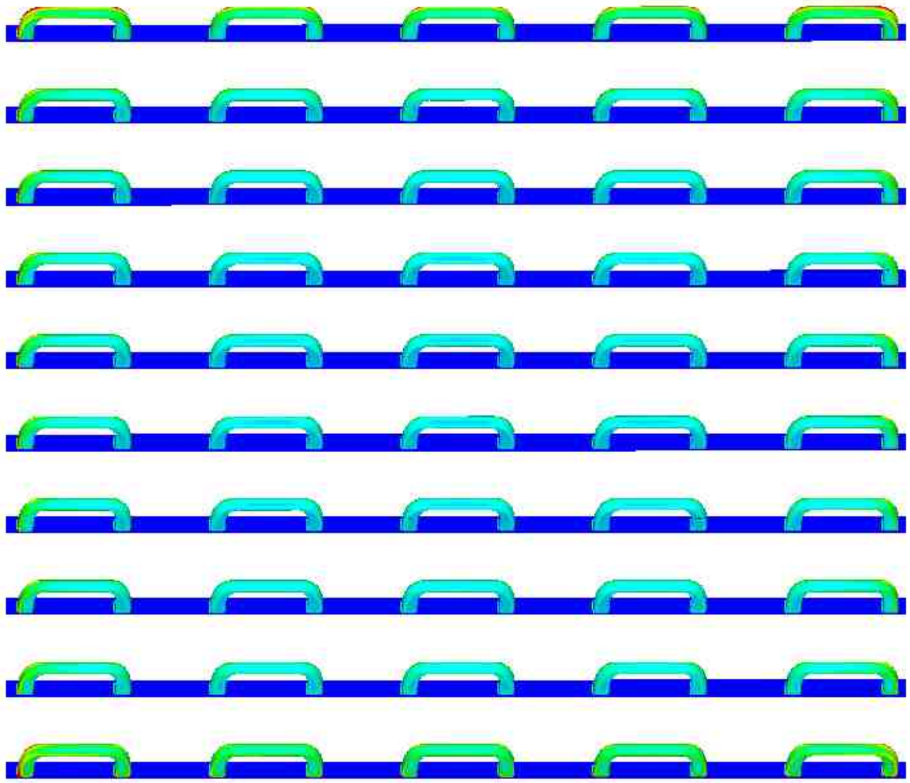

Figure 4: Overview of the layer thickness distribution over the rack

Additionally, thanks to the high accuracy and fine mesh resolution as used in this example, a very detailed current density and deposit distribution on each of the handles is obtained as is presented in figure 6, clearly showing the edge. The edges of the work piece attract more current giving rise to the well known nodules often encountered in nickel plating. Even if a difference in average current density per work piece of 20 % is acceptable, only 38 of the total 50 partswill meet these specifications. This means that the fall-out is almost 1 in 4.

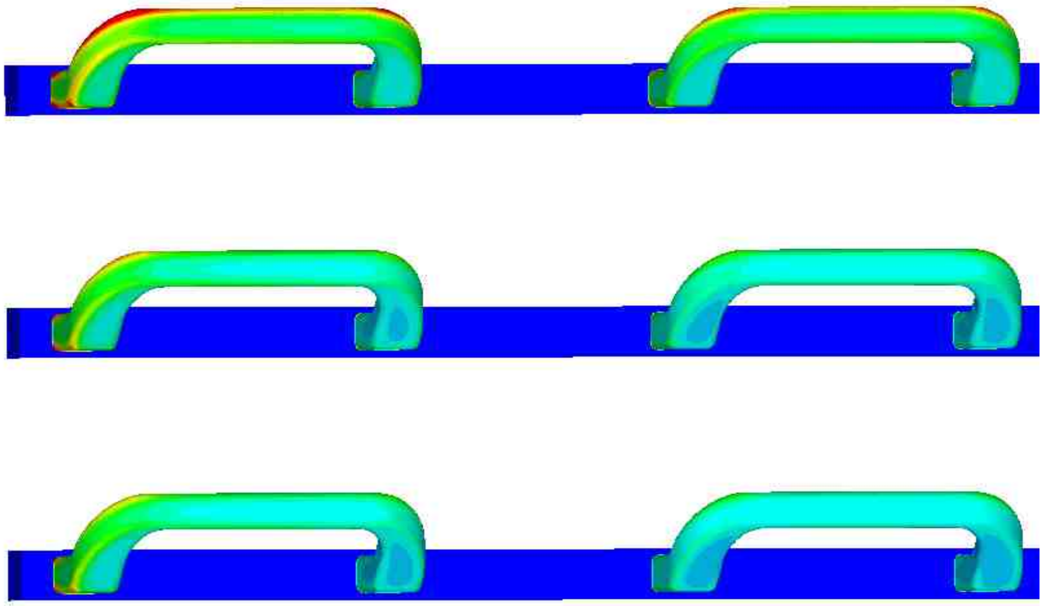

Figure 5: Deposit thickness distribution on handles on the outer side of the rack

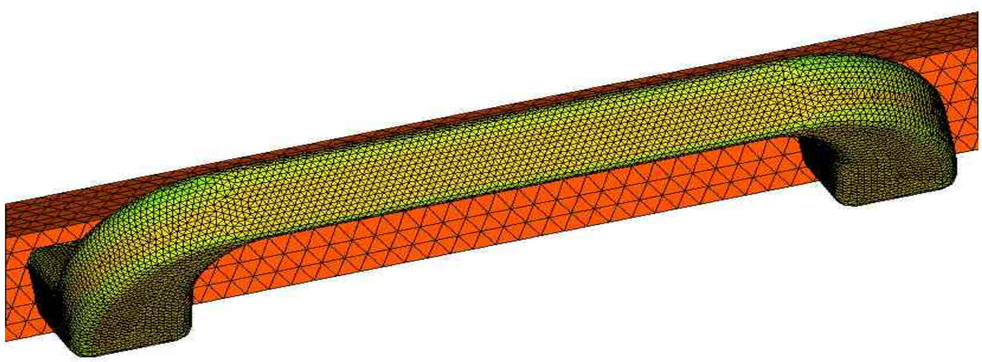

Figure 6: Current density distribution and mesh on a single handle

To avoid the highly non uniform macroscopic layer thickness distributions as encountered in the previous example, quite often a current thieve (current robber) is positioned around the rack. A typical design including such a current thieve is shown in figure 7.

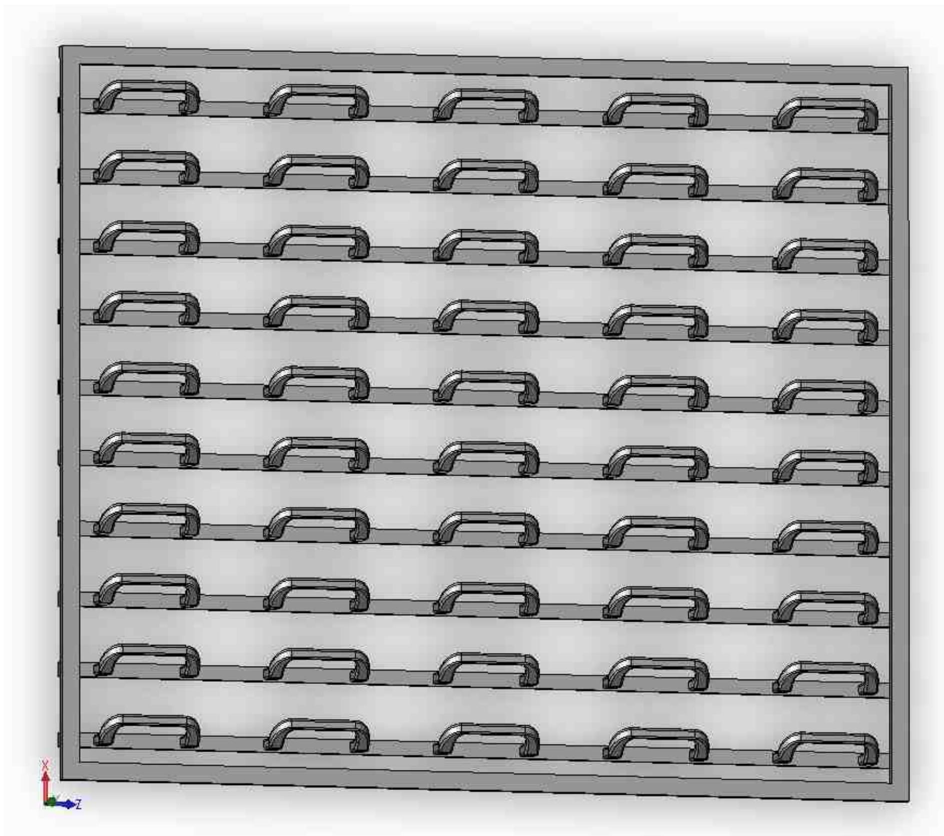

Figure 7: Rack configuration including current thieve

When the calculations are repeated including this current thieve, the macroscopic layer thickness distribution becomes much more uniform, as evident from figure 8. Remark that the scale used in this figure is the same as the one used for figure 4 and 5. In this case the spread of the total current per work piece is reduced to 6% compared with the average. In this example, all work pieces fall easily within the maximum deviation specification of 20% from the average layer thickness, increasing the yield to 100%.

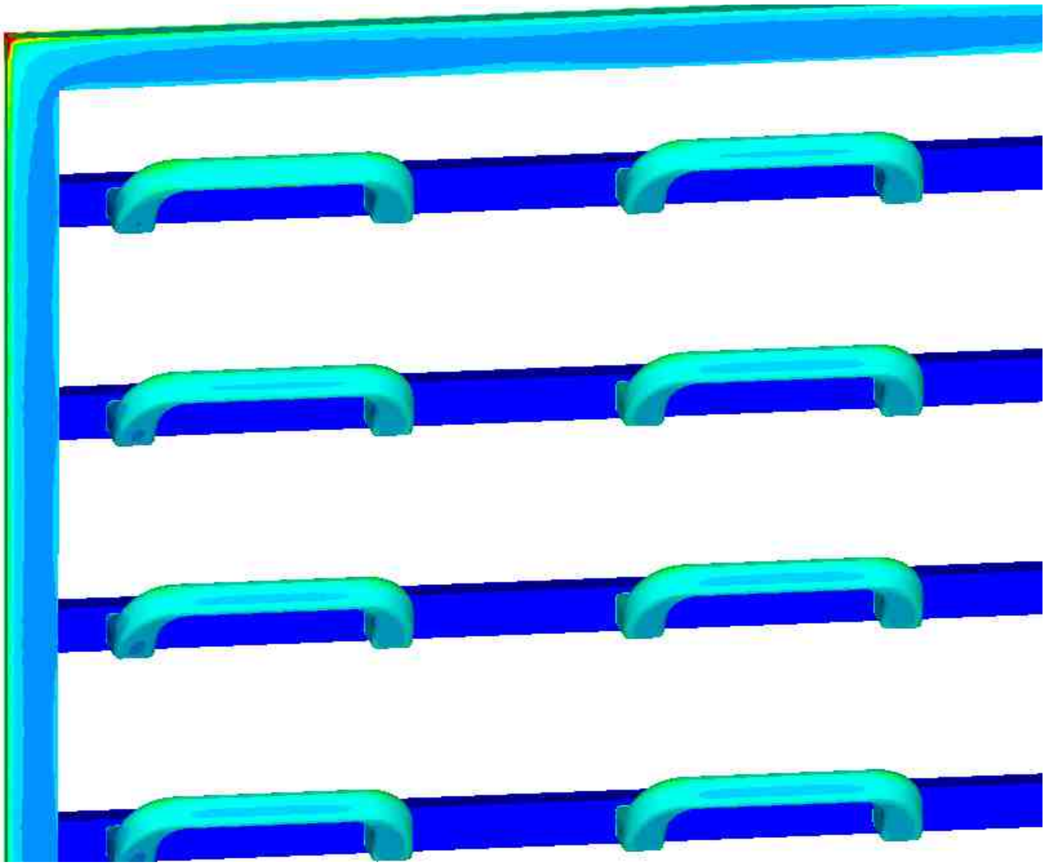

Figure 8: Layer thickness distribution including the current thieve

5. Computational specifications

The ElSyCa PlatingMaster tool runs under Windows. The total CPU times for the simulation of the current density and deposit thickness distribution of the complete plating configuration including rack and current thieve as discussed in section 4 range around *25 minutes* (6 iterations needed due to the non-linear boundary conditions) on a *3.0 GHz* PC, including triangular mesh generation.

6. Conclusions

The capabilities of the ElSyCa PlatingMaster tool for a fast CAD aided design of rack plating configurations have been illustrated. Furthermore, the influence of a current thieve on the uniformity of the deposit has been studied.

For plating applications where the use of bipolar pulse current rectifiers can improve both the deposit quality and uniformity, ElSyCa PlatingMaster also allows a full investigation of pulse current parameters (anodic and cathodic current, duty cycle, etc.), in combination with the standard reactor design tool kit.

To summarize, Elsyca PlatingMaster is a unique software solution, bringing major added value to electroplating and thin electroforming processes:

- Elsyca PlatingMaster enables to gain in-depth insight into & to master electrochemical processing steps. Elsyca's software can be used as a 'knowledge management system' to capture the implicit knowledge that is only present in the minds of a few experienced employees. It can also be used as a training tool to show employees the influence of different parameters on the process & product quality.

- Elsyca PlatingMaster software enables manufacturers to discuss the manufacturability of a product (cost, quality) based upon sound analytical data with the Design and/or Engineering departments but also with their customers.

- Elsyca PlatingMaster makes it possible to optimise process yield, product quality, through-put and customer service potential at the same time.

- And finally, Elsyca Platingmaster guarantees enormous cost & ecological savings from design to manufacturing phase through reliable & valid predictions of electrochemical reality: Equipment is designed "right-first-time"; Product development & time-to-market of new product designs can be speed up substantially; Trial-and-error is reduced significantly; Waste, energy and material consumption are reduced and post-treatment steps can be ruled out.

7. References

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