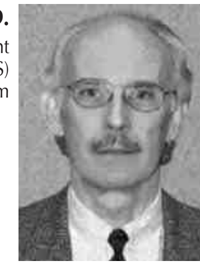
Eric W. Brooman, Ph.D.
Consultant
Materials & Processes Professional Services (M&PPS)
E-mail: ewbrooman@yahoo.com



Modeling of Facilities, Processes and Products

In the last column, the advantages of using modeling to shorten process development and optimization cycles, increase process efficiency, reduce rejects and rework, design fixturing and reduce resource requirements (labor, chemicals, other materials and utilities) were mentioned. As a corollary, the need for the many diverse, related skills and tools for component design, bath formulation and control using real time analytical methods, improved fixturing, selecting power supplies, process software development and so on was identified. In this column, we will focus on some recent developments relating to how facilities, processes and ultimately products can be improved in a competitive marketplace, and will describe a few, specific examples of applications to show just what can be accomplished with the tools and services available.

Three of the factors that impact increased productivity, improved products that meet or exceed customer satisfaction and life cycle cost goals or profitability, relate to the surface finishing facility itself, the appropriate surface finishing processes and how they are integrated, and the part or component design itself. How product design affects surface finishing processes has been covered elsewhere[1] and will not be discussed further, except to say that great strides have been made in recent years in finite element analysis (FEA), CAD/CAM 3-D modeling tools and rapid prototyping techniques - these could be the basis of a separate column in their own right!

Modeling of integrated facilities

Many surface finishing facilities have grown organically, by which we mean that, at first, only a few processes were offered, such as copper, nickel, chromium or zinc plating to meet specific customer requirements or market needs. As new markets developed, or customer requirements changed, other processes were added, often in a haphazard way because of lack of suitable space (usually because of the unavailability of capital for facility modification or expansion). This approach - where there was not the luxury of designing and installing a new facility from scratch - led to cramped working conditions and the need to share some processing steps, such as racking/unracking, masking/demasking and rinsing. In turn, such conditions led to waste, such as excessive part travel, additional handling and scheduling issues. In addition, the increased opportunities for making mistakes and cross-contamination often led to a decrease in part quality and a greater amount of rework or number of rejects.

A recent paper by Klink, *et al.*[2] addresses the problem of facility layout, including the optimum integration of processes in surface finishing facilities. It describes the difficulty many have in being able to “visualize the interdependencies of the various processes and process steps . . . when contemplating changes,” and provides some examples of tools that can be used, such as “value stream mapping,” “process flow diagrams,” “process relationship diagrams” and “process modeling tools.” Commercial software also exists to create and model “steady-state representations of process chemistry, drag-out, bleed, product out and other chemical depletion mechanisms” in surface finishing processes, as well as related waste treatment and metals or waste water recovery. These software tools are useful for modeling the effects of changing processing parameters, such as bath temperature, surface area, surface tension, evaporation rates and part configuration (drag-out). And as the paper points out, answers to “what-if scenarios” can be obtained quickly without having to resort to experimentation in a laboratory or on a processing line, both of which can be time consuming, costly and even sometimes interfere with production. Using modeling tools can expedite and facilitate making changes in a cost effective and timely manner by avoiding mistakes and using the available resources most effectively. Finally, as Klink, *et al.*[2] conclude, these tools can provide “documentation for effective master planning and production implementation” and “documentation essential for …” business plans and “… successful funding requests.”

Modeling of processes and products

Whereas the software tools described above generally relate to macro effects, such as size of the workload, mass and energy balances, equipment type, size and location and ergonomic considerations, commercial software and technical support also exist for focusing on specific processes, and even specific parts to improve coating efficiency, *e.g.*, to reduce the need for post treatments such as grinding to final dimensions, or to avoid environmental problems such as having to use maskants and remove them after plating. As an example,[3,4] special fixturing and conforming anodes have been used with success at Ogden Air Logistics Center, UT to plate hard chromium on selected areas of landing gear components. The improvements that resulted are claimed to be:

1. An increase in productivity of 260%
2. A reduction in hazardous waste of 95%
3. A reduction in operating cost of 60% and
4. A reduction in “post-plate” grinding of 40%.

These are significant numbers and the good news is that there are opportunities for other surface finishing applications to also benefit from such approaches.

The example of using electroplating as the process under consideration will be used in the discussion below, but the modeling tools mentioned also could be applied to anodizing, electrochemical machining, electropolishing or any other process that involves electrochemical reactions.

To achieve the benefits described above, an empirical approach to optimizing bath chemistry and tank and fixturing design - including the placement of anodes to improve current distribution (hence deposit thickness or surface modification uniformity) - would be very time consuming and expensive because of the number of variables involved and the interdependencies among them. Two-dimensional (2-D) and three-dimensional (3-D) models are commercially available* to screen the numerous combinations of variables to identify the one or two that best meet the required end result. Limited laboratory testing and shop floor trials can then proceed with some confidence that a satisfactory solution to the problem on hand can be implemented.

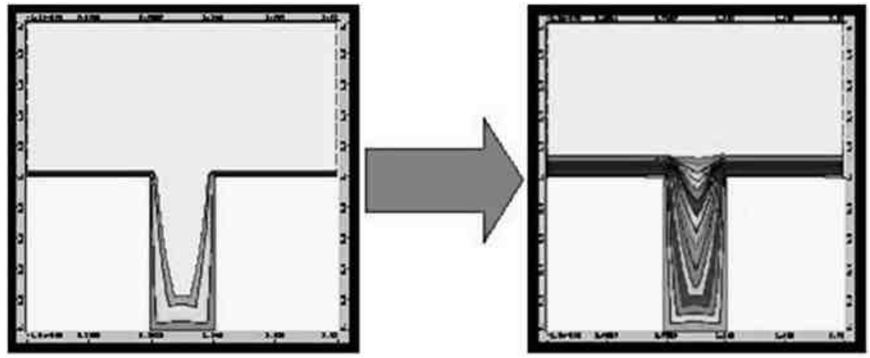


Figure 1—Modeling via and trench filling in semiconductor interconnects; a time step series showing the progression of a "super-fill" of a 2.5-μm trench through a "bottom-up" fill process (http://www.l-chem.com/cdw.html).

2-D Modeling

One commercial product originally developed some 20 years ago is the 2-D modeling software that can be used for electrochemical cell design and analysis.[5] The software can predict potential (voltage) and current distributions in a plane section of a chosen cell design and dimensions and, therefore, predict deposit thickness distribution as a function of time using an algorithm based on Faraday's Law. Other cell performance parameters that can be predicted are the operating overpotentials (voltage losses) at the electrodes, ohmic (resistance) losses in the bath and - with an available expert system - ionic transport and reaction kinetics data. Figure 1 shows the deposit thickness modeling of via and trench filling in semiconductor interconnects generated by this modeling software. Varying input parameters such as geometry, chemistry and operating conditions can indicate which set of conditions can provide the most effective filling into the via or trench.

The 2-D model has developed into a relatively sophisticated tool, the applications of which are only limited by the user's experience with the software, the technical support available and the inability to produce 3-D visualizations of plating and similar processes. However, besides optimizing a particular process and predicting deposit thickness distribution, the tool can be used to accomplish the following:

1. Rack design
2. Location, size and shape of thieves/robbers and shields
3. Mask design for selective plating and
4. Deposit texture/roughness.

3-D Modeling

More recently, a software tool has been developed that can import CAD/CAM engineering drawings of parts to be plated, along with basic physical and chemical properties of materials and plating solutions, to provide similar capabilities to the above modeling tool, but with the added advantage that the inputs are fully integrated and the results are presented in three dimensions. A recent paper presented at SUR/FIN 2006 described the tool and its application to nickel electroforming of molds, decorative plating of plumbing fixtures and, in an effort to select the best finish, predicted the different results (throwing power variations) between commercial hexavalent and trivalent plating baths.[6] Figure 2 from the presentation shows the simulation for the plating of shower heads from a Cr(III) bath, while Figure 3 is a similar simulation for a Cr(VI)

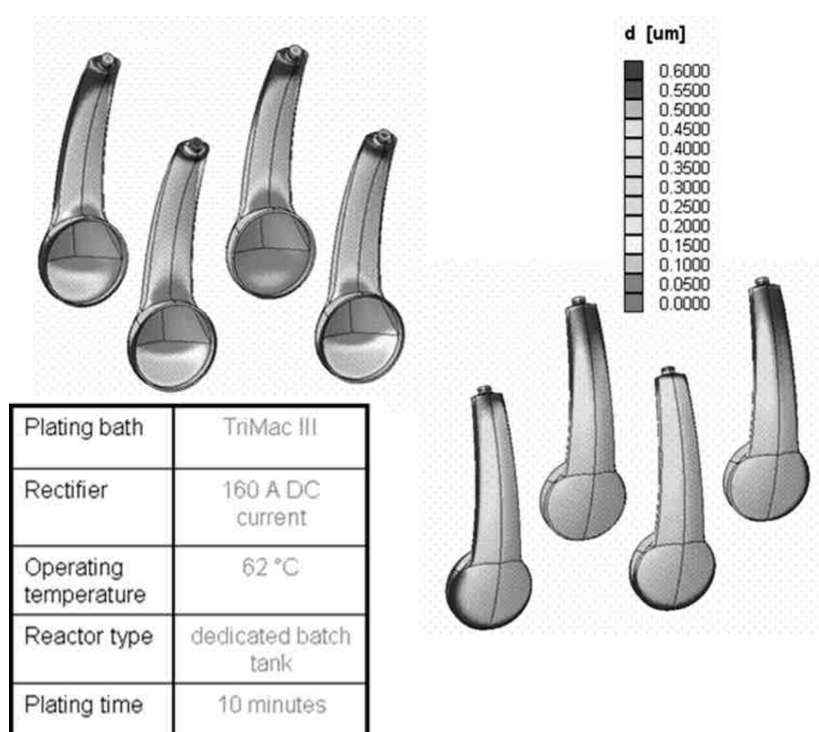
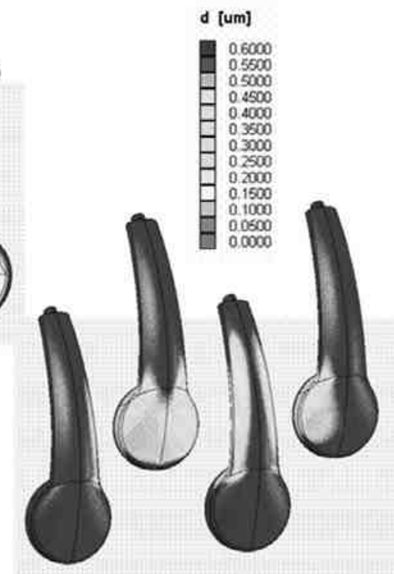


Figure 2—Plating simulation results from Cr(III) bath.

* *For example, L-Chem, Inc., computer-aided design and analysis of electrochemical cells (www.L-Chem.com) and Elsyca PlatingMaster electrochemical intelligence (www.elsyca.com).*



Plating bath	MACH 2
Rectifier	160 A DC current
Operating temperature	41 °C
Reactor type	dedicated batch reactor
Plating time	5 minutes

Figure 3—Plating simulation results from Cr(VI) bath.

bath. The results showed that, although the Cr(III) plating process was less efficient, the throwing power was better, giving a more uniform deposit thickness for the conditions selected.

Summary

In summary, modeling can be used to identify opportunities for improving existing surface finishing processes; for rapidly retooling fixtures and tanks when workloads change; for estimating the best and most cost effective ways of finishing parts when bidding on jobs; deciding if purchasing new bath chemistries, fixtures or equipment makes sense; preparing business cases for facility expansions or improvements and evaluating ways to remain in compliance with environmental regulations. Modeling also can bring some science to the art of plating and is an excellent opportunity for academe and industry to work together. Finally, such modeling tools could even be used to predict the capabilities of emerging surface finishing technologies and make comparisons with existing processes. *P&SF*

References

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4. V. Gadkari & D. Janke, "Precision Chrome Plating: Improving Plating Efficiency and Reducing Waste", project description handout, Battelle, Columbus, OH (2006).
5. E. Malyshev, Product information brochure: "Cell Design©: Computer Aided Design of Electrochemical Cells", L-Chem, Inc., Cleveland, OH, 2006, 4 pp. (also http://www.l-chem.com/cdw.html).
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Finishers' Think Tank

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There has been a great deal of practical experience with the trivalent clear (blue) chromates. Compared to the hexavalent clear chromates, the trivalent formulations:

- Typically extend a bath service life by two to three times in meeting salt spray requirements.
- Required less aggressive polishing, removing less zinc deposit, especially in low current density areas.
- Form a more distinctive blue color and are more tolerant to hot air drying.

From a waste treatment perspective, many trivalent chromates are much easier to waste treat. In most applications, pH adjustment of the spent solution with lime or dilute caustic solution precipitates trivalent chromium. The yellow and black trivalent chromates may require additional steps, depending on the requirements, based on formulation constituents.

ELV, RoHS and WEEE are neither formidable tasks nor should they be considered insurmountable. Dedicated research and development efforts have produced and marketed effective products, meeting or exceeding service life specifications. Diligent work continues as we can expect the introduction of newer generation products. The committees which authored the specific directives have also issued exceptions, to ease the requirements for compliance. The challenges include:

- Prioritizing what needs to be done by listening carefully and understanding the goals
- Developing a sense of urgency with regard to categorizing each part of a project's importance and when it should be completed
- Confirm the appropriate field evaluation meets the practical requirements.

These indicate the project or new system meets or exceeds the goals.

Change is good. Change is ongoing. It is a part of improvement that makes all the dedicated work and effort worthwhile. We are part of a worldwide industrial network working together in a young millennium. Wishing you all a healthy and prosperous New Year! *P&SF*