The integration of more and more complex functions such as wireless communication capabilities on chips or packages puts new demands on the manufacturing methods for top metal layers. High density interconnects and integrated passives require a combination of resolution, accuracy, thickness uniformity typically offered only by dual damascene processes. At the same time there is a need for thicker metal, high deposition rates and low cost per layer that is typically offered only by through mask plating processes. These combined requirements are difficult to address by most existing methods of today.

Replisaurus Technologies has taken a different approach with the development of the ElectroChemical Pattern Replication (ECPR) technology. [1] By combining the precision and resolution of advanced lithography with the efficiency of electrochemical deposition into one single electrochemical metal printing step the ECPR technology can offer a unique combination of resolution, dimensional accuracy, high deposition rates and low cost per layer, bridging the gap between front- and back end metallization.

This article explains the principles of the ECPR technology, its process characteristics and how it can be used for advanced packaging applications such as integrated passives, redistribution layers, fine-pitch copper pillars and via filling for 3D integration.

**ECPR – Enabling direct printing of metal patterns**

In the ECPR process, a template (master electrode), consisting of an electrically conducting electrode layer and a patterned layer of electrically insulating material is used. The master is firstly pre-filled with an anode material, such as copper, in the cavities of the insulating structures. During the print step the master is aligned to a substrate having a seed layer and then pressed against the substrate with an electrolyte applied between the two surfaces (Fig. 1a).

When put in contact, excessive electrolyte is forced away from the master electrode and substrate interface. Local electrochemical micro cells filled with electrolyte are formed in the cavities defined by the pattern of the master electrode (Fig. 1b). When an external potential is applied over the master electrode and substrate surfaces, electrochemical material transfer takes place inside each local micro cell. Metal is dissolved into ions from the pre-filled anode material in the master and transported through the electrolyte in each micro cell and deposited on the cathodic seed layer (Fig. 1c).

The purpose of the master electrode is both to accommodate the anode surface in each micro cell and to accurately define each active cathode area on the substrate by a conformal master-to-substrate contact. A conformal contact results in an accurate contact pattern on the substrate, corresponding to the master pattern.
Fab friendly process – Reducing complexity, cycle times and environmental impact

The ECPR technology offers an integrated solution involving the tool, processes and master electrode, reducing complexity in the manufacturing flow. By removing process steps and associated inspection and wafer transfer between multiple tools in the fab the total cycle time to manufacture a metal layer can be reduced from a few hours to minutes. Comparing the ECPR flow to a conventional through-mask plating line one single ECPR tool replaces the six tools used for resist coating, exposure, development, descum, electroplating and stripping. [2] The elimination of process step also reduces the consumption of toxic chemicals, making the ECPR process flow more environmentally friendly than existing methods. The process uses no photopolymers, developers, strippers or descum gases and only minimum amounts of plating chemistry.

Thickness uniformity independent of pattern density

One of the main technical advantages of ECPR is the ability to achieve a uniform plating height, independent of the pattern density. ECPR has the advantage of maintaining a 1:1 anode-to-cathode area ratio since the electrochemical microcells are formed by the cavities between the master and the substrate (Fig. 1). In this way the potential field lines do not bend across any isolating material and it is possible to get the same current density and uniform material distribution over the substrate despite varying active-area density, even for complex patterns.

In a conventional electroplating cell the anode-to-cathode area ratio can vary over the substrate depending on the density of the pattern. Local spots with low active area density will receive a higher current density.
than areas with high active area density due to the nature of electrolytic current distribution, known as current crowding. This results in varying deposition rates in different areas and uneven thickness distribution of the plated metal [4,5]. The problem is normally addressed by using advanced agitation equipment, adding organic additives to the electrolyte and taking the density into account when designing the pattern. Additional dummy patterns may be added to the design and repeated process optimization is typically needed when changing between two different designs. Despite these efforts, non uniform material distribution is always a problem associated with conventional electroplating processes, with various effects depending on the pattern that is plated.

**Microcell concept enables high plating rates**

The contact plating concept of ECPR, with each feature in a confined electrochemical microcell makes the electrochemistry and material transfer mechanisms that controls the process quite different from conventional electroplating. Each microcell in ECPR has a typical electrolyte volume of a few pico-liters and an electrode distance less than 10µm between the anode and cathode surfaces, which can be compared to a typical fountain plating tool often having circulating electrolyte volumes of 100 litres or more and a distance between the anode and cathode measured in decimetres.

For a conventional macro-cell process the electrolyte has to be agitated towards the wafer surface in order to give sufficient supply of metal ions. The efficiency and uniformity of the agitation determines the thickness of the diffusion layer created closest to the wafer surface, the layer where the electrolyte is considered stagnant and the material transfer is exerted mainly by diffusion. A thinner diffusion layer gives higher material transfer rates, and whereby a higher limiting current. In the case of ECPR the distance between the electrodes is less than 10µm and each diffusion layer (one on the anode and one on the cathode side) is then less than 5µm, which is less than what most agitation method can deliver, and significantly thinner than the diffusion layer created in the most advanced fountain plating cells. The thin diffusion layer of ECPR is a unique feature that makes it possible deposit high quality uniform copper at plating rates higher than 5µm/minute [1,2]

**Accurate dimensional control - CD and sidewall profile**

By accurate thin resist lithography and pattern transfer by dry etching, superior profile and CD control, high fidelity patterns and thereby well controlled cross section of the deposited metal patterns is possible. The pattern definition principle of ECPR is similar to nano-imprinting, and similar resolution capabilities as for NIL can be expected for ECPR. Up til today replication of 500nm lines / 250nm space has been demonstrated and it has been shown that CD variations in the replicated pattern were controlled entirely by the variations in the master electrode and that the variations introduced by the electrochemical pattern transfer itself was so small that it could not be seen in the measurements. [3]

Integrated passives, such as on-chip inductors for RF and wireless applications as seen in Figure 2, is one example where high accuracy pattern definition, and thickness uniformity can enable new advanced designs and functionality.
Summary
The ECPR technology introduces a new way to fabricate highly accurate metal patterns. The process combines patterning and metallization into one single process step, reducing complexity, cycle times and material consumption compared to conventional metallization techniques. By simplifying the process sequence Replisaurus has developed a highly reproducible metallization method that offers advanced process control functions and short feedback loops.

References