A Novel Method of Controlling Metal Deposition During a Pulse Plating Process

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During a barrel bath electroplating process, it is difficult to determine the current density relevant to metal deposition alone and in this connection, to provide the required metal deposit weight (or average thickness) with a high degree of accuracy. Our investigations have shown that the constant value of the overpotential near the cathode yields the constant value of current density expended on metal deposit. The value of the current efficiency in this case may be determined experimentally in the bath, and we can provide the required metal deposit weight (or average thickness) with high accuracy. Between the plating pulses, when the bath current is zero, one can measure the value of the overpotential near the cathode and store it. During the next plating pulse, one can provide an overpotential equal to the reference. A control system for metal deposit weight based on this method was designed and tested in a gold pulse plating process. The root-mean square error of the metal deposit weight required was less than one third of the error of a system with an up-dated ampere-minute meter.

Pulse current electrodeposition of metals has gained acceptance in a number of metal finishing industries as a way to improve the distribution properties and quality of a deposit, and to increase solution efficiency and plating rate. Pulse plating has been widely practiced in the electrodeposition of noble metals and their alloys, where plating processes are the most expensive. To date the pulse plating process has been far from user friendly and much remains to be done to make it so.[1]

One of the basic requirements of a pulse electroplating process is to provide the required metal deposit weight or average thickness with a high degree of accuracy. If the real deposit weight or thickness of the plating parts is more than that required by the user, the quantity of the covering metal and power consumption would increase. If the real weight or thickness is less than required, it is necessary to repeat the process. In both cases, the cost of electroplating increases. The real deposit weight during industrial plating processes is determined by an ampere-minute meter, which measures the total current passing through the bath. Total current is not wholly effective in depositing the metal. A portion of current is usually taken up by hydrogen evolution, and so it is necessary to take into account the current efficiency or so-called Faradaic efficiency, which is the ratio of the current used to deposit metal to the total current passing through the bath.[2] Only when the current efficiency is constant during a plating process and is known, can we determine the metal deposit weight with high accuracy by use of an ampere-minute meter, the so-called coulometric readout.

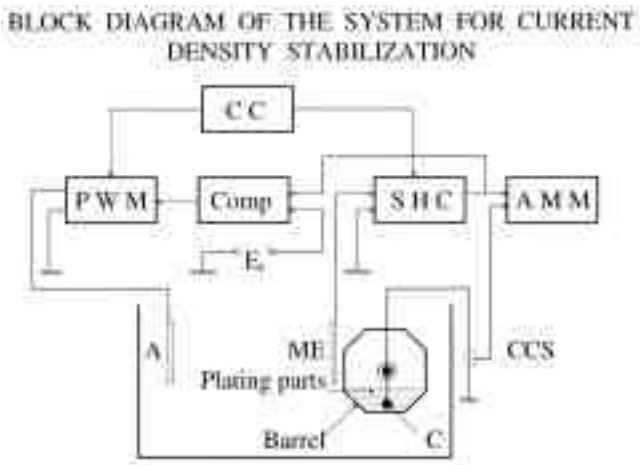

Fig. 1—Block diagram of the system for current density stabilization.

Some investigations in pulse plating made it possible to calculate the current density utilized for metal deposition and current density taken up by hydrogen evolution.[3] One can then find the current efficiency. Unfortunately, the calculations for barrel baths give but a rough estimate of current efficiency because cathodic surface is changed at random.

Barrel baths in pulse plating are usually supplied from a voltage source with a constant amplitude and width of pulse. When a barrel in the bath is rotated, the conductivity between small parts in the barrel and the total area of the cathodic surface is changed at random. The current density is changed too. The current efficiency is known to be a function of the current density[4], and so the current efficiency also changes. The known systems for current density stabilization with an immersed current density sensor can not work in the barrel bath.

Current density stabilization can be realized by the stabilization of the relative potential difference across the cathode-solution interface (PDCI) under a given set of fixed conditions (temperature, electrolyte composition, barrel rotation velocity). If the area of the cathodic surface is increased, for example, the current density would then be less than required, and the PDCI would decrease. We can increase the power supply voltage to increase the relative potential difference across the cathode-solution interface, and then the current density will be increased up to its required value. Therefore, to obtain a constant value of the current efficiency we must stabilize the PDCI. For its stabilization we have to measure the PDCI. In pulse plating this measurement may be carried out simply with the help of a measuring electrode placed near the barrel. It is unnecessary to use the systems which compensate for the voltage drop across the solution resistance. The PDCI is measured when the bath current is zero between the plating pulses and the cathodic double-layer capacitance has been charged. When the potential difference has been measured, the amplitude of the power supply voltage pulse should be changed to make the PDCI equal to the reference.

The block diagram of the system for current density stabilization is shown in Fig. 1. A, C, ME are anode, cathode and measuring electrode, respectively, and CCS is the cathodic current sensor.

A clock circuit (CC) supplies the timing pulses for the operation of the pulse-width modulator (PWM) and sample-holding circuit (SHC). The comparator (Comp) compares DC reference voltage E_r with the DC voltage from the output of the sample-holding circuit and supplies the PWM with

a DC voltage signal. The PWM provides voltage pulses feeding the plating bath. Their width depends on the value of the DC voltage supplied from the SHC . When the current of the PWM stops flowing through the bath, the SHC samples and holds the voltage of the measuring electrode (ME). This voltage is equal to the PDCI and, consequently, to the voltage across the cathodic double-layer capacitance (VDLC).

During the power supply voltage pulse from the PWM, the VDLC increases exponentially. With an increase of the PWM pulse width, the amplitude of the PDCI will be increased and vice versa.

If the current density is less than required, the VDLC would be less than the reference E_r, the output voltage of the SHC will fall, the output voltage of the comparator will increase, the width of the voltage pulse from PWM will grow and the amplitude of the PDCI will also increase. As the voltage of the cathodic double-layer capacitance approaches E_r, the current density will increase up to its required value. If the current density is more than required, the VDLC will be more than the reference E_r, the width of the voltage pulse will fall, the amplitude of the PDCI will decrease and the current density will approach the required value. Therefore, the current density and the current efficiency have been stabilized. The value of the current efficiency is refined experimentally and is entered into the ampere-minute meter (AMM). The AMM will now show the quantity of electricity expended on metal deposition. There is a good chance of providing the required metal deposit weight or average thickness with a high degree of accuracy by using a coulometric readout.

With help of this system, the pulse plating process can be controlled to obtain the metal deposit weight required. We enter into the AMM the quantity of the electricity which must flow through the bath to obtain the weight required and switch on the system. When the real quantity of electricity counted by the AMM is equal to the entered value, the system will switch off, and the plating is finished.

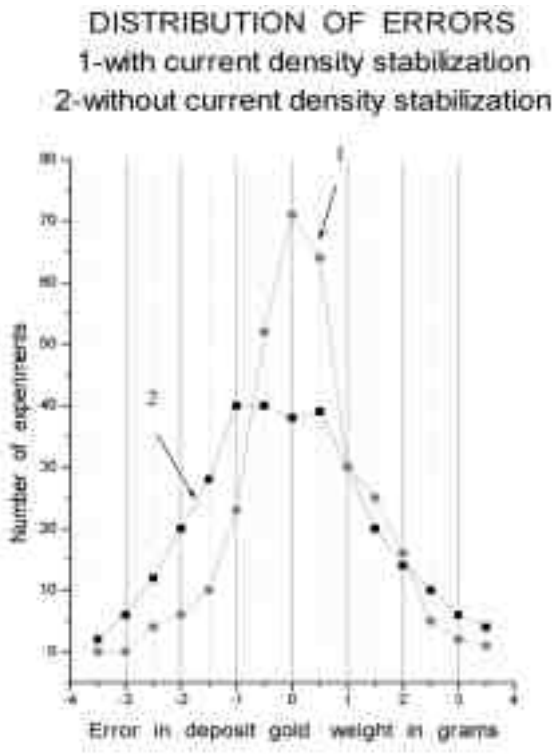

Fig. 2—Number of experiments vs. error in deposited gold weight.

There is one other way to control a plating process. By changing E_r, we can change the current density to provide the weight required in a specific time. This is important when a few barrel baths are placed in the same bath plating line.

We have investigated pulse plating of gold in a barrel bath under a given set of fixed conditions (temperature, electrolyte composition, barrel rotation velocity) in an acid electrolyte. Three-hundred-nine pulse-plating experiments have been carried out using the above-mentioned system in the barrel bath. The results of these experiments are shown in Fig. 2.

The weight of the gold deposit required in the experiment was 30 grams. Curve 1 of Fig. 2 illustrates a number of the experiments according to the weight difference in grams between the real weight of the deposited gold and the required one, *i.e.*, the errors in deposited gold weight. For comparison, curve 2 shows the results of the 309 pulse plating experiments under the same conditions that were carried out under coulometric readout control and without the system for current density stabilization. The root-mean square error of curve 1 is 1.39 times less than that of curve 2.

Conclusions

Systems with this current density stabilization method are adaptable to rack baths. The application of these systems provide:

- improved properties and quality of metal deposition
- increased accuracy for obtaining quantities required of metals from their alloys
- saving in metal deposited and reduced power consumption
- increasing the productivity output.

References

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Michael Gladstein received an MSc in automatics and remote control in 1964 and a PhD degree in measuring electronic devices in 1972 from the Moscow Energy Institute. He has worked more than 20 years in the field of development and design of control system and measuring converters. The main field of his scientific activity is experimental research of control systems for plating processes. Since 1991, he has been working in the field of control systems and robotics at the Ben-Gurion University, Israel.

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