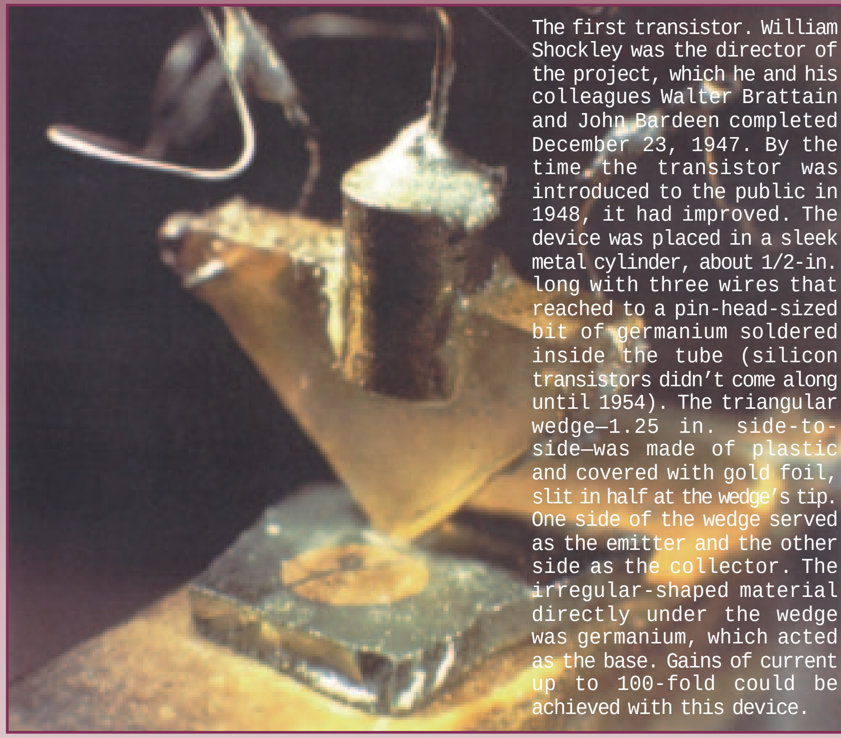
Electroplating: An Ancient Art Turned Into Leading-edge Technology

By Don Baudrand, CEF



The first transistor. William Shockley was the director of the project, which he and his colleagues Walter Brattain and John Bardeen completed December 23, 1947. By the time the transistor was introduced to the public in 1948, it had improved. The device was placed in a sleek metal cylinder, about 1/2-in. long with three wires that reached to a pin-head-sized bit of germanium soldered inside the tube (silicon transistors didn't come along until 1954). The triangular wedge—1.25 in. side-to-side—was made of plastic and covered with gold foil, slit in half at the wedge's tip. One side of the wedge served as the emitter and the other side as the collector. The irregular-shaped material directly under the wedge was germanium, which acted as the base. Gains of current up to 100-fold could be achieved with this device.

Early in its history, electroplating was mainly used for statuettes and decorative art objects that were made from copper, silver and gold. These items were finished by plating very thick deposits of the pure metal onto a mold made of clay or plaster-like material, which was removed after the plating was completed. Today, we call that method *electroforming,* and use it to produce waveguides, aircraft components and plastic molding for thousands of different items—from rubber boots and glove molds to phonograph records, CDs, prosthetics, auto dashboards, tail lights, dolls' heads and holographs. To say the least, electroplating is an ancient art that has evolved into leading-edge technology. In this overview, Don Baudrand provides ideas on what you could say about plating to somene who has no knowledge of the subject.

Electroplating, to the general public, usually means plated bumpers and jewelry items. In reality, such things represent only a small percentage of the plating industry, even without including the large segment involving tin plating of steel cans for the food industry.

Electroplating is essential for most industries, because it provides surface properties unattainable by any other means. In general, corrosion protection and wear resistance are the most recognized uses. The electronics industry, however, relies on plating for specific useful deposit characteristics, such as:

- Controlled resistance;
- High conductivity (the specific resistivity of nickel, for example, is about 7.4; copper, 1.7; gold, 1.4; silver, 1.1 micro Ohm cm—tin-lead solder, for comparison, is about 11);
- Magnetic properties;
- Bonding abilities, such as solderability, wire bonding, die (computer chip) bonding; brazability, and many other useful characteristics.

Electrochemistry—Electroless & Electrodeposition

Electrochemistry is defined as the science that deals with the interconversion between electrical and chemical energy. This interaction may involve the use of an electric current to bring about a chemical reaction, or a chemical reaction to generate an electric current. The branch of electrochemistry discussed here concerns electrodeposition and electroless deposition.

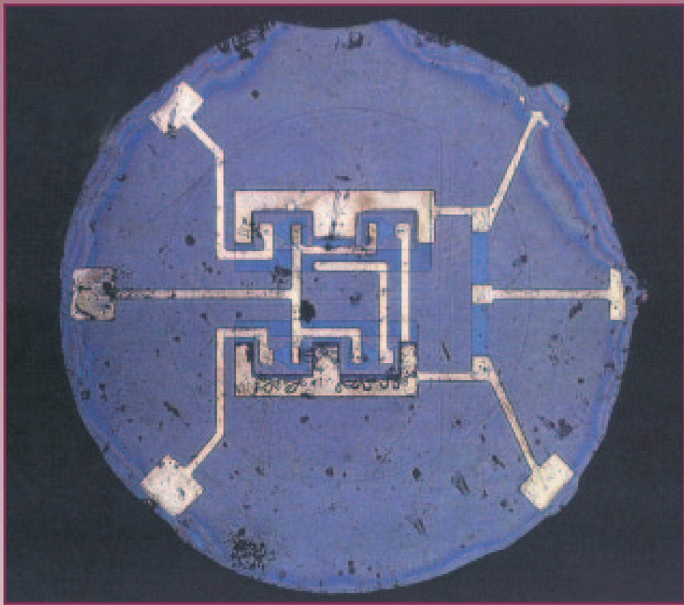
Electrodeposition

Electrodeposition (plating) occurs in a solution containing metal ions known as electrolytes. There are two electrodes: An anode (usually made of the metal to be deposited) and a cathode, onto which metal is deposited. When an electrical current (direct current, or DC) is applied to the system, metal is dissolved from the anode and deposited onto the cathode, which is the object to be plated. The process may sound simple, but there are many special considerations that can complicate it. The electrical current may come from a battery, which is rare, or from a rectifier that converts alternating current (AC) to direct current. (Plating is commonly-accomplished with direct current.)

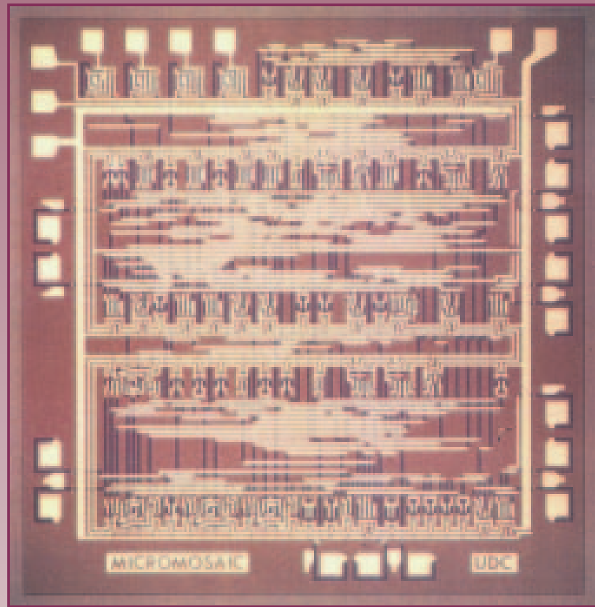
Preparation Steps

To achieve good adhesion of plated deposits, the part to be plated must be extremely clean and free from any films or oxides. The cleaning process steps are many, but when properly followed can result in adhesion that exceeds the strength of the weakest metal.

The complexity of a plating solution's chemistry, therefore, is directly related to the desired results. A simple copper plating solution, for example, would consist of copper sulfate and sulfuric acid, but the deposit achieved would be somewhat spongy and dull. Adding about 50 ppm of chloride ion, however, would



The first planar integrated circuit, 0.06 in. in diameter, developed in 1962 by Robert Noyce of Fairchild Semiconductor (later the founder of Intel).



First integrated circuit made with computer-aided design, 0.15 inches square, from Fairchild Semiconductor, mid-1960s.

result in a smooth deposit. The addition of organic compounds of very special nature, therefore, can achieve a brighter deposit with leveling characteristics. Plating chemistry requires the knowledge of not only electrochemistry, but organic chemistry, physical chemistry metallurgy, physics, ligand chemistry and chemical engineering—just to name a few of the more important disciplines.

When plating onto non-metals (non-conductors), the process becomes even more complicated. Each plastic and each grade of plastic requires a different preparation process. Plating onto hybrid circuits and other electronic devices requires specific processes, as well. When plating silver, gold, copper, nickel, or zinc, for example, the deposit will not be bright and smooth unless the basis metal is first prepared by polishing and buffing operations, cleaned in a multi-step process, acid-treated to remove oxides, rinsed in clean, deionized water and then plated in a plating solution containing organic compounds (or brighteners). Some solutions use leveling agents in addition to brighteners.

Electroless Deposition

In electroless plating, electrons are supplied from within the solution. The chemical compounds that supply electrons are known as reducing agents. Plating solutions are formulated so that plating only occurs on a surface that is catalytic to the chemical reduction reaction. A catalyst is a material that causes a chemical reaction to take place, but is not usually consumed in the process. Only a few metals are catalytic, and only a few can be plated by what is referred to as an autocatalytic deposition. Some examples include iron alloys, nickel, aluminum and palladium. There is also an electroless plating process by chemical replacement, but the deposits are usually non-adherent and, with some exceptions, are usually too thin to have any functional use.

Chemicals used to prepare materials to be electroplated, as well as the plating solutions themselves, are often classified as hazardous. The waste generated, therefore, must be treated in approved ways so that there is no physical or environmental danger. The plating industry has proven itself to be a leader in environmental protection. It is also, however, a target industry for the Occupational Safety and Health Administration (OSHA), which monitors and controls the quality of air emissions and wastewaters. The metal finishing industry is active in "policing" itself, and its record, on the whole, is exemplary.

It is obviously very expensive to meet the numerous requirements set forth by the U.S. government. Some of these requirements have set discharge limits to a sewer that are even stricter than the requirements placed on the food industry. As a result, many large captive shops are being forced to shut down, and approximately 20 percent of the smaller jobshops in the U.S. have closed because of the great expense associated with environmental regulations. The average plating shop in the U.S. employs fewer than 50 people.

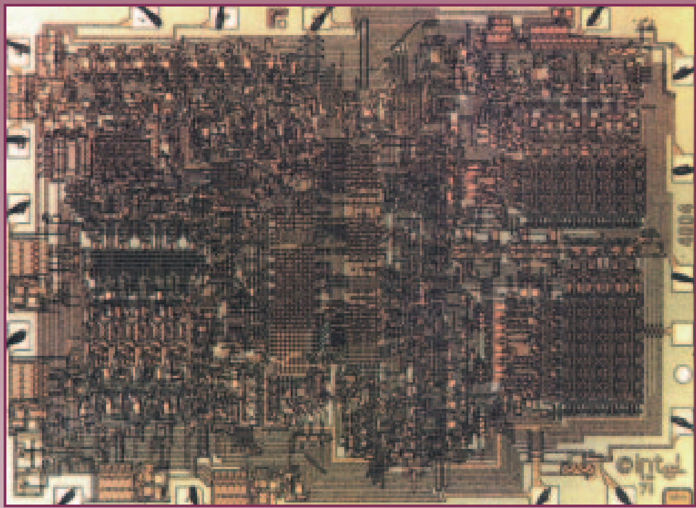
Plating for Electronics

The electronics industry depends on plating for its printed circuit boards, multi-chip modules, hybrid circuits, individual components and devices, etc. It would be virtually impossible to make computers without plating. The first personal computer, for example, had 29,000 transistors that could carry out 330,000 instructions per sec. The new microprocessors currently in use have more than six million transistors, and can carry out more than 300 million instructions per sec.

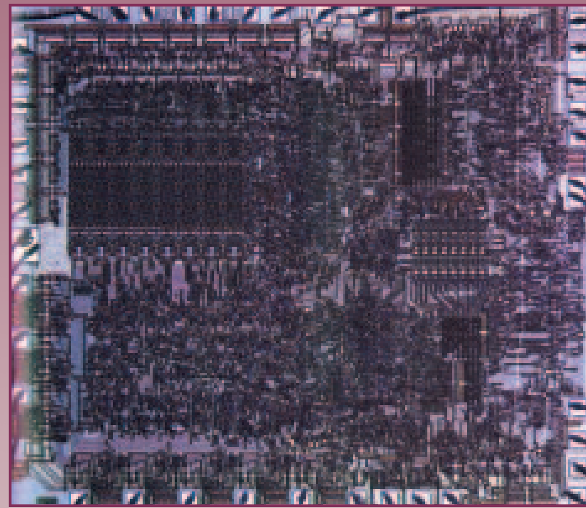
It is interesting to note that the electronics industry's earliest microprocessors are still up and running in microwave ovens, VCRs, car transmissions, cellular telephones and many other everyday items.[1]

Magnetic Devices & Memory Discs

Albert Fert had an inkling that he was onto something big. The University of Paris physicist knew that many metals exhibit a phenomenon called magnetoresistance (MR), also known as



First microprocessor, 0.11 x 0.15 in., from Intel, 1971. The 4004 can add two 4-bit numbers in about 11 millionths of a sec. With 2,300 MOS transistors, it can execute 60,000 operations/sec.



The first general purpose microprocessor (for personal computers), 0.165 x 0.191 in. From Intel, the 8-bit 8080 has 4,500 transistors and can execute about 200,000 instructions/sec. Today's Pentium and Power PC microprocessors, by comparison, have more than six million transistors and can carry 300 million instructions per sec.

magnetostriction, where metals exhibit slight changes in electrical resistance when placed in a magnetic field. Fert amplified the effect by designing materials consisting of very thin layers of plated metals. He made a sandwich of iron-plated chromium and iron, and found that it was 10 times better than standard metals. Many different combinations of metals provided even better characteristics.

Early applications included sensors that can determine when a car's wheels stop turning and begin skidding—the key to antilock brakes. Sensors can also measure engine speed to help lower emissions or raise fuel economy. Hearing aids, weighing devices, and memory chips that remember even when the power fails or is turned off are just some of the newer applications.

Magnetic random-access memory (MRAM) chips differ radically from dynamic random-access memory (DRAM) chips. The magnetic RAM chips will retain information without power, which not only cuts power consumption but allows a computer to store programs and data in its own rapid-access internal memory (rather than having to read it more slowly from hard discs). Another advantage of MR devices over other devices that "remember" is that MR devices offer longer life than so-called "flash" memory chips.

Today's recording heads for hard-disc drives and for mainframe computers use this technology to increase capacity to amazing numbers. The plain MR drives currently on the market pack about 564 megabits of information per in.^{2}, and newer offerings will handle 10 gigabits—17 times more! At 10 gigabits/in.^{2}, an entire movie, an encyclopedia or any number of things could be stored on a single disc.[2]

Memory discs have dramatically increased in capacity. A typical floppy disc, for example, will hold about 250 typewritten pages of information. A similar-sized hard disc—made by plating processes—will hold more than 25,000 pages of information. Now even smaller discs hold even more information, stored by means of magnetic materials.

A disc is made of aluminum, polished to a high finish, and plated with a nickel-phosphorus alloy that is hard and non-magnetic. Either a magnetic cobalt-phosphorus alloy or a chromium-cobalt alloy is then plated over the non-magnetic coating. The nickel-phosphorus and cobalt-phosphorus alloys are laid down by an electroless plating process, whereby electrons are supplied within the plating solution. The chromium-cobalt alloy is plated by vacuum sputtering. The magnetic recording layer is two- to three-millionths of an inch thick. Tiny magnetic domains laid end-to-end are produced when the recording head passes over the surface. The magnets are oriented with magnetic poles to form binary numbers or codes on the surface, which are easily read by the pick-up head. A floppy disc rotates at 300 rpm, while the hard disc (called a thin-film plated disc) rotates at 3600 rpm. Newer drives run even faster. Hard discs, therefore, can store and retrieve information much faster than floppy discs. Vertical magnetization, requiring a slightly different plating process, can more than double the capacity of hard discs.

CD Manufacturing

Plating plays an important role in several key aspects of manufacturing compact discs (CDs). The CD market encompasses not only audio, but a wide number of variations—super-density discs (SDs), CD-Is, CD-Rs, mini-DISCS and WORMS. Each optical memory storage device contains billions of bytes of information digitally encoded and stored as a series of microscopic pits—about one micron or less in size. The discs are created by stamping these pits onto a plastic (polycarbonate). The stampers are made by electroplating pure nickel onto the original recording. The recording is made by a laser beam melting tiny holes in a metal surface (tellurium) in the digital code from the sound or video signal.

Because electroplating can precisely duplicate the surface, plating on the recording to a thickness of 300 ±3 microns, and separating the plated deposit from the original recording results in tiny bumps exactly the size and shape of the pits. This then becomes the stamper, which can create 30,000–50,000 duplicate CDs before replacement is required. In actual precision, the first plating becomes the pattern (father) for the second (mother, now with pits), and the mother is plated to form the stamper. Many additional stampers are made from the mother, so that millions of CDs can be produced—each exactly alike—with nearly zero defects.[3]

Technology Status in the U.S. What Does the Future Hold?

Where does the U.S. stand in the technology race ... and why are we racing? There is a European Consortium that includes universities and many large corporations devoted to researching and developing giant magnetic resistance (GMR) devices for practical use on automobiles, military systems, and digital cassettes. In Japan, for example, a team of 30 researchers at Hitachi Ltd. is working on GMR devices—larger than any U.S. effort, according to Gary A. Printz, head of Magnetic Multilayer work at the Naval Research Laboratory in Washington, DC.

Other work on advanced technology in the U.S. is also lagging behind other countries. For the U.S. to be competitive in a global market, which is essential for economic stability and growth, it needs a greater increase in students pursuing technical fields.

The rewards can be great for those who succeed—such as knowing that you have made a significant contribution to the betterment of all mankind, and have enhanced the standard of living for everyone. It is vital that the U.S. become more dedicated to advanced technology research. Technical development is the key to our future. ***P&SF***

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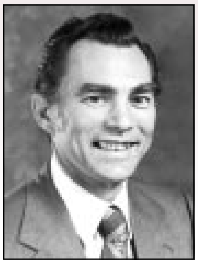
About the Author



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