

The Role of Electroless Nickel in Multi-Chip Module (MCM-C) Fabrication

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The use of multi-chip modules (MCM) has grown steadily in popularity. Recently the growth has been accelerated by demand for their versatile functionality and high reliability. Electroless nickel plating can enhance the functional characteristics and provide a shorter manufacturing path with highly reliable performance. Nickel-boron deposits have the widest use, but electroless nickel-phosphorus deposits also have a useful place in making MCM devices. This article discusses the preparation and plating processes for electroless nickel deposition on MCMs as well as the advantages and applications.

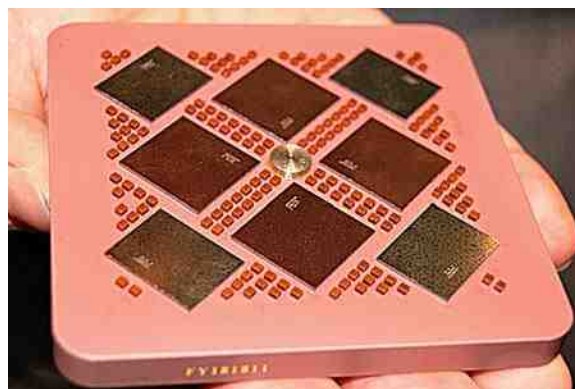
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Introduction

The demand for multi-chip modules has accelerated recently because of their versatility and high reliability. The demand for ever smaller devices requires changing materials and fabrication methods. Microelectronic devices have decreased in size to less than 0.25 μm . Integration levels of chips continue to increase. These factors require chip carriers with better heat dissipation characteristics, and an increase in the input/output (I/O) pin count for the new generation.¹

Substrate materials are chosen on the basis of thermal conductivity, thermal expansion, dielectric constant, dielectric strength, dissipation factor and surface finish. Alumina, silica, aluminum nitride, silicon carbide or glass/ceramics are used. Aluminum nitride (AlN) is finding wider usage. Diamond films have thermal conductivity values up to five times that of copper. Diamond films are being developed for use as heat sinks for high power radar, microwave and supercomputer applications. Plastics such as polyimides, benzocyclobutane and polyquinolines are finding increased use for MCM substrates.

Each type of substrate material requires special fabrication and metallization methods. Copper clad (thin copper, 2.0 μm and up) and nickel-clad polyimide films are now available for multi-layer fabrication. The role of electroless nickel in metallization, and protection of sputtered or chemical vapor deposited metal bond-



ing layers, as well as thick film metallization, are discussed in this paper.

Electroless nickel

Electroless nickel deposits, especially electroless nickel-boron can produce a surface with the characteristics necessary for mounting and connecting components. Most electroless nickel-boron deposits are solderable, brazable and can be wire and die-bonded. The low boron (0.2 to 1.0 wt%) are the most suitable for these applications. In some cases, low (2.0 to 4.5 wt%) phosphorus-containing electroless nickel deposits will be suitable for some of the functions, such as soldering and wire bonding.

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Electroless nickel deposits provide the needed corrosion protection for many of the metallizing materials used for circuit elements. They also provide conductivity improvement for metallizing materials. The specific conductivity of nickel-boron (0.2 wt%) is approximately 6.5 to 7.0 $\mu\Omega$ -cm. Values for 1.0 wt% boron deposits range from 9 to 15 $\mu\Omega$ -cm, while those for nickel-phosphorus (4.0 wt%) range from 20 to 30 $\mu\Omega$ -cm. For comparison, the specific conductivity of tin and lead are each about 11 $\mu\Omega$ -cm.

When it is necessary to use gold, electroless nickel deposits also serve as a diffusion barrier, preventing substrate metallization materials from penetrating into the gold, degrading gold characteristics such as wire bonding and soldering. The higher the boron content of the electroless nickel, the better will be the effectiveness of the diffusion barrier. In many instances, electroless nickel-boron will even serve well without a gold layer.

Soldering to electroless nickel deposits requires an activated flux (rosin mildly activated, RMA), a non-halide RA (rosin-activated) type or preferably a water-soluble non-halide flux. An example of a water-soluble non-corrosive flux is made from modified nonyl-phenol polyethylene dioxide, modified by the addition of triethanolamine to adjust the pH and help fluxing action synergistically, and about 5% dipropylene glycol to decrease tackiness and adjust viscosity for better screening.² Other commercial, non-corrosive active fluxes are available.

Wire bonding to electroless nickel is done using ultrasonic methods (high energy) for aluminum wire, and thermosonic methods for gold wire. Thermocompression techniques cannot be used to bond to electroless nickel deposits. Nickel-boron deposits lend themselves well to brazing. They are ideal for seal rings, as they can provide a perfect hermetic seal as measured by helium mass spectroscopy. Die bonding may be accomplished using gold-silicon eutectic or epoxy die attachment. Amine-hardened epoxy works quite well.

Alumina multi-layer packages using electroless nickel-boron plating have been well established for multilayer ceramic multi-chip modules. Substrates of 96% to 99% alumina have been used successfully and plated in high production automatic plating lines.

Aluminum nitride substrates

Aluminum nitride, however, poses some interesting challenges to provide good quality, adherent metallized and plated circuit elements. Aluminum nitride is an exceptionally difficult material to plate using electroless techniques.

Some electroless gold plating solutions have a very high pH, and aluminum nitride is very susceptible to solutions with even a mildly high pH. It has been observed that even deionized water with an average pH of 8.2 can have a detrimental effect on aluminum nitride. The effect of an alkaline solution on aluminum nitride is actually an etching of the surface. Exposed to a detergent solution for only seconds, the surface of aluminum nitride may be altered enough to reduce the adhesion of thick film metals substantially.

Electroless gold deposited on patterned aluminum nitride can have very poor adhesion. The gold solution may become contaminated with aluminum, which will quickly deactivate the solution. Non-patterned areas can be protected by using a sol-gel procedure to deposit a thin film of silicon oxide on the surface of the exposed aluminum nitride. The sol-gel is applied by immersion and then dried in a furnace. Due to differences in surface tension of the substrate and the metallized circuit areas, the oxide solution coats the ceramic substrate while only wetting the metallized pattern in insignificant amounts, thereby not interfering with subsequent plating.

The sol-gel must be baked slowly to complete the reaction and form the oxide film. The sol-gel consists of tetraethylborosilicate

solution. The film formed by dipping in the solution is air dried for 10 min, baked at 100°C for 10 min and then baked at 600°C. This removes all the organics, leaving a film of silicon oxide.³

A second protective film-forming technique is to heat-treat the aluminum nitride at 1000°C for 10 min in air. The reaction to form aluminum oxide requires moisture, so the humidity of the air is important.

The aluminum nitride can be metallized over the entire surface, patterned and etched. Electroless nickel and electroless gold can then be plated and or patterned, protecting the exposed aluminum nitride as mentioned above. Another technique is to metallize with electroless nickel and gold plate, pattern and etch the plating to form the circuit pattern.

Electroless nickel is plated from mild acid solutions. Electroless nickel-boron, which has the widest use for hybrid circuits, has a pH of from 6 to 6.8, while low phosphorus electroless nickel has a pH of from 5 to 7. Both types provide a suitable barrier layer and protect the metallization. Nickel-boron is usually the solution of choice because of its ease of soldering, wire bonding, brazing and die bonding, enhancing the gold characteristics. Gold plated deposits can be somewhat porous or thin, which causes more dependence on the sublayer to provide the desirable characteristics. In some cases gold may be omitted and the assembly operations done to the electroless nickel-boron only.

Plating process cycles

Molybdenum-manganese metallized ceramics or molybdenum metallization

1. *Alkaline clean.* Use ultrasonic cleaning if there is any possibility of ceramic dust on the parts to be plated. Rinse thoroughly. Deionized water is preferred.
2. *Remove glass.* To remove glass from the surface of the metal frit, two methods are used:
 - a. Immerse in a solution of 100 g/L potassium hydroxide (KOH) at 100°C (212°F) to boiling for 6 to 15 min. Rinse thoroughly.
 - b. Immerse in a solution of 1.0 lb./gal (120 g/L) of ammonium bifluoride or proprietary equivalent at room temperature for 5 to 12 min. Rinse thoroughly.Longer times in either treatment solution can result in loss of adhesion of the metal frit to the ceramic.
3. *Treat to remove traces of metallization in extraneous areas.* Metallization must be removed between circuit elements and edge flash, if any. This is done in a solution of 180 to 200 g/L potassium ferricyanide and 100 g/L sodium hydroxide. Parts are immersed for 30 to 50 sec at room temperature. Longer immersion time may result in loss of circuit dimensions or loss of adhesion of the metal frit to the ceramic. Rinse thoroughly.
4. *Acid dip.* Use 30% HCl or 1.0 lb./gal of acid salts, 30 to 45 sec at room temperature. Hot acids are sometimes used (60 to 88°C; 140 to 190°F). Rinse in DI water.
5. *Catalyze.* A choice of proprietary catalysts is available. Palladium chloride may also be used as follows: 0.05 to 0.2 g/L PdCl₂ with 2.0 g/L NaCl and 5.0 mL HCl added. Immerse for 30 sec to 1.0 min. Careful attention is required to establish the correct concentration of palladium and the time of immersion. High palladium or long immersion time results in poor adhesion of the subsequent plating due to excessive replacement reaction. Insufficient palladium concentration or too short an immersion time may result in missed plating. Rinse thoroughly, but use a short immersion time (10 to 15 sec).
6. *Acid dip.* Immerse in 3 to 10% HCl and rinse quickly, but thoroughly.
7. *Electroless nickel plate.*

Plating tungsten metallized ceramic

1. *Alkaline clean.* Use ultrasonic agitation to remove ceramic dust. Rinse thoroughly.
2. *Glass removal.* For high glass frits, immerse in 100 g/L potassium hydroxide (KOH) at from 100°C to boiling for 8 to 15 min, or ammonium bifluoride for 6 to 10 min to remove excess glass. Low glass metallizing formulas require less time to treat. Very low glass formulas may allow this step to be omitted. Rinse thoroughly.
3. *Activate tungsten.* Use a 180 to 200 g/L potassium ferricyanide and 100 g/L potassium hydroxide mixture at room temperature, with an immersion time of 20 to 50 sec. Rinse thoroughly.
4. *Acid treat.* Use 30% hydrochloric acid (HCl) or proprietary acid salts or sulfuric acid salts with 10 g/L ammonium bifluoride added. Rinse quickly but thoroughly.
5. *Catalyze.* A choice of proprietary catalysts is available. Palladium chloride may be used as in plating molybdenum-manganese or molybdenum metallization described above.
6. *Acid treat.* Use 5 to 10% hydrochloric acid for 30 sec. Rinse quickly but thoroughly.
7. *Electroless nickel plate.*

Plating silver or silver/copper thick film metallization

1. *Clean.* Mild alkaline clean. Rinse.
2. *Acid treat.* Immerse in a 3 to 10% nitric acid solution for 12 to 18 sec. Rinse.
3. *Electroless nickel-boron plate.*

Note: If a nickel-phosphorus deposit is specified, a nickel-boron preplate strike of 1 to 2 min should be used, followed by a rinse. Then electroless nickel-phosphorus plate.

Plating onto nickel-iron or nickel-cobalt pins and leads

1. *Clean.* Alkaline clean. Rinse.
2. *Acid treat.* Use 18% sulfuric acid at 66°C (150°F) or 50% HCl at the same temperature for 1 to 3 min. Or use a citrate-based proprietary pickle/conditioner, at 52 to 57°C (125 to 130°F).
3. *Nickel strike.* Use a low pH sulfamate nickel strike or Woods nickel strike for 3 to 4 min.

The sulfamate nickel strike is made as follows:

- (a) Dilute a 180 g/L (24 oz/gal) nickel sulfamate solution to 30 to 40 vol%.
- (b) Add 30 g/L (4.0 oz/gal) boric acid.
- (c) Lower the pH to 2.0 to 2.5 using sulfamic acid or SNAC. Further lower the pH to 1.0 to 1.4 using hydrochloric acid. Plate at 30 to 100 A/ft² at room temperature.

The Woods nickel strike is made as follows:

- (a) 240 g/L (32 oz/gal) nickel chloride in 32 to 35 fluid oz/gal concentrated hydrochloric acid (25 to 27%).
- (b) Plate at room temperature for 3 to 4 min.

4. *Electro- or electroless nickel plate.*

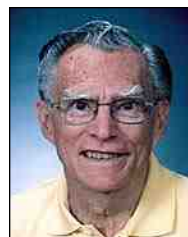
Procedure for nickel-iron-cobalt pins and lids

1. *Clean.* Use an alkaline cleaner. Rinse.
2. *Alkaline permanganate treat.* 88°C (190°F to boiling to remove scale and condition the metal.
3. *Citrate/pickle activator solution.* 52 to 57°C (125 to 135°F for 5 to 6 min. Rinse.
4. *Electroless nickel plate.*

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About the author



Mr. Don Baudrand, CEF has been an independent metal finishing consultant, based in Poulsbo, Washington, since 1994. He received his B.A. in Chemistry from Whittier College, California and did Graduate Work at the University of California - Berkeley. From 1954 to 1966, he was Owner and President of Electrochemical Laboratories, and until 1994, was Vice-President at Allied-Kelite. He is a member of several professional associations including NASF, the International Microelectronics and Packaging Society, SME, SAE, and the Institute of Metal Finishing. He holds 10 U.S. patents and numerous foreign patents and has authored over 70 published papers.

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