Application, Process Control and Requirements of Electroless Nickel Immersion Gold (ENIG) in PCB, High Density Microelectronics and Wafer

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This paper will outline the chemistry for Electroless Nickel Immersion Gold highlighting process control parameters. New applications related to High Density Printed Circuit Board substrates and Wafer will be investigated. Performance data of Immersion and Electroless Gold processes both Cyanide and Non Cyanide will be presented.

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Introduction

Electroless Nickel Immersion Gold (ENIG) is not a new technology.

The process has been used for many years in fields outside of the Printed Circuit Board industry.

Electroless Nickel is a highly developed engineering coating used as an alternative to Hard Chromium to impart hardness and wear properties to precision engineered parts requiring the added benefit of precise thickness profiles without the need for subsequent machining.

Immersion and Electroless systems produce even thickness distribution profiles that are second to none.

Immersion Gold has been widely used in the Decorative Industry for more than 25 years , very often this has been coated onto Nickel plated parts.

Its ability to cover complex shapes ,with ease, to produce a uniform immersion gold deposit on surfaces, that more traditional electrolytic gilding failed to satisfy led to rapid development of a variety of applications.

Immersion Gold coated parts were often too fragile to barrel plate, too small for jigging or simply of too complex a shape for electrolytic plating to achieve the desired uniform thickness.

Uses were varied in both electronic and decorative markets, ranging from small electronic contacts to decorative jewelry and larger ornamental artifacts.

Within the Printed Circuit industry it has also become a well established technology¹ and has been in use for well over a decade in large production volumes for Surface Mount Printed Circuit Boards to give a viable alternative to Hot Air Solder Leveled (HASL) boards.

Many thousands of successful Printed Circuit Boards are in use in the high technology devices we have all become accustomed to using in our daily lives including computers and the many mobile devices we use for communication and leisure.

Such a conformal coating will achieve the flatness required for the precise pick and place requirements of Surface Mount that HASL fails to deliver with re-flowed Tin-Lead plated deposits.

ENIG has become a leading surface finish in the Surface Mount Printed Circuit Industry, although many alternative technologies are also established, a significant market nevertheless exists and indeed its applications are expanding as demands become more exacting with the advent of microelectronics, BGA and Wafer technologies.

The standard technical approach has been for Printed Circuit manufacturers to source their process chemistry for such ENIG from a single source to establish a line ownership from the chemistry supplier. This offers advantages such that any technical issues can be addressed more easily without any conflict of interest that can occur with multiple sourcing of chemicals from different vendors.

Close liaison between the chemical supplier and the Printed Circuit producers is an essential part of a successful partnership to enable all necessary technical advances to be achieved.

As new technology moves forward the chemical supplier must also address the new challenges and provide necessary support and technical innovation in partnership with the Printed Circuit producer to generate new, improved products.

This paper will outline some of the new applications for ENIG and explain the challenges presented by these technology advances.

Some suggestions for process control and practical solutions to enable the new requirements to be met and exceeded will be described.

Initial Developments

A standard ENIG line will consist of a pretreatment, activation, Electroless Nickel and Immersion Gold² as shown schematically in *Fig 1*.



Fig 1 : Typical ENIG Process sequence

The front end of this sequence is relatively straightforward. It involves an Acid Clean and a Microetch / Chemical Polish process. There are many varieties of these to choose from ; the technology is mature from the chemical viewpoint and is within the realms of basic Printed Circuit Technology for cleaning and preparing Copper substrates prior to subsequent electrodeposition. We will focus attention on the Activation, Electroless Nickel and Immersion Gold processes highlighting the unique demands required by each application.

Applications

- Conventional Surface Mount PCB
- High Density PCB (HDI)
- BGA / UBM
- Lead Free Electronics

Conventional Surface Mount PCB

The Conventional PCB market as such presents few challenges to the ENIG process chemistry; the technology is mature with well over a decade of practical production experience.

A survey of the market in Asia³ revealed, most Printed Circuit producers were relatively comfortable with their process chemistry, but have some reservations.

The Electroless Nickel with a typical bathlife of five metal turnovers was seen to be a drawback., not only in chemical cost ,but in environmental issues ,a spent bath needs to be disposed of in an environmentally friendly way and with ISO 14000 becoming more commonplace then complete recycling becomes a preferred option.

Recent work has demonstrated regenerable Electroless Nickel are possible and certainly any way to extend the life of a process is to be applauded. However ,cost is also a key factor for success in what is a very competitive industry and the regeneration cost is being evaluated to determine the total benefit as part of the bigger picture.

ENIG presents some challenges for Soldermasks as the Electroless Nickel and Immersion Gold are often at Elevated Temperatures (75-95 ⁰C).

However compatability is no longer a serious concern as many leading suppliers have products to meet the needs.

Plant and Equipment for conventional Surface Mount PCB are also well developed.

Improved rinsing techniques ⁴to make maximum use of water are the areas where work is being done again driven by environmental and cost concerns.

Lower water usage usually means lower cost.

Reclaim of Palladium from spent activators is also an enviromental and cost effective way to prevent Palladium wastage. The turbulent cost of Palladium has led people to consider alternative activators, however more recent developments have seen activators emerge that operate successfully at low concentration 10-20 mg/l Pd (10-20 ppm) ; at this very low concentration cost issues become less significant when you consider a 100 litre tank would contain only 1-2 g Pd it brings it into perspective. Methods to selectively reclaim Palladium ,even at this low level are available⁵ using specially developed carbon based material impregnated with a reducing agent specific for Palladium Reduction.

These systems are attracting interest from ISO 14000 environmentally focussed companies.

High Density Interconnect (HDI)

High Density Interconnect (HDI) can enable significant increases in circuit density in PCBs.

This increased circuit density with high IO makes significantly smaller lighter and faster electronics.

Blind microvias are the key to achieving such high density and dimensions are ever reducing as demands increase for yet faster and lighter devices.

Blind microvias present some new challenges not directly related to the chemical aspects, but to physical aspects of plant design.

Adequate solution ingression and adequate rinsing and cleaning action in these blind via holes, of ever decreasing dimensions, is vital.

Dimensions of such micro vias are in the range 25 - 150 microns (1-6 mil) in diameter ^{6,7}, typically the aspect ratio does not exceed one. (i.e. the hole diameter = the hole depth).

In a wet chemistry blind via dimensions need careful consideration.

The problem is basically a fluid dynamics issue and thermodynamic influences on solution flow will be an essential part of an effective process line.

Solution concentration gradients ,within the diffusion layer of the solution contained in the microvia, will have a dramatic effect on bath performance, and wide variations must be avoided. Fresh solution must be brought into and out of the blind vias to enable effective performance particularly when dwell times are small.

In addition rinsing must be complete and thorough to prevent contamination issues by carry over of process chemicals.Remember too that residual chemicals will affect the performance of the subsequent chemical process so must be completely removed from the microvia.

A number of factors will have very significant effect on the performance of even the most chemically correct material.⁸

The design of the chemical process should take these factors into consideration and use them to assist the fluid dynamics.

- Viscosity
- Surface Tension
- Solution Density

- Solution Agitation
- Hole diameter
- Hole depth
- Surface roughness
- Temperature
- Time

Typical Acid Clean and Microetch processes operate at 20-30 0 C and with dwell times around 1 minute subsequent rinsing will be varied, but seldom exceeds 1 minute.

The effectiveness of solution ingression into and out of blind via holes is a key to success.

The use of surfactants to reduce surface tension and enable good penetration and wetting is often employed, but removal of such surfactants before the subsequent processing step is essential too.

Plant design can incorporate many variations including spray and immersion with or without the use of special nozzles and / or eductors designed to provide optimised rinsing within the confines of the specific plant design whether horizontal or vertical. Some authors have proposed the use of a brushing system to mechanically assist solution removal and change the fluid dynamics⁹.

The use of ultrasonic agitation has proved effective in other plating applications as a means of enabling good throw of chemicals into and out of recesses and this option has been experimented with in PCB plant design.

More recently in Japan the use of a vibratory agitator ¹⁰ has begun to gain acceptance with claims of increased performance when compared to a conventional ultrasonic agitation. The method relies on a series of parallel vanes subjected to a vibrational energy .The frequency of vibration can be adjusted to give the ideal agitation for a specific plant design and size.

The agitation achieved is uniform throughout the plating tank and being of a vibratory nature it dislodges any solution, and bubbles held in recesses and enables fresh solution to circulate into and out of the blind via holes with maximum efficiency.

A negative aspect is that the agitator must be mounted on a separate framework on many plants and given sufficient cushioning to prevent the plant being shaken apart. This demonstration of the potential energy of the system shows the energy available for achieving the desired result.

In a similar fashion to pulse plating the trick is to find the "window" where the focus of this energy can achieve the solution flow dynamics necessary to penetrate these blind holes effectively.

Once optimised , the same agitation conditions may be applied throughout the line to achieve the desired results.

Activation

Palladium activators are used in conventional Surface mount PCBs. In HDI the same activation mechanism is used, but a number of differing types are emerging to suit specific applications.

Key factors for concern are ensuring selectivity of activation onto exposed copper only; bridging between fine tracks and any deposition of metal onto the base substrate or soldermask cannot be tolerated.

A summary of some features and benefits of respective systems is shown in *Fig 2*.

Typically such baths are replaced regularly after around 5 days production throughput or 5 metal turnovers. Often throughput is described in terms of surface area processed ,but care needs to be taken when using such comparisons as the coated area will vary enormously from board to board. The effect of drag out and any recycling of process chemicals should be taken into consideration..

For such an activate it is recommended that the Palladium concentration is monitored for process control ,it is usually straightforward by AAS or ICP analysis.

Feature	Low HCl type	High HCl type	Non-HCl
Delledium		20 mm	200
Palladium	10 ppm	20 ppm	SOOppin
Concentration			
Fine Pattern	Good	Excellent	Excellent
Soloctivity	Good	Excellent	Excellent
Selectivity	0000	Liteenent	Literient
Catalytic for	Excellent	Good	Good
Plating			
Soldermask	Excellent	Good	Good
Compatability			
Copper	Excellent	Good	Excellent
Compatability			
Lack of plant	Excellent	Poor	Excellent
Corrosion			
Environment	Excellent	Good	Excellent
Bath Life	Excellent	Excellent	Excellent
Cost	Low	Low	High
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Fig 2: Comparison of some key features of typically available Palladium Activators.

BGA / UBM

Many of the factors described for HDI are also applicable to UMB and specific plants to address the needs are available. A significant amount of work has been done in this area by IZM Fraunhofer Institute¹¹

The front end of the sequence differs here as the wafer substrate is an aluminised surface and requires a careful Zincate treatment prior to Electroless Nickel and Immersion Gold.

ENIG provides an ideal surface for UBM, the sequence is out lined in Fig 3 and Fig 4.

Lead Free

ENIG was introduced to give a flat surface and an alternative to Hot Air Solder Levelled deposits (HASL).

It is a natural progression therefore that such surface finishes should be considered as part of the Lead Free requirement that is receiving increased attention as Japanese and European legislation become closer to implementation.

Surface finishes such as Immersion Silver and OSP are being put forward as alternatives to ENIG for all applications.

Lead Free solder alternatives do present some challenges to these alternative finishes.

It has been demonstrated ¹² that the wettability of OSP is not as good as ENIG for the many alternative materials being considered for Lead Free. All such alloys need a system that will tolerate higher temperature of operation (260 ⁰C).

Many alloys being considered, it can be said that Cu/Sn and tertiary alloys of Cu/Ag/Sn are emerging as favoured finishes by many investigative bodies. Some examples are shown in Fig 5.

North America	Europe	Japan
Sn/Cu	Sn/Cu	Sn/Cu
Sn/Ag	Sn/Ag	Sn/Ag
Sn/Ag/Cu	Sn/Ag/Cu	Sn/Ag/Cu
Sn/Ag/Cu/Sb	Sn/Ag/Cu/Sb	Sn/Ag/Bi
Sn/Ag/Bi	Sn/Ag/Bi	Sn/Ag/Bi/Cu
	Sn/Ag/Bi/Sb	Sn/Ag/Bi/Cu/Ge
		Sn/Zn

Fig 5: Examples of Lead Free Alloys under consideration by geographic region

Immersion Tin whilst giving better performance than OSP still falls behind ENIG in a direct

comparison¹² of voiding when a Lead Free Solder is applied .

It should be remembered however that the OSP is simply a coating to protect Copper and in conventional Tin/ Lead solder some very positive results have been reported ^{13, 14}.

OSPs when subjected to thermal cycling have demonstrated inferior durability in direct comparison to ENIG ¹⁵, this is not a surprising fact as the OSP finish does not have the luxury of a Nickel barrier to enhance its corrosion protection of the underlying copper material.

Within microelectronics there are applications for OSP, Immersion Silver, Immersion and Electroless Palladium also have benefits.

As Lead Free technology develops then the specific advantages of each surface finish will emerge.

It is very likely that each will have a niche market where the individual properties provided will satisfy the need; at a cost that is economically viable.

A significant amount of testing of the various Lead Free alloys for both Plated finishes and Solder Pastes still needs to be completed before a full conclusion can be drawn.

Initial tests indicate that ENIG is a suitable solderability protector for both conventional and Lead Free applications.

Concerns with ENIG

Whilst ENIG has been widely accepted as a suitable finish there are areas for concern.

Much work has been done to isolate the cause of the "*Black Pad''* phenomena that has occurred on some assambled devices ,such as BGA.

The conclusion of these investigations is that the Black Pad originates from corrosion of the Nickel deposit by the Immersion Gold plating process^{16, 17}. This corrosion will manifest itself as a Black Pad

with poor solderability.

The corrosion can be enhanced by various means including :-

- Pad geometry
- Fast plating rates in the Immersion Gold
- Low Phosphorous content in the Elecroless Nickel

Some investigators have artificially produced such Black Pads¹⁶ by introduction of "Stray electrical corrosion potentials" clearly demonstrating the phenomena.

Also the phenomena does not exist with Electrolytic Nickel^{17.}

Solder Bump Formation using ENIG



1. Zincate



2. Electroless Nickel + Gold



3. Solder Paste



4. Reflow

Fig 3 UBM Process Sequence for Solder Bump

ENIG for UBM



<u>Fig 4 : Schematic showing stages in ENIG for UBM</u> <u>metallisation</u>

Understanding a problem is the first stage in solving it. Electrolytic processing is not feasible for micrelectronics so immersion and electroless systems need modification or careful control.

Non Cyanide systems offer a way forward and the possibility of two stage plating systems using Immersion Palladium or a combination of Immersion Gold followed by Elecroless or Immersion Non Cyanide Gold are all possibilities to eleviate "Black Pad."

Non cyanide systems are available and some typical operating conditions are shown in Fig 6 compared to conventional cyanide systems.

	Cyanide Immersion	Non Cyanide Immersion	Non Cyanide Electroless
Gold	2.0	3.0	4.0
(g/l)			
pН	5.2	7.0	7.0
Temperature	90	75	70
(⁰ C)			
Plating Rate	10 mins	10 mins	10 Mins
(Microns)	0.07 µm	0.01µm	0.15µm
Thickness	0.2	0.2	3.0
Attainable			
(µm)			

Fig 6 : Comparison of Cyanide and Non-Cyanide Immersion and Electroless Gold

Summary and Conclusions

- ENIG has a strong presence in microelectronics.
- Technology advances are tailored to meet the needs of the growing market for microelectronics that cannot be met with conventional Electroplated deposits.
- HDI offers some challenges to the wet chemistry processing that can be satisfied by a combination of chemical and mechanical means to address the challenge presented by microvias.
- As a suitable coating for UBM, ENIG is already being used successfully and specific plants are built to achieve the desired result.
- For the emerging Lead Free requirements ENIG appears to offer a suitable solderability protection for the higher temperature alloys that are likely to be the future generation.

• Non Cyanide Immersion and Electroless Gold Process are available to address the *Black Pad* phenomena caused by corrosion from the cyanide immersion Gold processes.

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