Further Developments in Gold Plating Technology for Microelectronics

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This paper will outline the status of Gold Plating Technology in Microelectronics ,in particular, Pure Gold, and the technical requirements in terms of physical properties required for specific applications such as Bondable Pure Gold for BGA application.

Current practice in BGA technology will be outlined and some practical guidelines for Process Control will be explored.

Comparisons will be drawn between Acid Hard Gold and Pure Gold technology, in terms of contamination resistance,and the impact of such contaminants on the final deposit composition achieved , related to defined specifications.

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Introduction

This paper follows on from the one presented by the authors at SURFIN 98 entitled `Precious Metal Applications in Microelectronics`

We will focus in particular on Pure Gold Plating electrolytic, electroless and immersion processes will be covered outlining the operating parameters and defining applications in particular to the rapidly changing electronic packaging market within microelectronics.

In particular the effect of contamination on the deposit composition; comparing a Modern Pure Gold Plating bath with traditional Pure Gold Plating processes.

Applications

Specific applications for the use of Gold have expanded as electronics has become more precise in its requirements.

Previously Gold was used primarily as an interconnect material for Printed Circuit Boards and Electronic Connectors, with a smaller usage in High Performance Semi-Conductor devices.

The market is changing and in many cases has already changed with Surface Mount Technology demanding flatter surfaces for high density fine line boards. In this area the key requirement is a flatter surface which enables the automatic placement of components which on high density boards could not be achieved with conventional Tin –Lead finishes.

Electroless Nickel and Immersion Gold (ENIG) is the preferred finish for such applications as it produces a flat surface of uniform thickness ,being an Electroless system this is an inherent characteristic.

Electroplated Tin-Lead cannot achieve such flat surfaces as it is necessary to plate a thicker deposit and reflow the material ;this reflow ,often Hot Air Solder Levelled, (HASL) will create a thickness variation that is acceptable for low,density boards ,but cannot be tolerated in high-density fine line boards.

Mismatch of height can lead to an unacceptable level of rejects as a result of dry joints on the surface mounted components.

This technology is being driven by the need for faster, lighter, smaller requirements for hand held devices together with the higher demands placed on the specification of larger devices where space within the electronic storage area is limited.

Other areas where there is a need for faster, lighter and smaller devices is within the components themselves , which are mounted onto the boards ,as their requirements have become more demanding in terms of interconnects per square so the need for alternative technology to meet these demands has increased.

Ball Grid Array (BGA) technology is become more common place in electronic devices ,in particular for portable devices , Laptop / Palmtop computers, Personal Organisers, Mobile Phones & Pagers, Digital Camera and Video cameras are all significant markets that require such technology.

Conventional Technology has limitations on the interconnect per square and the advantages of BGA over Lead Frame Technology can be seen in the size of component footprint.

A BGA device will always be smaller and hence the possibility of higher density boards becomes a reality. This is achieved as in a BGA device the output leads are not restricted to peripheral leads only. Interconnections are made over the entire underside of the device via solderballs to the motherboard.

Gold is used within the device and a key requirement of Gold in BGA technology is wire bondability , as the current technology requires Wirebonding to connect the BGA to the integrated circuit itself.

The gold itself may be deposited either Electrolytically or Electroless and may use cyanide or Non Cyanide Electrolytes. The key requirement being to deposit a wirebondable Gold onto the BGA substrate.

Requirements of a Pure Gold Process for BGA application

- Must be Bondable
- Must be tolerant to metallic contamination
- Must have High Deposit Purity
- Must exhibit Good Thickness Distribution
- Must exhibit good Pore Closure and Corrosion resistance.
- Must have good Storage / Shelf life

Bondability

For the Gold plating to serve its function in a BGA device it must be bondable.

Wirebonding is used throughout the microelectronics industry to interconnect IC chips to substrates and output terminals.

Process control is by means of Pull tests; details of these Pull tests can be found in MIL-STD-883 Method 2011 Destruct Pull Test.

Details of this test were presented at SURFIN 98 by the authors and will not be repeated here , other than to emphasise the essential requirement of tight laboratory procedures to ensure reproducibility and consistency of the test.

Tolerance to Contamination

Pure Gold baths by their very nature will be susceptible to contamination , or will they ?

Consider a typical Acid Hard Gold bath contaminated with Iron (Fig 1) ; it can clearly be seen that as the Iron contamination increase so the quantity of Iron in the electroplated deposit increases dramatically.

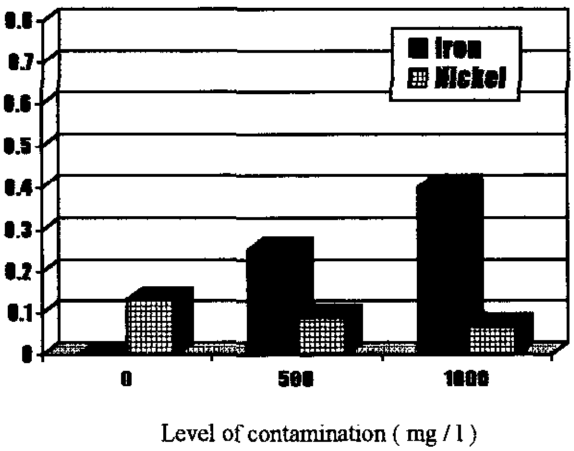


*Figure 1: Graph of Nickel Brightened **Acid Hard Gold** bath showing effect of Iron contamination on the deposit composition..*

It can also be noted that this particular chemistry is designed such that a controlled deposition of the transition metal brightener also occurs , in this example Nickel.

Contamination levels referred to regarding Pure Gold baths are very often quoted on the safe side to ensure compliance with specifications and ensure a Pure Gold deposit is achieved.

Contaminant	Typical Recommended Maximum (mg/l)
Copper	100
Nickel	100
Iron	100

Figure 2: Typical contamination levels suggested by suppliers for Traditional Pure Gold Plating baths

Understandably , the ideal level for any contaminant level is zero , by the very definition of contamination is ,at best, an undesirable material and ,at worst a potential threat to quality of production output.

However , if you consider the status of a Modern highly developed Pure Gold electroplating bath for microelectronic applications , you will discover that in fact they are more robust processes than you would imagine.

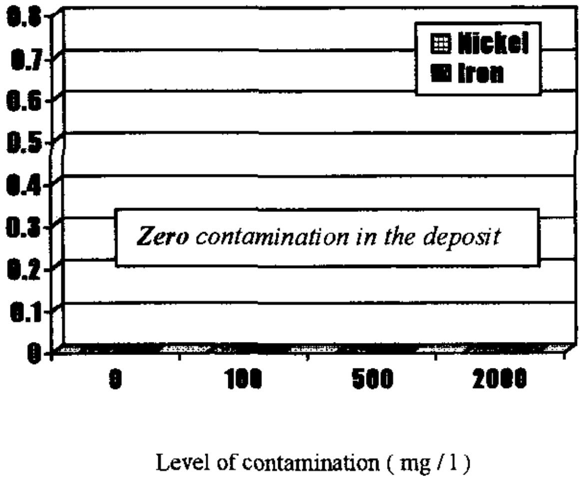


*Figure 3. Graph of Modern **Pure Gold** bath showing effect of Iron and Nickel contamination on the deposit composition*

Consider the tolerance level of two typical contaminants , Nickel and Iron. Laboratory trials were conducted to evaluate the deposit purity of such a bath deliberately contaminated with Nickel and Iron up to 2.0 g/l .The data is presented in Fig 2.

It can be seen that even at relatively high contamination levels the quantity of co-deposition is zero in stark contrast to the result obtained for Acid Hard Gold plating baths with similar contaminant levels, and the recommended maximum for Traditional Pure Gold Plating baths..

The reason for this is, in reality, the basis of Acid Gold Chemistry ; which is designed such that at the pH range, typically 3.5-5.0 , any transition metal will co-deposit , readily , but in a controlled manner.

As pH increases to 5.5 the transition metals form strong cyanide complexes with available cyanide generated from the reduction of Gold from Gold Potassium Cyanide.

These cyanide complexes are also readily soluble at higher pH and hence play no part in the deposition process; they are also very stable.

For example if you consider Cobalt, the cyano-cobaltate complex is one of the most stable complexes known, in fact when complexed with Co III, cyanide ceases to be toxic.

Hence a Pure Gold operated at just below neutral pH, typically, pH 6.0 – 6.5 ,will also demonstrate this ability to block the deposition of any *transition metal that forms a strong cyanide complex.*

Modern Pure Gold baths will contain additional strong ligands to ensure that even residual free transition metal contaminants , uncomplexed by Cyanide , are also immediately complexed by the electrolyte itself.

It has been shown that a Pure Gold bath with up to 2 g/l Nickel still exhibits Bond Pull strengths equivalent to a bath with zero impurities present.

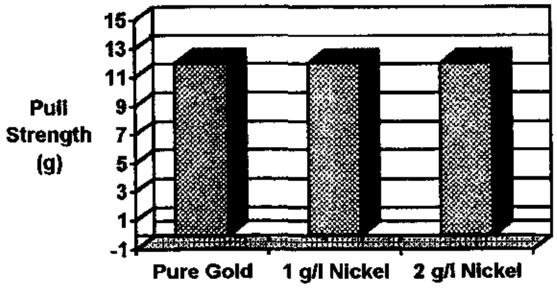


Figure 4: Pull strength of Pure Gold bath with and without Nickel contamination present.

Hence in reality it seems that a bath may tolerate this level of contamination without any compromise of bond strength and reliability.

Whilst experimental work supports the tolerance to contamination being very robust, in practice users will restrict the level to well below the maximum tolerable and the table below gives some typical maximum levels accepted by the industry.

Contaminant	**Recommended Maximum for Modern Pure Gold bath (mg/l)**
Copper	250
Nickel	1000
Iron	500

Figure 4: Typical contamination levels for Modern Pure Gold baths metallic tolerance for wire bonding application.

The largest market segment is for Electroplated Pure Gold, largely because from the chemistry viewpoint it is the most advanced technology and easiest to implement.

The market is dominated by cyanide processes, as it reduces cost , in the majority of cases Gold potassium Cyanide is a cheaper raw material than other non cyanide possibilities.

Smaller devices and microBGA require Electroless processing, as there simply isn't room on the device for a Plating bar and the current necessary to apply cannot be carried by the fine line circuitry employed.

Whichever process is employed the requirements of the Gold are the same; it must be bondable and provide a consistent quality of deposit over the entire circuit.

Processes are available in both Cyanide and Non cyanide versions. As is typical for many processes the cyanide containing baths are generally faster and easier to control.

Many types of BGA exist and are constantly changing in their structures and designs.

Plastic BGA (PBGA), Ceramic BGA (CBGA), Micro BGA (μBGA), Multi Chip Module Plastic BGA (MCM.PBGA,) ,Flexible BGA (FleXBGA). and Fine-Pitched BGA (FPBGA) are just some of many established styles of BGA.

They differ in their construction for functionality and ease of assembly ,and possess differing characteristics for each specific application , but from the Gold plating viewpoint they have identical requirements : they need a soft bondable Pure Gold deposit.

Some examples of typical structures of BGA devices are shown below to indicate the areas where Pure Gold and wirebonding is required.

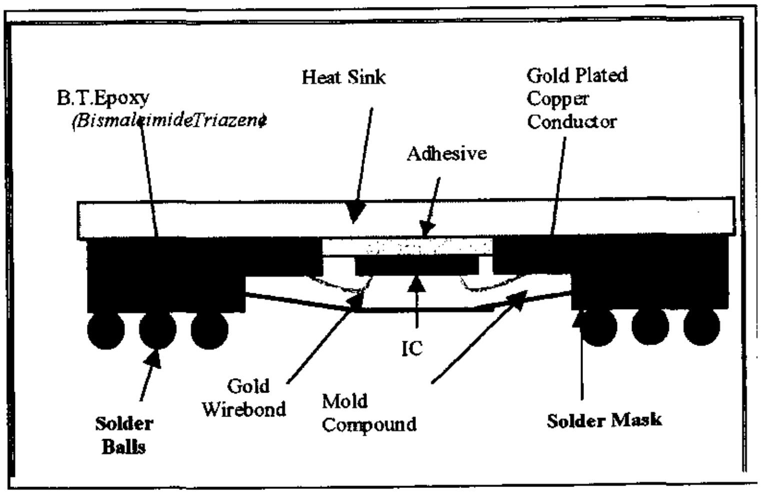


Figure 5 : Schematic section through Cavity Down Plastic Ball Grid Array showing Gold Wire Bonding.

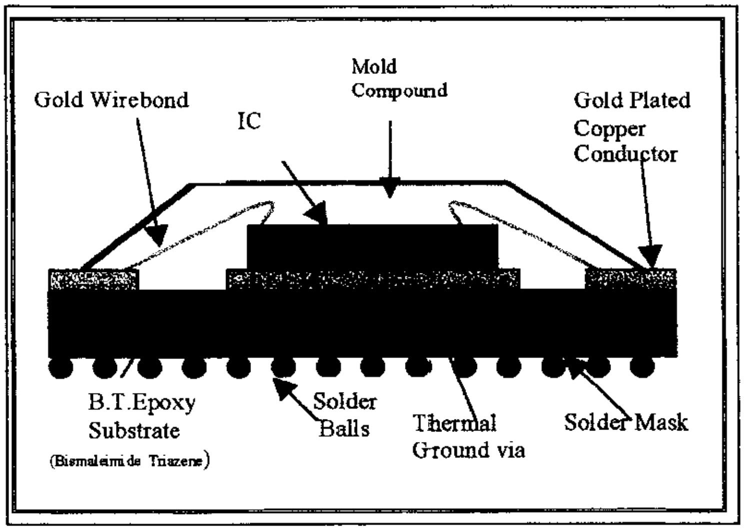


Figure 6 : Schematic section through Plastic Ball Grid Array (PBGA) showing Gold Wire Bonding.

The differing styles suggest that a wide range of production techniques would be employed , but basically the industry is using a conventional Printed Circuit based technology as the processing format , with large tanks and big boards to cope with the production throughput.
A typical sequence for BGA being :

- ***Acid Clean***
- ***Microetch***
- ***Nickel Plate***
- ***Gold Strike***
- ***Gold Plate***

As you can see this is traditional Printed Circuit Board processing and indeed the plant and equipment is often very similar in construction , but with design features to enhance distribution profiles to achieve uniform Thickness Distribution.

Board sizes are often 48 inch x 48 inch and plants will plate these often double sided boards on racks of 4 panels ,so the dimensions of the Gold Plating tank, must be capable to accept such sizes with corresponding Pretreatment and Nickel process tanks.

Current densities follow that used in the traditional Pure Gold Electroplating tanks and typically 0.5 – 1.0 A/dm2 is used.

Whilst this technique currently meets the market need , the future suggests that a higher speed of deposition would be required to meet volume growth targets in a similar way to the fast deposition speeds evolved for Semi-Conductor Lead Frames.

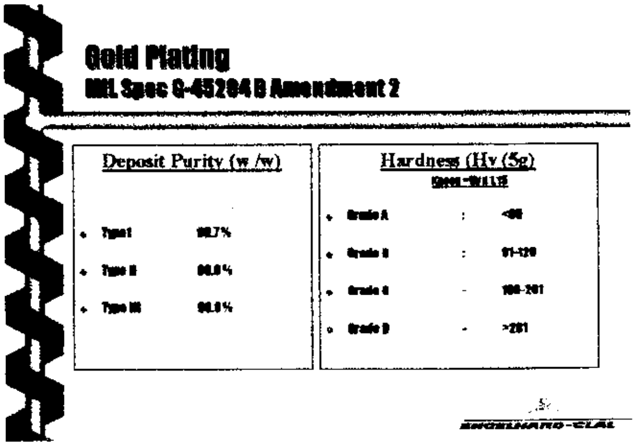
The fleXBGA offers the most likely way forward in this area as already is possible to produce such designs using a Polyimide material on a continuous reel to reel system. The fleXBGA is reinforced prior to assembly by the addition of a rigid heat sink to the rear side of the flexible circuit prior to assembly onto the mother board.

By comparison to the established Lead Frame technology the current densities applied are presently still relatively low , but as machine design matures the ability to control agitation and deposition speed over the wide area of a BGA circuit will enable faster deposition speeds to be achieved.

Pulse Plating can present some benefits here and the technology for High Speed Pure Gold electrodeposition for microelectronics is already a field proven process in the Lead Frame industry.

Deposit Purity

In addition to its physical properties such as bond strength, the deposit purity can also be considered as a parameter, which needs to be tightly controlled. We have already seen that the presence of base metal contaminants can be kept under control, but how about other potential impurities ?



Gold Plating
MIL Spec G-45204 B Amendment 2

Deposit Purity (w /w)

Hardness (Hv (5g)

Figure 7 : MIL Spec G-45204 B defining all categories of Gold Electroplates

Even the tightest military specification for Gold demands only 99.9% Gold and a hardness less than 90 Hv (5g).

Hence it is possible to have present up to 0.1% of impurities by weight ,providing they do not impact on the deposit hardness.

Naturally any electroplated deposit can contain such elements as Carbon and Potassium together with the possibility of Hydrogen.

In a Pure Gold bath however ,with high cathode efficiency, then the possibility of Hydrogen is greatly reduced ; whilst Carbon and Potassium remain possibilities from occlusions of conducting salts and breakdown products of cyanide from Gold Potassium Cyanide reduction.

Grain Refiners

Semi-metals such as Arsenic, Thallium, Selenium, and indeed Lead are sometimes used to enhance the deposit appearance and reduce the grain size of a Gold deposit.

These materials work very well with Pure Gold deposits and are often present at very low levels

The theory on their mechanism is fairly simple and explains how they can operate at such low levels and create such a dramatic effect on the deposit.

The theory is that the elements absorb onto the cathode surface evenly where they catalytically enhance the nucleation sites of the gold.

In the absence of these 'Brighteners' the gold neucleates at growth sites such as crystal dislocations on the cathode; but the catalytic effect of the semi-metal encourages more even deposition by creating more growth points.

The effect can be regarded as`Catalytic` because the charged species, for example Tl^+, is available for re-adsorption.

This means that consumption of such materials is very low and the concern regarding co-deposition is really unfounded as the level of such materials can be monitored and the consumption level is very low and can be considered to really be only replacing drag out losses.

The purity of the deposits remains intact with the only impact being an increase in the deposit hardness as a result of the reduced grain size.

For BGA production currently over 85% of users in Asia use Gold Plating system containing a semi metal with totally Pure Gold processes making up the remainder of the market.

With totally Pure Gold Plating processes then the use of Pulse Plating can be applied to enhance the Grain structure and obtain the desired surface finish.

Distribution of Thickness

Electroless systems offer significant advantages in terms of distribution, being Electroless *they produce very even consistent thickness profile* regardless of the circuit design; the gold being deposited by chemical means onto the desired circuit. however there is also a need for Gold to be sparingly deposited on the Land areas for the Solder Ball attachment where an excess of Gold Plating may adversely affect the strength of the Tin Lead to Gold bond holding the Solder Balls to the underside of the BGA.

Cell design can therefore play an important ancillary role in controlling deposition on the required BGA surfaces to achieve the desired result.

Electrolytic baths for Pure Gold tend to exhibit High Cathode efficiencies, generally in excess of 95%; this inherent high Cathode efficiency that is demonstrable over a wide Current Density range tends to favour poor distribution profiles, with increased thickness in line with Current Density variation across the BGA.

Work has shown that careful electrolyte design can result in a Pure gold plating bath that exhibits high cathode efficiency whilst maintaining a good distribution profile. A number of differing formulations were compared under standard conditions in Hull Cell tests initially to determine the thickness Profile under identical conditions for these baths.

This work was described in the paper presented by the author at SURFIN 98.

Bondability

For the Gold plating to serve its function in a BGA device it must be bondable.

Mechanical testing can produce data by which Bonds may be compared but a significant amount of practical observations can be made to further clarify the success or failure of a joint

Low magnification observation will enable a study to be made of wirebonds; which should have a consistent appearance, with wire always placed in the same orientation .The joint should show no signs of visual cracking, in particular at the joint `heel`.Also a uniformity of the Ball shape in a Ball joint, with no `Golfclubbing` , this results in an asymmetrical appearance to the joint.

A common problem Wedge Bonding is cracking at the Heel, this type of fault is often caused by vibration at the bond head during bonding resulting in a shift after the wedge bond is formed; misalignment of the tooling can also contribute to this phenomena.

Contamination of the bond by impurities can also be observed. Some factors such as Epoxy Bleed out, badly oxidised surfaces can be seen easily, others such as contamination with trace elements will require analysis by Scanning Electron Microscopy (SEM) and EDAX (Energy Dispersive X- Ray); to *produce photographs of defects and analytical data* to explain the defects seen.

Bonding Results : Thermosonic Bonding

The following graphs show some laboratory data for Pull Strength of a Gold wire bond onto a Pure Gold Deposit plated on top of 5 Microns of Nickel on a Printed Circuit Board.

In these tests the trend is more important than the precise value, as these were laboratory tests only.

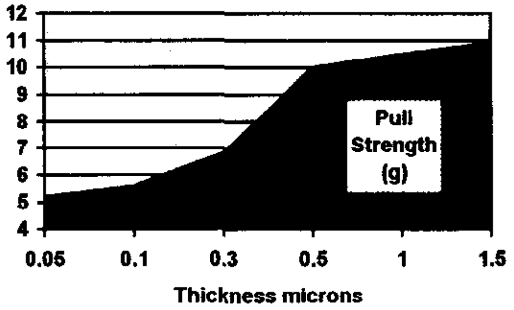


Figure 7: Pull Strength Vs Gold Thickness showing increased Pull strength above 0.5 Microns Gold

The graph shows that even on very thin Gold deposits it is possible to achieve a bond on the freshly plated part. Bond strength increases up to around 0.5 microns; no significant increase occurs between 0.5 and 1.5 Microns.

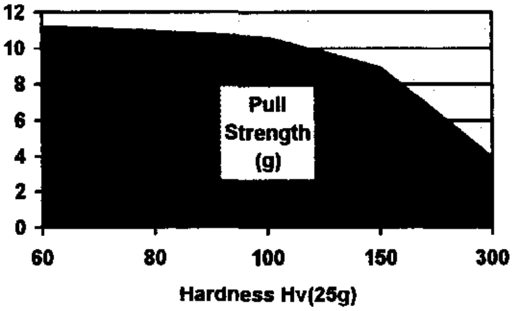


Figure 8: Pull Strength Vs Gold deposit Hardness showing decreased Pull strength above 100 Hv (Gold Thickness = 0.5 Microns)

It can be seen that the hardness of the Gold deposit has a significant effect on the Pull strength. This is not surprising as Hardness has a direct relationship to the grain size of the deposit.

A harder deposit will have a smaller grain size and a brighter appearance usually, but not always, achieved by the addition of a semi metal grain refiner.

The decrease in Pull Strength may therefore be caused by either the grain size or the semi metal grain refiner.

Harder deposits generated without the use of semi metal grain refiners also exhibit this trend, suggesting the mechanism is more related to the grain size or hardness rather than the means by which it is achieved.

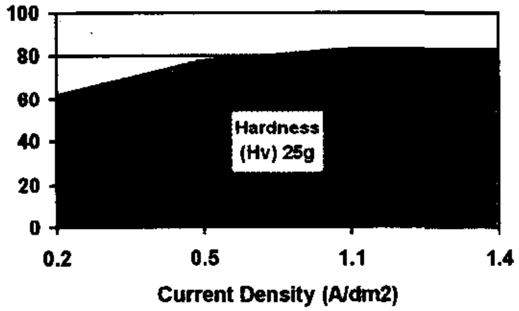


Figure 9 : Deposit Hardness Vs Current Density for a proprietary gold plating bath.

Control of deposit Hardness therefore appears to be a key factor in achieving a consistent Pull Strength.

The chart below shows data achieved from a Proprietary Gold Plating bath incorporating a semi metal grain refiner showing the relationship between Hardness and Current Density. It can be seen that a consistent hardness is achieved over the typical operating current Densities for such a process and in all cases below the 100 Hv value above which Pull strengths usually decrease.

The Gold Plating process and the Bonding process itself must be closely controlled to ensure consistent results, also the testing should be carried out under strictly controlled conditions to ensure that results obtained can be compared to previous data from the same laboratory.

When comparing data from differing laboratories; care should be taken to ensure the results are comparable in every respect. This should include comparing all available data on the bonding conditions and test procedures, often comparing this type of data will reveal significant differences in the test procedures that once rectified eliminate the apparent discrepancies in the quoted Pull Test value.

In addition to the Physical requirements of the deposit itself; in BGA and many Printed Circuit related applications the need for Resist compatibility of the Gold plating process is an additional requirement.

To ensure this vital stage is not overlooked it is wise to work closely with resist suppliers to ensure the resist and Gold plating process are mutually compatible.

This usually involves a uv scan of the Gold plating solution after prolonged exposure to photo resist chemicals to detect any organic material that may have leached out. In addition to this visual examination of resist edges to examine any undercut or brittleness *induced by the plating process is also prudent.*

Soldermasks

Printed Circuit Boards whether for ENIG or for Pure Gold for BGA application will invariably require a soldermask to be applied.

Naturally this is a key area for consideration when selecting the chemistry for the process line ; any soldermask must be fully compatible with the complete line chemistry to ensure no loss of definition of the areas requiring such masking.

Screen printed photoresists may be used where line definition will tolerate such procedure ,but photoimagable masks are more commonly used for high density boards.

In many cases these are two or three part epoxy packs.

Typical failure mechanism for soldermasks are undercutting and pinholing that lead to exfoliation and plating onto non desirable areas.

These defects can readily be identified by optical microscopy at 40x magnification ,so are as such easy defects to detect, but difficult defects to rectify. Often a failed Soldermask will result in a scrapped high value board as rework of such boards is often difficult or impractical.

Naturally selection of the correct soldermask is only the first stage , and most leading suppliers are able to offer a range of soldermasks to meet the exacting demands of microelectronics.

The method of application and process control in application are critical for success.

Curtain coating is the preferred technique of application , but many still use the screen printing method where dimensions permit in Europe.

Electrostatic horizontal spray is also a growing trend in application , particularly in theUSA.

However even prior to application the quality and cleanliness of the substrate onto which the soldermask is to be applied must be considered.

Pretreatment must leave a chemically clean surface that is receptive to the soldermask and preferably allowing some degree of mechanical 'key' onto the substrate , such surface textures may be obtained by careful brushing of the ,usually , copper surface or a microetch to give a uniform etched surface ideal for physical attachment.

This pretreatment can be carried out by chemical , mechanical brushing or pumice spray units. For some photoresists the application of adhesion promoting oxide layers is recommended but this is not necessary with more advanced products.

Holding times and intermediate storage should be kept to a minimum ,and naturally only an absolutely dry surface should be coated.

Curtain coating machines control the viscosity *and temperature of application according to the* manufacturers specification.

Solvents must be `flashed off' under controlled conditions for consistent results typically, between 20-40 C for around 10 minutes. Final drying ovens at 80 C are usually operated for 20 minutes per coat applied.

The soldermask is exposed typically around 350-420 nm dependent on parameters with 100-150 mJ /cm2. The material is developed using a Sodium Carbonate solution (around 1%) for 60-90 seconds and inspected for defects ,as at this stage the board may be salvaged if problems are noted.

Thermal curing typically 150 C for 60 minutes, for some soldermasks a uv bump is required, but care needs to be taken to avoid brittle soldermasks sung this technique.

The degree of curing and temperature / time are also critical. An over baked soldermask will be brittle whist an under baked soldermask will tend to leach out organic material and potentially poison the electroplating bath ,over a period of time.

Environmental pressure is pushing the industry towards fully aqueous-alkaline developable soldermasks.

Process Parameters

The following tables give typical operating parameters for various Pure Gold processes.

They are meant to demonstrate the scope of the processes rather than define precise operating conditions, which will of course vary from one bath to another.

Cell design will influence the speed of deposition and the rates quoted for each processes are not the maximum possible , but simply examples from field experience of processes in production environments.

Often the Gold speed is influenced by a rate determining step earlier in the process line , such as pretreatment or Nickel Plating stages

Process Parameters for Pure Gold Processes for BGA

Parameter	**Unit**	**Range**
Gold	g/l	8-10
pH	-	6.0-7.0
Temperature	^0C	60-70
Current Density *	A/dm^2	0.5-1.5

Figure 10
Pure Gold (Manual line) BGA

Parameter	**Unit**	**Range**
Gold	g/l	2-4
pH	-	6.0-7.0
Temperature	^0C	80-95
Speed	µ/ hr	0.5-2.0

Fig 13 Electroless Pure Gold
(Manual line) BGA (Cyanide type)

Parameter	**Unit**	**Range**
Gold	g/l	8-10
pH	-	6.0-7.0
Temperature	^0C	60-70
Current Density *	A/dm^2	1.0-3.0

Fig 11
Pure Gold (Semi Automatic / Continuous) BGA

Parameter	**Unit**	**Range**
Gold	g/l	2-4
pH	-	6.0-7.5
Temperature	^0C	70-75
Speed	µ/ hr	0.5-1.0

Fig 14 Electroless Pure Gold
(Manual line) BGA (Non-Cyanide type)

Parameter	**Unit**	**Range**
Gold	g/l	8-10
pH	-	6.0-7.0
Temperature	^0C	60-70
Current Density * (Pulse Plated)	A/dm^2	10-40

Fig 12
Pure Gold (High Speed) Semi Conductor

Parameter	**Unit**	**Range**
Gold	g/l	1-2
pH	-	5.0-6.0
Temperature	^0C	85-95
Immersion time	minutes	10

Fig 15 Immersion Pure Gold system ENIG
(Manual and semi-automatic line)

* Dependent on agitation and Plant design.

Summary

Technology for Gold application in microelectronics continues to advance with solutions designed to specifically meet the exacting demands and rapidly changing designs in the electronic packaging industry.

Processes are available, and already being used in production environments to enable ,Electrolytic, Electroless and Immersion deposition of Pure Bondable Gold deposits for BGA technology.

The Future

Higher production speeds will be demanded as volumes for BGA increase and output speed becomes a cost concern for producers.

Electroless systems will become more robust and their applications expand as the package size ever decreases. Again deposition speed ,which is currently a limitation will need to be improved as technology advances.

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