MATERIALS INTERACTION DURING SOLDERING AND ISOTHERMAL AGEING OF Sn-Pb AND Sn-Ag-Cu SOLDERS ON ELECTROLESS Ni/ Au SURFACE FINISH

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DEDICATION

Specially dedicated to...
Dearest dad & mum,
for their endless love and support

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ABSTRACT

In flip chip interconnection an under bump metallurgy (UBM) is required to provide a diffusion barrier, an adhesion and a solderable surface. Among the various UBM systems available the electroless nickel / immersion gold (ENIG) has received greater attention in recent years due to its low cost and because it does not require a mask. Most of the time, however, the electroless nickel layer contains phosphorus when hypophosphite is used as the reducing agent. In the present study, the effect of phosphorus content in the electroless nickel/immersion gold under bump metallurgy has been examined and the effect of isothermal aging at 150 °C for up to 500 hours on the formation and resultant morphology of the intermetallics formed between eutectic Pb-Sn solder and Sn-Ag-Cu lead-free solder and electroless Ni-P / immersion Au UBM has also been investigated. Structural examination and measurements of the average thickness of the growing intermetallic compounds on cross-sectioned solder joints made from the Sn-Ag-Cu solder revealed that the thickness of these intermetallic compounds increases as the phosphorus content in the electroless nickel decreases. On the other hand, in Pb-Sn eutectic solder the intermetallic compound thickness increases with increasing phosphorus content in the electroless nickel layer. Thermal ageing of the soldered joints led to the formation of several types of intermetallic compounds with different morphologies.

ABSTRAK

Dalam salingan hubungan serpihan flip, *under bump metallurgy* (UBM) diperlukan untuk memberi suatu halangan serapan, rekatan dan permukaan yang boleh dipateri. Dalam pelbagai sistem-sistem UBM sediada, nikel tanpa elektrod/emas rendaman (ENIG) telah mendapat banyak perhatian semenjak kebelakangan ini. Ini disebabkan kosnya yang rendah dan ianya tidak memerlukan topeng. Walau bagaimanapun, nikel tanpa elekrod lazimnya mengandungi fosforus apabila hipofosfit digunakan sebagai ejen penurun. Dalam kajian ini, kesan kandungan fosforus dalam nikel tanpa elektrod/emas rendaman *under bump metallurgy* telah dikaji. Kajian juga telah dilakukan ke atas kesan penuaan sesuhu pada suhu 150°C sehingga 500 jam ke atas pembentukan dan morfologi sebatian antara logam yang terbentuk di antara pateri Pb-Sn eutektik dan pateri tanpa plumbum Sn-Ag-Cu dan Ni-P tanpa elektrod/emas rendaman UBM. Pemeriksaan struktur dan pengukuran ketebalan purata sebatian antara logam yang tumbuh ke atas sambungan pateri yang diperbuat daripada pateri Sn-Ag-Cu menunjukkan ketebalan sebatian antara logam tersebut bertambah apabila kandungan fosfur di dalam nikel tanpa elektrod berkurangan. Sebaliknya pula, bagi pateri eutectic Pb-Sn, ketebalan sebatian antara logam bertambah dengan pertambahan kandungan fosfur di dalam lapisan nikel tanpa elektrod. Penuaan haba ke atas sambungan terpateri menghasilkan pembentukan pelbagai jenis sebatian antara logam dengan morfologi yang berbeza.

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dissipation through the back of the die to the plastic packaging. This allows higher currents with the same package size and design.

Electrical performance is enhanced when solder balls replace wire bonds because the solder balls have a lower resistance and can carry a higher current. This is especially important for use in portable and battery-driven devices, where the package needs to be small and consume less power. Flip chip connected components have the advantages when running at higher frequencies compared to their wire-bonded counterparts. This is particularly important with the ever-increasing switching speeds of today's communication and processing components.

Using flip chip technology enables engineers to pack larger dies into the same package area compared with conventional wire bonded packaging (Figure 1.1). The space that is required for the wire bond on the lead-frame and the epoxy bleed-out around the chip can then be used for a larger die size. This offers several opportunities for a package designer, such as adding more functions in the same device without needing to change the package type or size. This translates into cost savings in two ways: there are more functions in the same package, and using the same package means no changes and the same surface area on the PCB side.

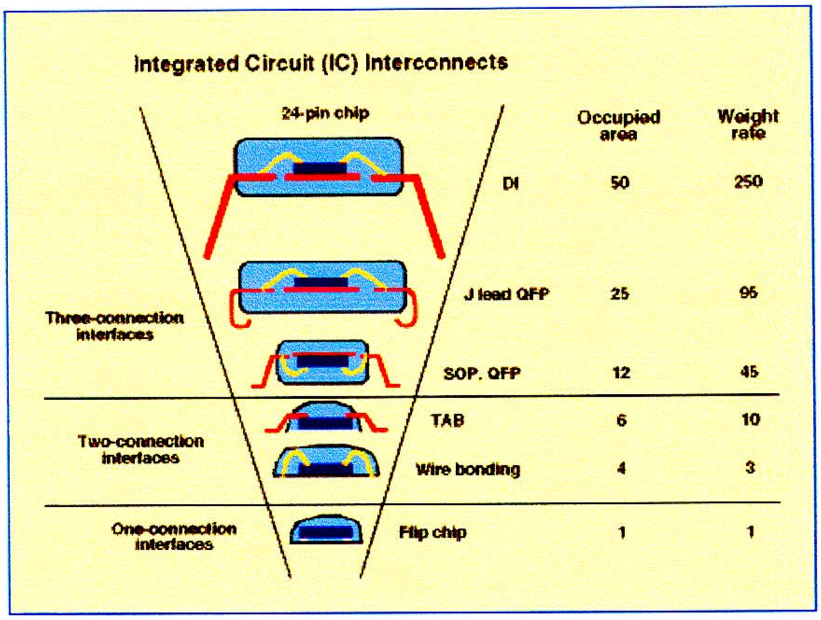

Figure 1.1 – Space saving by using flip-chip connection

Reliability is one of the chief issues for semiconductor manufacturers when selecting a soldered flip-chip interconnection system. Both mechanical fatigue and corrosion of the solder joint can significantly affect the performance of a solder-based interconnect system during service. Reliability also becomes a concern during service, when ambient temperature fluctuations result in differential thermal expansion between the various components of a flip chip assembly. The expansion mismatch between these components imposes strains that produce mechanical stresses at the solder joint and die surface. These stresses are the driving force for damage mechanisms, such as crack growth and interfacial delamination. The magnitude of the stresses is determined by the assembly stiffness and the inelastic deformation properties of the solder joint. The rate of the damage process is influenced by stress, temperature and environment.

1.2. Project Background and Rational

Flip chip interconnects play the key role in the miniaturization of microelectronic packaging (MEP). The expectation on flip chip joint is relatively high as it is expected to carry increasing mechanical, electrical and thermal loading, while it is getting smaller and smaller. This may create a possibility of failure due to these demands from users and manufacturers. The solder composition, the substrate and underfill materials, and the severity of the environment influence the reliability of solder joints. Most precisely, the material characteristics control the key factor of joint failure.

Intermetallic formation and growth affects the reliability of solder joints. Until the connection is cooled for handling, the intermetallic layer will continue to grow. The growth rate is linear with the square root of time at a specific temperature and exponential with temperature. This growth is controlled by the diffusion of interacting atoms to the interface. Intermetallics have properties that arise from a mixture of metallic and covalent bonds, which are strong with a high modulus. This bonding is good for connections until their growth governs the property of the joint;

it is then deemed detrimental to the joint when it grows thicker. This is because most of the intermetallics are brittle.

Due to the severe effect caused by the intermetallics, there is a choice of using diffusion barrier layers, that is choosing a material with lower dissolution rate, and plate it over the base metal so that it will dissolve into the solder to form a thinner intermetallic layer instead of the base metal. In the case of copper as base metal and Sn-Pb as solder material, it is usual to deposit a layer of nickel and gold through an electroless process. However, up to 99% of the electroless nickel plating solution in the market uses hypophosphite as reducing agent. An alloy of nickel and phosphorus is usually deposited instead of pure nickel, making phosphorus another factor influencing the joint reliability.

For solder materials, there is a trend moving towards the replacement of lead-base solder with lead-free solders. The reasons are: (1) lead and its compounds are ranked among the top 10 hazardous materials and (2) lead is the number one environmental threat to children. It has been reported that in the past decade, on average approximately 20,000 tons of lead each year have been used globally among electronic manufacturers. This amount is about 7 percent of total lead consumption worldwide[1]. Therefore, sooner or later, the market will come to a total shift from lead-based to lead-free solder material for environmental/health concern.

1.3 Objective of the Research

The main objective of the present research is to study the effect of factors such as phosphorus content in the electroless nickel plating, immersion gold layer thickness and solid state ageing on the intermetallics formed at solder joints made between eutectic tin-lead (Sn-Pb) and lead-free (Sn-Ag-Cu) solders and Cu/Ni/Au under bump metallurgy.

1.4 Significance of the Research

Controlling the electroless plating process in order to ensure the right phosphorus content in the deposition is the first requirement to fulfill the objectives of this research. Even though electroless plating is not a new technology in the finishing industry, its applications are however mostly for coating large components such as molds, foundry tooling, bearing, shafts, valves and so on. Most of the plating solutions available in the market are designed for general metal finishing (GMF). In circuit board industry, this process is being operated under drastically different conditions than those for which the GMF baths were formulated. For example, it has low bath loading and low replenishment rates as compared to the other components mentioned above. How do these factors affect the deposition quality and phosphorus content? Which is why this process needs to be re-studied in order to provide better understanding of this process, and consequently helping in the improvement of this process, especially in controlling the phosphorus content.

Previous research in the literature focused more on under bump metallurgy (UBM) structures based on aluminium pad metallization but studies on the use of electroless nickel (Ni-P) as a UBM are not widespread. Thus, an attempt is made in the present work to investigate this new UBM structure in terms of the morphology of the intermetallics formed. Understanding the factors affecting the behavior of intermetallics will help in the development of knowledge involved in the process control of soldering. Other than the expected intermetallics layer(s), the phosphorus content in the deposition lead to the formation of P-rich layer in reflowed solder joint. Therefore, it is essential to characterize the formation of such intermetallics in order to understand better the joint's behavior. It would provide engineers a clearer view of what is happening in the solder joint and to what extent the intermetallics may become detrimental to the solder joint so that more consideration factors for future design and material selection could be provided.

This same reason is also applicable to the significance of studying the aging effect on the intermetallics formed between the solder material and materials in the under bump metallurgy.

1.5 Scope of the Research

The materials interaction study in the current research project refers to the interaction between the materials that form the under bump metallurgy (nickel and gold) and the materials of the solder alloy used. The work focuses on the characterization of the intermetallics formed between eutectic Pb-Sn solder and lead-free Sn-Ag-Cu solder and under bump metallurgy made of Cu-Ni-Au (Figure 1.2). The Ni/Au layers are processed by the electroless Ni/ immersion Au processes. Particular attention is given to the effect of phosphorus content in the electroless Ni layer on the type, morphology, distribution and thickness of the intermetallics formed. The effects of the immersion gold layer and solid state ageing at elevated temperature on the intermetallics formed are also investigated.

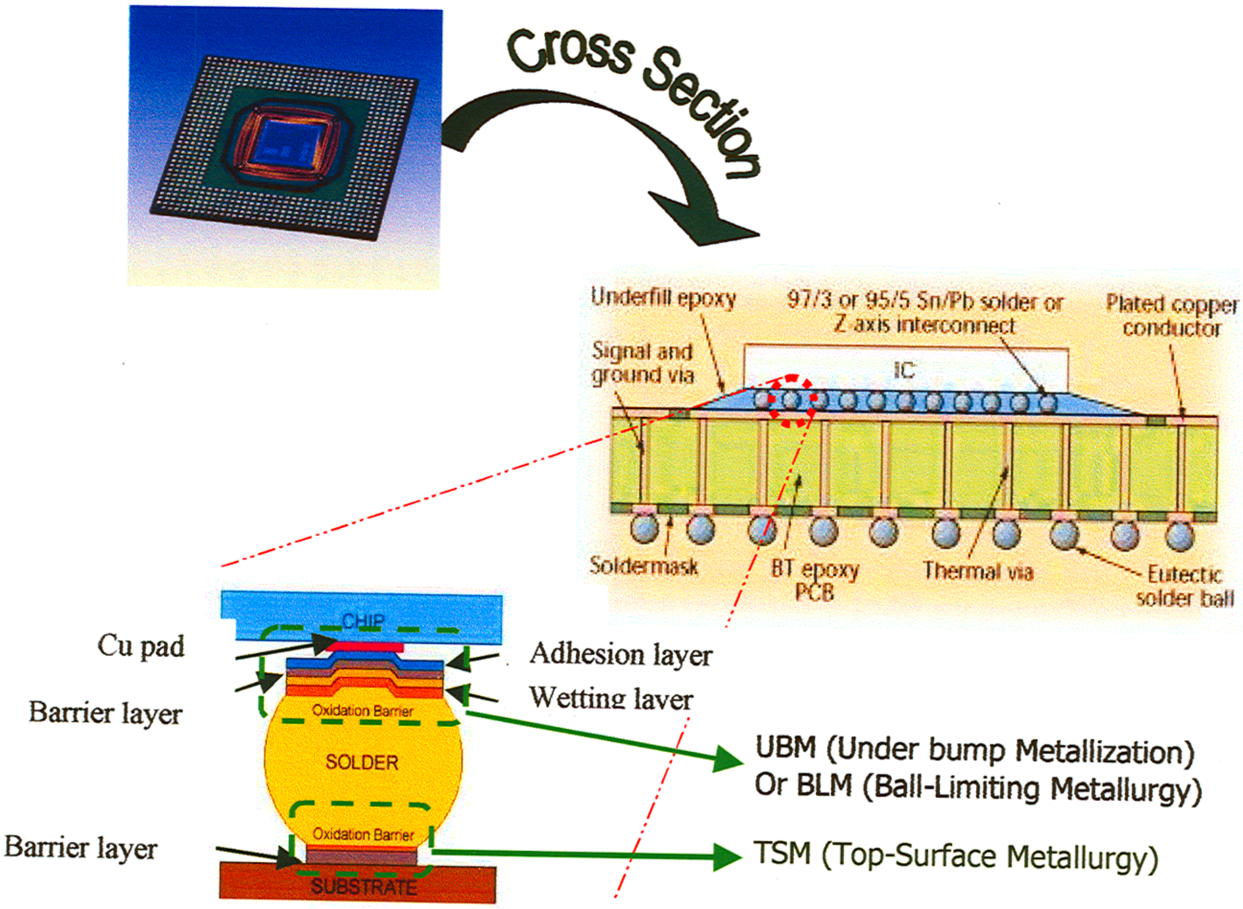

Figure 1.2: Structure of Flip Chip Assembly Technology

The factors that control the quantity, morphology and distribution of intermetallic compounds within the soldered joints will be examined. However, a wide range of substrate conditions, different phosphorus content and gold thickness, will be studied. The effect of ageing on the intermetallics will also be investigated.

1.6 Structure of Thesis

This thesis comprises five chapters. Chapter one is an introduction in which problem statement, objective of the research and scope of work are presented. The literature review is divided into two parts. Part one is presented in chapter two and covers the basics on electronic packaging and methods of bonding (wire bonding, tape automated bonding and flip chip bonding), and discusses the principles of soldering and solder materials. The chapter also presents the concept of solder bumping in flip chip bonding and discusses the main techniques available.

The second part of chapter two mainly describes the processes of electroless nickel plating and immersion gold which were selected to build the under bump metallurgy investigated in the project.

In chapter three, the detailed experimental procedure taken in this research to achieve the goals set at the beginning of the project is described. In chapter four, results and discussion, the author presents all experimental results obtained and evidence to support them. Finally, in chapter five, a set of conclusions is presented.

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