LEAD FINISHING IN SEMICONDUCTOR DEVICES: SOLDERING

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PREFACE

Soldering as a metallurgical bonding technique has a long history going back to pre-biblical times. The tremendous increase in the use of electronics in many aspects of our life makes its importance more widespread than ever before.

Solder coating is a form of electronic component lead finish, which is required for good solderability when the components are assembled on a PCB. Lead finishings used to be mainly gold and silver plated. However, with certain solderability and silver migration problems, coupled with the astronomical rise in the cost of the precious metals, tin or solder platings have become common. A plated tin lead finish has a major disadvantage that whisker growths are frequently observed on the tin plated leads. Such growth will have serious electrical shorting. It was widely believed that the addition of about 5-10 % lead (Pb) helps to eliminate such growth. However, solder plating does not solve whisker growth problem as there were many occasions where whisker growth on the solder plated leads is observed. Nevertheless, when the process is well under control, such defects can be kept minimal. An alternative lead finish is hot solder coating, by exploiting the relatively low melting point of solder. The wetting of the base metal surface by molten solder is the primary essential for soldering to take place and this wetting occurs quickly (about 3-5 seconds), thus, the soldering process is viable from a production standpoint.

A plating process typically consists of a series of chemical treatments and rinse processes. For example, in a semiconductor device leads plating, the use of strong acids, acid salts, are not uncommon. These chemicals are corrosive. The general baseline is as follows:

Descale Water Activation Water Acid etch
 H_2SO_4 ----> Rinse ----> $\text{NaF}/\text{H}_2\text{O}_2$ -----> Rinse -> H_2SO_4 ---->

Water Plate Water Dry
 Rinse-----> ----> Rinse ----->

The quality of the plated lead depends on how well the whole plating line is controlled, e.g., chemical concentration, additives, time, current, contaminations, etc. Moreover, the thickness distribution of the leads are not easily controlled unless a perfect plating jig is designed and plating process controls are excellent. In terms of quality and reliability, lead finishing by plating has two drawbacks. Firstly, plated coatings are known to be porous and thus may not withstand aging over long storage, unless suitable plating controls like additives are used, plating conditions and suitable plating thickness are optimised. And secondly, plating process is mostly done at room temperature and does not correspond to the actual customer's PCB assembly process (i.e. hot soldering). This second "shortcoming" may be overcome with a modified reliability testing method. Thus, product philosophy, management and market considerations are to be considered when one decides on the mode of lead finishing. There are advantages, apart from quality and reliability issues as mentioned earlier, of hot dip soldering (usually by wave soldering). In the wave soldering, the steps are relatively simpler and shorter; the process can be at least semi-automated. The machine setup is as follows:

Fluxer --> Preheat --> Molten Solder --> Rinse----> Dry

The chemicals in the soldering used are fewer; flux and perhaps preclean acids. However, the plastic package is subjected to a large temperature difference when it reaches the molten solder, with temperature typically 240-260 deg c. This temperature could create device reliability problems, especially when a chloride flux is used. Thus, we have a potential reliability problem unless we can solve the temperature difference related effects. The choice and selection of flux, molding compound, lead frame and other assembly materials are very critical when high reliability products are made. There is nothing "black magic" about successful soldering plastic encapsulated IC leads with minimum yield loss. Basic understanding and total process controls are the key factors to achieve such a goal.

The main reasons, which explain why a lead finish like a solder coating is important, are listed below:

1. It protects the base metal against corrosion.
2. It makes devices solderable, which is an essential requirement for mounting chips to a printed circuit board.
3. It serves as a good cosmetic finish to the finished products.

The *raison d'être* for writing this book is to highlight the salient theoretical and operational aspects of semiconductor IC lead soldering. This book is written primarily for Semiconductor device leads wave soldering. However, this book is also recommended as a reference material for engineer/technician of electronics industry, science, production, and chemical engineering of university/polytechnics for topics like solderability, corrosion, leads finishing process control, and analytical techniques.

This book covers 8 areas:

SOLDER DIP OPERATION

SOLDER

LEADFRAME MATERIALS

FLUX

CORROSION IN MICROELECTRONIC DEVICES

POST SOLDER DIP RINSING

SOLDERING QUALITY

ANALYTICAL METHODS

In chapter 1, an introductory text on the plastic encapsulated device lead soldering machine and its accessories, IC assembly flow and total process control is described. A brief discussion on total process control is presented as a tool to achieve zero defect lead wave soldering.

Chapters 2 through 4 provide some information on the materials involved in the soldering process. Chapter 2 deals with the general aspects of tin-lead alloy metallurgy, and the effects of metallic impurities on the soldering process and the quality of lead solder coating. The intermetallic layer formation between a substrate and solder and its effect on the adhesion and solderability of the lead finish are also discussed. The emphasis of chapter 3 is mainly on the nature of leadframe material surface oxidation and solderability. Fluxes are used in a IC backend process (for example, lead soldering) because the leads are badly solderable due to the IC assembly process flow where heat treatments are involved. Chapter 4 deals with the basics of flux ingredients. There is room for further work on the mechanism of flux-metal substrate-molten solder reaction.

IC lead wave soldering is a corrosive process in an IC assembly, irrespective of the type of flux used. Thus, a chapter on IC lead and chip corrosion and their prevention is discussed (in chapter 5). Corrosion is a very broad subject, thus, the writer chooses to touch on the essentials which are dear to the heart (and the pocket) of the S/C industry: aluminium corrosion and device lead corrosion. The scope of chapter 5 covers 3 areas : basic electrochemistry, mechanism of pin leads and aluminium corrosion, means of moisture ingress and sources of ionic contaminations. Thus, cleanliness in IC industry is of cardinal importance. Cleanliness controls in the incoming materials used in the assembly and at various critical IC assembly points (for example, premolding, molding and lead finishing) are vital factors affecting yield, quality and reliability.

A somewhat detailed discussion of post solder dip rinsing and the quality of soldered leads is written in chapter 6 and 7 respectively. Because of the stringent solderability requirements, aggressive and water soluble flux is often used in the soldering. Defective soldering is thus reduced. However, it is well known that the conductive flux residues on the package could be a reliability problem, unless the whole operation has an effective control on the package cleanliness. Chapter 6 describes basic ionics concept, methods of cleanliness measurement, various manufacturing controls and monitor to improve the overall cleanliness of the soldered package. Solderability failure of IC device lead indicates a manufacturing defect, thus, it is advisable to find out the root cause(s) . Chapter 7 is devoted to discuss various defects encountered and suggestions to improve the solderability performance with a systematic approach.

In the past, elaborate analytical practices were not part of the lead finishing management philosophy. The reasons could be financial and manpower constraints. With increasing complexity in the IC production technology, the use of various analytical methods would enable the process people to understand the why and the how of a manufacturing problem. Chapter 8 covers some simple chemical analysis of solder, rinse water, flux residues, etc.. Contaminants on leads are best dealt with surface analysis. Since scanning electron microscopy with EDX is a common analytical tool with easily available literature and textbooks, the writer chooses to concentrate more on the application of Auger analysis in the S/C packaging industry.

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The comments made in this book are my own. In no event shall Texas Instruments be liable to anyone for special, collateral, incidental, or consequential damages in connection with or arising out of this publication .

I am grateful to the generosity of Texas Instruments in allowing me to use the computer facilities. It is impossible to achieve goals in life without a great deal of help and this book is no exception. It is a pleasure to work with Tiers/ex-Tiers who are/were involved in solder dip process/operation; their meticulous work and enthusiasm contributed significantly towards a better understanding of IC lead soldering. I would like to thank Mr. Y.K.Swee for the encouragement and general discussion on the contents of this monograph. I would also like to express my special thanks to Mr. Lee Kok Choy, the DRAM product manager of Texas Instruments, Singapore for his support and encouragement. Special thanks and regards go to Dr. Graham Wright of Chemistry Department, the University of Auckland , Auckland, who was kind to read chapter 5 on corrosion and suggested many improvements. I am also additionally grateful to Dr. Sam Li of the National University of Singapore and Mr. Kwa Yew Yang of Intersil Singapore, Mr. Joe O'Hare of Texas Instruments,Houston for their comments on the scripts. I take sole responsibility for any error, omission and limitation. Finally,I would like to thank Rosemary, Catherine Fung and Yang Hsao Hsien, inspite of their busy workload, for typing this manuscript.

LIST OF ABBREVIATION AND ACRONYMS

AAS	Atomic Absorption Spectroscopy
AES	Auger Electron Spectroscopy
CDP	Concentration Depth Profiling
DI Water	Deionised Water
EDX	Energy Dispersive X-Ray
EMC	Epoxy Molding Compound
EMF	Electromotive Force
ESCA	Electron Spectroscopy for Chemical Analysis
IC	Integrated Circuit
ICP	Inductively Coupled Plasma
IQC	Incoming Quality Control
LCL	Lower Control Limit
L/F	Leadframe
MIL STD	Military Standards
O/G S/T	Outgoing Solderability Test
PCT	Pressure Cooker Test
PED	Plastic Encapsulated Device
PPM	Parts per million
QC	Quality Control
S/C	Semiconductor
SEM	Scanning Electron Microscopy
S.G.	Specific Gravity
SIC	Semiconductor Integrated Circuit
SIMS	Secondary Ion Mass Spectroscopy
SPC	Statistical Process Control
S/T	Solderability Test
THB	Temperature Humidity with Biased Voltage
UCL	Upper Control Limit
V/M	Visual Mechanical

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