UNIVERSITI PUTRA MALAYSIA

THE DEVELOPMENT OF A NO-CLEAN SOLDER FOR RADIO FREQUENCY POWER MODULE

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By

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To

My parents and family
for their past and present encouragement and support

My lovely wife, Hazatul Aini
for her assistance, motivation, endurance and encouragement

All who have involved in my present and future success

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CFC	Chlorofluorocarbon
cfh	Cubic foot per hour
ESD	Electrostatics Discharge Test
FITS	Failures per Billion Device Hours
GaAs FET	Gallium Arsenide Field Effect Transistor
HASL	Hot Air Soldering Levelling
HCl	Hydrochloric Acid
HTSL	High Temperature Storage Life
I.O.L	Intermittent Operating Life
IPC	The Institute For Packaging And Interconnecting Electronic Circuits
MIL-STD	Military Standard
MOSCAP	Metal Oxide Semiconductor Capacitor
NVM	Non Volatile Matter
OA	Organic Acid
PCB	Printed Circuit Board
ppm	Part per million
QFP	Quad Flat Package
R	Rosin
RA	Activated Rosin
RF	Radio Frequency

RH	Relative Humidity
RMA	Mildly Activated Rosin
RSA	Strongly Activated Rosin Fluxes
RSM	Random Surface Methodology
SA	Synthetic Activated
SIR	Surface Insulation Resistance
SMC's	Surface Mount Components
SMD	Surface Mount Diode
SMT	Surface Mount Technology
TEC	Thermal Expansion Coefficient
TGA	Thermo Gravimetry Analysis
UNEP	The United Nations Environment Program
VM	Volatile Matter

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Chairman : Associate Professor Ir. Dr. Barkawi b. Sahari

Faculty : Engineering

The pursue of CFC elimination in many industries has opened up opportunity for the development of substitutes of CFC. No-clean solder is just one of the many examples in response to this need. This project describes the development of no-clean solder for radio frequency (RF) Power Module. Nine no-clean solder paste candidates ranging from different solder paste suppliers which are Heraeus, Indalloy, Multicore, Qualitek, Asahi Solders, Demetron, Koki, SCM and Alphametals were selected. Five solder preliminary tests which are flux weight loss, wetting, slump, solder balling, flux spread and four solder printing characteristics which are paste rolling solder coverage, solder fillet and joint texture were used as a tool to select the best no-clean solder that meet the product requirements. Heraeus and Indalloy no-clean solder pastes showed better results compared to others but still required some process changes. Two methods were used in order to eliminate the solder defects which are the development of the new stencil and new soldering reflow profile. These methods able to resolve the solder defects problem such as flux overflow, solder cold joint, solder splashing and solder balling formation. The selected no-clean solder paste together with the normal production solder paste known as control solder paste were further subjected to the paste level evaluations and the reliability tests. It was found that the Heraeus and Indalloy no-clean solder paste are the best candidates for no-clean solder process capability. The results of these tests are presented and discussed in this thesis.

Abstrak untuk tesis ini dikemukakan kepada Senat Universiti Pertanian Malaysia sebagai memenuhi sebahagian dari syarat untuk ijazah M.S in Manufacturing System Engineering.

PENGHASILAN PATERI TANPA BASUH UNTUK PRODUK MODUL BERKUASA FREKUENSI RADIO

Oleh

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Di dalam usaha membasmi penggunaan CFC, kebanyakan industri pada amnya telah mencuba sedaya-upaya mengenalpasti bahan atau kaedah yang sesuai bagi menggantikannya. Oleh yang demikian, pateri tanpa basuh di dapati merupakan salah satu contoh yang sesuai untuk digunakan. Projek ini membicarakan kaedah serta teknik yang digunakan bagi mewujudkan kebolehan penggunaan pateri tanpa basuh di dalam produk Modul Berkuasa Frekuensi Radio. Sembilan calon pateri tanpa basuh daripada vendor yang berbeza iaitu Heraeus, Indalloy, Multicore, Qualitek, Asahi Solders, Demetron, Koki, SCM dan Alphametals telah dipilih. Lima ujian awal pateri iaitu kehilangan berat fluks, keupayaan membasahi permukaan, keupayaan mengecut, pembentukan bebola pateri, kebolehgerakkan fluks serta empat kaedah pencetakan pateri iaitu pergerakan pateri, keupayaan merangkumi permukaan, keupayaan membentuk pengisi dan tekstur permukaan digunakan sebagai kaedah atau metodologi bagi memilih calon yang terbaik dan sesuai yang mana memenuhi keperluan produk tersebut. Dari analisis yang dijalankan di dapati pateri Heraeus dan Indalloy memperlihatkan keputusan

yang baik berbanding dengan pateri-pateri yang lain, namun ia masih memerlukan pengubahsuaian dari segi proses serta kaedah penggunaannya ke atas produk tersebut. Oleh yang demikian, dua kaedah telah digunakan bagi mengurangkan kecacatan pada pateri iaitu proses penghasilan rekabentuk terbaru stencil serta profil peleburan pateri. Kaedah tersebut di dapati berjaya membantu mengurangkan kecacatan pada pateri iaitu seperti pergerakan tidak terkawal fluks, pateri tidak melebur, percikan pateri dan pembentukan bebola pateri. Pateri yang terpilih bersama-sama dengan pateri normal yang biasanya digunakan sebagai pateri di dalam proses penghasilan produk ini, dibawa melalui beberapa siri ujian lagi seperti ujian-ujian keupayaan pateri serta ujian-ujian kebolehharapan elektrikal dan mekanikal. Di dapati pateri Heraeus dan Indalloy merupakan calon terbaik bagi mencapai keupayaan proses pateri tanpa basuh. Keputusan-keputusan dari siri ujian ini dibincangkan dengan lebih terperinci di dalam tesis ini.

CHAPTER 1

INTRODUCTION

Surface Mount Technology (SMT) is the application of science and engineering principles to board-level assembly, by placing components and devices on the surface of circuit board instead of through-the-board. This concept has been utilized in hybrid assembly since the 1960s by interconnecting chip resistors, chip capacitors, and bare semiconductor dies on hybrid substrates. Since the flat pack package became available in the 1970s, interconnection to boards has utilized the surface mounting concept. Nevertheless, the potential of surface mounting was not fully utilized and explored until the early 1980s. The impact of surface mounting on printed circuit assembly has been most dramatic since the inception of through-hole printed wiring boards in the mid-1950s. It is also one of the most significant developments in the electronic era.

The merits of surface mount technology are quite straightforward. In simple terms, surface mount technology provides superior performance/cost ratio for printed circuit board manufacturing. Most analyses show that the use of surface mount technology is on rising curve. Throughout the world, the replacement of leaded components by surface mounted components (SMCs) is expected to have reached 50 percent by 1990. For an electronic circuit to function, each part must be connected to the others. The usual way to do this is to mount the components on a printed circuit board.

In conventional board assembly, each component has a number of leads, or fine wires, which are connected to the circuit by soldering them into holes in the board. This is often called through-hole assembly. As circuit become both smaller and more complex, components with leads become less desirable. They take up valuable space on the board, which could be used by more components. The leads are also prone to damage from vibration. These are particular drawbacks in very small circuits, such as those used in cameras and those intended for military use. In surface mount technology (SMT), the leads of the components are very short and often beneath the body of the components. No holes are drilled in the circuit board, which reduces its cost. Each component is simply laid in its appropriate place in the circuit. They are attached to the board with solder paste and then soldered to it.

Solder Paste

Solder paste is one of several interconnecting materials that can serve as a bonding agent between metallic surfaces of an assembly, under proper conditions. Solder paste, in the deformable viscoelastic form, can be applied in a selected shape and size and can be readily adapted to automation. Its tacky characteristic provides the capability of holding parts in position without additional adhesives before forming permanent bonds. The metallic nature of solder paste provides relatively high electrical and thermal conductivity. With these principal merits, solder paste is a viable interconnecting material, providing electrical, thermal, and mechanical properties applicable to electronics assemblies.

From a technological point of view, paste involves the interplay of several scientific disciplines. Science and technologies utilized include metallurgy, particle technology, chemistry, physics, rheology and formulation technology. In addition to metallurgy and particle technology, the physical, chemical, thermal and rheological properties of flux systems are equally important to the performance and characteristics of the resulting paste.

Furthermore how the ingredients are formulated and how the formula is processed are crucial to the properties and parameters of flux system. With respect to performance, solder paste is categorized into four areas : applicability, solderability, residue characteristics and joint integrity. Applicability refers to the ability of a paste to be adapted to a specific paste-applying technique such as dot-dispensing, screen printing or stencil printing. Solderability is intended to be used in a broad sense which is the ability of a paste to wet the surfaces to be joined with complete coalescence of solder powder particles and to achieve a reliable metallurgical bond. Residue characteristics cover the physical and chemical properties of the resulting chemical mixture after solder (e.g. corrosivity, activity, tackiness, hardness, compatibility with cleaning process). Solder joint integrity is the ultimate performance of the solder joint after the soldering process in terms of mechanical properties, resistance to adverse environment and its compatibility with service condtions. Solder paste used in SMT manufacturing requires cleaning since cleaning improves the reliability and performance of the printed circuit boards. In fact, most of the cleaning chemical used contains CFC.

No-Clean Solder Paste

The No-Clean solder has been widely accepted in the electronics assembly industry ever since the inception of the Montreal Protocol in 1987. The pursue of CFC elimination use in many industries has opened up opportunities for the development of substitutes of CFC. The Institute For

Packaging And Interconnecting Electronic Circuits (IPC) test methods and specific ionic contamination tests (ANSI/IPC-SM-782) defined no-clean solder and related materials as a material that can be deposited on PCB, provide an acceptable wetting action and do not require cleaning.

It is not certain where the no-clean electronics revolution started but is no doubt that one is taking place. The amended Montreal Protocol and The United Nations Environment Program (UNEP), have both clearly outlined the objective that CFC's must be eliminated from the production process by the January 1, 1996. No-clean solder is just one of the many examples in response to this need. No-clean, low residue or no residues are all used to describe materials currently replacing fluxes in applications where cleaning would have been considered necessary. Attention has been given to the quantity of residue remaining after soldering with no-clean solder. The lower the residue remains, the better it is. Thus low solids materials have been developed which are capable of leaving the PCB visually clean. However, the criterion of a visually clean PCB does not necessarily satisfy all applications. Therefore the interpretation of the no residue fluxes should be made with respect to the analysis techniques such as SIR (Surface Insulation Resistance), Ionic Contamination, Electromigration and Accelerated Testing performance and TGA (Thermo Gravimetry Analysis). Our ultimate goal is to achieve a soldering process whereby cleaning process after reflow is no longer needed. This means that no or very minimal flux residues is left behind on PCB. The challenge is to ensure wirebonding can be done even if the units are not cleaned.

In this project entitled " The Development of No-Clean Solder for Radio Frequency Power Module", the objectives of this project are :-

a. To develop a no-clean solder process capability in Motorola Semiconductor Sdn Bhd, Seremban.

b. To eliminate the chemical waste and the CFC cleaning chemical which will support the corporate goal towards the environmental friendly company.

c. To reduce the product's cycle time and achieve the cost reduction target in RF Power Module.

CHAPTER 2

LITERATURE REVIEW

Introduction

This project is concerned with the methods to develop the no-clean solder process for radio frequency Power Module. The review is, therefore restricted to literature directly related to this method of development and application. For this reason, a great deal of attention is given to describing the solder component, method to eliminate solder defects, evaluating the most suitable paste for particular component type and establishing correct procedures for evaluation and manufacturing. In the remainder of this chapter, literature relating to the environment concern on the chemical waste is being reviewed.

Solder Paste Components

In order to grasp a full understanding on how the no clean paste works, one has to know the solder paste chemistry and what are those components that made up the solder paste. Solder paste by definition is a homogeneous, stable mixture of flux, solder powder and medium (Nimmo, 1992). The flux is designed to clean off the surface of the solder powder and the surface to be soldered. Actually, it reduces the metal oxides that are present on the surface of the metals. In addition, the flux is required to protect the oxide free alloy powder from re-oxidation during a transportation and storage or subsequent use. The medium is used primarily as a carrier for the spherical, powdered alloy particles and as a carrier for the flux system (Bukhari, 1996). The medium itself must be of a suitable material which is capable of providing the material with a suitable rheology. When processed in the correct manner under reflow conditions in a production environment it will readily form consistent and reliable solder joints free from defects (Nimmo, 1992).

The typical mildly activated rosin (RMA) paste fluxes which contain 60-70% of non volatile matter (NVM) contributes to the rheology of the solder paste which assists the products to show excellent printing characteristics, tack life and solder balling performance (Nimmo, 1993). There are two main constituents in solder paste which are solder alloy powder and flux.

Solder Alloy Powder

The particle size, shape and distribution helps to determine the paste rheology. The actual composition of solder paste, by weight is usually in the range of :

Solder alloy powder = 88-91%

Flux or vehicle = 12 - 9%

Most manufacturers follow this range when making up the solder paste for fine pitch printing. Eutectic tin-lead is a typical alloy used for solder paste. Trace elements are often added, and these elements can change the characteristics of the solder paste regarding its printing performance. Elements such as silver (Ag), copper (Cu) and zinc (Zn) are commonly found within solder alloy. Federal specification QQ-S-571E specifies the limits of trace elements for Sn/Pb (Hwang, 1989). The elements under specification include Sb, Bi, Cu, Fe, Zn, Al, As and Cd, and their limits are shown in Table 1. The solder alloy composition used in SMT process is Sn62.

Table 1 : Solder alloy specifications per Federal Specification QQ-S-571E

Element	Sn63	Sn62	Sn60
Sn	62.5 to 63.5	61.5 to 62.5	59.5 to 61.5
Pb	Remainder	Remainder	Remainder
Sb	0.20 to 0.50	0.20 to 0.50	0.20 to 0.50
Bi	0.25	0.25	0.25
Ag	-	1.75 to 2.25	-
Cu	0.08	0.08	0.08
Fe	0.02	0.02	0.02
Zn	0.005	0.005	0.005
Al	0.005	0.005	0.005
As	0.03	0.03	0.03
Total of others	0.08	0.08	0.08

Silver lowers the melting point of the solder paste (eg. 2% silver reduces melting point by 4°C, ie. from 183°C to 179°C). This addition makes the connection more conductive and helps creates a more cosmetic appearance. The source of tin and lead used in solder alloy also determines the trace elements and amount found in the alloy, as the purity can fluctuate from continent to continent, thereby affecting solder alloy characteristics.

Impurities of zinc (Zn), aluminium (Al) and cadmium (Cd) may cause poor adhesion and joint grittiness. The presence of iron (Fe) and copper (Cu) beyond specified limits may also make the solder joint gritty. However, copper (Cu) at 0.1% is found to improve the creep resistance of tin-lead solders (Hwang, 1989). The addition of antimony (Sb) up to 6% of tin content in tin-lead solder increases creep strength. Its small concentration retards tin pest (an allotropic transformation to amorphous gray tin) (Hwang, 1989). The elements of arsenic (As) and bismuth (Bi) at the concentration larger than 0.3% cause dewetting of the tin-lead solders (Hwang, 1989).