RADIATION DOSES EFFECT ON MICROMECHANICAL PROPERTIES, MICROSTRUCTURE EVOLUTION AND THERMAL STABILITY OF Sn-Ag-Cu SOLDER

NUR FARISA NADIA BINTI MOHMAD LEHAN

MASTER OF SCIENCE
(PHYSICS)

UNIVERSITI PERTAHANAN NASIONAL
MALAYSIA

2022

RADIATION DOSES EFFECT ON MICROMECHANICAL PROPERTIES, MICROSTRUCTURE EVOLUTION AND THERMAL STABILITY OF Sn-Ag-Cu SOLDER

NUR FARISA NADIA BINTI MOHMAD LEHAN

Thesis submitted to the Centre for Graduate Studies, Universiti Pertahanan Nasional Malaysia, in fulfilment of the requirements for the Degree of Master of Science (Physics)

2022

ABSTRACT

Radiation particles with enough energy to break the chemical bonds of the materials, such as gamma radiation, may affect the performance of the solder joints. In this research, the physical and mechanical properties, microstructure evolution and thermal stability of lead-free solder joints radiated with gamma radiation were investigated. Prior to characterization, the solder pastes of tin-silver copper ($SnAg_3Cu_{0.5}$; SAC305) was manually deposited on the printed circuit board using a stencil printing method and reflow soldering process. Subsequently, the solder was exposed to low doses (5-50 Gy) of gamma radiation. As gamma radiation dose increased, the thickness of the intermetallic compound (IMC) layer of the solder increased suggesting that gamma radiation had coarsened the grain size of SAC305 solder. The contact angle remained to have good wettability. XRD results show the presence of the β-Sn, Cu_6Sn_5 and Ag_3Sn phases. The nanoindentation test revealed the occurrence of pop-in events due to the atomic distortion and dislocation density of the SAC305 samples. The hardness and reduced modulus values increased up to 15 Gy owing to the disturbance in the atomic arrangement of the solder material. However, the values decreased as the radiation dose increased (50 Gy) which could be linked to the presence of voids and irregular IMC. The eutectic phase area showed a parallel trend to the hardness value obtained due to the coarsening of β-Sn and IMC particles in the solder. Microstructure observation of the solder revealed that Cu_6Sn_5 and Ag_3Sn compounds dominated the intermetallic layer in the Sn matrix. Thermal analysis showed that the radiation does not affect the performance and reliability of the solder. These findings are expected to be used as a basis in understanding the effect of radiation on the physical, mechanical properties, microstructure evolution and thermal stability resulting to the reliability of solder joints.

Keywords:

micromechanical, microstructural, solder, thermal stability, radiation

ABSTRAK

Zarah sinaran dengan tenaga yang mencukupi untuk memutuskan ikatan kimia bahan, seperti sinaran gama, boleh menjejaskan prestasi sambungan pateri. Dalam penyelidikan ini, sifat fizikal dan mekanikal, evolusi struktur mikro dan kestabilan terma sambungan pateri bebas plumbum yang tersinar gama telah diselidiki. Sebelum pencirian, pes pateri tembaga timah-perak (SnAg3Cu0.5; SAC305) digunakan secara manual pada papan litar bercetak menggunakan kaedah cetakan stensil dan proses pematerian aliran semula. Selepas itu, pateri terdedah kepada sinaran gama dos rendah (5-50 Gy). Apabila dos sinaran gama meningkat, ketebalan lapisan sebatian antara logam (IMC) pateri juga meningkat, menunjukkan bahawa sinaran gama telah mengasarkan saiz butiran pateri SAC305. Sudut sentuhan kekal mempunyai kebolehbasahan yang baik. Keputusan XRD menunjukkan kewujudan fasa β-Sn, Cu_6Sn_5 dan Ag_3Sn. Ujian pelekukan nano menunjukkan kejadian perubahan mendadak (pop-in) disebabkan herotan atom dan ketumpatan kehelan sampel SAC305. Nilai kekerasan dan modulus terkurang meningkat sehingga 15 Gy disebabkan oleh gangguan dalam susunan atom bahan pateri. Walau bagaimanapun, nilai tersebut menurun apabila dos sinaran meningkat (50 Gy) yang boleh dikaitkan dengan kehadiran lompang dan IMC yang tidak tersusun. Luas fasa eutektik menunjukkan arah aliran selari dengan nilai kekerasan yang diperoleh akibat kekasaran zarah β-Sn dan IMC dalam pateri. Pemerhatian struktur mikro pateri mendedahkan bahawa sebatian Cu_6Sn_5 dan Ag_3Sn mendominasi lapisan antara logam dalam matriks Sn. Analisis haba menunjukkan bahawa sinaran tidak menjejaskan prestasi dan kebolehpercayaan pateri. Penemuan ini dijangka akan digunakan sebagai asas dalam memahami kesan sinaran ke atas sifat fizikal, mekanikal, evolusi mikrostuktur dan kestabilan terma yang mengakibatkan kebolehpercayaan sambungan pateri.

Kata kunci:

mikromekanikal, struktur mikro, pateri, kestabilan terma, radiasi

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the Most Merciful.

All praises to Allah and His blessing for the completion of the thesis. I thank Allah for all of the opportunities, trials, and strength that He had granted for me to finish writing the thesis. My humblest gratitude to the holy Prophet Muhammad (Peace be upon him) whose way of life has been a continues guidance for me.

First and foremost, I would like to express my heartfelt gratitude to my supervisor, Dr. Wan Yusmawati binti Wan Yusoff for her expertise, academic supervision and guidance, her words of encouragements, understanding and invaluable advice throughout the journey. I also would like to thank my co-supervisors; Prof Madya Dr. Ku Zarina binti Ku Ahmad, Dr. Mohamad Faizal bin Abdullah and Dr. Azuraida binti Amat for their constant support and availability, provided throughout my time as their student. I also would like to thank the Ministry of High Education and National Defence University of Malaysia for providing the financial support needed along my master journey.

Finally, I wholeheartedly give my thanks to all of my family members especially my parents for their continued love, belief and support given, for without them, it would have impossible for me to finish my time as a master student. May Allah S.W.T. reciprocate the kindness of all the parties that directly and indirectly involved.

The accomplishment of my master’s degree thesis is not only a milestone in my life but also a starting point from which I can aim to fly higher in the future. In shaa Allah

APPROVAL

The Examination Committee has met on **19 September 2022** to conduct the final examination of **Nur Farisa Nadia Binti Mohmad Lehan** on his degree thesis entitled **Radiation Dose Effect on Micromechanical Properties, Microstructure Evolution and Thermal Stability of Sn-Ag-Cu Solder.**

The committee recommends that the student be awarded the of Name of Degree (Specialisation).

Members of the Examination Committee were as follows.

Prof. Madya Ts. Dr. Norhana binti Abdul Halim
Defence Foundation Centre
Universiti Pertahanan Nasional Malaysia
(Chairman)

Ts. Dr. Fadhlina binti Che Ros
Defence Foundation Centre
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Prof. Ts. Dr. Norinsan Kamil bin Othman
Science and Technology Faculty
National University of Malaysia
(External Examiner)

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science (Physics)**. The members of the Supervisory Committee were as follows.

Dr. Wan Yusmawati Binti Wan Yusoff
Centre of Foundation Defence
Universiti Pertahanan Nasional Malaysia
(Main Supervisor)

Prof Madya Dr. Ku Zarina Binti Ku Ahmad
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Mohamad Faizal Bin Abdullah
Faculty of Engineering
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

Dr. Azuraida Binti Amat
Centre of Foundation Defence
Universiti Pertahanan Nasional Malaysia
(Co-Supervisor)

UNIVERSITI PERTAHANAN NASIONAL MALAYSIA

DECLARATION OF THESIS

Student's full name : Nur Farisa Nadia Binti Mohmad Lehan

Date of birth : 27/2/1995

Title :Radiation Dose Effect on Micromechanical Properties, Microstructure Evolution and Thermal Stability of Sn-Ag-Cu Solder

Academic session : 2020/2021

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

I further declare that this thesis is classified as:

☐ **CONFIDENTIAL** (Contains confidential information under the official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organisation where research was done)*

☐ **OPEN ACCESS** I agree that my thesis to be published as online open access (full text)

I acknowledge that Universiti Pertahanan Nasional Malaysia reserves the right as follows.

1. The thesis is the property of Universiti Pertahanan Nasional Malaysia.
2. The library of Universiti Pertahanan Nasional Malaysia has the right to make copies for the purpose of research only.
3. The library has the right to make copies of the thesis for academic exchange.

____________________	______________________________
Signature	**Signature of Supervisor/Dean of CGS/ Chief Librarian
950227115128	Dr. Wan Yusmawati Binti Wan Yusoff
IC/Passport No.	**Name of Supervisor/Dean of CGS/ Chief Librarian
Date:	Date:

*If the thesis is CONFIDENTAL OR RESTRICTED, please attach the letter from the organisation with period and reasons for confidentiality and restriction.
** Witness

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Ag - Argentum
Au - Gold
Au-Sn - Gold-Tin
BGA - Ball Grid Array
Bi - Bismuth
Cd - Cadmium
Cu - Copper
Co-60 - Cobalt-60
EDS - Energy Dispersive X-ray Spectroscopy
EMR - Electromagnetic Radiation
FESEM - Field Emission Scanning Electron Microscopy
FIB - Focussed Ion Beam
Ge - Germanium
HCl - Hydrochloric acid
HRTEM - High-resolution Transmission Electron Microscopy
IMC - Intermetallic Compound
In - Indium
IPC - Institute for Printed Circuits
PCB - Printed Circuit Board
P-h - Load-depth
PTH - Plated through-hole
Pu - Plutonium
Ra - Radium
RoHS - Restriction of Hazardous Substances
Sb - Antimony
SiC - Silicon Carbide
SMT - Surface Mount Technology

Sn-Ag-Cu, SAC - Tin-Silver-Copper

Sn-Cu - Tin-Copper

Sn-Pb - Tin-Lead

STA - Simultaneous Thermal Analyzer

SVPC - Solder Value Product Council

Th - Thorium

U - Uranium

XRD - X-Ray Diffraction

LIST OF SYMBOLS

A - dose rate
A_c - projected contact area
A_o - initial activity
α - alpha
β - beta
c - speed of light
˚C - Celsius
d - *d*-spacing
dh - change of displacement
dP - change of load
E - reduced modulus
E_i - reduced elastic modulus
E_r - initial elastic reduced modulus
e - indenter geometry
e^+ - proton
e- - electron
H - hardness
h - depth
h_c - contact depth
h_f - final displacement
h_{max} - maximum depth
hv - energy of directional photon
hv' - energy of scattering photon
m_0c^2 - rest mass of electron
n - poisson's ratio
P - load
P_{max} - contact depth
S - stiffness
s - second

T - temperature

t - time

$t_{1/2}$ - half life

v - velocity

v_i - poisson’s ratio for indenter

γ - gamma radiation

λ - wavelength

θ - angle

$^\circ$ - degree

CHAPTER 1

INTRODUCTION

1.1 Background

The word ‘electronic’ is originated from the word electron, a branch of science dealing with theories and use of devices in which the electrons travel through a vacuum, gas, or a semiconductor medium. For the past centuries, the usage of electronic devices covers almost the entire field of application such as in communications systems, consumer and industrial electronics, medical sciences, radiation-related fields, defense (military hardware) and aeronautical applications. With the rapid development of electrical products, there has been a notable revolution in the miniaturization and increased functionality of electronic devices. In electronic devices, the types of interconnections available are wire bonding, conductive adhesive, and solder joints with the most popular interconnection being solder joints. Wireless and portable gadgets are becoming more popular, necessitating the development of a smaller and more compact solder joints. Thus, assessing the reliability of electronic products is the utmost priority in electronic industries to ensure a long term performance (Thambi, 2018). Reliability is the ability of a system or component to perform its required functions with certain conditions for a specific period of time. The reliability evaluation is used to determine the failure rate of a solder junction over the course of its service life. Solder joints, however, is the weakest link in electronic packages, with failure rates at its joints was over half of the percentage (Wen et al., 2020). In every device, parts with a high chance of failing occurrence are the interconnections. Metallic wire bond, conductive adhesive and solder joint are some of the interconnections and among the three, solder is the most popular and was used in many types of products and fields. Hence, it is important to fully investigate the reliability of the solder to ensure the durability of the devices.

In the electronic industry, solder is an alloy used to make mechanical and electrical connections between components and substrates. Soldering is the process of linking metals together by using solder pastes to form joining components having a lower melting temperature than the adjoining metal. This process could have affected the reliability of electronics devices as there is a growth of intermetallic compound (IMC) layer when the solder material reacts with the substrate material. The IMC continues to grow thicker and in time affect the solder joint in the event of any vibration or mechanical stress applied to the substrate. This is owning to the brittle nature of the crystal-like intermetallic compared to the amorphous solder. Wen et al. (2020) relates the growth of interfacial IMC layer degrades the performance of gold-tin (AuSn) alloy solder joint.

Worldwide, over 20 million pounds of tin-lead (Sn-Pb) solders are manufactured annually. As of July 2006, Restriction of Hazardous Substances (RoHS)