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CORRELATION BETWEEN GAMMA RADIATION DOSE ON HARDNESS, THICKNESS OF INTERMETALLIC COMPOUND AND CONTACT ANGLE

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ABSTRACT

In this study, the effect of low dose gamma radiation on the hardness and the microstructural properties of SAC305 solder was characterized. The solder paste was applied to the printed circuit board via stencil printing and reflow soldering, and then subjected to low doses of gamma radiation (5, 10, 15, 20 and 25 Gy). After the exposure, the samples undergo metallographic procedure prior to the indentation test. The hardness, intermetallic compound (IMC) thickness, and contact angle after irradiation were observed via nanoindentation and optical microscope. It was found that, the percentage of hardness increased by 43.05% up to 15 Gy exposure and gradually decreased to 11.54% for 25 Gy due to disturbance in the atomic arrangements of materials in the solder. Gamma radiation altered the microstructure of SAC305 solder resulting ~~a~~ change in IMC thickness as the radiation increases. The contact angle measured for SAC305 solder were in the range of acceptable wetting (24-35˚), ensuring its solderability.

Keywords: Gamma radiation; Hardness; IMC thickness; Microstructure; Sn-Ag-Cu solder

INTRODUCTION

Eutectic or near eutectic Tin-Lead (Sn-Pb) solders are most widely used among of the conventional soldering alloy. For decades, Sn-Pb solders systems are utilized mostly in electronic packaging industry due to its excellent mechanical properties, adequate solderability and reliability [1]. However, due to the increasing environmental and human health concerns over the toxicity of lead, governments have established laws to prohibit the use of Pb from electronic application. Hence, tin-based solder systems were deemed as a suitable replacement. The ternary eutectic Tin-silver-copper (Sn-Ag-Cu, SAC) based solder stood out the most for its low temperatures and excellent wettability [2]. As the electronic packaging industry getting more known, assessing the reliability of electronic products is the utmost priority in electronic industries.

There are greater demands have been placed on reliable solders with excellent resistance to specific service condition especially those of satellites. However, solder joint is the weakest part of electronic devices as demonstrated by the statistic that more than 60% failures of electronics have occurred at this location [3]. Solder joint failures occur due to thermal stress owing to the coefficient of thermal expansion (CTE) mismatch of the combination of materials. According to Ren et al.[4], the presence of intermetallic compounds (IMC) between molten solder and substrates tend to decrease the mechanical properties of the whole joint as it was brittle in nature. Thus, microstructural, and mechanical properties studies of solder joints under space environment (such as radiation) are particularly important to enhance its reliability.

Ionizing radiation such as gamma energies can cause ionization of atoms of the medium through which the particles pass and became ionized or charged. Exploring the reaction of ionizing radiation on material are always under the spotlight especially concerning its effect on the device performance. The interaction of gamma radiation with metal induced boundary electrons in the atoms to excite into the conduction band. If the energy of the input gamma ray was more than the threshold, which was in the range of 33-40 eV, the secondary electrons formed by the incident gamma ray further disturbed the atom arrangement [5]. Yusoff et al. [6] found that there were changes in grain structure with the presence of dislocation in the irradiated gold (Au) ball bond after the exposure to gamma radiation. Thus, this opened a very important possibilities on microstructural changes and behavior of solder material after exposure to gamma radiation. Therefore, this study aimed to explore the correlation between hardness, IMC, and contact angle of the solder after exposure to gamma radiation.

EXPERIMENTAL DETAILS

Lead-free solder pastes of $SnAg_3Cu_{0.5}$ (SAC305) was manually deposited onto the printed circuit board through stencil printing to form a solder joint. Prior to radiation, the samples were reflowed soldering at 260°C (peak temperature). The soldered samples were subjected to an industrial Excel 220 Gamma Cell irradiator with Co-60 source at a rate of 0.93 kGy/h. Five different doses of gamma radiation (5, 10, 15, 20 and 25 Gy) were introduced to soldered sample with specific rate dose of 0.8427 kGy/hr. The exposure time is calculated and tabulated in Table 1. Then, the samples were cold mounted with epoxy resin, then ground with 400 to 1200 grit silicon carbide abrasive paper and polished with DP Nap polishing cloth, liquid lubricant of 1 and 0.25 μm diamond spray. The indentation was done at the centre of solder joint with Berkovich tip using a Bruker-Hysitron TI950 Triboindenter. During loading, a constant rate of 0.5 mN/s was applied to the solder surface reaching the maximum load of 10 mN, held for 10 s then unloading. As it reaches 90 per cent of unloading, a 60 s hold time was applied for thermal drift correction. The samples were etched (5% hydrochloric acid and 95% methanol) and analyzed using an optical microscope for microstructural analysis based on the previous study by Oliver and Pharr [7]. The hardness values for the solder were obtained from the nanoindentation testing. The microstructures, and the formation of IMC on soldered samples were examined under an optical microscope. The Average IMC thickness was obtained using ImageJ software where the total thickness was divided by 100 as done by Yusoff [8]. The average of 10 measurements of the contact angles were calculated using ImageJ software.

Table 1: Exposure time

Dose (Gy)	Exposure time (s)
5	21.35
10	42.71
15	60.00
20	84.00
25	102.0

RESULTS AND DISCUSSIONS

From nanoindentation, the values of load and depth of the sample were recorded simultaneously. According to Dwivedi et al. [9] hardness of a material is the resistance of the material to the occurrence of plastic deformation due to applied force and was associated with the imperfections in the region of where the indentation occurred. Figure 1 show the change of hardness of the SAC305 solder after exposure to gamma radiation. The hardness for the control sample is 0.26 GPa similar to value reported by Che Ani et al. [10]. Exposure to 5 to 15 Gy gamma radiation increases the hardness by 42.31%. This behavior may be due to the change of atomic arrangement of the solder material caused by radiation affecting the hardness ductility of solder [6]. Gamma rays produced electrons that were energetic enough to cause displacements [11,12]. The process of photoelectric and Compton effect might be primarily responsible for the displacements, as both processes may produce electrons with greater energies than the threshold values. However, starting from 20 to 25 Gy, the hardness decreased as the exposure dose increased. This results in agreement with those of Wen et al. [9] who found that an exposure to Co-60 gamma ray up to 1000 h caused a significant deterioration in the shear strength of AuSn solder sample due to irregular intermetallic compounds (IMC) and the formation of voids.

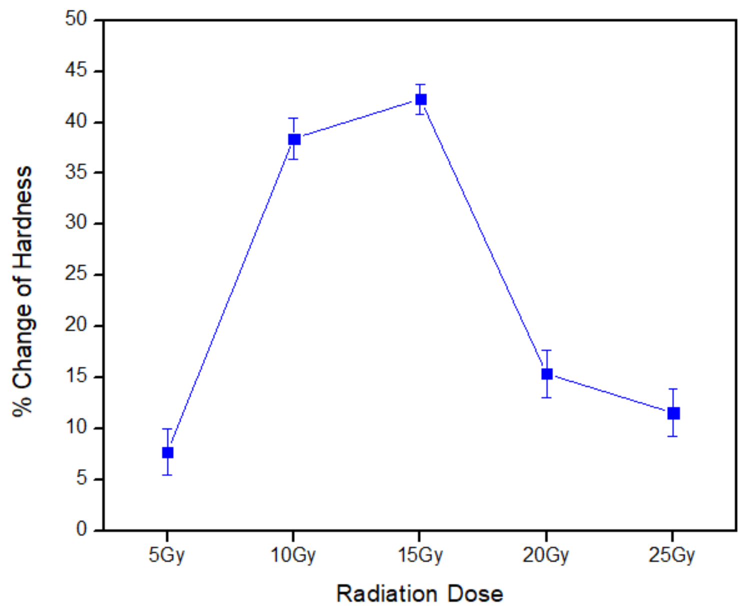

Figure 1: The hardness percentage of SAC305 in conjunction with increased gamma energies

The correlation for the values of the IMC thickness and contact angle were tabulated in Table 2. As exposure dose increased, the values of IMC thickness increased. For the contact angle, the value obtained were in the range of 24-35°. The microstructure of the control and radiated SAC305 was observed using an optical microscope and the IMC thickness was analyzed by using ImageJ software. Figure 2 showed the micrograph of SAC305 solder. The IMC thickness of the examined solders increased as the radiation dose increased proving that gamma radiation able to alter the microstructure of SAC305 solder, resulting an increment in IMC thickness as shown in Figure 2(a). For the control sample, the IMC generated between the solder and copper substrate is thin and scallop-like. However, after irradiated, the interface becomes uneven, multiple outshoots occur, and were observed to be inclined away from the substrate pad. The outshoots grew as the radiation dose increased, causing changes in the IMC thickness. The heat generated by the gamma rays is believed to play an important role in the increment of IMC formation. IMC growth is regarded as a common diffusion growth that should be restricted by interdiffusion of substrate and solder components [13]. The contact angle measured for the wettability of SAC305 solder indicates the solderability and soldering condition. Figure 2(b) shows the cross section of the solder alloy. The contact angle for all samples radiated with different doses of gamma were in the range of 24-35° (Table

2). It was suggested that all of the solder samples had good wettability because the contact angles were less than 90°, which is clearly acceptable for industrial standards. When the contact angle is smaller than 90° ($\theta < 90°$), the degree of spreading of a solder alloy on the substrate is greater, hence the wettability improves [14].

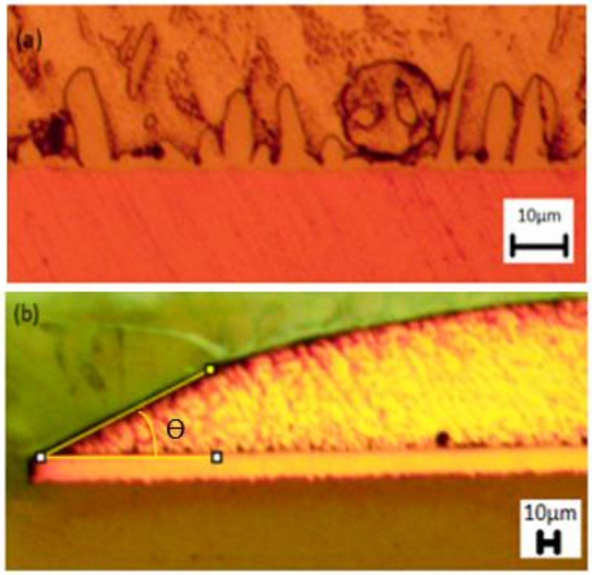

Figure 2: (a) The IMC thickness and (b) the contact angle of SAC305 solder

Table 2: The value of hardness, IMC thickness and grain size of SAC305 solder

Sample (Gy)	IMC Thickness (µm)	Contact angle (θ)
Control	4.97	24.45
5	5.24	16.16
10	6.53	28.27
15	6.56	25.04
20	6.80	35.87
25	6.83	34.93

CONCLUSION

The percentage change of hardness, intermetallic compound (IMC) thickness, and the contact angle after irradiation were observed via nanoindentation and optical microscope. It can be concluded that the percentage of hardness of IMC decreased with the increment of gamma radiation dose. Nevertheless, gamma radiation caused instability in the microstructure of the radiated solder thus increased the thickness of IMC between the solder and the copper substrate after the exposure to radiation. The contact angle measured for SAC305 solder were in the range of acceptable wetting, ensuring its solderability.

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REFERENCES

[1] Zhang, J., Hai, Z., Thirugnanasambandam, S., Evans, J. L., & Bozack, M. J. *International Symposium on Microelectronics*, ***2012***(1), 000801–000808. (2012).

[2] Cheng, S., Huang, C. M., & Pecht, M. (2017). *Microelectronics Reliability*, ***75*** 77–95 (2016)

[3] Wen, L., Xue, S., Wang, L., Liu, H., & Wu, J. *Journal of Materials Science: Materials in Electronics*, **31**(9) 7200–7210 (2020)

[4] Ren, G., Wilding, I. J., & Collins, M. N. *Journal of Alloys and Compounds*, ***665*** 251–260 (2016)

[5] El-Ashram, T., & Asaad, Y. *Radiation Effects and Defects in Solids*, ***163***(10) 843-849 (2008)

[6] Yusoff, W. Y. W., Ismail, R., Jalar, A., Othman, N. K., & Abdul Rahman, I. *Materials Characterization* **93** 125-135 (2014)

[7] Oliver, W., & Pharr, G. *Journal of Materials Research*, ***7***(6) 1564-1583 (1992)

[8] Wan Yusoff, W. Y., Ismail, N., Safee, N. S., Ismail, A., Jalar, A. & Abu Bakar, M. *Soldering and Surface Mount Technology*, **31**(2) 102–108 (2019)

[9] Dwivedi, N., Kumar, S., & Malik, H. K. *Applied Surface Science*, **257**(23) 9953–9959 (2011)

[10] Che Ani, F., Jalar, A., Ismail, R., Othman, N. K., Khor, C. Y., Samsudin, Z., Abdullah, M. Z., Azmi, A. *Arabian Journal for Science and Engineering*, **41**(5) 1813–1823 (2016)

[11] Thomson D.O., & Holmes D.K. *Journal of Physics and Chemistry of Solids*, **1** 275-278 (1957)

[12] Oen O.S., & Holmes D.K. *Journal of Applied Physics*, **30**(8) 1289-1295 (1959)
[13] Zeng, G., Xue, S., Zhang, L., Gao, L., Dai, W., & Luo, J. *Journal of Materials Science: Materials in Electronics*, **21** 421–440 (2010)
[14] Yuan Y & Lee T R. (2013). Contact angle and wetting properties. In G. Bracco, B. Holst (Eds.), Surface science techniques: Springer series in surface sciences. Berlin: Springer, 3-34.