Effect of Gamma Radiation and Thermal Cycle on Hardness Properties of Au Ball Bond

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Abstract : Effect of gamma radiation and thermal cycle test of Au ball bond on hardness properties has been investigated. The Au ball bond was subjected to gamma radiation with 5 Gy. Afterwards, thermal cycle test was performed using temperature cycle of (-65) °C to 150 °C for 10, 100, and 1000 cycles. Nanoindentation test was carried out to obtain the hardness properties of Au ball bond. Irradiated package shows an increasing in their hardness. The hardness of the ball bond keeps increased after exposure to thermal cycles up to 1000 cycles for as-received sample. However, for irradiated Au ball bond, the value of hardness increased as the cycle increased up to 100 cycles and decreased as the cycles number increased to 1000. The decrease in the hardness value due to the coarsening behavior of the grain size of the Au and recystallization process. These nanoindentation results are important in assessing the strength of Au ball bond after exposure to synergic effect of both radiation and thermal cycles.

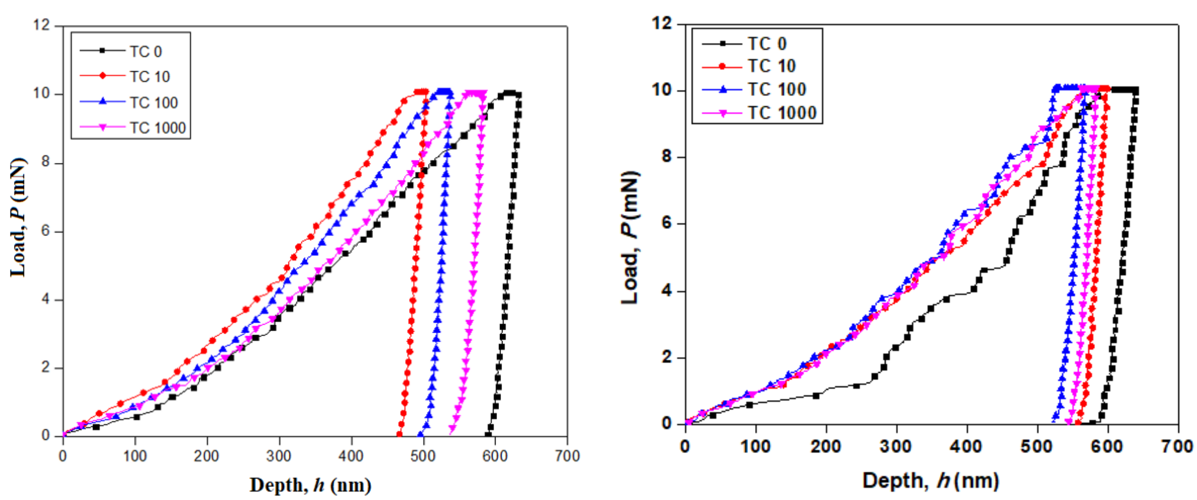
Keywords: gamma radiation, Au ball bond, nanoindentation technique, thermal cycle test

Radiation propagates through the materials and transfers its energy resulting either in terms of dissociation, ionization or excitation. Ionization initiates physical changes of irradiated material that may potentially affect its electrical, chemical and mechanical properties [1]. Radiation in the form of gamma ray have the capability to displace atoms from their lattice sites and cause changes in structure of the materials, thus altering the properties of the material.

In electronics industry, gold (Au) wire bonding is commonly used as an interconnection material due to its good mechanical properties and superior electrical resistivity. During electronics application such as power switch on/off condition, the electronic package is subjected to temperature cyclic (TC) exposure. The rate of failure in electronic increases with the number of thermal cycles [2]. It is important to understand the ability of the interconnection in electronic package to survive with mechanical stresses induced by alternating low and high temperature extreme condition. Several studies have been conducted based on the TC effect of package and electronics materials [3,4,5]. However, the synergic effect of both radiation and TC has fewer reported. Therefore, this present study concentrates on the synergic effect of gamma radiation and TC on Au ball bond towards hardness properties.

This study used similar thermal cycle experiment and analysis with our previous work done [5]. Quad Flat No-Lead package with Au ball bond interconnect was used as the sample. The package was exposed to 5Gy of gamma ray from a Co-60 source and operating dose of 2.45 kGy/h by using industrial Excel 220 Gamma Cell. Following irradiation activities, thermal cycle test was performed using a thermal chamber (TPS, Tenney) based on condition C of the JESD22-A104D [6]. The profile used in this study was (-65) °C to (+150) °C with 15 minutes upper and lower soak temperature time, 14.3 °C/min of the temperature ramp and the cycle completed in 1 hour. Two batch of samples (as-received and irradiated) with three group number of cycles namely 10, 100 and 1000 cycles of TC were denoted as TC 0 (without TC), TC 10, TC 100 and TC 1000, respectively were prepared for the present analysis. In this study, the as-received (TC 0) package was used as control samples. The cross-section perpendicular to the interconnection interface was done using metallography technique including mounting, grinding and polishing process to produce flat and smooth surface. The nanoindentation test was carried out using Micro Materials Nanotest™. The hardness value was extracted from load-displacement (P-h) data obtained based on the Oliver and Pharr method.

Indentation was performed at the center of Au ball bond. Figure 1 shows the P-h curves for (a) as-received and (b) irradiated Au ball bond with different number TC. For as-received sample subjected to 10 cycles shows the more occurrence of pop-in event as compared to as-received sample and other as-received sample with 100 and 1000 cycles. This pop-in event decreased as the number of cycle increased. From Figure 1(b), it shows that after being subjected to 5 Gy gamma radiation, the Au ball bond exhibited more occurrence of pop-in events compared to as-received sample. These pop-in events occurred mainly due to the local discontinuities during loading for irradiated sample. Based on our previous report [7], this pop-in event also is due to the dislocation of atom on the microstructure as a result of the gamma radiation. However, after irradiated sample exposed to thermal cycle, the pop-in event decreased as the number of cycle increased. This may be due to the thermal cycles improves the point defect by rearrangement of the atom in the lattice.



(a) (b)

Fig. 1: The variation of *P-h* curve for (a) as-received and (b) irradiated Au ball bond with different TC

Figure 2 shows the value of hardness for (a) as-received and (b) irradiated Au ball bond with different TC. The value of hardness was tabulated in Table 1. For as-received Au ball bond, it was found that after subjected 10 number of cycle, the hardness was increased. However, the hardness value was decreased as the number of cycle increased from 10 to 1000 cycles. This result is in agreement with Ravi et al. [8] which found that the occurance of nucleation of dislocation due to high dislocation density in the austenitic stainless steel. Exposure to the thermal cycle test cause the evolution of microstructure [9]. For irradiated Au ball bond, the hardness increase with the increasing number of cycles up to 100 cycle. However, the value of hardness was decreased as the number of cycle is increased to 1000 cycles. The decreasing in the hardness values due to the coarsening behavior of the grain size of the Au and recystallization process [9,10]. According to Ri and Saka [11], exposure to thermal cycle causes defects (dislocation and vacancies) in every grain accumulated at the grain boundary through dislocation glide plane. This causes the defect density of the grain boundary to increase as the number of cycles increases resulting in an increase of the grain boundary.

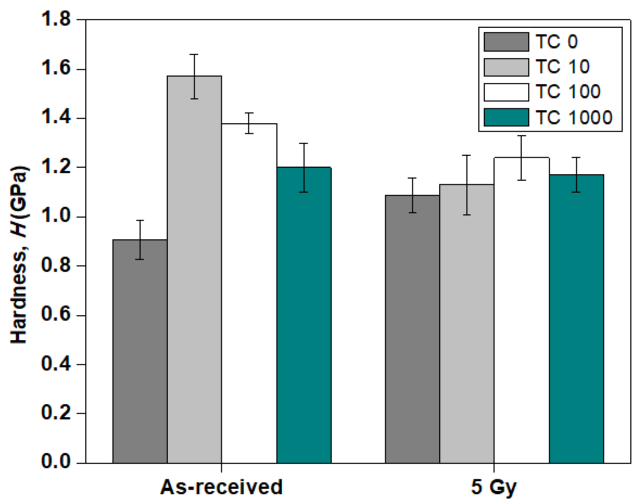


Figure 2: The variation of hardness value for (a) as-received and (b) irradiated Au ball bond with different TC

Table 1: Hardness value of as-received and radiated Au ball bond

Radiation Dose	Hardness Value (GPa)			
	Without TC	TC 10	TC 100	TC 1000
As-received	0.91	1.57	1.38	1.20
5 Gy	1.09	1.13	1.24	1.17

In conclusion, the synergy effect of both gamma radiation (5 Gy) and thermal cycle on hardness properties of Au ball bond has been investigated. The hardness of the Au ball bond was increased after exposure to gamma radiation. After subjected to thermal cycle, the hardness values increasing with the increasing number of cycles up to 100 cycle. However, the value of hardness was decreased as the number of cycle is increased to 1000 cycles. The decreasing in the hardness values due to the coarsening behavior of the grain size of the Au and recystallization process. The nano indentation result is important in assessing the strength of Au ball bond after exposure to synergic effect of both radiation and thermal cycles.

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References

[1]. Was, G.S. 2016. Fundamentals of Radiation Materials Science: Metals and Alloys. Springer, New York.
[2]. Lippiatt, J., Westerberg, S. & Rose, D. 2018. The Impact of a Faster Thermal Cycling Profile on PV Cell Interconnect Cycles to Failure. Proceeding of 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC), 3819-3824.
[3]. Rovitto, M., Morelli, A., Passagrilli, C. & Villa, C.M. 2018. Dynamic Warpage Analysis of QFP Packages during Soldering Reflow Process and Thermal Cycle 2018 IEEE 68th Electronic Components and Technology Conference, 1893-1898.
[4]. Chen, D.Y. & Osterman, M. 2017. Effect of corner staking on the fatigue life of BGA under thermal cycling. Proceedings of the ASME 2017 International Technical Conference and Exhibition on Packaging and Integration of Electronic and Photonic Microsystems, IPACK2017-74249.
[5]. Yusoff, W.Y.W., Jalar, A., Othman, N.K. & Abdul Rahman, I. 2014. Effects of thermal cycling on the mechanical properties of gold wire bonding. IEEE International Conference of Semiconductor (ICSE 2014) Proceeding: 537-540
[6]. JESD22-A104D. 2009. Temperature Cycling. Arlington: Joint Electron Devices Engineering Council.
[7]. Yusoff, W.Y.W., Ismail, R., Jalar, A., Othman, N.K. & Abdul Rahman, I. 2014. Microstructural evolution and micromechanical properties of gamma-irradiated Au ball bonds. Mater. Charact. 93: 129-135.
[8]. Ravi Kumar, B., Das, S.K., Sharma, S. & Sahu, J.K. 2010. Effect of thermal cycles on heavily cold deformed AISI 304L austenitic stainless steel. Mater. Sci. Eng. A 527(4-5): 875-882.
[9]. Boumerzoug, Z., Raouache, E. & Delaunois, F. 2011. Thermal cycle simulation of welding process in low carbon steel. Mater. Sci. Eng. A 530: 191-195.
[10]. Cho, J.Y., Kim, K., Oh, J., Moon, J., lee, J., Cho, Y. & Rollett, A. 2003. Recrystallization and grain growth of cold-drawn gold wire bonding. Metall. Mater. Trans. A 34: 1113-1125.
[11]. Ri, S. & Saka, M. 2012. Diffusion-fatigue interaction effect on hillock formation in aluminium thin films under thermal cycle testing. Mater. Lett. 79: 139-141.