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Dimensional and Structural Stability of Gamma Irradiated Stacked Die Quad Flat No Leads (QFN)

(Kestabilan Dimensi dan Struktur Dai Bertingkat Tanpa Kaki (QFN) Tersinar Gamma)

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ABSTRACT

The physical properties and structural stability of the Quad Flat No-Leads (QFN) package with different gamma radiation doses have been investigated. The packages were irradiated with Co-60 gamma radiation with varying doses of 5 Gy, 50 Gy, 500 Gy, 5 kGy and 50 kGy with operating dose of 2.54 kGy/h at room temperature. The infinite focus microscope (IFM) was used to measure the dimensional change and slanting/warpage behaviour, while the 3D CT Scan X-ray machine was used to determine the occurrence of deflection on a wire in package due to exposure. It is believed that radiation effect on ceramic filler in the epoxy mold compound (EMC) plays an important role to induce the defects and resulted in swelling of the package. The slanting/warpage behaviour is believed to be caused by the swelling behaviour of ceramic filler and further induced structural stability. The induced stress on the EMC structural after the dimensional change and slanting/warpage failure leads to the occurrence of wire sweep. The finding suggests that defect production in swelled ceramic filler leads to the occurrence of dimensional and structure instability.

Keywords: Dimensional change; gamma radiation; QFN; structure stability

ABSTRAK

Kestabilan sifat fizikal dan struktur pakej cip tanpa kaki (QFN) dengan dos sinar gama yang berbeza telah dikaji. Pakej diradiasikan dengan sinaran Co-60 gama dengan pelbagai dos 5 Gy, 50 Gy, 500 Gy, 5 kGy dan 50 kGy serta dos operasi 2.54 kGy/jam pada suhu bilik. Mikroskop fokus infinit (IFM) telah digunakan untuk mengukur perubahan dimensi dan kelakuan serong/keledingan, manakala mesin 3D CT sinar x telah digunakan untuk menentukan berlakunya pesongan pada wayar di dalam pakej disebabkan oleh pendedahan. Dipercayai bahawa kesan sinaran pada pengisi seramik dalam acuan sebatian epoksi (EMC) memainkan peranan yang penting dalam mendorong kecacatan dan menyebabkan pembengkakan pakej. Kelakuan serong/keledingan dipercayai disebabkan oleh kelakuan pembengkakan pengisi seramik dan seterusnya mendorong ketidakstabilan struktur. Aruhan tegasan pada struktur EMC selepas perubahan dimensi dan kegagalan serong/keledingan membawa kepada berlakunya pesongan wayar. Penemuan ini menunjukkan bahawa penghasilan kecacatan dalam pembengkakan pengisi seramik membawa kepada berlakunya dimensi dan struktur tidak stabil.

Kata kunci: Kestabilan struktur; perubahan dimensi; QFN; sinar gama

INTRODUCTION

In the electronic industry, the reliability of microelectronic package has become increasingly important. Quad Flat No-lead (QFN) package is a microelectronics package consists of leadframe as substrate, an epoxy molding compound (EMC) as encapsulate material, epoxy, silicone die and gold wire as interconnection (Ahmad et al. 2007) as shown in Figure 1. The EMC itself consists of other materials such as epoxy resin, phenolic resin, ceramic filler (SiC and AlN), coupling agent, release agent and curing agents (Komori & Sakamoto 2009), where each material has its own functions and roles. Ceramic materials are widely used in the electronic industry due to high reliability and temperature performance. In the EMC, ceramics are important to balance the coefficient of thermal expansion (CTE) of the polymer encapsulated due to its low CTE properties, especially under extreme conditions (Chung 1995). The ceramic filler has also been used to enhance the strength of the EMC. The AlN and SiC have low CTE, which are 4.0×10^{-6} K^{-1} and 4.5×10^{-6} K^{-1}, respectively (Chmielewski & Weglewski 2013; Kang & Kang 2006). The package's miniature size, combined with its diversity of functions, superior thermal and electrical performance, makes it suitable for portable electronic products such as cell phone, laptop and personal digital assistant (PDA) (Huang & Lin 2013).

Gamma ray is one of the ionizing radiations which affects material's stability and reliability of the product. Electronic products in outer space may be exposed to a variety of radiation sources including gamma rays. Exposure to radiation could degrade the critical properties (mechanical and chemical) of structural materials such as metals, polymers and ceramics (Rao et al. 2008). QFN is

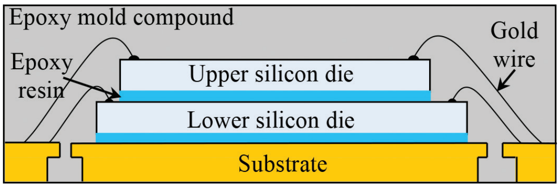

FIGURE 1. Cross section view of stacked die QFN

one of the semiconductor package technologies that are essential as components for outer space product such as satellite sensor (Yusoff et al. 2011). Gamma rays tend to interact with solid materials to excite the electron and interact with the nucleus (Hughes & Pooley 1975). The subsequent scattering of the emission photon may induce fast electron. This electron particle could strike the nucleus of the radiated atom and transferred its momentum energy on it. The electron particle with large amount of energy tends to displace the target atom and thus results in atomic displacement (Hughes & Pooley 1975). A stable Frenkel pair is produced when the minimum amount of the threshold displacement energy is achieved (Zinkle & Kinoshita 1997). The threshold energy values of the material normally in the range of 30 to 50 eV (Weber et al. 1998). In addition, the effect of gamma radiation on the dimensional and structural stability of the semiconductor package needs to be investigated in relation to its reliability. This study concentrate on the effect of gamma irradiation on the dimension and structural properties of the semiconductor package by focusing on the effects of the ceramic filler in EMC.

MATERIALS AND METHODS

The stacked die QFN was chosen to investigate the gamma radiation effect on structural and dimensional properties. The package has 48 leads with the overall size of 7×7 mm and thickness of 0.85 mm, which developed by researchers from Universiti Kebangsaan Malaysia, Malaysia. The samples were irradiated by using Co-60 source of Gamma Cell (Excel 220) with the operating rate of 2.54 kGy/h at room temperature. The irradiation doses of 5 Gy, 50 Gy, 500 Gy, 5 kGy and 50 kGy were exposed separately onto the samples. The occurrences of dimensional changes and warpage were determined by using Infinite focus microscope (IFM, Alicona), while the structural property was measured with 3D CT Scan X-ray machine (HMX CT-160Xi). Figure 2(a) shows the location of measurement

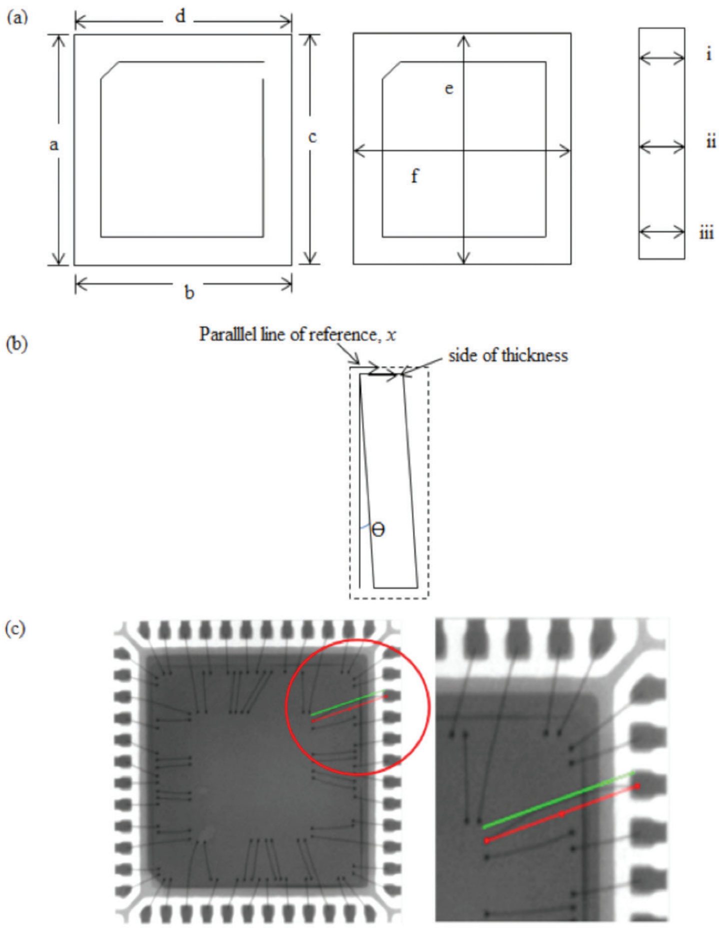

FIGURE 2. Measurement methods (a) Top view and side view dimension, (b) warpage and (c) wire sweep

point on the package that was considered in this measurement. The 45° cut on the package was used as a point of reference. The dimensional change was measured before and after exposed to gamma radiation. Afterwards, the changes in slant and warpage, θ were measured by using IFM with the method as shown in Figure 2(b). In this method, the rectangular box was used to confirm the parallel lines between *x* (as line of references) and QFN side. In this study, changes in wire sweep of the package were also considered. These changes were determined by using 2D image of 3D CT-Scan as shown in Figure 2(c). The wire sweep percentage between the maximum sweep point and wire position was obtained by using the parallel line (red and green line). Red line was used to fix the position point of the gold wire whereas green line was used to position the maximum wires sweep point.

RESULTS AND DISCUSSION

The changes in dimension of the semiconductor package after exposure are shown in Figure 3 and all the values are tabulated in Table 1. Negative values represent the

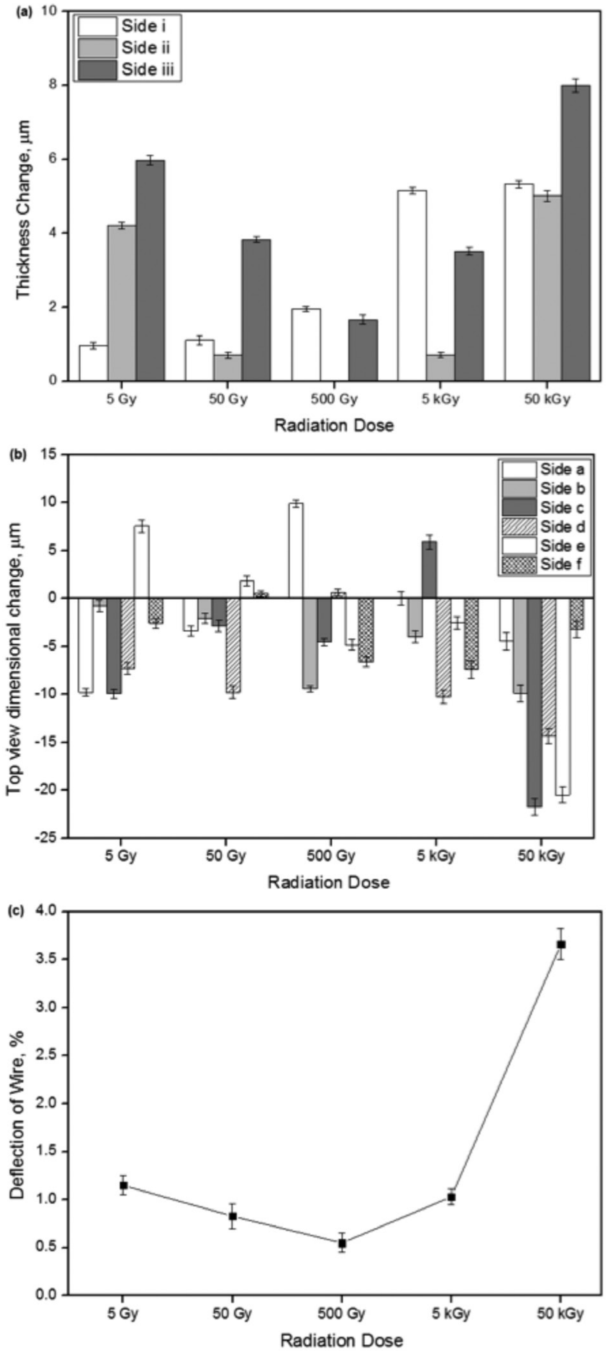

FIGURE 3. (a) Top view dimensional change (b) thickness change and (c) wire sweep change with gamma radiation dose

TABLE 1. The top view dimension, thickness and wire deflection at different radiation dose

Dose	Top view dimension change, μm						Thickness change, μm			Wire deflection, %
	a	b	c	d	e	f	i	ii	iii	
5 Gy	-9.7750	-0.7340	-9.9250	-7.2370	7.5670	-2.5500	0.9600	4.2100	5.9800	1.15
50 Gy	-3.3600	-2.0500	-2.8530	-9.7670	1.8670	0.5170	1.1100	0.7100	3.8300	0.83
500 Gy	9.9150	-9.3950	-4.5000	0.6470	-4.8000	-6.6000	1.9500	0.0000	1.6700	0.55
5 kGy	-0.0003	-3.9630	5.9250	-10.2540	-2.5330	-7.4000	5.1600	0.7200	3.5200	1.03
50 kGy	-4.4290	-9.8750	-21.7500	-14.3200	-20.4500	-3.1670	5.3300	5.0100	8.0000	3.66

shrinkage of packages, whereas the positive values represent the swelling of package. The overall view shows the decreasing values of the top view dimension. In contrast, an increasing value was obtained for the thickness or side view dimensional change. The lowest increment of the thickness value is for 500 Gy, which is in the range of 0.00 – 1.95 μm. It is suggested that exposure to gamma radiation has induced the swelling in the EMC of QFN package.

Table 1 and Figure 3(c) show the changes in wire sweep values and its trends against different radiation doses. From the observation, the wire sweep failure occurs mostly at the corner of the package (Abdullah et al. 2008) and its direction imprecise. The slanting/warpage of the package leads to the change in the side view dimensions, thus induced the stress to the gold wire and produced wire sweep failure. However, from the IFM observation, the variation of the slanting/warpage degree, θ was relatively small (subdegree ranged) and is difficult to measure directly. Moreover, the ceramic filler content in the EMC is capable of influencing the wire sweep behaviour (Ardebili & Pecht 2009). By comparing the trends in the Figure 3(b) and 3(c), it is believed that the wire sweep changes were also affected by the change of the package thickness. The occurrence of the slanting/warpage behaviour might be induced by top view dimensional change as be seen in the Figure 3(a).

Gamma radiation induced collision between gamma ray and atom constituting the material. High-energy gamma rays have a tendency to interact with and transfer energy to atom. A sufficient amount of kinetic energy may displace the atoms from their original position, which would results in creation of vacancies and interstitials. This formation of defects (vacancy and interstitial) in the crystalline materials are Frenkel pair (Lemaignan 2010). Exposure to gamma radiation tends to displace the lattice atom in the ceramics and leads to the formation of Frenkel pair. Each material has their threshold displacement energy, E_d to initiate atomic displacement (Hughes & Pooley 1975). The E_d values of Si, C and sublattice Al, N are ~ 35 – 110 eV, ~ 20 eV, 27 eV and 35 eV, respectively (Gao et al. 2002; Kinoshita 2007; Weber et al. 1998; Zinkle & Kinoshita 1997). Iseki et al. (1993) suggested that the change of crystal volume was related to the defects. It is believed that the interstitial atoms may expand the volume of crystal. Vacancies could expand or shrink the crystal but total volume change of Frenkel pair formation should be swelled (Iseki et al. 1993). SiC (4.5×10^{-6} K^{-1}) and AlN (4.0×10^{-6} K^{-1}) fillers in the EMC are used to stabilize the structure of package in the extreme conditions. From the obtained results, it can be hypothesized that the ceramic filler became unstable after exposed to gamma radiation. The swelling of the AlN and SiC in the EMC was resulted in the increase of side view dimensions as seen in Figure 3(b) and in the decrease of the top view dimensions. The shrinkage of top view dimensions might be due to the occurrence of warpage. The change of the warpage behaviours had changed the structure of package and stress to the filler content in the EMC was borne on the gold wire and lead to the wire sweep behaviour. From the results obtained, it is suggested that exposure to 500 Gy of gamma radiation has the least changes in the dimensions and structure of package. This study shows that the AlN and SiC in the EMC is the most stable under the exposure of 500 Gy as compared with other doses. It can be summarized that gamma radiation dose plays an important role since it affects the dimension, structural and failure of the ceramic material which may degrade the functionality of the device. Therefore, the radiation-materials-interaction should be considered for designing packaging material within radiation environment.

Conclusion

The dimensional and structural properties of the gamma irradiated stacked die QFN was successfully investigated. AlN and SiC in the EMC that was used to balance the CTE of the package became unstable after exposure to gamma radiation. The top and side view dimensions were found to have shrunk and swollen, respectively. The swelling effect of the ceramic fillers in the EMC adversely affected the structure stability and warpage failure. The occurrence of wire sweep was due to the warpage behaviour and dimension and the subsequently stress of the filler content within the EMC. Thus, the slanting/warpage and wire sweep behaviour occurrence is believed to be correlated with each other.

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