Impact of X-Ray Inspection on Spansion® Flash Memory

Application Note
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1. Introduction

X-ray inspection is a commonly employed tool used to gauge the quality of solder connections on surface mounted BGA packaged devices on circuit boards. It has been well established that semiconductor ICs can suffer damage from (dis)charging effects caused by X-ray energy. The purpose of this application note is to provide guidance on the assessment and mitigation of risks associated with X-ray inspection of Spansion Flash memory components.

2. X-Ray Inspection Impact on Programmed Data

X-rays behave basically the same as visible light rays, since both are wavelike forms of electromagnetic energy carried by particles called photons. The difference between X-rays and visible light rays is a 10,000-fold difference in energy for individual photons, which is inversely proportional to wavelength.

X-rays have been shown to perturb the distribution of threshold voltage (V_t) of individual programmed bits within Flash memory arrays. A significant negative perturbation in the V_t of a programmed bit will result in the incorrect sensing of the programmed bit logic state during a read operation, e.g. a read data operation incorrectly returns a logic state of "1" when it should return a logic state of "0" for a programmed bit. The impact of a read failure on system performance can range from benign to catastrophic.

A variety of factors influence the programmed bit V_t perturbation, including:

- X-ray energy spectrum

X-ray radiation has been found to modulate programmed V_t distribution perturbation. X-rays with energies up to 9 KeV have been shown to be particularly damaging to Flash memory cells. Adequate X-ray inspection imaging does not require X-rays in the <9 KeV energy spectrum. Analysis has shown that 50 µm Cu traces are best imaged with X-ray energy of 9-20 KeV and that solder components, e.g. tin and lead, are well-imaged by X-rays over the energy range of 10-50 KeV.

- X-ray inspection equipment

The size of the perturbed population (number of bits affected) has been found to be modulated by dose, which varies as the square of the KV_{peak} used during inspection, linearly with tube current, and inversely with distance from X-ray tube to Flash device being inspected. X-ray energy and flux (dose rate) has been found to vary significantly among commonly used X-ray inspection equipment. Laminography-based equipment has been found to be particularly damaging to Flash memory due to its highly concentrated and powerful X-ray beams.

- X-ray exposure time

The size of the perturbed population (number of bits affected) increases linearly with X-ray inspection time. However, programmed V_t change is NOT linear with dose or time. The change in programmed V_t varies as the square root of time, while dose varies as the 1.5 power of time.

- Flash semiconductor process feature size

Flash semiconductor process feature size has been found to modulate program V_t distribution. Devices built with newer, smaller feature sizes are expected to have slightly worse sensitivity to a given X-ray inspection when compared to older technology devices.

3. Risk Assessment and Mitigation

Evaluations have shown that any X-ray exposure results in a negative shift in programmed V_t distributions. It is difficult to assess the impact on programmed bit V_t distribution based on specific X-ray inspection implementations because the V_t disturb phenomenon is the result of the accumulated effects of discrete interactions of high energy photons with individual memory cells, each with unique physical characteristics resulting from natural semiconductor process variation.

As a result, to ensure maximum data integrity for programmed bits, X-ray exposure after programming should be avoided.

Where it is deemed necessary to perform X-ray inspection, programming and X-ray inspection methodology should be carefully considered to minimize the probability of significant programmed V_t disturbance which could result in a read data error.

A variety of control methods should be considered, including:

- Use of appropriate X-ray filter

Spansion and AMD have shown that filtering of specific X-ray energy levels can be used to minimize damage to X-ray sensitive semiconductor ICs.

See http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=1176469

and

http://www.spansion.com/application_notes/Dose_Minimization_Xray_Inspect_AN_01_e.pdf

Spansion recommends that appropriate filtering be used in all X-ray inspection of circuit boards with Flash memory. A thin 300 µm zinc filter has been determined to be a very effective agent to absorb very soft X-rays (9 KeV and smaller) to which silicon is particularly vulnerable, yet transmits the soft and medium energy X-rays required to obtain good imaging. Zinc foil can be integrated with the inspection “carrier” or put near the X-ray source on the X-ray inspection equipment. AMD was issued a patent (free usage is encouraged) for the use of zinc filtering that enables X-ray inspection users to protect proper performance (enter 6,751,294 into http://www.freepatentsonline.com to get full text *.pdf for this patent).

The use of a 1 mm aluminum filter has also been proven effective in reducing negative programmed V_t distribution perturbation. Commonly used X-ray equipment filters made of beryllium, copper, and stainless steel have been proven ineffective in mitigating the damaging effects of soft X-rays.

- Minimize pre-programming and replace exposed data

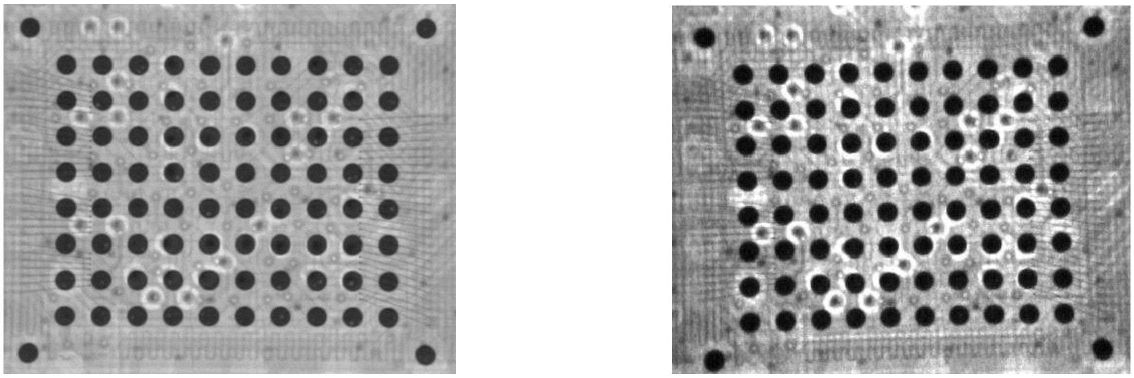
Pre-programming of the Flash prior to X-ray inspection must be minimized to reduce the population of programmed bits exposed to potential harmful X-rays. It is recommended that only the minimal amount of data required to configure the circuit board should be pre-programmed, e.g. boot loader. During post-X-ray inspection circuit board level testing, all pre-programmed data should be replaced, e.g. erased and re-programmed, to repair any negative programmed bit V_t perturbation resultant from X-ray exposure. All additional data required for system operation should be programmed during post-X-ray inspection circuit board level test.

- Minimize KV_{peak} and X-ray tube current

Use the smallest KV_{peak} possible that still produces adequate images, recommending near 50 KV_{peak} rather than 80-160 KV_{peak}. This action reduces number of bits affected by 5-fold (for 50 vs. 110 KV_{peak} or 9-fold vs. 160 KV_{peak}). More importantly threshold voltage change is improved by 2-fold for 50 KV vs. 110 KV (3-fold vs. 160 KV).

Use of the smallest X-ray tube current possible that still produces adequate images, recommending near (or smaller than) 20 µA rather than traditional 40 µA. This action reduces number of bits affected by 2-fold and threshold voltage change by 1.4-fold.

Figure 3.1 Example — Adequate Imaging Possible with Reduced KV_{peak} and X-ray Tube Current



110 KV_{peak} @ 40 µA “more appealing”

550 KV_{peak} @ 20 µA “higher contrast”

- Maximize distance between X-ray source and Flash

Use as a large X-ray tube to sample distance as possible (low magnification) because X-ray dose varies inversely with distance.

- Minimize X-ray exposure time

Use the shortest inspection time possible to achieve a suitable image. In the case of Flash memory, X-ray inspection is used for BGA solder reflow process control, an action which should be accomplishable via inspection on a sampling basis rather than 100% inspection.

- Minimize total accumulated X-ray dose

Dosimeter measurement can be used as a first order tool for the assessment of risk of read failures due to significant negative programmed bit V_t perturbation resulting from X-ray exposure. Dosimeter measurements can not be used go / no-go determination of risk. Any X-ray inspection resulting in a total dose at the device level in excess of 10 Rads, whether measured by dosimeter or calculated from inspection parameters, should be considered potentially damaging; any and all risk mitigation methodologies mentioned above must be employed for such inspections. For dose values below 10 Rads, risk mitigation should be employed whenever possible.

- Delete X-ray inspection altogether,

Instead use an electrical detection technique. One example is based on IEEE 1149 Boundary Scan.

See http://ieeexplore.ieee.org/iel5/7481/20326/00938734.pdf

and

http://www.ieee.li/pdf/viewgraphs_jtag_boundary_scan.pdf

IEEE 1149 permits “internal nodes” on a PCB to be examined by reading a shift register connected to all the pins from all devices on the PCB. This method does require an extra design feature for future system-level products, but can be implemented with standard Spansion products.

4. Summary

Evaluations have shown that any X-ray exposure to programmed Flash memory will result in an undesirable shift in programmed bit threshold voltages, the result of which is degraded data readability and the potential for system failure. As such, X-ray exposure should be avoided where possible and minimized where avoidance is not possible.

Due to the variability in Flash silicon, X-ray spectrums and X-ray equipment capabilities, it is not possible to provide specific guidelines on acceptable and unacceptable X-ray exposure criteria, e.g. maximum safe dose rate, maximum safe exposure time, etc....

When X-ray inspection is utilized on Flash memory, Spansion recommends:

- the use of Zn or Al filtering to minimize exposure to harmful soft X-rays,
- the minimization of pre-programming and the replacement of all data exposed to X-ray inspection,
- the minimization of X-ray dosage, energy and flux via selection or tuning of X-ray inspection equipment.

5. Revision History

Section	Description
Revision 01 (October 30, 2008)	
	Initial release

Colophon

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