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AN98547

Dose Minimization During X-ray Inspection of Surface-Mounted Flash ICs

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AN98547 is intended to help customers who perform X-ray inspection of surface-mounted ICs on circuit boards.

1 Introduction

This document is intended to help customers who perform X-ray inspection of surface-mounted ICs on circuit boards. 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 the energy for individual photons (energy is inverse to wavelength). Just as filtering of visible light wavelengths (i.e. energies) can be used effectively to prevent damage to photosensitive materials, Cypress 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.)

It has been well established that semiconductor ICs can suffer damage from (dis)charging effects caused by X-ray energy. While this phenomenon does not always result in a hard failure, customers might have no way to recover from the effects of the X-ray exposure. Cypress studies have shown that there is a change in threshold voltage as a function of X-ray dose. It is the purpose of this Application Note to show how such damage can be mitigated and how a user can achieve a state where X-ray effects will be undetectable.

In many cases inspection instruments subject ICs to X-ray dose values that are significantly greater than what is necessary to achieve successful inspection. The key is to minimize the total cumulative dose to the IC while achieving a useful inspection image.

The goal of Cypress's recent experimentation was to extend from small floating gate devices to large capacity MirrorBit™ devices. As memory capacity has grown roughly 50-fold in the interim, it is now necessary to see more subtle effects. When we examine normal probability plots for threshold voltage of current devices, we see wider “tails.” As there are so many more bits on these high capacity devices, some bits are closer to the point at which we would see read errors. This larger number of “tail bits” increases the probability of a read failure on a given device.

We observe a perfect Gaussian (normal) threshold voltage distribution for programmed bits (erased bits are not affected by X-rays). After X-ray irradiation a small number of the bits are found in a second normal distribution, but Cypress expects no read errors if recommendations 1-5 are followed, as the change in V_t would be so small. As X-ray dose increases, the size of the perturbed population (number of bits affected) increases linearly with X-ray inspection time. However, threshold voltage change is NOT linear with dose or time. We find the change in threshold voltage to vary as square root of time, while dose varies as the 1.5 power of time. More importantly, dose varies as the square of the KV_{peak} used during inspection, linearly with tube current, and inversely with distance from X-ray tube to IC being inspected. Apart from X-ray energy and flux, we find a Zinc filter to be extraordinarily effective, for which we estimate that read errors would be reduced by more than 100X. While there is no condition which is absolutely safe against X-ray exposure, it is possible to make X-ray inspection mild enough that read errors will not be seen.

2 Cypress Recommends

1. Using a 300 μm thick Zn filter is the single most important change. A thin zinc filter is a very effective agent to absorb very soft X-rays to which silicon is particularly vulnerable, yet transmit soft and medium energy X-rays required to obtain good. Zinc foil can be integrated with the inspection “carrier” or put near the X-ray source. 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).

2. Using the smallest KV_{peak} possible that still produces adequate images, recommending near 50 KV_{peak} rather than 80-110 KV_{peak}. This action reduces number of bits affected by 5-fold (for 50 vs. 110 KV_{peak}) and threshold voltage change by 2-fold.
3. Using 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.
4. Use as a large X-ray tube to sample distance as possible (low magnification) because X-ray dose varies inversely with distance.
5. Use the shortest inspection time possible, preferably on a sampling basis rather than 100%. If X-ray inspection is used after Surface Mount Technology (soldering components to Printed Circuit Boards), refresh data, i.e. program same data again in system without erasure for floating gate devices, but erase and reprogram for MirrorBit® devices.

Prudent Practice, Best Known Methods – Future

6. Another strategy is NOT to use X-ray inspection at all, but instead to use an electrical detection technique, namely 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 the PCB to be examined by reading a shift register. However, this method does require an extra design feature for future system-level products.

As a general rule, customers should limit the cumulative X-ray inspection exposure to the SMT memory devices to as small a value as possible, as this minimizes the number of bits affected AND the perturbation to each affected bit.

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