Radiation Measurement Technologies for Evaluating Soft Errors

● Ryozo Takasu

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Two radiation measurement technologies for estimating and lowering the occurrence rate of "soft errors" are introduced. Radiation such as fast neutrons (generated by cosmic rays) and α-rays (generated by the impurities in materials composing LSIs) cause incorrect operations—known as soft errors—in computer systems. Since soft errors undermine the reliability of mission-critical products such as backbone servers, it is necessary to estimate and reduce their occurrence rate. To enable experimental measurements of neutron and α-ray dose rates, my coworkers and I have developed and utilized a vacuum α-ray tracking method—for measuring the amount of α-rays with high sensitivity—as well as a cosmic ray neutron spectrometer. With these two technologies, it has become possible to measure the radiation dose rate in low-α-ray-emitting materials, which has been impossible until now, and the neutron dose rate in arbitrary environments such as mountainous regions and to estimate the soft error rate accurately. Moreover, these technologies make it possible to select materials with low α-ray emissivity and choose environments with a low neutron dose rate, thereby contributing to improvements in computer system reliability.

1. Introduction

When LSIs are exposed to radiation such as fast neutrons or α-rays, operational malfunctions such as data bit inversions in memories and improper operation of logic circuits can occur. These are called "soft errors". Although such problems alone do not cause mechanical failure, they can, in the worst case, lead to system stoppages. Soft errors are therefore likely to degrade the reliability of mission-critical products such as backbone servers. At the same time, as the mounting density and capacity of LSIs continue to rise, soft errors are becoming a more-serious problem, and the requirements concerning them are becoming tougher to satisfy.

To correctly estimate and take steps to reduce the occurrence rate of soft errors (soft error rate), it is necessary to measure the amounts of α-rays with high sensitivity and measure the neutrons causing the errors. For that purpose, we have developed a highly sensitive α-ray dose measuring method and a neutron spectrometer. They make it possible to measure the radiation dose from low-α-ray-emitting materials (hitherto impossible) and the neutron dose in computer system usage locations and high-flux environments such as mountainous regions. Consequently, the soft error rate can be estimated precisely. Moreover, by selecting low-α-ray-emitting materials and low-neutron-dose environments, it is now possible to lower the actual soft error rate and hence improve the reliability of computer systems.

This paper describes the methods that we have developed for measuring α-ray and neutron

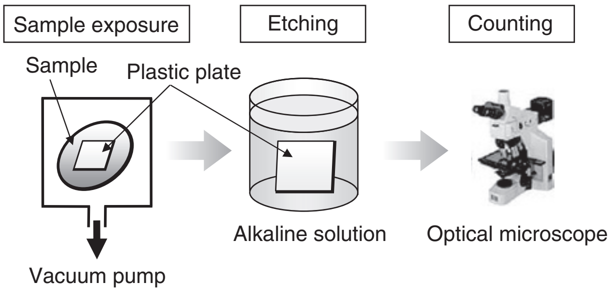

Figure 1
Measurement procedure of vacuum α-ray tracking method.

Figure 2
Optical-microscope image of etch pit.

radiation doses. Note that throughout this paper, the word "neutrons" refers to fast neutrons, i.e., high-energy neutrons.

2. High-sensitivity α-ray measurement method

2.1 Background

Alpha particles (α-rays) are generated by radioactive nuclei (such as isotopes of uranium, thorium, and polonium) contained in the materials that make up LSIs (especially in sealing materials, solder, and interconnection layers). To evaluate the reliability of computer systems, one needs a method for accurately estimating the soft error rate. However, the sensitivity of the conventional α-ray dose measurement method is too low, so it has only been possible to conclude that the α-ray dose was below the detection limit. Thus, estimations based on the minimum detection rate often overestimated, possibly substantially, the soft error rate. Moreover, even if low-emissivity materials were selected to reduce the soft error rate, there was no method of measuring the dose rate. The conventional method of measuring α-ray doses uses a gas-flow proportional counter. This method electrically detects the ionization of gaseous molecules caused by α-rays, so it is influenced by various noise effects. In practice, its sensitivity[note)] is $1\times10^{-3}\,\alpha\text{h}^{-1}\,\text{cm}^{-2}$ and hard to improve. Consequently, a more sensitive method is needed.

note) The unit of sensitivity is the number of α-particles emitted from a 1-cm^2 area of a sample in one hour.

2.2 New measurement method

We have developed new method for measuring α-ray dose rates that is thirty times more sensitive than the conventional method. It uses a special plastic plate to detect α-rays, which gives it excellent robustness against noise. Furthermore, to reduce the effect of atmospheric background radiation, the measurement is performed under vacuum. As a result, a detection limit of $3.2\times10^{-5}\,\alpha\text{h}^{-1}\,\text{cm}^{-2}$ has been achieved. The measurement procedure of our vacuum α-ray tracking method is shown schematically in **Figure 1**. When the plastic detector plate contacts the measurement sample under vacuum, α-rays emitted from the sample leave tracks on the plastic plate. These tracks are invisible, so an etching process is applied to transform them into etch pits, which can be examined optically (**Figure 2**) and counted using an optical microscope. Thus, the evaluation is based on a simple principle.

2.3 Measurement results

The vacuum α-ray tracking method was used to measure the α-ray doses from LSI materials, which have hitherto been impossible to measure owing to the inadequate sensitivity of conventional methods. We obtained the following results: for copper-interconnection film (10 µm thick), the α-ray dose was $1.5\times10^{-4}\,\alpha\text{h}^{-1}\,\text{cm}^{-2}$ and for two types of lead-free solder (more than

100 µm thick), the doses were 5.6×10^{-4} αh^{-1} cm^{-2} and 2.2×10^{-4} αh^{-1} cm^{-2}.

The measured dose was used to calculate the soft error rate, and the calculated rate agrees well with the experimentally measured one. This agreement shows that the model used for calculating the soft error rate is correct. Therefore, in the future development of LSIs, it will be possible to select materials that generate few α-rays, which should make it possible to fabricate LSIs with lower soft error rates. Moreover, this method works with a smaller sample area than that needed for conventional methods, so it can be used to measure multiple samples in a vacuum chamber in parallel.

3. Cosmic-ray neutron measurement method

3.1 Background

The earth is constantly being hit by high-energy cosmic rays (mainly protons), from outer space, which generate neutrons (cosmic ray neutrons) in the earth's atmosphere. When these neutrons strike an LSI circuit, they can cause soft errors in that circuit. The neutron radiation dose rate varies with altitude above sea level and location on the earth (i.e., geomagnetic latitude) as well as with terrestrial weather conditions and solar activity. Moreover, it also depends on the cosmic ray shielding effect of structures such as buildings. Consequently, to calculate the soft error rate accurately, we must measure the neutron dosage in both the error-occurrence (i.e., high neutron flux) environment and the circuit usage environment. To perform both these measurements, we need a method for filtering out high-energy (over 10 MeV) neutrons (namely, those that cause soft errors) and measuring their dosage. However, no apparatus that can perform such measurements is available on the market. Consequently, it has been difficult to measure neutron dosages in the field at the actual locations where LSIs are used because the neutron detectors were too big and thus not transportable.

3.2 Measurement method

Our apparatus for measuring neutron spectra is a multisphere-type neutron spectrometer first suggested by Bonner et al.[1] It has multiple neutron detectors (each with a different neutron energy response function) and calculates neutron spectra by means of an unfolding calculation based on the count rate recorded by each detector. More specifically, it utilizes six kinds of detector. The response function of each detector was obtained by calibration at the neutron standardization facility of the National Institute of Advanced Industrial Science and Technology (Tsukuba, Japan) on the basis of Monte Carlo simulation results. Through this procedure, we obtained spectra for cosmic ray neutrons in the energy range from 25 meV (thermal neutrons) to 1000 MeV.

3.3 Measurement results

The neutron spectrometer was transported to and tested in two locations: Fujitsu Akiruno Technology Center (Tokyo metropolitan area; elevation: 170 m) and the Subaru Telescope at the summit of Mauna Kea (Hawaii, USA; elevation: 4200 m). Since atmospheric shielding is weak at high altitudes, high neutron doses can be expected, and high-altitude measurements can be performed in about one tenth the time needed for sea-level measurements. (Soft-error-rate measurements performed at low altitude usually require durations of years for measurements in parallel.)

The equipment for measuring neutron spectra and soft error rates simultaneously is shown in **Figure 3**. A major feature of this equipment is that it can measure the neutron dose rate and soft error rate in the same environment simultaneously because it is compact enough to be transportable. Example neutron spectra obtained with this spectrometer are shown in **Figure 4**. Comparing the outdoor

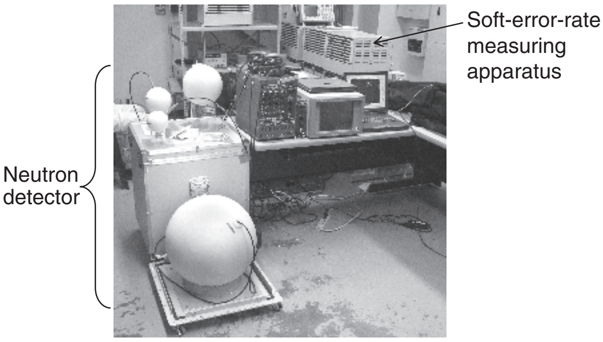

Figure 3
Simultaneous measurement of neutron spectrum and soft-error rate.

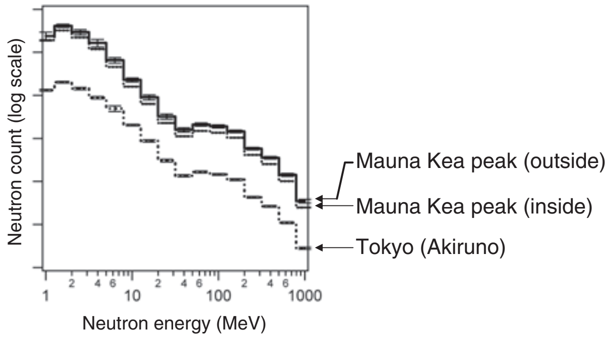

Figure 4
Observed neutron spectra.

measurements (i.e., not shielded by buildings) for the two different locations, we found that the radiation dosage on Mauna Kea was twenty times that in Tokyo. Furthermore, comparing indoor and outdoor results at the same location (Mauna Kea), we found that the dosage inside the building (which acted as a shield) was half that recorded outside the building.

The shielding effect of a building depends on the building's construction, and the neuron dose rate received by a computer will differ according to its installation environment. Our neutron spectrometer can be taken into environments where computers are set up. Therefore, it can help forecast the soft error rate in such environments.

4. Conclusion

A high-sensitivity α-ray measurement method (vacuum α-ray tracking method) and a fast-neutron measurement method have been developed. As the scale of computers keeps increasing, with the rise in parallel computing and so on, the reliability demanded of computers is also rising because of the wide variety of environments in which computers are used. Considering these circumstances, we believe that our two radiation-measurement methods will help improve the reliability of Fujitsu products.

Reference

1) R. I. Bramblett et al.: A New Type of Neutron Spectrometer. *Nuclear Instruments and Methods*, Vol. 9, No. 1, pp. 1–12 (1960).

Ryozo Takasu
Fujitsu Laboratories Ltd.
Dr. Takasu received a B.S. degree in Pharmaceutical Sciences from Toyama Medical and Pharmaceutical University, Toyama, Japan in 1991, an M.S. degree in Pharmaceutical Engineering from Kanazawa University, Kanazawa, Japan in 1994, and a Ph.D. degree in Functional Molecular Science from the Graduate University for Advanced Studies, Institute for Molecular Science, Okazaki, Japan in 1997. In 2001, he joined Fujitsu Laboratories Ltd., Atsugi, Japan, where he has been engaged in the development of new analytical techniques.