

CCD's post shipment blemish and cosmic ray

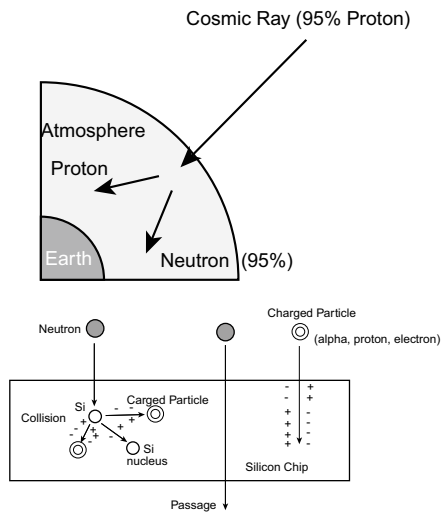
The effects of cosmic rays on semiconductors used at ground level were ignored, or little known, until IBM presented the results of an extensive study in 1996. (IBM Journal of Research and Development, vol. 40)

This study revealed a significant effect that natural cosmic rays have on memory chips; specifically, that cosmic rays cause a high percentage of soft errors. The architecture of a CCD image sensor is similar to that of a memory chip, but the impact of cosmic radiation is more severe and permanent.

In the CCD and CCD Camera industry, cosmic radiation been known to cause post-shipment blemishes or defects, where a single-pixel white defect suddenly occurs at a random location, even though the CCD was tested and certified at the factory to be blemish-free.

In this paper, we will discuss the main study performed at IBM, as well as an analysis performed by the Sony to relate this phenomenon to CCD manufacturing.

Cosmic Rays

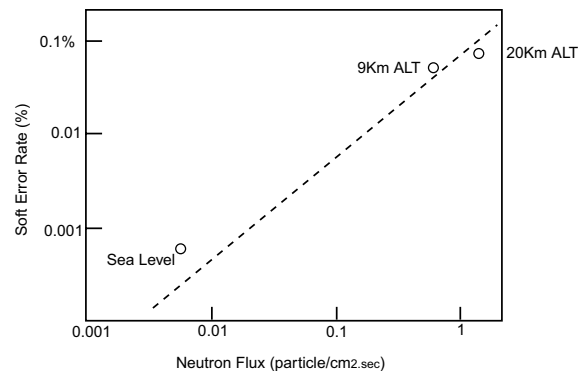
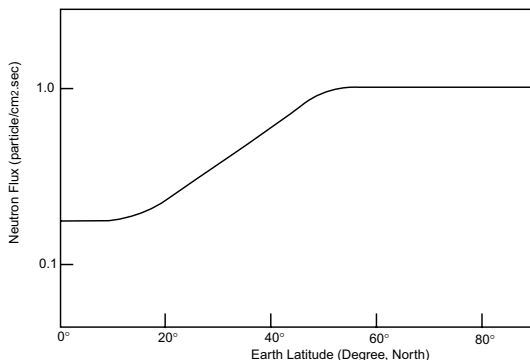


It is well known that memory chips (MOS or CMOS structure) experience occasional errors at random memory cell locations. The errors are transient; once the cell is refreshed, the error is corrected. This type of temporary defect is called a "soft error." One of the primary causes behind this phenomenon is natural radiation from Alpha particle sources. The major sources of Alpha particle emission have been found in the semiconductor material itself, as well as the materials used in packaging the die, and natural radiation from the ground (i.e. Radon.) In the IBM study, however, it was revealed that Cosmic Radiation also plays a significant role.

Alpha particle emission within the semiconductor material itself is negligible today, due to continuous improvements in semiconductor and packaging materials over the years. Cosmic Rays, however, continue to be a rare, but nonetheless harmful, source of radiation. Cosmic Rays, which are 95% protons, collide with the atmosphere to create energetic neutrons. The high-energy neutrons are capable of penetrating buildings, even those constructed with concrete walls up to 200 meters thick. When energetic neutrons strike silicon, the majority pass through without causing damage. If the energetic neutron happens to strike a nucleus in the silicon lattice, however, it results in the creation of charge particles. In the worst case, the collision can cause a dislocation of the silicon atom in the lattice.

When the collision causes a release of charged particles, the effect is typically transient. In the case of a memory chip, the resulting error is removed in the next refresh cycle of the memory cell. The same is generally true with a CCD – the effected captured image has a permanent artifact, but the problem disappears in the next captured frame.

If the incident radiation causes a dislocation of a Silicon atom, however, the damage can be permanent. In a CCD, a dislocated silicon atom can cause a change in channel potential, and the creation of local charge generation site, which can result in a permanent bright pixel. The affected pixel will have a slightly higher signal than its neighbors. The degree of the difference is proportional to the severity of the damage in the affected pixel, and is in general proportional to the energy of the incident particle.



Neutron Density

The IBM study shows that the soft error rate is proportional to the density of the incident energetic neutrons. The magnetic field of the earth forms a dipole, which causes the cosmic ray density at the surface of the earth to be highest near the poles, and lowest near the equator. Altitude also effects cosmic ray density. The neutron density at an altitude of 20,000 meters is nearly 100 times greater than that at sea level.

Post-Shipment Blemish

The probability of the occurrence of post-shipment a bright point blemish in a CCD image sensor, and the severity of the resulting defect, is proportional to the ambient neutron density. The physical size of the CCD die, and the depth of the photoactive region of the CCD also affect the probability of damage. A larger CCD has more surface area, so it has a higher probability of being struck by energetic neutrons. A CCD with a deeper active region – such as a sensor designed for high near infrared sensitivity, also has a higher probability of damage because the likelihood of a particle collision within the active regions is proportional to the distance the particle travels through the silicon. Interline CCD Image sensors optimized for Near Infrared response have a deeper active layer than standard interline CCDs.

A grade-A blemish-free CCD is specified to have less than 3 millivolts of signal under dark conditions (deviation from average signal level at 60 Degrees C). The post-shipment blemish probability per week at ground level is: 2.2% for a 2/3-inch CCD, 1.6% for a $\frac{1}{2}$ -inch CCD and 0.9% for a 1/3-inch CCD. The probability of a post-shipment blemish probability for a $\frac{1}{2}$ -inch NIR (Near Infrared) image sensor is approximately 6% due to the thicker active region.

If the blemish defect level is defined at 10 mV, the probability of the occurrence of a blemish is reduced to 0.7% for a 2/3-inch image CCD, 0.55% for a $\frac{1}{2}$ -inch CCD, 0.3% for a 1/3-inch CCD and 2.0% for a $\frac{1}{2}$ -inch NIR CCD.

Transportation by airplane

Shipment by air carries a much higher probability for the occurrence of white blemishes.

The following shows a typical example:

For a CCD manufactured in Japan and transported by air to JAI PULNiX's Sunnyvale, CA camera manufacturing facility, the flight takes around 13.5 hours. Shipment of completed cameras from the JAI PULNiX plant to our European offices requires an additional 15 hours of airborne time. The probability of the occurrence of a white blemish resulting due to total air transportation time is provided in the table below.

Blemish level > mV	1.4 mV	3.5 mV	7 mV	10.5 mV
Probability Japan - PULNiX per flight	11.3 %	8.4 %	5.1 %	3.3 %
Probability PULNiX - Europe per flight	12.6 %	9.3 %	5.7 %	3.7 %
Probability at ground per week Tokyo	0.9 %	0.4 %	0.2 %	0.2 %
Probability at ground per week Europe	2.0 %	0.9 %	0.5 %	0.3 %

Suggestions for critical applications

This phenomenon, which affects all CCDs and CCD Cameras, has only recently been identified. Post-shipment blemishes can occur randomly in any CCD. If your application is extremely sensitive to low-level white blemishes, JAI PULNiX suggests that you compensate for the variation by using background subtraction or any other pertinent method. Pixels affected by post-shipment blemishes remain light sensitive, but have a slight signal offset due to the added signal resulting from the defect.

JAI PULNiX cameras undergo thorough testing before they are shipped from the plant in Sunnyvale. Once the camera leaves the factory, we cannot protect the sensor from incident cosmic radiation. For the vast majority of applications, the occurrence of low-level pixel defects due to cosmic radiation is a non-issue. For the most demanding applications, however, the small probability of the occurrence of a low-level pixel defect should be taken into consideration in the overall imaging system design.

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