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An Overview of Effects of Space Radiation on the Electronics

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1. Introduction

The first Korean astronaut successfully carried out the scientific experiments at International Space Station (ISS) in April 2008. Due to the government's strong will and support for the field of space, Korea has enhanced its space technology based on the accomplishments in space development. On October 12~16, 2009 the 60th International Astronautical Congress (IAC) was held in Daejeon. IAC 2009 must serve as a place for the extensive exchange of global space technology and information in order to speed up the development of space technology in Korea. With regard for space research and development, the radiation effects in space have been reviewed from the viewpoint of electronics.

2. Space Radiation

Space radiation is different from the kinds of radiation on Earth, such as X-rays or gamma rays. It is made up of three kinds of radiation, all representing ionizing radiation as follows[1]:

(1) particles trapped in the Earth's magnetic fields – electrons and protons,
(2) particles shot into space during solar flares (solar particle events) – high energy protons,
(3) galactic cosmic rays – high energy protons and heavy ions.

Ionizing radiation can knock the electrons out of any atom it strikes. The interactions of these particles with electronics is too complex to well describe and also difficult to simulate them in the ground-based testing facilities. At high energies (millions of electron volts, eV), the particles have sufficient energy to ionize atoms in materials through which they propagate. At lower energies (below thousands of eV), their effects range from charge accumulations on surface to material degradations. The space radiation also can produce more particles, including neutrons as the secondary particles.

2.1 Space Environment

The space environment contains phenomena that are potentially hazard to the technological system. However, many of these hazards result from plasmas and higher energy electrons. Since space radiation comes in many forms, it affects electronic components in diverse way. The space environment can make havoc of unprotected electronics. The exposures to energetic particles can degrade device performance over time, ultimately leading to component failure. Heavy ions, neutrons, and protons can scatter the atoms in a semiconductor lattice, introducing noise and error sources. Cosmic rays and energetic particles speeding through space can strike microcircuits at sensitive locations, causing immediate upsets or transient events commonly known as single-event effects. Table 1 shows up the main categories of space radiation and indicates the feasibility of shielding each type in a typical satellite, for example and also typical effects on electronics by radiation exposure[2].

Table 1. Space Radiation: Categories

Radiation environment	Shielding feasibility	Typical radiation effects
Total ionizing Dose(TID)	Some	- Threshold shift in CMOS leading to failure of logic gates - CMOS field-oxide charge trapping, loss of isolation, excessive power-supply currents - Power transistor threshold shifts, loss of on/off control - Gain degradation in bipolar junction transistors
Neutron or proton flux events	Some	- Displacement damage effects - Gain degradation in bipolar junction transistors - Severe degradation of charge coupled devices (CCDs) and dynamic memory allocation performance - Damage to photo-detectors
Single-event phenomena	Some	- Ionization "track" by single heavy ion - Temporary logic scramble - Single bit errors in static memories - Localized latchup in CMOS integrated circuits - Gate rupture of power transistors - Temporary upset of analog devices such as amplifiers - Burnout of diodes, transistors - Discharge of capacitors

2.2 Space Electronics

The various means by which heavy ions, protons, and electrons interact with electronics has been investigated.

The typical integrated circuit contains various elements such as capacitors, resistors, and transistors embedded in a silicon (Si) substrate and connected by metallic vias ("holes" that allow electrical connections between front-side metal and the back-side ground plane or between planes in a multilayer structures). Where, a "hole" is the absence of an electron, or a missing bond that can hop from atom to atom like a positive charge carrier. These elements are separated by dielectrics and covered by protective layers and glasses. Various types of semiconductors are used in microelectronics. For example, the negative metal-oxide semiconductor (NMOS) transistor's operation is based on the flow of negatively charged electrons. The positive metal-oxide semiconductor (PMOS) transistor operates being based on the flow of positive charges, carried by holes. The CMOS employs both of these on the same chip. The CMOS technology is commonly found in digital circuits such as microprocessors and memories, analog circuits such as operational amplifiers, and mixed-signal devices such as analog-to-digital converters. All of these are generally found in the space electronics.

3. Radiation Dosimetry

When energetic particles enter a target material, they ionize some of the atoms of the target by breaking bonds. This requires, 2 ~ 20 eV per bond depending on the material. The ability of the radiation to deposit energy per unit mass of the target material is defined as the "radiation dose" expressed in Gy (gray) unit. For the Si target material, it is customary to use Gy(Si) because the different materials have different abilities to absorb energy from a given ionizing radiation field.

3.1 Total Dose Effect

Total dose refers to the integrated radiation dose that is acquired by space electronics over a certain period of time. The energetic ions can cause damage to materials by breaking and/or rearranging atomic bonds. In general, after exposure to sufficient total dose radiation, most insulating materials such as capacitor dielectrics, circuit-board materials, and cabling insulators become less insulating or become more electrically leaky. Similarly, certain conductive materials such as metal-film resistors can change their characteristics under exposure to total dose radiation. The metal conductors and magnetic materials tend to show the radiation hardness to radiation effects. Semiconductor devices in particular exhibit a number of interesting effects. However, it is important to choose materials and components for space electronics that have the necessary radiation tolerance for the given mission. The most ubiquitous component is the MOS transistor. In a CMOS logic gate consisting of NMOS and PMOS transistors, the output will be frozen at either a "1" or a "0" after a sufficient dose is accumulated, and the device will cease to function. Bipolar-junction transistors are also sensitive to total ionizing dose. Degradation such as a loss of conductance and an increase in noise are capable of causing circuit failures.

3.2 Neutron or Proton Damage

When highly energetic neutrons or protons penetrate the crystal lattice of a semiconductor, atoms can get displaced through several mechanisms. If the incident particles transfer its enough energy (~ 25 eV) to Si nucleus, the nucleus gets knocked out of position. Then the resulting crystal lattice contains voids where Si atoms occupied and clusters where they came to rest. These sites well known as traps or recombination centers, respectively, can be a source of problems in some semiconductor devices. When the transistor is exposed to neutrons or protons, displacement damages and new recombination centers are created. Higher rates of recombination and also lower transistor gain result in the transistor fails in bipolar integrated circuits because its gain too low to provide amplification.

3.3 Single-Event Effects

This category of radiation effects is the only one in which a high energy single particle is the source of the electronic trouble[2]. Highly energetic ions such as cosmic rays can easily penetrate the structure of space electronics, pass through internal components, and exit the structure in a straight line. Because the heavy particles are omni-directional, they impinge on an integrated circuit at random times and locations. While an energetic ion passes through a semiconductor device in a picoseconds, it leaves behind a "track" or column of ionized material. If a cosmic ray passes through the drain region of an NMOS transistor, a short is momentarily created between the substrate and the drain terminal. When this happens, the amount of charges being collected from the ion tracks is significant and cause a single-event upset.

4. Conclusions

The investigations of how energetic particles interact with electronics in harsh space are presently important for space research and development in Korea. Therefore, it is fairly proposed that understanding effects of space radiation on the electronics is the first step in establishing the national space radiation standards associated with radiation-hardening technology for electronics[3,4].

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