Review Article

Journal of Advanced Materials Science and Engineering

Application of Materials in Radiation Hardening

Bahman Zohuri*

Adjunct Professor, Computer Science and Electrical, Computer Engineering, New Mexico.

***Correspondence:**
Bahman Zohuri, Ph.D., Adjunct Professor, Artificial Intelligence and Machine Learning, New Mexico.

Received: 23 May 2021; **Accepted:** 10 June 2021

Citation: Zohuri B. Application of Materials in Radiation Hardening. J Adv Mater Sci Eng. 2021; 1(1): 1-4.

ABSTRACT

Radiation shielding is an imperative as radiation can be serious concern within in such environment, where this environment can be either natural or man-made. The natural radiation source like solar wind that is consisting of Electron, Gamma, Protons, Neutrons, or Van Allen Belt, etc. while, the source of man-made is nuclear power facilities or either Exo-Atmospheric or Endo-Atmospheric nuclear explosion. The effects of nuclear explosions produce both immediate and delayed destructive effects, that requires choice of right and proper protective materials for ICs to be shielded and survivable in such radiation environment driven by a nuclear weapon burst. Nuclear weapon effects in term of blast, thermal radiation, electromagnetic pulse, and prompt ionizing radiation, etc. are part of concerns for choosing the proper materials. Radiation shielding is based on the principle of attenuation, which is the ability to reduce a waves or ray's effect by blocking or bouncing particles through a barrier material. This short review is discussing different holistic issues in respect to selected materials and integrated circuits in respect to survivability and shielding within a radiation environment, either man-made or natural.

Keywords
Integrated Circuits, Digital Circuits, Radiation Shielding, Electromagnetic Pulse, Electromagnetic Interference, Electromagnetic Compatibility.

Introduction
To start with, we introduce the basic concept of radiation by describing what it is and then we move on to introduce types of shielding materials that we need to protect our assets, as well as going through different radiation types of radiation as illustrated in Figure-1, that we need to shield ourselves, biologically, health care wise and medical imaging to the yields from nuclear energy burst, nuclear medicine and non-destructive testing cross different industries and on earth and in the space as well as ground assets within defense communities.

With today's usage of electronic gadgets, we are relying more and more on telecommunication via satellites and other means that solid state Integrated Circuits (ICs) that are in heavy use in our remote locations and even passing through solid structures.

As we have illustrated in Figure-1 elements radiation is consistent of Alpha (α), Beta (β), Gamma (δ), and Neutron (n) particles within any X-Ray radiation of Cold or Hot type radiation.

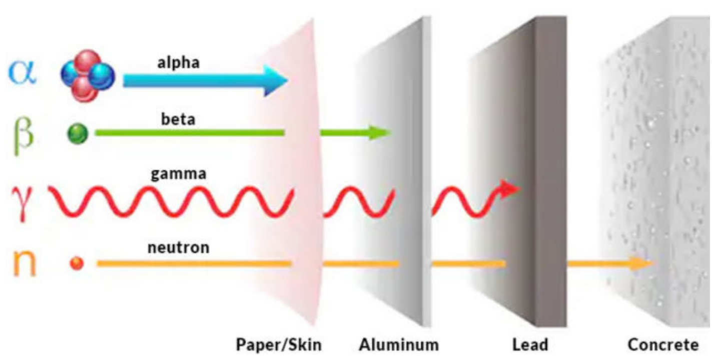

Figure 1: Particle Radiation Characteristics (Courtesy of Paul Rochus, marsmetal.com).

In case of naturally induced radiation, Figure-2 is presentation of such source in form of Solar Winds, Galactic, and Extra-Galactic sources or even Earth's Magnetic Field and Van Allen Belts can be considered as natural radiation sources as illustrated in Figure 3.

Man-made radiation source could be introduced by means nuclear detonation, industrial nuclear power plants facilities, industrial or medical X-Ray systems, radioisotope projects, particle accelerator work, and a number of other circumstances as illustrated in Figure 3.

Containing radiation and preventing it from causing physical harm to employees or their surroundings is an important part of operating equipment that emits potentially hazardous rays. Preserving both human safety and structural material that may be compromised from radiation exposure are vital concerns, as well as shielding sensitive materials, such as electronic devices and photographic film.

The process of regulating the effects and degree of penetration of radioactive rays varies according to the type of radiation involved. Indirectly ionizing radiation, which includes neutrons, gamma rays, and x-rays, is categorized separately from directly ionizing radiation, which involves charged particles. Different radiation shielding materials are better suited for certain types of radiation than others, as determined by the interaction between specific particles and the elemental properties of the shielding material.

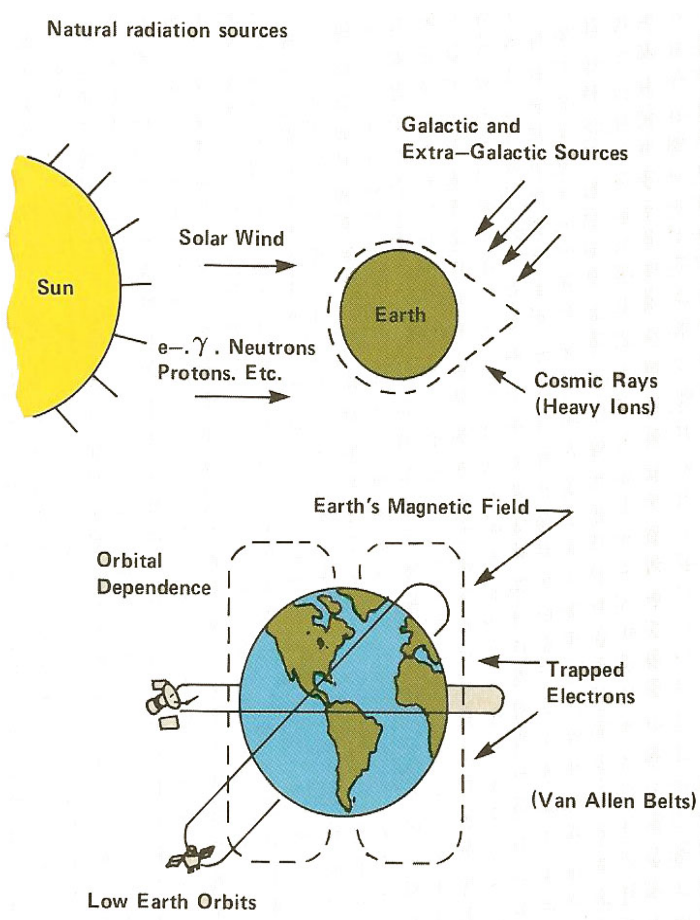

Figure 2: Natural Radiation Source (Source: Defense Electronics June 1988).

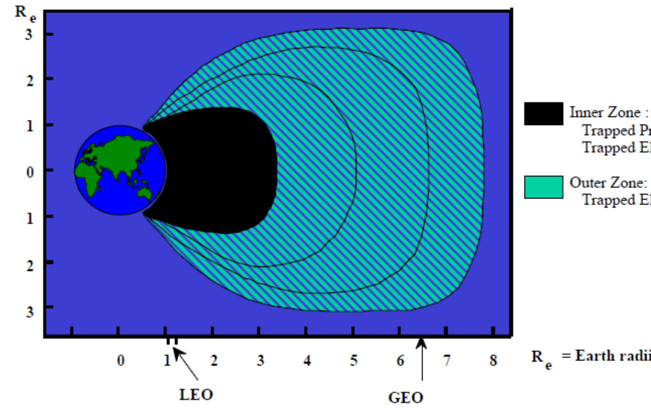

Figure 3: Radiation Environment (Source; The Aerospace Corporation, 2001).

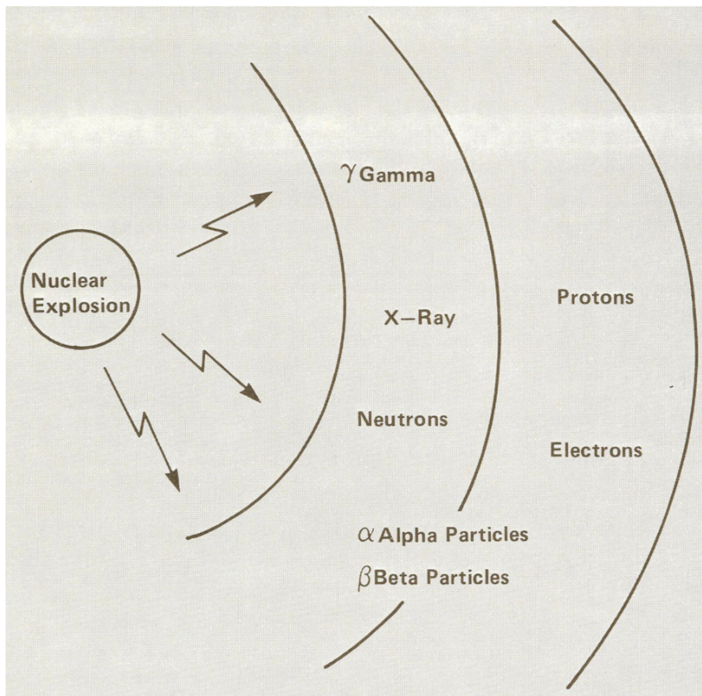

Figure 4: Man-Made Nuclear Explosion Radiation Source (Source: Defense Electronics June 1988).

The process of regulating the effects and degree of penetration of radioactive rays varies according to the type of radiation involved. Indirectly ionizing radiation, which includes neutrons, gamma rays, and x-rays, is categorized separately from directly ionizing radiation, which involves charged particles. Different radiation shielding materials are better suited for certain types of radiation than others are, as determined by the interaction between specific particles and the elemental properties of the shielding material.

Moreover, in the case of digital circuits, this can lead to results that are inaccurate or unintelligible. It is a particularly serious problem in designing artificial satellites, spacecraft, military aircraft, nuclear power stations and nuclear weapons. Typical sources of exposure of electronics to ionizing radiation are the Van

Allen radiation belts for satellites, nuclear reactors in power plants for sensors and control circuits, residual radiation from isotopes in chip packaging materials, cosmic radiation for spacecraft and high-altitude aircraft and nuclear explosions for potentially all military and civilian electronics [1].

As part of protecting the ICs or any other assets against radiation threat is the shielding and packaging materials. Is the way to go, as it was stated in above.

When it comes to protecting against radiation, the basic radiation protection principals or radiation safety tips involve time, distance, and shielding. Time, in this case, means to limit exposure to the minimum amount possible. Distance means staying as far from radiation sources as possible as a best practice. The intensity of radiation generally follows the inverse square law, meaning that it falls off with the square of the distance from the source. Moving twice the distance away from a source of radiation reduces the intensity of exposure by a factor of $1/2^2$ or one fourth the value.

Beyond time and distance, making use of effective shielding is the other approach to managing exposure to radiation.

But what materials protect against radiation? The most common ones used include lead, concrete, and water - or a combination of these.

Radiation shielding is based on the principle of radiation attenuation, which is the ability to reduce a wave or ray's effect by blocking or bouncing particles through a barrier material.

Charged particles may be attenuated by losing energy to reactions with electrons in the barrier, while x-ray and gamma radiation are attenuated through photoemission, scattering, or pair production. Neutrons can be made less harmful through a combination of elastic and inelastic scattering, and most neutron barriers are constructed with materials that encourage these processes. The main types of radiation encountered in industrial projects are defined as below.

X-Ray and Gamma Radiation Shielding Materials

Generally speaking, in most common cases, radiation such as X-Ray or Gamm-Radiation source, either natural or man-made, high density-density materials with high atomic number Z are more effective than low-density with atomic number Z alternatively has a better shielding effect for blocking or reducing the intensity of radiation.

However, low-density materials can compensate for the disparity with increased thickness, which is as significant as density in shielding applications. Lead is particularly well-suited for lessening the effect of gamma rays and X-Rays due to its high atomic number. This number refers to the number of protons within an atom, so a lead atom has a relatively high number of protons along with a corresponding number of electrons. These electrons block many of the gamma and x-ray particles that try to pass through a lead barrier, and the degree of protection can be compounded with thicker shielding barriers. However, it is important to remember that there is still potential for some rays making it through shielding and that an absolute barrier may not be possible in many situations [2].

Alpha and Beta Shielding

In most cases, high-density materials are more effective than low-density alternatives for blocking or reducing the intensity of radiation. However, low-density materials can compensate for the disparity with increased thickness, which is as significant as density in shielding applications. Lead is particularly well-suited for lessening the effect of gamma rays and x-rays due to its high atomic number. This number refers to the number of protons within an atom, so a lead atom has a relatively high number of protons along with a corresponding number of electrons. These electrons block many of the gamma and x-ray particles that try to pass through a lead barrier, and the degree of protection can be compounded with thicker shielding barriers. However, it is important to remember that there is still potential for some rays making it through shielding and that an absolute barrier may not be possible in many situations [2].

Neutron Shielding

Material such as Lead is quite ineffective for blocking neutron radiation, as neutrons are uncharged and can simply pass through dense materials. Materials composed of low atomic number elements are preferable for stopping this type of radiation because they have a higher probability of forming cross-sections that will interact with the neutrons. Hydrogen and hydrogen-based materials are well suited for this task. Compounds with a high concentration of hydrogen atoms, such as water, form efficient neutron barriers in addition to being relatively inexpensive shielding substances. However, low-density materials can emit gamma rays when blocking neutrons, meaning that neutron radiation shielding is most effective when it incorporates both high and low atomic number elements. The low-density material can disperse the neutrons through elastic scattering, while the high-density segments block the subsequent gamma rays with inelastic scattering [3].

Because neutron radiation presents so many inherent dangers, top-of-the-line neutron shielding protection is critical. Neutrons have neither a positive nor a negative charge, resulting in a wide range of energy and mass levels that must be blocked. Neutron radiation dangers, therefore, must be handled with the utmost care and attention to detail, whether dealing with nuclear power facilities, medical X-Ray systems, radioisotope projects, or particle accelerator work. Hazardous rays can cause serious and long-lasting physical harm to the people exposed to them, and structural material and environments can also be damaged beyond repair by radioactive waves. Electronic devices and photographic film, in particular, are a couple of the more sensitive mediums that can be easily damaged [3].

In case of man-made situation similar scenarios as defined in above are also applicable, where out of space assets need to be protected accordingly.

Radiation Effects on Electronic Systems

Radiation effects on electronic system has been known more than 4 decades ago and has been under study and consideration by military as part of their shielding and survivability of their assets bot in space and ground as well due to impact of Electro-Magnetic Pulse (EMP), which causes also a phenomena know as Electro-Magnetic Interference (EMI). Protecting the Integrated Circuits (ICs) against EMP and EMI is rather an imperative issue that requires a radiation hardened solutions that should prevent any latch up that may take place in solid-state integrated circuits.

Today's technologies in radiation hardening are offering many modern approaches for producing radiation hardened solutions, where the electronic components and systems are highly susceptible to damage and functions caused by ionizing radiation environments either natural or man-made one. These environments may be encountered in high altitude flight and in outer space, as well as in the vicinity of nuclear reactor devices or nuclear detonation as well. However, in case of ensuring the reliable operation of electronics subjected to such environments, a variety of techniques can be employed to make them radiation tolerant.

These modern approaches to discipline of radiation hardening combines information from solid states and semiconductor device physics, electronic circuit analysis and synthesis, nuclear physics, electromagnetics, and statistical inferences theory.

Few of these modern approaches are name here as:
1. Rad Hard by Design Components.
2. Spot Shielding.
3. Error-Correction Code (ECC) Memory.
4. Commercial Off-the-Shelf Components.
5. Space-Qualified Designers and Manufacturers

Detailed description of each of above approaches beyond the scope of this short review article and readers should do their own investigation over Internet.

In summary, radiation hardening is the process of making electronic components and circuits resistant to damage or malfunction caused by high levels of ionizing radiation (particle radiation and high-energy electromagnetic radiation) especially for environments in outer space (especially beyond the low Earth orbit), around nuclear reactors and particle accelerators, or during nuclear accidents or nuclear warfare.

Most semiconductor electronic components are susceptible to radiation damage, and radiation-hardened components are based on their non-hardened equivalents, with some design and manufacturing variations that reduce the susceptibility to radiation damage. Due to the extensive development and testing required to produce a radiation-tolerant design of a microelectronic chip, radiation-hardened chips tend to lag behind the most recent developments.

Radiation-hardened products are typically tested to one or more resultant effects tests, including Total Ionizing Dose (TID), Enhanced Low Dose Rate Effects (ELDRS), neutron and proton displacement damage, and Single Event Effects (SEEs).

Conclusion

With the development of astronautic techniques, the radiation effects on Integrated Circuits (ICs) have been recognized by people. Environments with high levels of ionizing radiation create special design challenges for ICs. To ensure the proper operation of such systems, manufacturers of integrated circuits and sensors intended for the military aerospace markets adopt various methods of radiation hardening.

The environmental conditions that the shielding is placed in is also important to consider. How well a material can withstand heat, if the shielding will be moved and potentially bumped and if the material must hold any structural load are all important factors in the environment that need to be considered. Shielding properties can change when put under stress or heated. Dents and damage to the material may also lessen the ability for a material to shield properly [6].

Safety is important in selecting the right shielding solutions. Leaded glass for example comes in several options including safety glass. Clear Leaded Acrylic is also a viable option to making durable clear shielding that is shatter resistant. Exposed lead may not be permitted in some scenarios due to the toxicity of lead, so polymers mixed with bismuth, tungsten or iron may be a better, non-toxic alternative [4].

Cost is an important to consider when selecting the appropriate shielding material for a job. Lead is a very effective and inexpensive shielding material compared to materials like tungsten and could work just as well for many scenarios. Related to cost, another factor that needs to be considered is the ease of shipping, handling, and installation. Choosing between installing leaded drywall or sheet lead is one example where shipping and installation need to be considered [4].

References

1. Holmes-Siedle AG, Adams L. Handbook of Radiation Effects. Oxford University Press, England.2002.
2. https://www.thomasnet.com\Radiation Shielding Materials-A Guide.mht
3. https://www.frontier-cf252.com/neutron-shielding/
4. Paul Rochus Shielding Technician, prochus@marsmetal.com.