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Monte Carlo Simulation of Cosmic Radiation induced Neutron Spectrum during Air Transport of Packaged Semiconductors

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1. Introduction

The Galactic Cosmic Rays (GCRs) are highly energyetic particles that flow into our solar system from outer space. These GCRs collide with atoms and molecules, mainly oxygen and nitrogen when they enter the Earth's atmosphere. The interaction produces a cascade of lighter particles such as neutron, pion, electron, muon, and photon. The neutrons occupy large amount at the flight altitude of approximately 10 km, which can induce severe failures of packaged semiconductors in air transport. The origin of permanent damage in semiconductor due to neutron is suspected in the cases where the insulating property of oxide layer is destroyed. When some defects are created and overlapped in the oxide layer by displacement, a conduction path can be generated. This degradation of oxide layer results in the short channel effect of MOSFET in the semiconductor. The other thing is breakdown caused by electron hole pairs in the silicon substrate near the gate oxide. Nowadays, the thickness of the oxide layer is not only thin under 10 nm, but also has a sharp structure, therefore, the electric field become dense. The dielectric breakdown of the oxide layer can occur owing to the large electric field. To prevent the huge economic loss because of failure in semiconductor during air transport, the neutron energy spectrum reaching to the semiconductor should be obtained. Therefore, in this study, Monte Carlo simulation was performed to predict the neutron energy spectrum at the flight altitude and after passing the different packaging box.

2. Methods and Results

In this section, some of the calculation techniques used to calculate the neutron spectrum are described. Since Monte Carlo N-Particle (MCNP) code was realeased recently and includes the most recent cosmic ray data, the Monte Carlo simulation was performed using MCNP 6.2 code [1].

2.1 Cosmic Source Option

The cosmic ray source built in MCNP is energy spectrum of proton and alpha at 65 km altitude depending on the date and location on the Earth. Since proton and alpha account for 99% of primary cosmic rays, it is reasonable to consider that only these two particles contribute to generate secondary cosmic rays when they react with atmosphere. The date and location are related to the solar modulation and the geomagnetic filed on the Earth, respectively. To verify the spectrum of the primary cosmic ray at 65 km altitude, the vacuum cylinder was created and the spectrums are presented in Fig. 1. The proton and alpha spectrum follows the sine graph with a period of 11 years which is coincident with solar modulation.

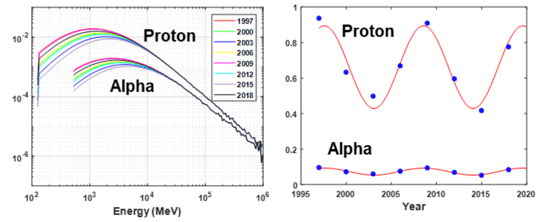


Fig.1 The primary cosmic ray spectrum at the 65 km altitude built in MCNP code.

2.2 Neutron Spectrum at the Flight Altitude

The cylinder with 65 km height and 50 km diameter was used to calculate the neutron spectrum at the flight altitude generated by interactions of primary cosmic rays and the Earth's atmosphere. The density is changed according to the altitdude using the measured data [2].

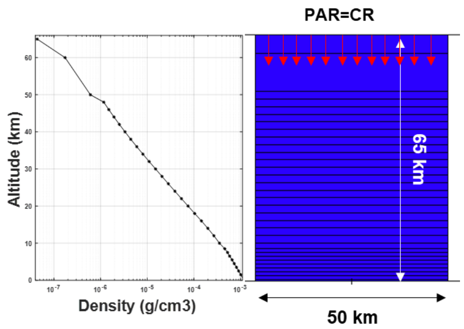


Fig. 2. Simulation geometry to calculate neutron spectrum outside the airplane.

The neutron spectrum obtained from above MCNP model is represented in Fig. 3, which has highly similar shape with previous research [3].

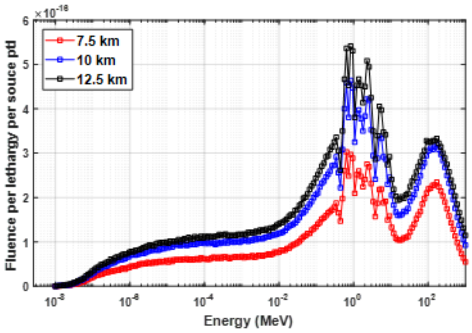


Fig. 3. The neutron energy spectrum at the flitght altitude.

2.3 Neutron Spectrum passing after the Packaging Box

Fig. 4 shows the MCNP geometry to calculate the neutron spectrum passing after airplane and the packaging box. The material of airplane surface has thickness of 6 mm with aluminum and carbon fibers. The packaging box material was assumed to 10 mm thickness consisted of cellulose and polyethylene. The neutron spectrum at each position was represented in Fig. 5. The thermal neutrons are increased when the neutrons pass through the packaging material because the polyethylene of the packaging material deaccelerate the fast neutrons to thermal range because of its low atomic number.

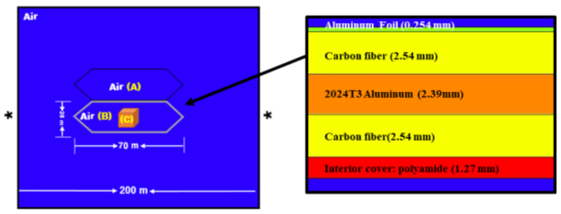


Fig. 4. The neutron energy spectrum at the flitght altitude.

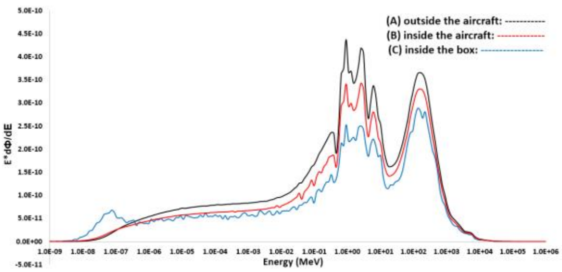
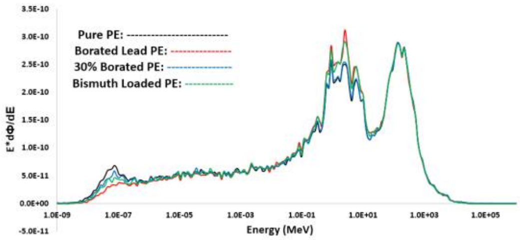


Fig. 5. The neutron spectrum at each position of interest.

2.4. Neutron Spectrum of Various Packaging Box Material

To optimize the neutron spectrum that encounter the semiconductor inside the packaging box, four commercial polyethylene (PE) material such as pure PE, borated lead PE, 30% borated PE, and bismuth loaded PE were adopted. The neutron spectrums for theses cases were represented in Fig. 6.



When the borated lead PE was used, the thermal neutrons are least generated. This is because the boron included in this PE has large neutron absorption cross section particularly in thermal range. However, the boron composition was increased in the PE, the PE is decreased, which weaken the slowing down of fast neutrons to thermal neutrons.

3. Conclusion

Monte Carlo simulations using MCNP 6.2 were done to obtain neutron spectrum at the flight altitude and inside the semiconductor packaging box. As a result, the packaging box material can affect the quantity of neutrons especially for thermal range. For the optimization of packaging box material, further study about correlation between the neutron spectrum and the failure of semiconductor would be required.

REFERENCES

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