CAN RADIATION DAMAGE ELECTRONIC COMPONENTS?

PRESENTED BY CREATIVE ELECTRON
What kind of ionizing radiation semiconductors are most frequently subject to?

- **Electromagnetic:**
  - X-rays
  - Gamma rays

- **Subatomic particles:**
  - Protons
  - Neutrons
  - Electrons
  - Pions
  - Muons
## Not all radiation is equal

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Alpha (α)</th>
<th>Proton (p)</th>
<th>Beta (β) or Electron (e)</th>
<th>Photon (γ or X ray)</th>
<th>Neutron (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>$^{4}2\alpha$ or He$^{2+}$</td>
<td>$^{1}1p$ or H$^{1+}$</td>
<td>$^{0}0e$ or β</td>
<td>$^{0}0\gamma$</td>
<td>$^{1}0n$</td>
</tr>
<tr>
<td>Charge</td>
<td>+2</td>
<td>+1</td>
<td>–1</td>
<td>neutral</td>
<td>neutral</td>
</tr>
<tr>
<td>Ionization</td>
<td>Direct</td>
<td>Direct</td>
<td>Direct</td>
<td>Indirect</td>
<td>Indirect</td>
</tr>
<tr>
<td>Mass (amu)</td>
<td>4.001506</td>
<td>1.007276</td>
<td>0.00054858</td>
<td>1.008665</td>
<td></td>
</tr>
<tr>
<td>Velocity (cm/sec)</td>
<td>6.944×10$^8$</td>
<td>1.38×10$^9$</td>
<td>2.82×10$^{10}$</td>
<td>c=2.998×10$^{10}$</td>
<td></td>
</tr>
<tr>
<td>Speed of Light</td>
<td>2.3%</td>
<td>4.6%</td>
<td>94.1%</td>
<td>100%</td>
<td>4.6%</td>
</tr>
<tr>
<td>Range in Air</td>
<td>0.56 cm</td>
<td>1.81 cm</td>
<td>319 cm</td>
<td>82,000 cm*</td>
<td>39,250 cm*</td>
</tr>
</tbody>
</table>

*range based on a 99.9% reduction

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**Alpha particle:**
- Easily stopped
- Least penetrating

**Beta particle:**
- Very much smaller
- More penetrating

**Gamma ray and X-ray:**
- Pure energy with no mass
- Most penetrating

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K. E. Holbert, Radiation Effects Damage

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What are the sources of exposure for semiconductors?

- **Background**
  - Terrestrial: dependent on location.
  - Cosmic: dependent on altitude.

- **Man made**
  - Inspection on airports, ports, post offices, and delivery companies.
  - Inspection for quality assurance, failure analysis, and counterfeit detection.
What are the factors that increase the probability of component damage?

- **Radiation type:** Larger particles have higher probability of damage due to their cross section. Electromagnetic radiation such as gamma or x-rays need a huge amount of energy to cause bulk damage on silicon.

- **Energy:** The energy will be one of the main factors that will define the probability of interaction with matter.

- **Radiation flux:** Higher fluxes will increase the probability of damaged if the minimum energy threshold is reached.

- **Exposure time:** The time of exposure combined with the three factors above will define the total dose that the part is submitted.
What kind of damage radiation can cause on semiconductors?

- **Bulk damage**: Occurs when the energy transferred to the silicon atom is sufficient to remove it from the crystal lattice. This damage is permanent.

- The great majority of currently available X-ray inspection systems simply don’t have enough energy to cause this kind of damage.

- **Surface damage**: the passage of ionizing radiation in the silicon oxide on semiconductors causes the build up of trapped charge in the oxide layers of the semiconductor. With time, or high flux, the e-h pairs created in the oxide either recombine or move towards the SiO2-Si interface, altering the characteristics of the semiconductor.

- **Single event upset**: is a change of logical state caused by passage of radiation. This does not cause permanent damage on the semiconductor. It has potential to alter microcode or configware resident on certain devices such as FPGA’s and memory circuits.
Putting radiation exposure in perspective: Transportation exposure

When cosmic rays enter the Earth's atmosphere they collide with molecules, mainly oxygen and nitrogen, to produce a cascade of billions of lighter particles, a so-called air shower.

An average of 0.6 mR per hour at cruise altitude.
Radiation type: Neutrons, protons, pions, muons, and gamma.
Putting radiation exposure in perspective: Mandatory inspection

• Any kind of cargo (including electronic parts) can go under mandatory x-ray inspection in ports of entry and airports.
• It is not unusual to have electronic components being inspected with x-ray machines several times when moving from one country to another.
• Port and airport x-ray machines are not designed to limit the amount of radiation cargo is exposed to.
• Exposure due to these systems can easily accumulate to several hundreds of mR.
Putting radiation exposure in perspective:
Counterfeit and quality control X-ray systems

- Typically X-ray systems deployed for counterfeit detection and quality control are in the range of 50kV to 150kV.
- A good digital image can be achieved with an exposure time between 200 and 500ms.
- Considering that x-ray systems expose parts for only 1.5s at 80kV as a benchmark. Each inspected part will receive on average 50mR of total dose.
How we minimize radiation exposure?

- Radiation Dose
  - Time
  - Radiation level
  - Distance

- Time ➔ Automation for reels, trays, tubes
- Radiation level ➔ Shielding
- Distance ➔ CCD Camera
Automation is key to reduce exposure

- Each component exposed to radiation for only 1.5s
- Automated image acquisition
- No human interference to take image of each component
Automated Reel-to-Reel Inspection
Shielding – only expose part on field of view
Distance

\[ D = d_1 + d_2 \]

\[ E \propto \frac{1}{d_1^2} \]

\[ M \propto \frac{1}{d_2} \]
Summary

- Particles (protons, electrons) cause more damage to semiconductors than photons (x-ray)
- X-ray inspection systems used for counterfeit detection don’t have enough energy (<120kV) to cause bulk damage to silicon
- Radiation type, power, distance, and time matters a lot
- Automated systems expose components to an average of 50mR (0.050R)
- Most components show failures starting at least at a few thousands of R, or millions of mR
- Commercial airplanes are exposed to ~30,000mR of background radiation that has more particles than what’s found in x-ray cabinet
- Wide safety margin to inspect components using x-rays
- Most radiation tolerance tests are done with particles, not photons

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