RADIATIONHARDENINGOF SEMICONDUCTORS

Nidhi Chauhan, monakumari , poojakumari

DRONACHARYA COLLEGE OF ENGINEERING,GURGAON

ABSTRACT: **The purpose of this paper is to explain and demonstrate the effects of radiation on semiconductors and need of radiation hardening for electronic components to resolve the problems caused by ionising radiations(particle radiation and high energy electromagnetic radiations).**

I. INTRODUCTION

Radiation hardening is the act of making electronic components and systems resistant to damage or malfunctions caused by ionizing radiation such as those encountered in outer space, high altitude flight, around nuclear reactors, particle accelerators, during nuclear warfare and nuclear accidents.

Most semiconductor electronic components are susceptible to radiation damage; radiation hardened components are based on their non-hardened equivalents with some design & manufacturing variations that reduce the susceptibility to radiation damage. Due to extensive development& testing required these chips tend to lag behind the most recent developments.

these products are tested by many tests including Total ionizing dose(TDL), enhanced low dose rate effects(ELDRS), neutron & proton displacement damage and single event effects(SEE,SET,SEL&SEB).

II. PROBLEMS CAUSED BY RADIATIONS

Environment with high levels of ionizing radiation createspecial design challenges. A single charged particle can knock thousands of electrons loose, causing electronic noise& signal spikes. In digital circuits this can cause results which are inaccurate or unintelligible. This is particularly a serious problem in the design of artificial satellites, spacecrafts, military aircrafts, nuclear power stations and nuclear weapons. In order to ensure proper operation manufacturers of IC'S and sensors employ various methods of radiation hardening.

III. MAJOR RADIATION DAMAGE SOURCES

Typical sources of exposure of electronics to ionizing radiation are: (i) Van Allen radiation belts for satellites, (ii) nuclear reactors in power plants for sensors& control circuits, (iii) particle accelerators for control electronics particularly particle detector devices, (iv) residual radiation from isotopes in chip packaging materials, (v) cosmic radiation for spacecrafts and high altitude aircrafts,(vi) nuclear explosions for potentially and military.

IV. RADIATION EFFECTS ON ELECRONICS

- FUNDAMENTAL MECHANISMS:

(i) Lattice Displacement:caused by neutrons, protons, alpha particles, heavy ions and very high energy gamma photons. They change the damage and increasing the no. of recombination carriers and worsening the analog properties of the affected semiconductor junctions. This type of problem is particularly significant in bipolar transistors which are dependent on minority carriers in their base regions, increased losses caused by recombination cause loss of the transistor gain.

(ii)Ionisation Effects: are caused by charged particles including the ones with energy too low to cause lattice effects. The ionization effects are usually transient, creating glitches and soft errors but can lead to destruction of the device if they trigger other damage mechanisms. Gradual accumulation of holes in the oxide layer in MOSFET transistor leads to worsening of the performance.

- RESULTANT EFFECTS:

(i) Neutron effects: A neutron interacting with semiconductor lattice will displace its atoms. This leads to an increase in the count of recombination centres and deep level defects, reducing the lifetime of minority carriers thus affecting bipolar devices more thenCMOS ones. GaAS, LEDs, common in optocouplers are very sensitive to neutrons.

(ii) Total ionizing dose effects: The cumulative damage of the semiconductor lattice caused by the ionizing radiation over the explosion time. It is measured in rads and causes slow gradual degradation of the device performance. In CMOS devices the radiation creates electron hole pairs in the gate insulation layers which causes photocurrents during their recombination and the holes trapped in the lattice defects in the insulator create a persistent gate biasing and influence the transistors threshold voltage, making the p-type ones more difficult to switch ON.

(iii) Systems generated EMP effects(SGEMP) are caused by the radiation flash travelling through the equipment and causing local ionization and electric current in the material of the chips, circuit boards cables.

- DIGITAL DAMAGE (Single event effects (SEE)):are phenomenon affecting mostly digital devices. When a high energy particle travels through a semiconductor it leaves an ionized track behind. This ionization may cause a highly localised effect similar to the transient dose one a begin glitch in the output, a less begin bit flip in the memory or a register or especially in high power transistors, a destructive latch up and burnout.

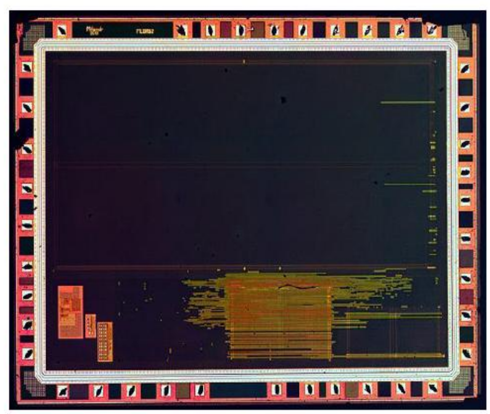
(i) Single event upsets(SEU) or transient radiation effects in electronics are state changes of memory or register bits caused by a single ion interacting with the chip. They do not cause lasting damage to the device, but may cause lasting problems to a system which cannot recover from such an error.

(ii) Single event latchup(SEL): can occur in any chip with a parasitic PNPN structure. A heavy ion or a high energy proton passing through one of the 2 inner transistor junctions can turn on the thyristor like structure which then stays shorted until the device is power cycled.

(iii) Single event induced burnout(SEB): happens when the charge collected from an ionization event discharges in the form of a spurious signal travelling through the circuit.

(iv) Single event induced burnout(SED): may occur in power MOSFETS when the substrate right under the source region gets forward biased and the drain source voltage of the parasitic structures. The resulting high current & local overheating then may destroy the device.

- SEE TESTING: While proton beams are widely used for SEE testing due to availability,at lower energies proton irradiation can often underestimate SEE susceptibility. White neutron beams-while ostensibly the most representative. SEE test method-are usually derived from solid target based sources, resulting in flux non uniformity and small beam areas. The disadvantages of both proton & spallation neutron sources can be avoided by using mono-energetic 14 MeV neutrons for SEE testing. The first developed SEE testing laboratory in Canada in currently being established in southern Ontario under the name RE Labs inc.
- RADIATION-HARDENING TECHNIQUES:

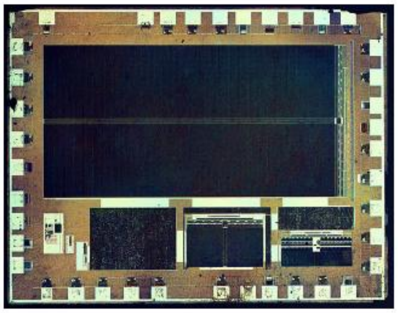


Radiation hardened die of the 1886VE10 microcontroller prior to metalization etching

- PHYSICAL: Hardened chips are often manufactured on insulating substances instead of the usual semiconductors wafers. Silicon on insulator(SOI) andSapphire(SOS) are commonly used.
- Bipolar integrating circuits generally have higher radiation tolerance then CMOS circuits. The low power Schottky(LS) 5400 series can withstand

1000 krad and many ECL devices can withstand 10000 krad.

- Magnetoresistive RAM or MRAM is considered a likely candidate to provide radiation hardened, rewritable, nonvolatile conductor memory.



Radiation hardened die of the 1886VE10 microcontroller after a metalization etching process has been used

- Shielding the package against radioactivity to reduce exposure of the bare devices.
- Capacitor base DRAM is ofter replaced by more rugged SRAM.
- Choice of substrate with wide band gap, which gives it higher tolerance to deep-level defects e.g. Silicon Carbide or Gallium Nitride.

V. MILITARY AND SPACE INDUSTRY APPLICATION

Radiation hardened & radiation tolerant components are often used in military & space applications. These applications may include.

- POL Applications.
- Satellite system power supply.
- Step down switching regulator.
- Microprocessor,FPGA Power source
- High efficiency,low voltage Subsystem power supply.

VI. NUCLEAR HARDENESS FOR TELE COMMUNICATION

In telecommunication the term nuclear hardness has the following meaning:

(i) An expression of the extent to which the performance of a system,facility or device in expected to degrade in a given nuclear environment.

(ii) The physical attributes of a system or electronic component that will allow survival in an environment that includes nuclear radiation & electromagnetic pulses(EMP).

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