Radiation-Induced Current Leakage Between Two n-MOSFET’s

Introduction
The Simulation Standard article “Simulating Radiation-Induced Shifts in MOSFET Threshold Voltage” gives a brief overview of the ways that ionizing radiation can affect semiconductor devices, and considers insulator charging in particular. In the Victory Device User’s Manual there is a more extensive discussion of radiation effects. Here we look at how insulator charging due to ionizing radiation can induce a leakage current between two MOSFET’s separated by a trench.

Simulation
To demonstrate how exposure to high-energy radiation can lead to a breakdown of the isolation between separate devices, we shall use Victory Device to simulate a pair of n-MOSFET’s, separated by a trench, that are bombarded by x-rays. The structure and doping of these MOSFET’s are shown in Figure 1.

In Victory Device, the radiation models only apply to semiconductors. Consequently, to model radiation effects in an insulator, you must tell Victory Device to regard the material as a semiconductor. To do this, set the SEMICONDUCTOR flag on an appropriate MATERIAL statement. You may also need to define a limited number of semiconductor properties for the material. For this simulation, we set the following:

```plaintext
# Semiconductor properties for oxynitride material material=oxynitride semiconductor material material=oxynitride nc300=2e19 \ nv300=2e19 eg300=9 affinity=0.9 \ permittivity=3.9 mun=1 mup=1e-3 m.vthp=1

# Semiconductor properties for oxide material material=oxide semiconductor material material=oxide nc300=2e19 \ nv300=2e19 eg300=9 affinity=0.9 \ mun=1 mup=1e-3 m.vthp=1
```

We also specify the following traps within the oxide and oxynitride materials, and on the interfaces between oxynitride and silicon:

```plaintext
intoxidecharging r1material=oxynitride \ r2material=silicon jmodel.p nt.p=1e14 \ sigmat.p=1.5e-13 sigman.p=1e-30 \ sigmaph.p=1.5e-13 jmodel.n nt.n=1e4 \ sigmat.n=1e-30 sigmap.n=1e-30 \ sigmaph.n=1e-30 mfp.phonon=0.013

oxidecharging material=oxynitride \ jmodel.p nt.p=2e18 sigmat.p=1.5e-13 \ sigman.p=1e-30 sigmaph.p=1.5e-13 \ jmodel.n nt.n=1e10 sigmat.n=1e-30 \ sigmap.n=1e-30 sigmaph.n=1e-30

oxidecharging material=oxide \ vmodel.p nt.p=2e18 sigmat.p=1.5e-17 \ sigman.p=1e-34 sigmaph.p=1.5e-13 \ vmodel.n nt.n=1e10 sigmat.n=2e-32 \ sigmap.n=2e-32 sigmaph.n=1e-30
```

The source of radiation will be x-rays at a dose-rate of 1 rad/s:

```plaintext
# Radiation environment radiation doserate=1 Xray
```

In the paired n-MOSFET structure shown in Figure 1, there is a polysilicon layer in the trench. This layer is present for stress-relief, but may act as a floating electrode. For the purpose of illustrating radiation-induced leakage around the trench, our simulation assumes that this polysilicon layer (labeled “anode” in the figure) has floated to a bias of 1 V, although this represents something of a worst-case scenario. With a bias of 50 mV on the electrode labeled “vdd”, we use Victory Device to simulate the device performance as it is irradiated up to a dose of 4 M-rad, in order to examine the effect of dose on the leakage current. Also, at dose levels of 0, 1, 2, 3, and 4 M-rad, we sweep the “vdd” bias between 0 V and 1 V to see how the
leakage current is affected by it.

Results
As the paired n-MOSFET device is irradiated, a charge builds up within the oxide layer in the trench. This is illustrated in Figure 2, which shows the ionized donor-trap concentration along a cut-plane 0.1 μm below the top of the device.

The charge that has built up within the oxide layer opens a channel around the trench. A leakage current flows in this channel from the “vdd” electrode to the “ground” electrode. Figure 3 shows the current density vectors in the device, after it has received a radiation dose of 4 M-rad.

As continued exposure to radiation builds up charge in the trench oxide, the leakage channel widens and the leakage current increases. Figure 4 shows how the calculated leakage current from the “vdd” electrode increases as a function of the radiation dose under conditions of constant bias.

At any given radiation dose-level, the magnitude of the leakage current around the trench depends on the bias put on the nearby electrodes. Figure 5 shows how the calculated leakage current depends on the “vdd” bias and the radiation dose. Notice that as the dose is increased from 1 M-rad to 2 M-rad, the dependence of the leakage current on the vdd voltage (the slope of the curves in the figure) increases as well.

Conclusion
We have shown how ionizing radiation can create a leakage path around a trench that separates two MOSFET’s. The leakage path is produced because radiation causes charging of the trench oxide, and the charged oxide then acts as the gate of a parasitic MOSFET that forms around the trench, between the “vdd” and “ground” electrodes of the simulated device. The leakage current increases the power consumption of the device, and may facilitate latchup. A simulator such as Victory Device, which can model radiation effects, can help to identify potential problems like this in electronic devices that will be exposed to ionizing radiation.

References