3D SOI NMOSFET Simulation Using VICTORY DEVICE

Abstract

SOI MOSFETs can exhibit a kink in their I_d/V_d curves, which is caused by impact ionization, floating potentials, and other effects. One way of suppressing this kink effect is to supply the device with a body contact. With a body contact, however, the geometry of the device becomes fully three dimensional. In this paper, we show how an SOI MOSFET with a body contact can be simulated in VICTORY DEVICE. 3D visualizations from the VICTORY DEVICE results illustrate how the body contact acts to suppress the kink effect.

Motivation

Silicon-on-Insulator (SOI) technology continues to see application in state-of-the-art CMOS designs, because of the performance advantages it offers compared to devices on a silicon substrate. These advantages include higher switching speed, lower power consumption, smaller size, resistance to latch-up, reduced temperature sensitivity and lower substrate noise. On the other hand, SOI devices may experience history effects, greater self heating, and the possibility of improper circuit operation due to parasitic bipolar currents [1,2].

One complication in SOI MOS structures is that the body of the device floats electrically, being insulated from the substrate by the buried oxide layer. If the device is biased in the saturation region and the drain-to-source bias is larger than the bandgap of silicon, impact ionization near the drain end of the gate contact results in the generation of a large number of electron/hole pairs. The excess holes first migrate towards the buried oxide below the gate, raising the potential of that region. From there, they migrate towards the source and recombine with source electrons. Meanwhile, the excess electrons from the impact ionization migrate to the drain, increasing the drain current. The combination of these effects leads to an anomalous increase in the drain current, known as the kink effect because it produces a kink in the I_d/V_d curve [2,3].

Since the kink effect is often undesirable, various techniques have been developed to suppress it [3,4,5]. One of these is to supply the device with a body contact, which provides a path for holes to leave the device without going through the source. With a body contact, the geometry of an SOI MOSFET becomes fundamentally three-dimensional, since the body contact does not lie in the vertical plane defined by the source, gate, and drain. Consequently, an SOI MOSFET with a body contact can only be simulated properly by a 3D device simulator.

In this paper, we will show how an SOI NMOSFET with a body contact can be simulated using Silvaco's VICTORY DEVICE application.

Methodology

DevEdit was used to create structures representing SOI NMOSFETs with and without body contacts. Overall, both devices were 3 μm wide by 4 μm long. The silicon body was 200 nm thick, on top of a buried oxide layer 400 nm thick. Boron doping at a concentration of 2.0×10^{17} was applied to the body as a whole, while the wells below the source and drain were doped with arsenic at a concentration of 1.0×10^{20}. The source and drain contacts were each 50 nm thick and 400 nm wide, and were modeled as aluminum. Gate oxide thickness was 17 nm, while the gate itself was 33 nm thick. Both gate and gate oxide were 1 μm wide. In DevEdit, the gate contact material was specified as aluminum, but in VICTORY DEVICE it was simulated using the workfunction and thermal properties corresponding to n-type polysilicon.

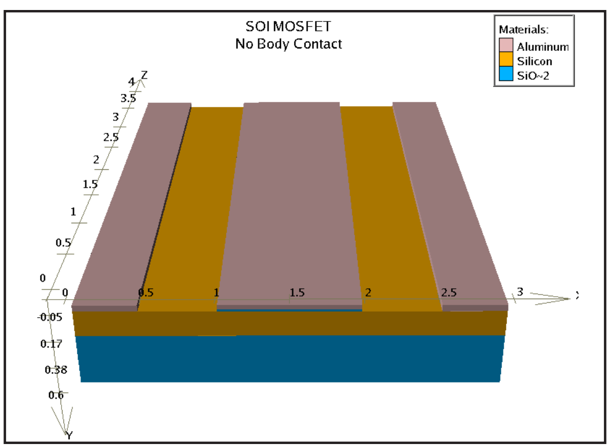

Figure 1. SOI NMOSFET with no body contact.

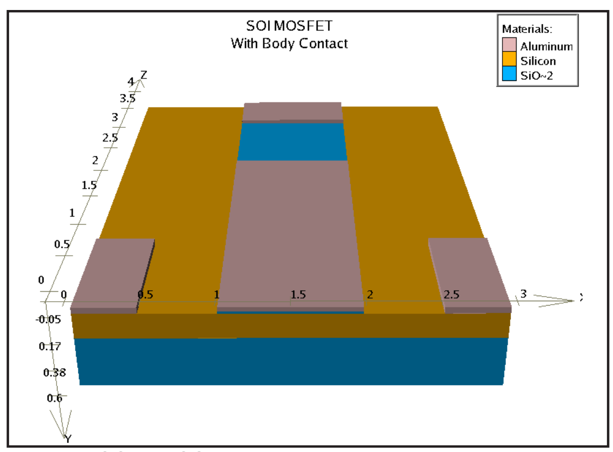

Figure 2. SOI NMOSFET with a body contact.

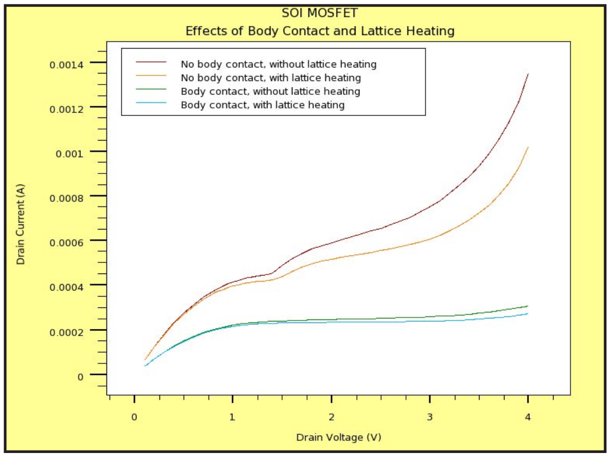

Figure 3. Id/Vd curves showing effects of body contact and heating.

In the device with the body contact, the source and drain contacts were each 1 μm long, but the gate contact was 2.5 μm long and the gate oxide was 3.5 μm long. Located at the end of the gate oxide, the body contact was 50 nm thick, 1 μm wide, and 500 nm long. In the device without the body contact, the gate oxide and source, drain, and gate contacts all extended the full 4 μm length of the device. The resulting structures are shown in Figures 1 and 2.

These two structures were then simulated in VICTORY DEVICE. Carrier mobility was treated using the Lombardi CVT model: a general purpose mobility model including concentration, temperature, and electrical field dependence. Impact ionization was treated using Selberherr's model [6]. Other physical effects that were modeled include Shockley–Read–Hall recombination, Auger recombination, and bandgap narrowing in the presence of heavy doping.

Two simulations were run for each structure: One simulation with lattice heating, and one without. In each case, the gate bias was raised to 3V, then an I_d/V_d curve was generated by ramping the drain bias from 0.2V to 4V. For the simulations that included lattice heating, the substrate was maintained at a temperature of 300K.

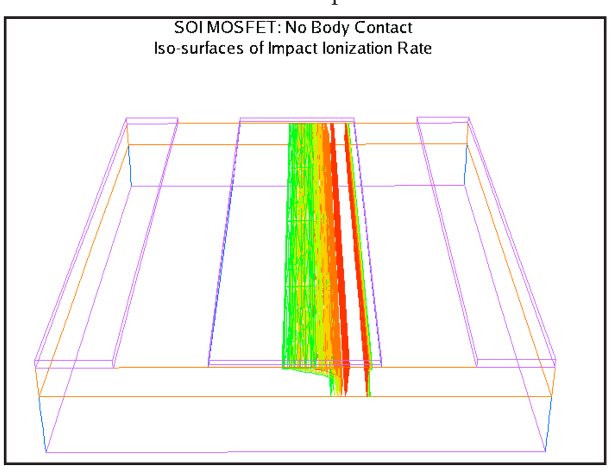

Figure 4. Impact ionization iso-surfaces when body contact is absent.

Simulation Results

Figure 3 displays the I_d/V_d curves from the four simulations. As the figure illustrates, the presence of a body contact suppresses the kink effect. Suppression of the kink effect also reduces the effects of lattice heating.

Figures 4 and 5 illustrate the difference in the impact ionization patterns caused by the presence of a body contact. These figures correspond to the conditions when the gate bias, V_g = 3V, and the drain bias, V_d = 4V. The maximum generation rate in both cases is 10^{30} electron-hole pairs/(cm^3·s).

Figures 6 and 7 show contours of the hole concentration on the surfaces of the silicon and oxide regions. The scale in these figures is logarithmic, so the maximum concentration shown in each case is 10^{20} holes/cm^3. Again, V_g = 3V, and V_d = 4V. In the device without the body contact, the hole concentration is relatively high throughout the region between and underneath the source and gate contacts. On the other hand, in the device with the body contact, the hole concentration is relatively high only near the body contact and near the buried oxide layer beneath the gate.

Figure 8 shows the recombination rate, for the device without a body contact. Most of the recombination takes place at the edge of the gate contact, where holes created by impact ionization encounter electrons coming from the source. The equivalent figure for the device with the body contact is not shown, because the recombination rate for that device is negligible in comparison.

Figure 9 shows a front view of the hole current vectors, for the device without a body contact. These vectors are all parallel to the plane of the paper. The largest hole currents originate in the impact ionization zone near the right end of the gate contact. From there they first drift towards the buried oxide, then turn horizontal and head towards the source. The hole current diminishes in the recombination zone, below the left edge of the gate.

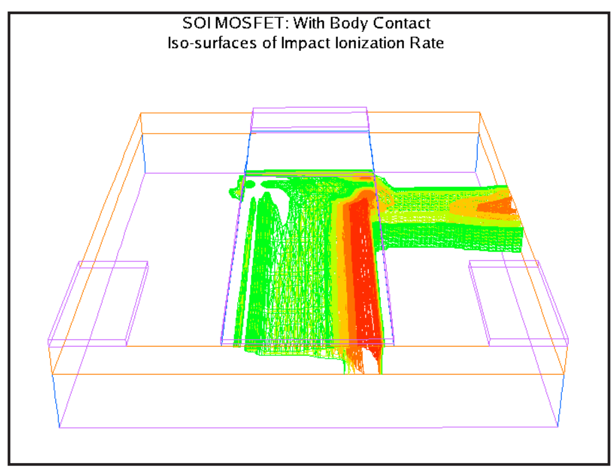

Figure 5. Impact ionization iso-surfaces when body contact is present.

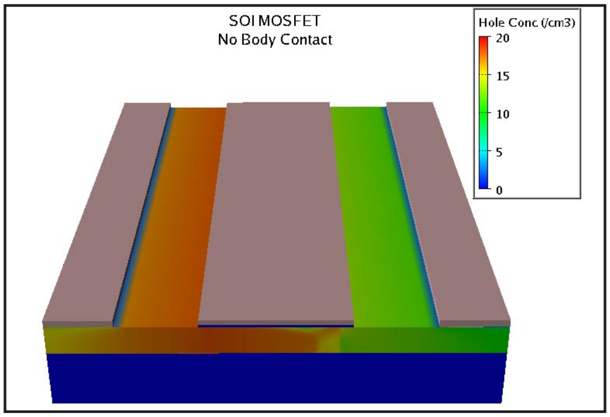

Figure 6. Hole concentration contours when body contact is absent.

Figure 10 shows a top view of the hole current vectors, for the device with the body contact. Although these vectors do have a non-zero component in the y-direction (into the paper in this view), it is the components in the x-z plane that are of interest here. These show that in this case, the holes generated by impact ionization are swept towards the body contact, instead of towards the source.

Conclusion

When a body contact is used to suppress the kink effect in an SOI NMOSFET, quantities including the impact ionization, the hole density, and the hole current vectors all take on a three-dimensional structure. Simulation of such a device in VICTORY DEVICE permits these 3D effects to be accurately accounted for and visualized.

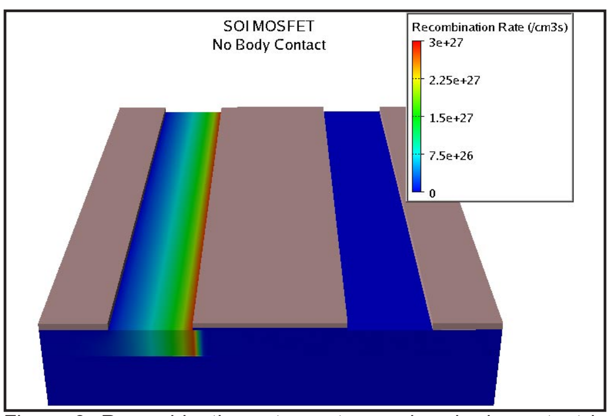

Figure 8. Recombination rate contours when body contact is absent.

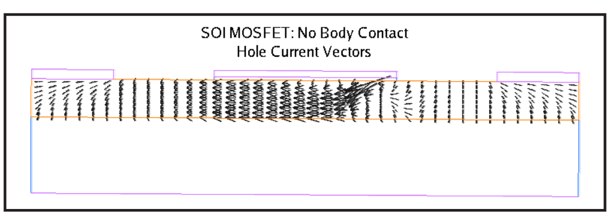

Figure 9. Front view of hole current vectors when body contact is absent.

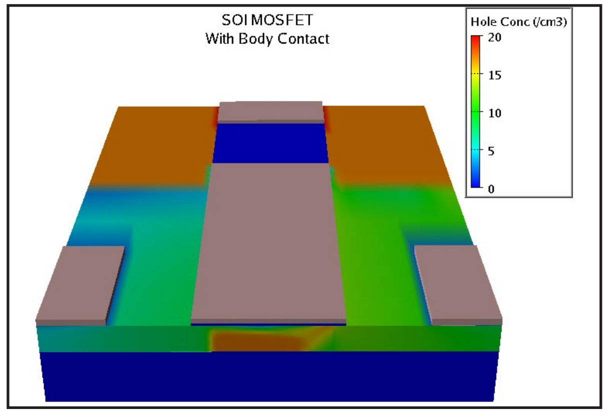

Figure 7. Hole concentration contours when body contact is present.

References

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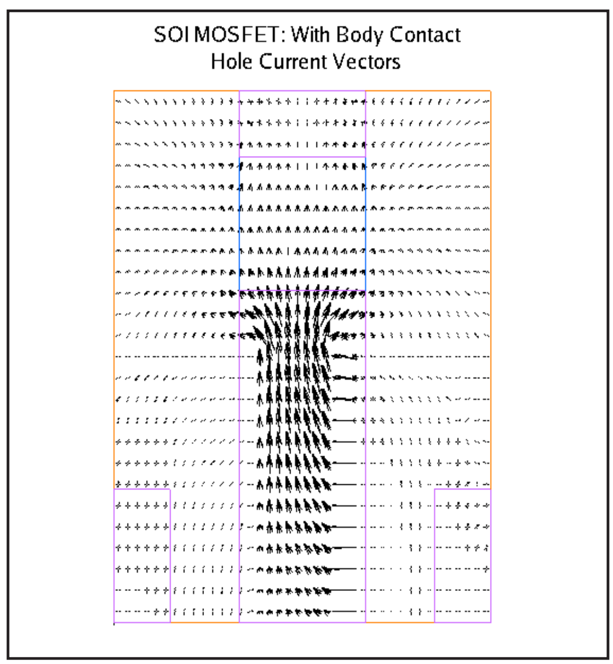

Figure 10. Top view of hole current vectors when body contact is present.