Modeling of Avalanche Breakdown in Silicon and Gallium Nitride High-Voltage Diodes Using COMSOL®

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Abstract

For high-power semiconductor devices to function correctly, it is imperative to manage the electric fields inside of the device. This is typically done using an edge termination scheme such as guard rings or junction termination extensions. Edge terminations are used to spread localized electric fields to eliminate field crowding within the device. This will prevent premature breakdown, thus avoiding catastrophic destruction of the device. Simulations of the electric field profile inside of such devices at high applied bias provide insight into optimal design configurations. Using simulations tools prior to device fabrication dramatically decreases both cost and manufacturing time.

State-of-the-art research on power devices focuses on wide-bandgap materials such as silicon carbide (SiC) and gallium nitride (GaN). The high bandgap of GaN, 3.4 eV compared to 1.1 eV in silicon (Si), and the associated high critical electric field (> 4 MV/cm) result in theoretically predicted and experimentally confirmed performance levels superior to Si and SiC. Performance metrics of power diodes often cite Baliga's figure of merit, which considers both the reverse breakdown voltage and the forward specific on-resistance of a device to determine its overall performance. However, GaN is a novel and challenging material to not only fabricate, but also to simulate.

In this work we report on simulations of vertical Si and GaN p-i-n diodes utilizing the Semiconductor Module in the COMSOL Multiphysics® software. The impact ionization generation and trap-assisted recombination models are used to predict breakdown characteristics in the device. A simple planar design, a design without edge termination, and a single guard ring device are demonstrated and compared. The planar junction device provides a convenient theoretical limit of the device performance. The device without an edge termination exemplifies the problem of field crowding and resulting early breakdown of a poorly designed device. In contrast, the single guard ring simulation shows the increased performance due to even a simple edge termination scheme. Important meshing concerns will be addressed, as will the difficulties associated with modeling GaN.

These results are compared to results from SILVACO® TCAD, a mature semiconductor modeling software package (www.silvaco.com). For most parameters, the default COMSOL® material parameters are used. However, in both programs, custom impact ionization parameters are used to achieve the critical electric field of 4 MV/cm needed for GaN. Differences in software capabilities are addressed.

Figures used in the abstract

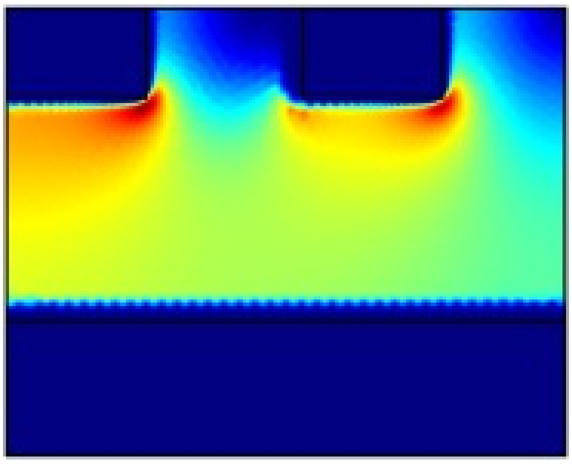

Figure 1: Electric field profile of a single-guard-ring silicon diode at breakdown. High field regions indicate where impact ionization will occur.