Device Modeling and Characterization of 4H-SiC Bipolar Junction Transistor

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Motivation

The wide bandgap and high thermal conductivity of Silicon Carbide (SiC) enables design of power devices that can operate at high power and high temperature. Moreover, other properties of SiC, such as high saturation velocity and high breakdown field, can improve switching loss and switching speed in power devices.

We need excellent dynamic characteristics such as fast switching for automobile applications, for which we are now fabricating SiC power BJTs (Bipolar Junction Transistors).

This research's purpose is to model and characterize the Suppressed Surface Recombination structure (SSR)-BJT using a unique 4H-SiC device simulator, and then confirm the dynamic characteristics using this device modeling.

Why SiC is needed for automobile?

- Increasing demand for Electric-powered vehicles:
  - HEV (Hybrid Electric Vehicle)
  - FCV (Fuel Cell Vehicle)
  - EV (Electric Vehicle)
- Higher power density is required for electric power converters (DC/DC converter, Inverter).
- Si-IGBT (Insulated Gate Bipolar Transistor) is reaching performance limits.

Why we research BJTs?

SiC devices for electric-powered vehicles
- MOS-FET (Metal Oxide Semiconductor - Field Effect Transistor)
- J-FET (Junction-FET)
- BJT

Advantages
- Low on-resistance
- High operation temperature

Disadvantage
- Current control devices

→Need to improve current gain

Semiconductor equations

The Drift Diffusion model is frequently used to describe semiconductor devices. It consists of five equations; the Poisson equation, the electron and hole current continuity equations and the electron and hole current equations.

Poisson Equation:
$$\nabla^2\phi = -\frac{q}{\varepsilon}\left(-n + p + N_D^+ - N_A^-\right)$$

Electron current continuity equation:
$$q\frac{\partial n}{\partial t} = \nabla\cdot\vec{J}_n - q\left(R - G\right)$$

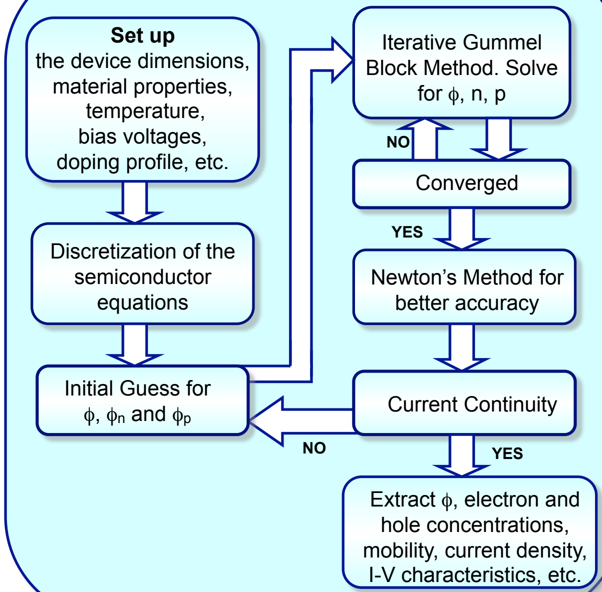
Hole current continuity equation:
$$-q\frac{\partial p}{\partial t} = \nabla\cdot\vec{J}_p + q\left(R - G\right)$$

Electron current equation:
$$\vec{J}_n = -qn\mu_n\nabla\phi + q\nabla(nD_n)$$

Hole current equation:
$$\vec{J}_p = -qp\mu_p\nabla\phi - q\nabla(pD_p)$$

For steady state analysis, the electron and hole concentrations do not change with time and so both the continuity equations are equal to zero. The equations for J_n and J_p are substituted in the continuity equations. The Poisson equation and the electron and hole continuity equations are solved for ϕ, *n* and *p*.

Steps for numerical solution



Important device models for high current gain

Incomplete Ionization model

Poisson's equation includes the ionized impurity concentrations. For high doped regions such as n+ emitter and p+ channel, incomplete ionization model is essential to characterize physical operation and calculate correct current gain.

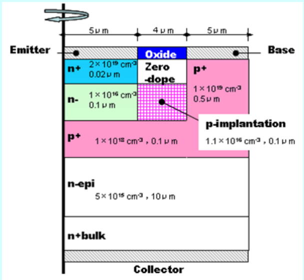
Shockley Read Hall (SRH) model

- This is the recombination model depending on doping concentration

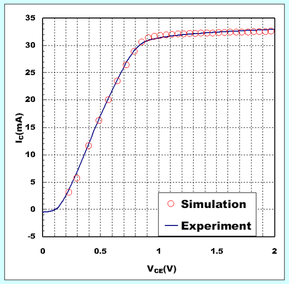
$$U = \sigma\cdot V_{th}\cdot N_t\frac{p\cdot n - n_i^2}{n + p + 2n_i\cdot\cosh\left(\frac{E_t - E_i}{kT}\right)}$$

- The SSR-BJT structure forms high resistivity layer by p-type ion implantation to decrease carrier density on the SiC region between the emitter and the base, and thereby reduces surface recombination

Device structure and I-V forward characteristic



Device modeling of SSR-BJT (Active area=1.5×10^{-4}cm^{-2})



I-V forward characteristic

Current Gain=64@2V

Ron=3.2mΩ·cm^2 @100A/cm^2

Future work

- Static characteristics for large-area devices
- Switching transient behavior for dynamic characterization