Gunn Diode Modeling in APSYS

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Transferred Electron Effect

- Found in materials such as GaAs, negative differential resistance (NDR) as electrons get transferred from Gamma to L band valleys at high fields.
- Implemented in Crosslight default macro through field-dependent mobility model n.gaas.
Gunn Diode

- Basic GaAs n-type unipolar device with ohmic contacts
- Generates microwave self-pulsations under experimental DC bias (Gunn, 1963)

N = 1e22 m^-3
Steady-State Simulation

From Drift-Diffusion model, no pulsations can be observed under steady-state conditions (all $\frac{d}{dt}$ terms are zero)
I-V Curve: Lack of NDR

- No NDR observed: presence of field spikes at n/n+ interfaces and non-uniform field in n region. Situation more complex than many textbook models.
- Localized high-field regions means reduced velocity (NDR) also localized ($\mathbf{v} = \mu \mathbf{F}$).
- To maintain net current continuity in steady-state, increased carrier density in those regions ($\mathbf{J}_n = n\mu \mathbf{v} E_{fn} \approx n \mathbf{v}$)
Transient Simulation

- Step response (10->11 V step applied over 1 fs)
- Perturbation rapidly decays to new steady-state
- No self-pulsation is observed: why?
• Initial voltage pulse introduces an accumulation region ($n>n_0$) which propagates towards the anode in order to accommodate the new voltage bias.
• Field perturbation from voltage pulsed “merged” into existing high-field region: no formation of separate field domains.
Temporal Evolution – Carrier Density

![Graph showing temporal evolution of carrier density over distance](graph.png)
Temporal Evolution – Electric Field

![Graph showing the temporal evolution of an electric field. The graph plots the electric field strength (V/cm) against distance (micron). The field initially decreases and then sharply drops at a certain point.](Image)

- **Field** $y$ (V/cm)
- **Distance** (micron)
- **t=0**
Lack Of Self-Pulsation For Trapped Anode Domain

- Instability required for self-pulsation not present in this device
- Current oscillations => carrier density (electron) pulses traveling from cathode to anode
- In order to support this without external oscillating voltage, carrier pulse must regenerate after reaching anode
- Device must have distinct high/low field regions where carrier densities can build up before drifting across the device
- No “seed” for oscillation defined for this device: needs doping and/or trap inhomogeneity to create localized field build-up
Gunn Diode With Notch Doping

- Modified version of 1st design with a small region of low-doped GaAs near the cathode
- Doping notch provides “seed” of dipole for self-pulsation

![Diagram of Gunn Diode with Notch Doping]
Steady-State Simulation

- Similar steady-state I-V without NDR
Transient Simulation

- Step response (10->11 V step applied over 1 fs). Max. step 1 ps.
- Perturbation rapidly builds up into steady self-pulsation
- T~40 ps => f ~25 GHz
Gunn Domains

- Perturbation introduces a dipole which propagates in the device
- When part of the dipole gets absorbed at the anode, it gets regenerated near the cathode, leading to self-pulsation
• Dipole induces local field separate from the one caused by the applied bias
Temporal Evolution – Carrier Density

![Graph showing the temporal evolution of carrier density over distance (micron)].

Log (Elec. Conc./cm^3) vs Distance (micron)
Temporal Evolution – Electric Field
Self-Pulsation Mechanism

• After initial pulse, applied voltage is constant

• Voltage drop across drift region: $\Delta V = \int \vec{F} \cdot d\vec{l}$

• When part of the dipole is absorbed, new high-field region must be created to maintain $\Delta V$ (“equal-areas rule”)

• This allows the dipole to be recreated and propagate again. From Sze: “Transit-Time Dipole-Layer Mode”

• Period of self-pulsation linked to transit time of the domain across the drift region
Conclusion

• Demonstration of self-pulsating Gunn diode.
• Transient simulation with perturbation key to observing the effect
• Inhomogeneity in carrier/field profiles key to seeding the self-pulsation.
• Perturbations must be defined by user since transient Drift-Diffusion is not a stochastic noise-driven model.
• Early experimental observations likely due to unintentional fluctuations of doping profiles.
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