HICUM/L2 v2.30 overview

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OUTLINE

- Introduction/Overview
- Improved formulation of transfer current
- Improved temperature dependence
- Charge storage at heterojunction barrier
- Minor changes in ICK formulation
- Minor improvement of capacitance equations
- Summary of new parameters

Introduction/Overview

- Release of HICUM/L2 v2.30 for DotFive only.
- Future official release date open, in the following slides marked as CMC release.
- New features:
  - Improved formulation of transfer current
  - Charge storage effects at heterojunction barrier
  - Improved temperature dependences
  - Minor change in I_{CK} formulation
- Some differences between both releases.
  - Will be shown in this presentation to avoid confusion.
- Full compatibility to recent versions, i.e. all effects can be turned off by default parameters. Except for:
  - Temperature dependence of h_{fE} and h_{fC}, where compatibility is achieved by *flcomp.*
  - C_{rBi} (as already changed in v2.24).

Improved formulation of transfer current

Bias dependent h_{jEi}

- Already presented at HICUM WS 09.
- Implementation

$$h_{jEi} = h_{jEi0}\frac{\exp(u)-1}{u} \quad \text{with} \quad u = a_{hjEi}\left(1-\left(1-\frac{v_j}{V_{DEi}}\right)^{z_{Ei}}\right)$$

- The junction voltage is limited to V_{DEi} and 0.

$$x_{upp} = \frac{V_{DEi}-V_{BEi}}{r_{h_{jEi}}V_T}\left(x_{upp} = \frac{V_{DEi}-V_{BEi}}{V_{h_{jEi}}}\right) \text{ and } v_{j,upp} = V_{DEi}-\left(\frac{r_{h_{jEi}}V_T}{V_{h_{jEi}}}\right)\frac{x_{upp}-\sqrt{x_{upp}^2+a_{fi}}}{2}$$

CMC DotFive

combined with

$$x_{low} = \frac{v_{j,upp}-V_T}{V_T} \quad \text{and} \quad v_j = V_T\left(1+\frac{x_{low}+\sqrt{x_{low}^2+a_{fi}}}{2}\right)-V_{corr}$$

Improved formulation of transfer current (cont.)

Bias dependent h_{jEi}

- Last term avoids numerical problems when using very small r_{hjEi} caused by using of two smoothing functions.

$$V_{corr} = \left(\frac{x_{lim,upp} + \sqrt{x_{lim,upp}^2 + a_{fi}}}{2} - x_{lim,upp} \right) V_T \quad \text{with} \quad x_{lim,upp} = \frac{V_{DEi} - V_T}{V_T}$$

- Temperature dependence

DotFive release

$$a_{hjEi}(T) = a_{hjEi}(T_0) \frac{C_{jEi0}(T_0)}{C_{jEi}(T)} \left(\frac{T_0}{T}\right)^{\zeta_{a_{hjEi}}}$$

and

$$h_{jEi0}(T) = h_{jEi}(T_0) \exp\left[\frac{\Delta V_{jBE}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$\exp[r_{a_{hjEi}}(a_{hjEi}(T_0) - a_{hjEi}(T))]$$

CMC release

$$a_{hjEi}(T) = a_{hjEi}(T_0) \left(\frac{T_0}{T}\right)^{\zeta_{hjEi}}$$

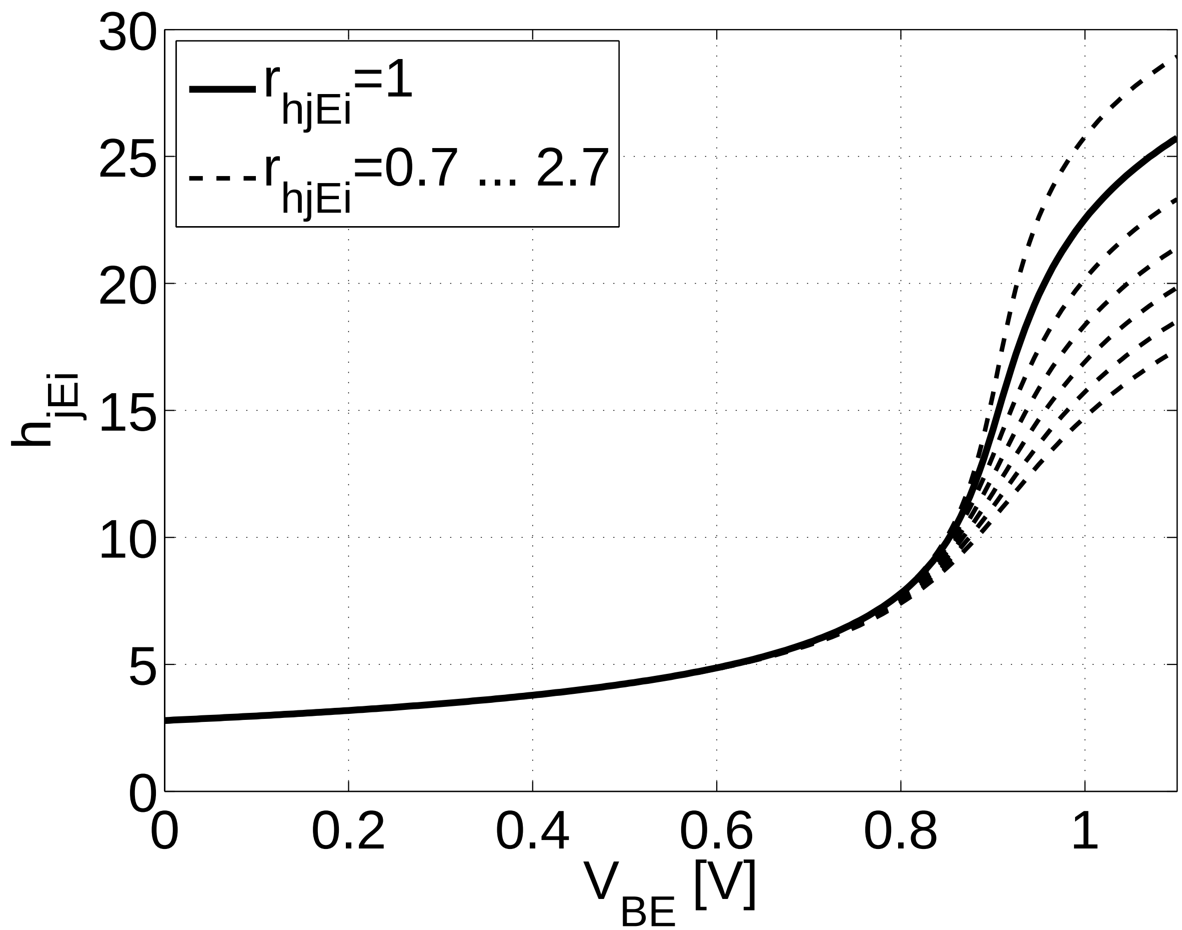
and

$$h_{jEi0}(T) = h_{jEi}(T_0) \exp\left[\frac{\Delta V_{gBE}}{V_T}\left(\left(\frac{T}{T_0}\right)^{\zeta_{gBE}} - 1\right)\right]$$

Improved formulation of transfer current (cont.)

Bias dependent h_{jEi}

- Transition to high bias region (i.e. V_{DEi}) can be adjusted by r_{hjEi} (and V_{hjEi}).



Improved formulation of transfer current (cont.)

Low current minority charge

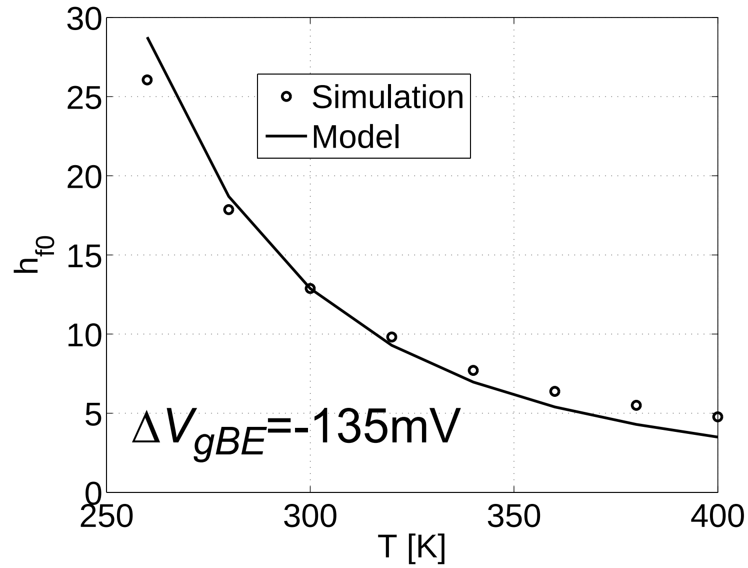
- Low current minority charge Q_f is mainly located in base region and BE-SRC.
- For graded Germanium content, the Q_{fBE} "sees" a different n_i than the minorities in the base.
- This effect leads to a very low Q_{p0}, when extracted from transfer current.

$\Rightarrow$ Introduction of weight factor for Q_{f0}.

$$Q_{f,T} = h_{f0}Q_{f0} + h_{fE}\Delta Q_{Ef} + \Delta Q_{Bf} + h_{fC}\Delta Q_{Cf}$$

- Temperature dependence due to bandgap difference.

$$h_{f0}(T) = h_{f0}(T_0)\exp\left[\frac{\Delta V_{gBE}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

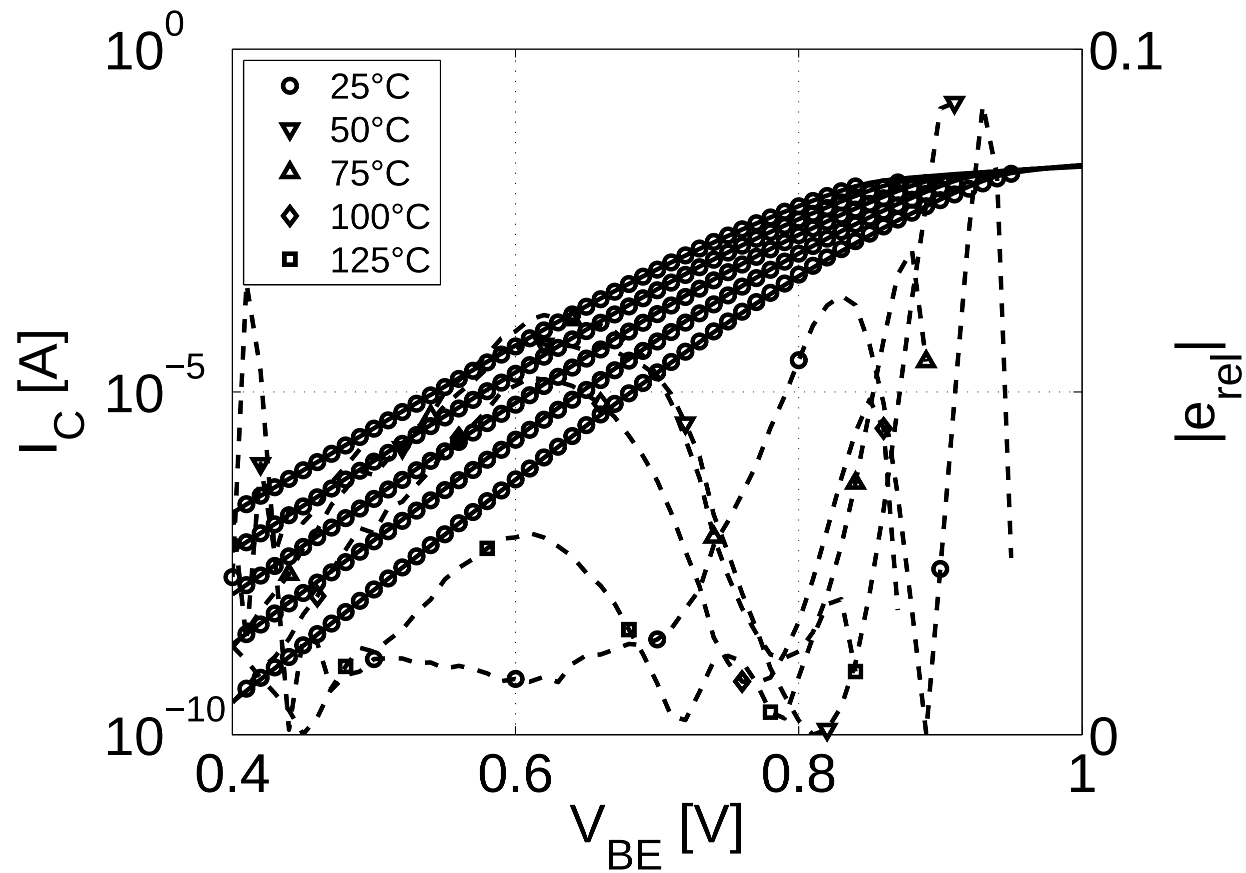


- Effect on transfer current shown in HICUM WS 09.

Improved formulation of transfer current (cont.)

Experimental results

- B3T technology, V_{BC}=0 V, Temp=[25 50 75 100 125] °C



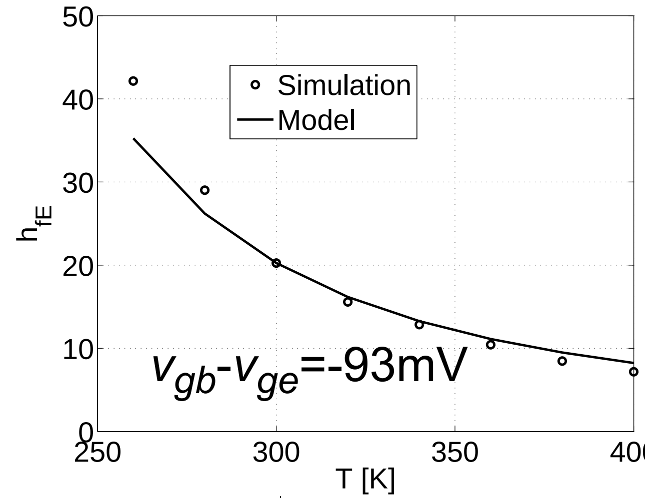
Improved temperature dependence

- New temperature dependence for high current weight factors.
- Based on bandgap difference between base and emitter or collector, respectively.

$$h_{fE}(T) = h_{fE}(T_0)\exp\left[\frac{v_{gb} - v_{ge}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

and

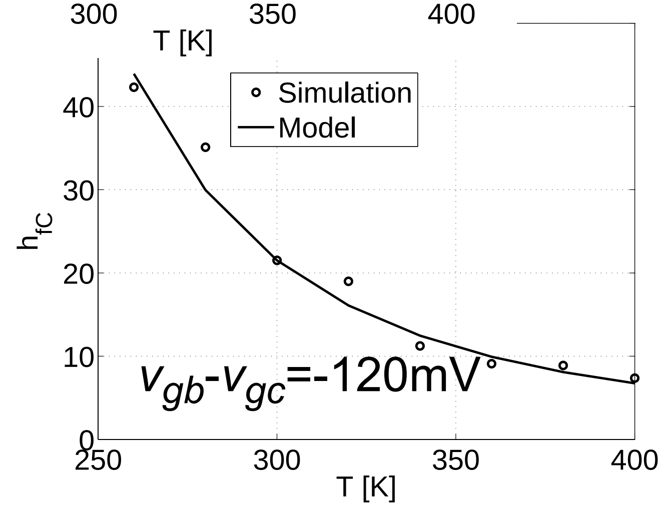
$$h_{fC}(T) = h_{fC}(T_0)\exp\left[\frac{v_{gb} - v_{gc}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$



- Bandgap voltages already available.

  $\Rightarrow$ No new parameter were introduced.

- In Dotfive release equations are always turned on.
- in CMC-release, equations can be turned on by *flcomp*=2.3 (or higher).



Charge storage at heterojunction barrier

- High current minority charge extended by barrier related part.

$$Q_{f,h} = \Delta Q_{Ef} + \Delta Q_{Bf,b} + \Delta Q_{Bf,c} + \Delta Q_{Cf,c}$$

- Barrier related term calculated by a bias dependent barrier voltage.

$$\Delta Q_{Bf,b} = \tau_{Bfvs} i_{Tf} \left[\exp\left(\frac{\Delta V_C}{V_T}\right) - 1 \right]$$

with already existing

$$\tau_{Bfvs} = (1 - f_{\tau hc}) \tau_{hCs}$$

- Kirk-effect related transit times are "delayed" by the formation of the barrier:

$$\Delta Q_{fh,c} = \tau_{hCs} i_{Tf} w^2 \exp\left(\frac{\Delta V_C - V_{Cbar}}{V_T}\right)$$

Charge storage at heterojunction barrier (cont.)

- Barrier voltage bias dependent by transfer current and internal collector voltage (via I_{CK}).
- Two formulations

I

(implemented in both releases)

$$\Delta V_C = V_{Cbar} \frac{i_{bar} + \sqrt{i_{bar}^2 + a_{Cbar}}}{1 + \sqrt{1 + a_{Cbar}}}$$

with

$$i_{bar} = 1 - \left(\frac{I_{CK}}{i_{Tf}}\right)^{\beta_{Cbar}}$$

- New parameters
  - V_{Cbar} , a_{Cbar} , β_{Cbar}
  - In DotFive release a_{Cbar} merged with a_{hC}
  - V_{Cbar}=0 turns barrier extension off

II

(possibly implemented in CMC-release)

$$\Delta V_{cB} = V_{cBar} \exp\left(-\frac{2}{i_{bar} + \sqrt{i_{bar}^2 + a_{cBar}}}\right)$$

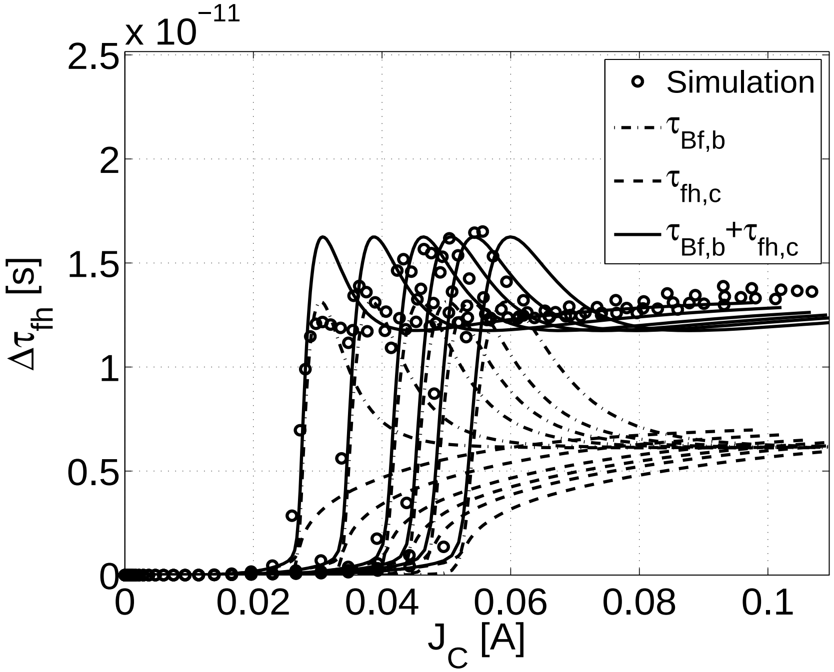
with

$$i_{bar} = \frac{i_{Tf} - I_{CK}}{I_{cBar}}$$

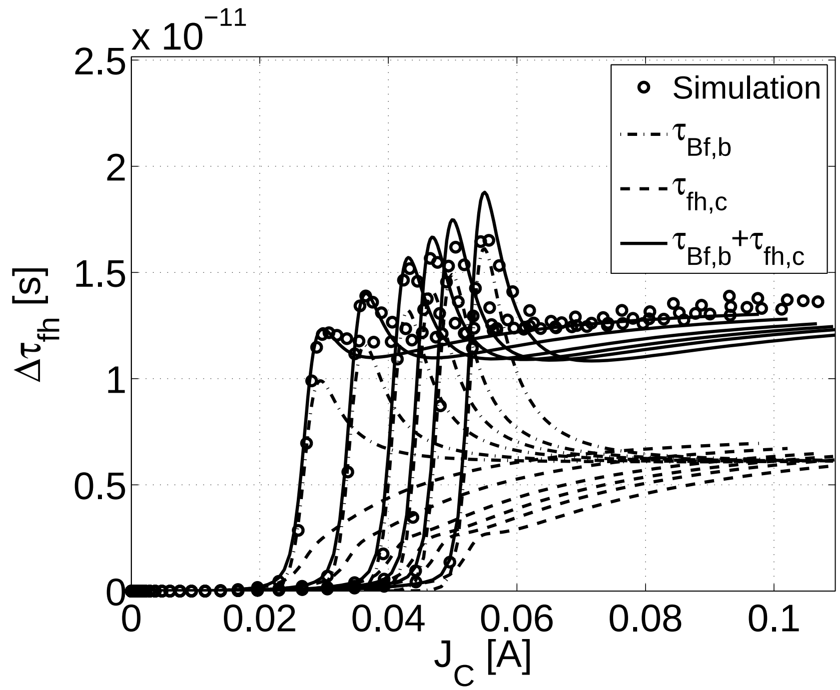
- New parameters
  - V_{Cbar} , a_{Cbar} , I_{cBar}
  - V_{Cbar}=0 turns barrier extension off

Charge storage at heterojunction barrier (cont.)

- Verification on 1D device simulations
- Using equation I



- Using equation II



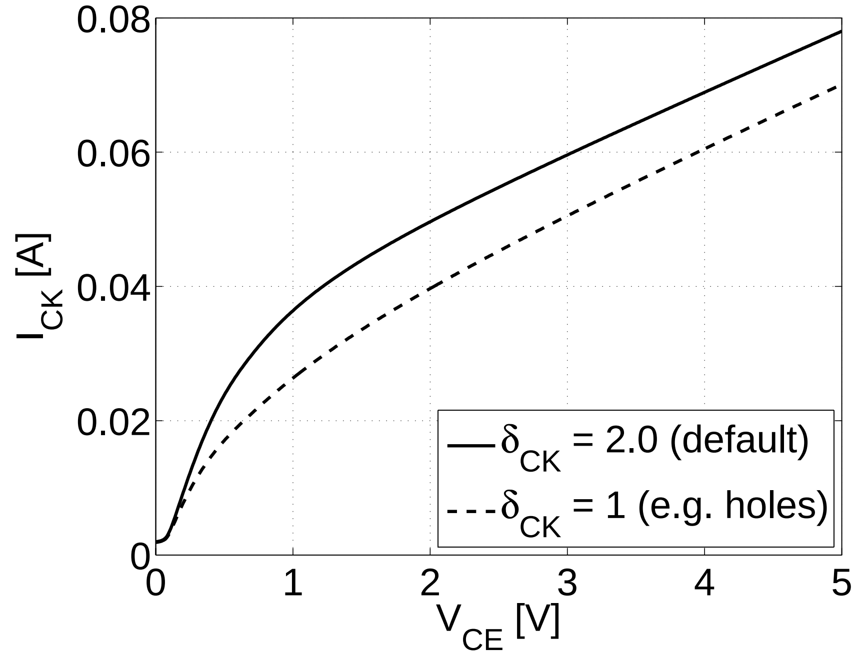
- II shows an increasing barrier effect with increasing V_{CE}, while I has a constant "overshoot".
- The behavior of II reflects simulation results much better than I.

Minor changes in I_{CK} formulation

- New equation

$$I_{CK} = \frac{v_{ceff}}{r_{Ci0}} \frac{1}{\left(1 + \left(\frac{v_{ceff}}{V_{lim}}\right)^{\delta_{CK}}\right)^{1/\delta_{CK}}} \left[1 + \frac{x + \sqrt{x^2 - a_{ickpt}}}{2}\right]$$

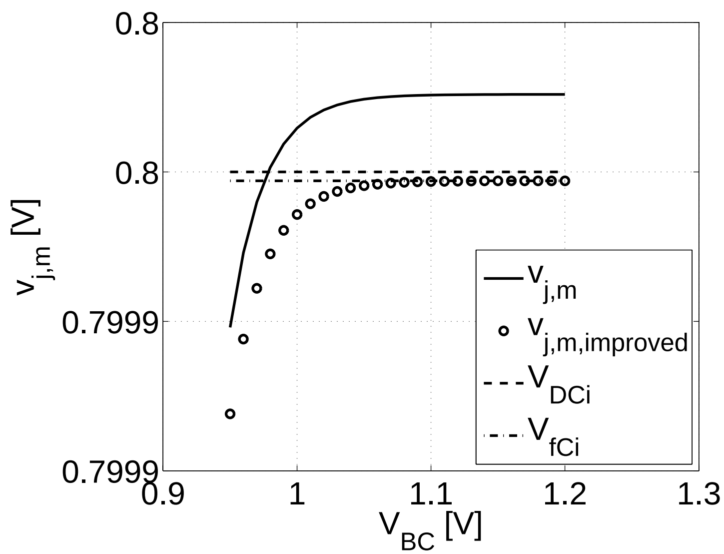
- Introducing δ_{CK} as new parameter.
- Defaults to original equation for δ_{CK}=2

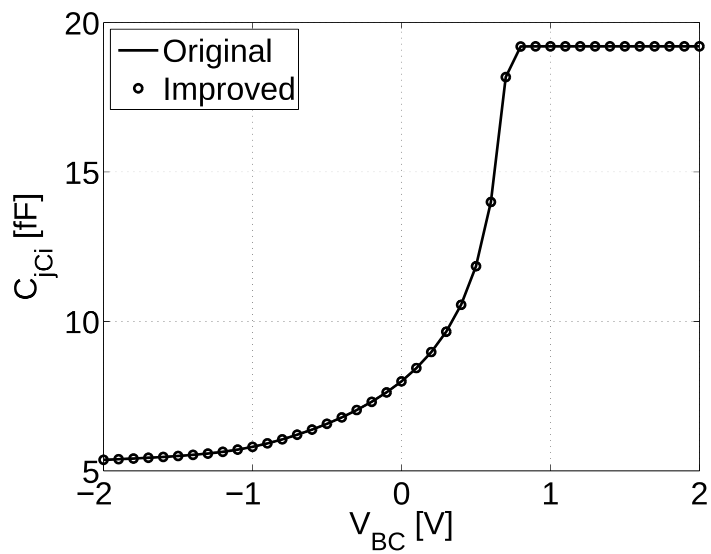


Minor improvement of capacitance equations

- Equations including punch-through (i.e. C_{BC} and C_{CS}).
- Possible numerical errors for z very small, caused by multiple smoothing functions.
- $v_{j,m}$ may become larger than V_D.
- Solution by subtracting an estimate of the maximum error for very high voltages.

$$v_{j,m} = -V_{jPCi} + V_r \ln[1 + e_{j,m}] - \frac{V_r}{\exp\left(\frac{V_{jPCi} + V_{fCi}}{V_r}\right)}$$





Numerically stable without visible influence on results.

Summary of new parameters

Parameter	Default	Name DotFive release	Name CMC release	Description
δ_{CK}	2.0	delta_ck	delck	Fitting parameter for I_{CK}-equation
V_{Cbar}	0	vcbar	vcbar	Heterojunction barrier voltage
a_{Cbar}	0.1	ahc (merged with existing parameter)	ahc or acbar (decision not yet done)	Fitting parameter for onset of barrier voltage
β_{Cbar}	1	beta_cbar	betcbar	Fitting parameter for onset of barrier voltage
h_{jEi0}	1	hjei	hjei	Low bias weight factor for BE-junction charge
a_{hjEi}	0	ahjei	ahjei	Parameter describing the slope of $h_{jEi}(V_{BE})$
r_{hjEi}	1	-	rhjei	High voltage fitting parameter for $h_{jEi}(V_{BE})$
V_{hjEi}	0.07	rhjei	-	
h_{f0}	1	hf0	hf0	Weight factor for low current minority charge.

Summary of new parameters (cont.)

Parameter	Default	Name DotFive release	Name CMC release	Description
ΔV_{gBE}	0	dvjbe	dvgbe	Bandgap difference between Base and BE-junction.
ζ_{ahjEi}	1	zetaah	-	Fitting parameter for temperature dependence of a_{hjEi}
ζ_{hjEi}	1	-	zetahjei	
r_{ahjEi}	1	rahjei	-	Fitting parameter for temperature dependence of h_{jEi0}
ζ_{gBE}	1	-	zetavgbe	

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