HICUM Models - A Status Overview

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OUTLINE

- HICUM/L2
  - V2.30 release
  - Model Support
  - Experimental verification
  - Model Run-time comparison
- HICUM/L0 Support Activities

HICUM/L2

- New *HICUM/L2 version 2.30* model
  => final code released *publicly* on 24th May, 2011
- New release note describing all extensions and changes and CMC suggested QA results are available on web

Users are requested to fill out brief questionnaire for code access

- helps us to keep track of users
- requires users to acknowledge copyrights
- CR notice is also included into the code

- summary of improvements described on next slides

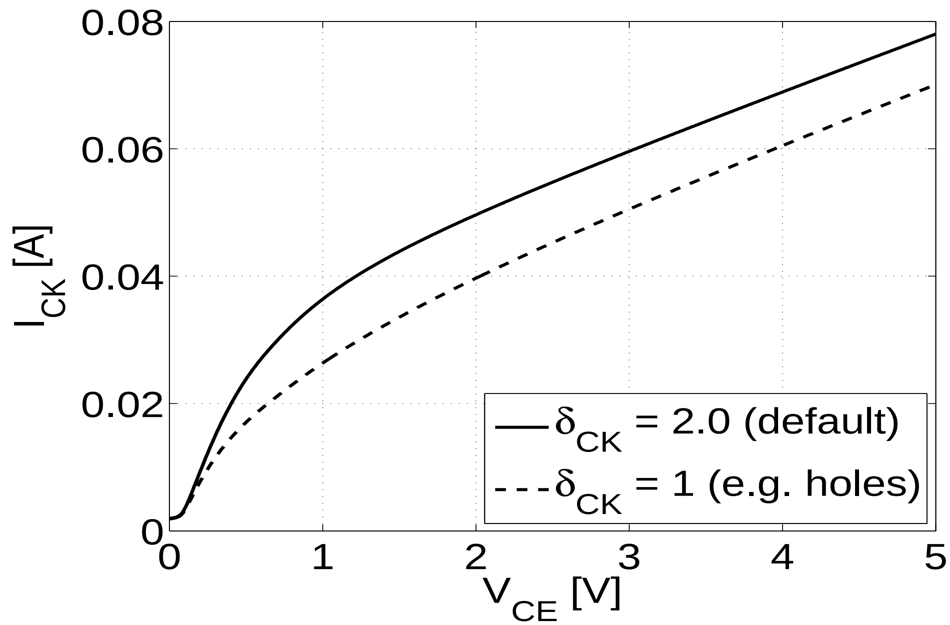
- tests were run in
  - SPECTRE
  - ADS

New features

Modified formulation of critical current (I_{CK})

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

- *Default δ_{ck} = 2* compatible with previous versions (typical for npn)



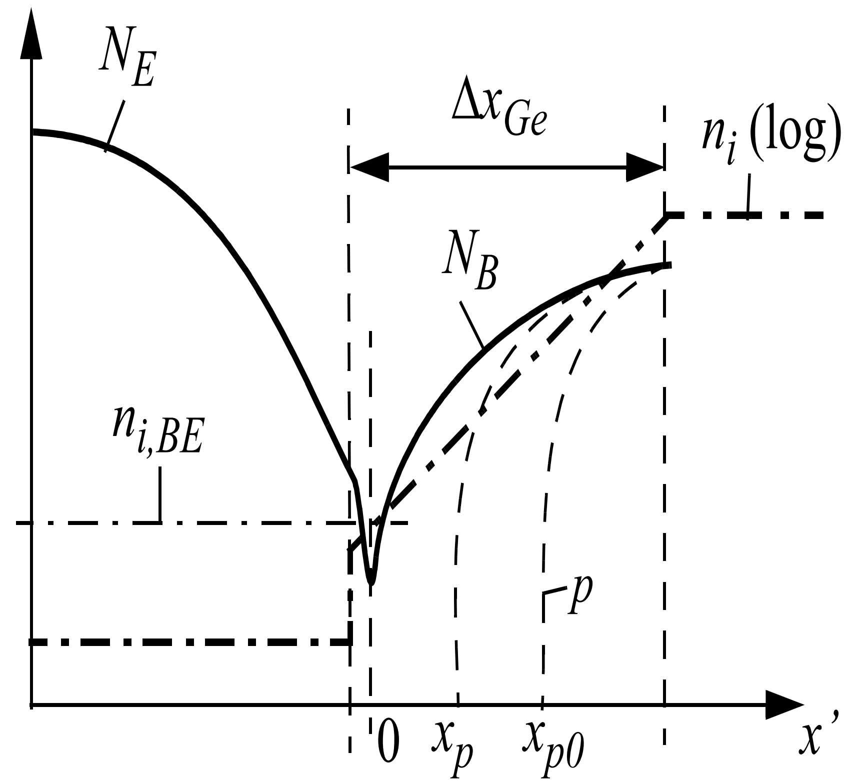
New features (cont'd.)

transfer current: weight factor for BE depletion charge

- compositional Ge grading causes different weighting of charge stored close to BE junction (Q_{jEi}, Q_f) compared to zero-bias charge Q_{p0}

$$h_{jEi} = h_{jEi0} \frac{\exp\left[a_{hjEi}\left(1-\left(1-\frac{V_{BEi}}{V_{DEi}}\right)^{z_{Ei}}\right)\right]}{a_{hjEi}\left(1-\left(1-\frac{V_{BEi}}{V_{DEi}}\right)^{z_{Ei}}\right)}$$

- Default $a_{hjEi} = 0$ is compatible with previous versions



=> crucial for high-performance technologies

New features (cont'd.)

transfer current: weight factors for the minority charge

- Newly added weight factor h_{f0} for *low-injection minority charge*

$$Q_{f,T} = h_{f0}Q_{f0} + h_{fE}\Delta Q_{fE} + \Delta Q + h_{fC}\Delta Q_{fC}$$

  - *default* $h_{f0} = 1$ compatible with previous version
  - caused by significant charge contribution from outside neutral base

=> very important for high-performance technologies

- High current weight factors h_{fE} and h_{fC} are modeled *temperature dependent*

New features (cont'd.)

minority charge: BC barrier effect explicitely included

- bias dependent barrier voltage

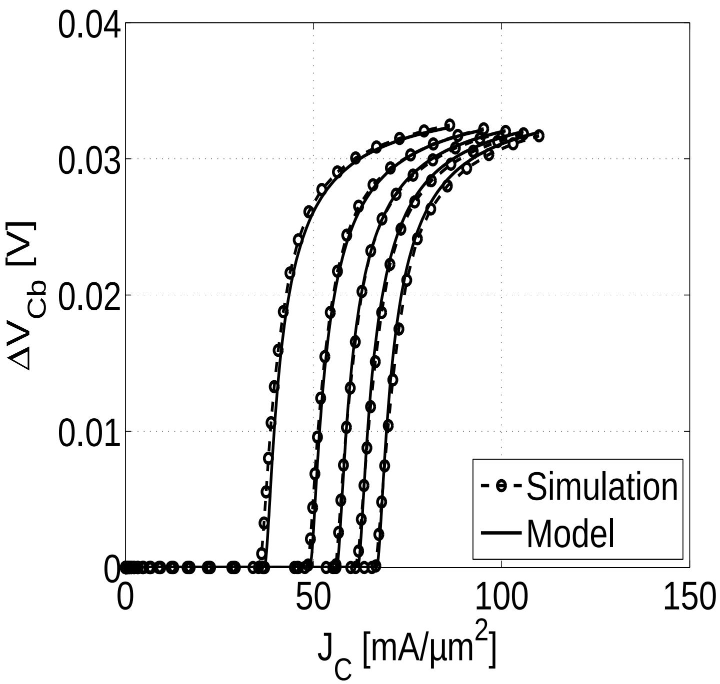
$$\Delta V_{cBar} = V_{CBar}\exp\left(-\frac{2}{i_{Bar}+\sqrt{i_{Bar}^{2}+a_{cBar}}}\right)$$

with $i_{Bar} = (i_{Tf}-I_{CK})/i_{cBar}$

  - $V_{cBar} = 0$ turns off extension

- new barrier related minority charge in base region:

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



=> important for high-performance technologies

New features (cont'd.)

- Modification of temperature dependent *BE* recombination currents

$$I_{RE(i,p)S}(T) = I_{RE(i,p)S0}\left(\frac{T}{T_0}\right)^{\frac{m_g}{m_{RE(i,p)}}} \exp\left[\frac{1}{m_{RE(i,p)}}\frac{V_{gBEeff}}{V_T}\left(\frac{T}{T_0}-1\right)\right]$$

  - setting *flcomp=2.2* reduces the equation to that of previous versions

- Additional flicker noise contribution for emitter resistance R_E

$$\overline{I_{rE}^2} = \frac{K_{fre}\cdot I_E^{A_{fre}}}{f} + \frac{4kT}{R_E} \qquad \text{(default } K_{fre} = 0\text{)}$$

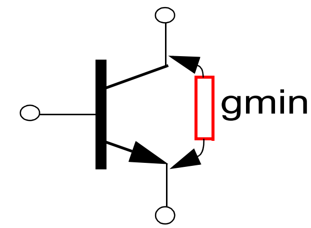
- Thermal resistance is modeled temperature dependent

$$R_{th}(T) = R_{th}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{rth}} \qquad \text{(default } \zeta_{rth} = 0\text{)}$$

New features (cont'd.)

- Lateral NQS effect: switch back to version 2.23 implementation
  => use of *"ddx"* operator *only* for determination of *diffusion capacitances* (see slides of last meeting)

- Added additional *"Gmin (=1e-12)"* between internal collector & emitter node
  => for transfer current (I_T) source



- Temperature dependence of emitter transit time *tef0* is removed
  - setting *flcomp=2.2* or *lower* makes former equations available

- Backward compatibility options through flag *flcomp*:
  - *flcomp = 0* or *2.1* => old temperature dependence (v2.1 or older)
  - *flcomp = 2.2* => temperature dependent equations of previous versions
  - *flcomp = 2.3* => temperature dependence of *tef0* is turned-off & new formulation for BE-recombination current is active

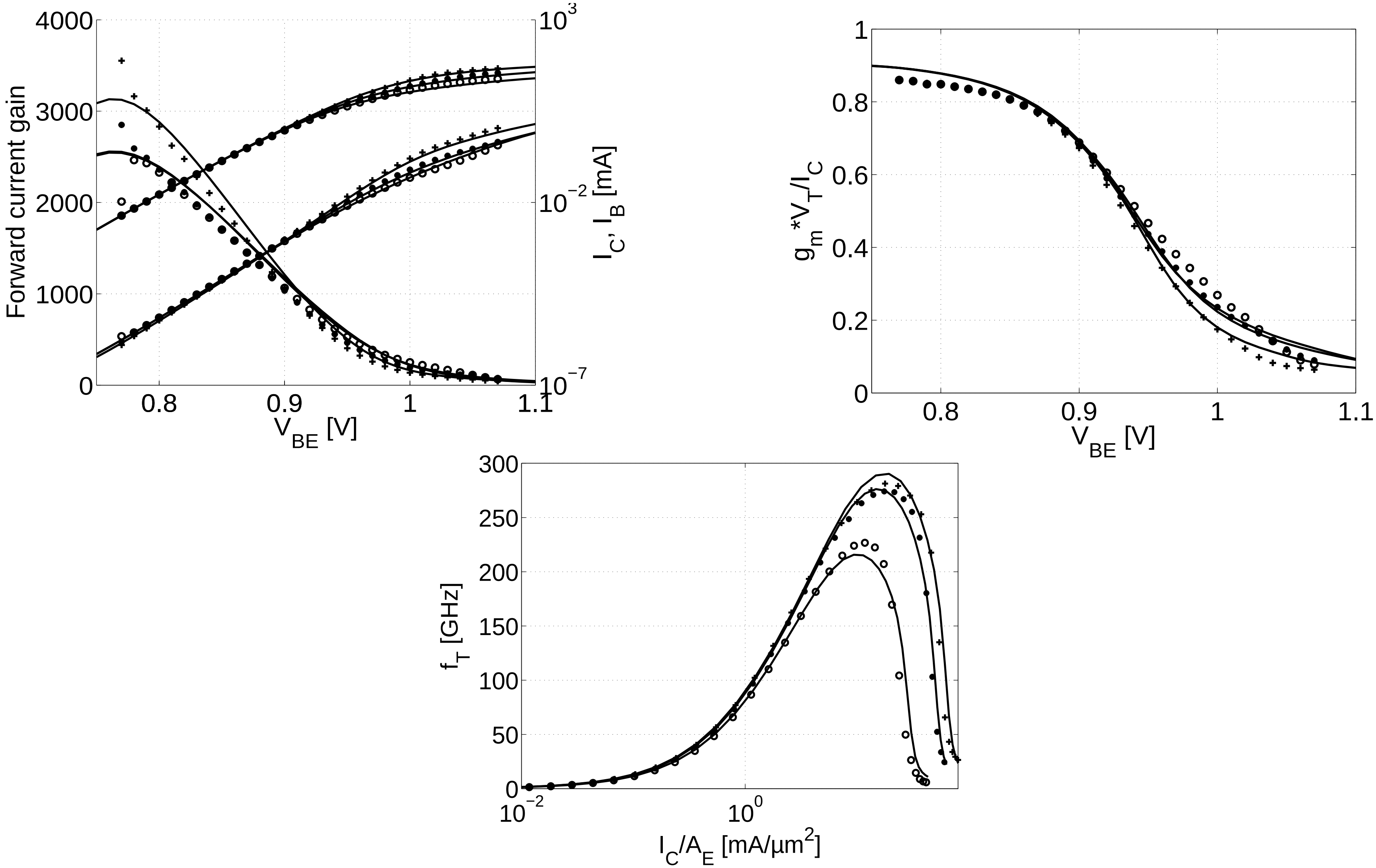
Newly added model parameters

Parameter	Default	Description
δ_{CK}	2	Mobility field factor for I_{CK}
a_{hjEi}	0	Parameter describing the slope of $h_{jEi}(V_{BE})$
r_{hjEi}	1	Smoothing parameter for $h_{jEi}(V_{BE})$ at high voltage.
ΔV_{gBE}	0	Bandgap difference between base & BE-junction (for h_{jEi0}, h_{f0})
ζ_{hjEi}	1	Temperature coefficient for a_{hjEi}
ζ_{VgBE}	1	Temperature coefficient for h_{jEi0}
h_{f0}	1	Weight factor for the low current minority charge
V_{cBar}	0	Barrier voltage
a_{cBar}	1	Smoothing parameter for barrier voltage
i_{cBar}	1	Normalization parameter
ζ_{rth}	1	Temperature coefficient for R_{th}
K_{frE}	0	R_E flicker noise coefficient
A_{frE}	2	R_E flicker noise exponent factor

HICUM/L2 v2.30 experimental verification

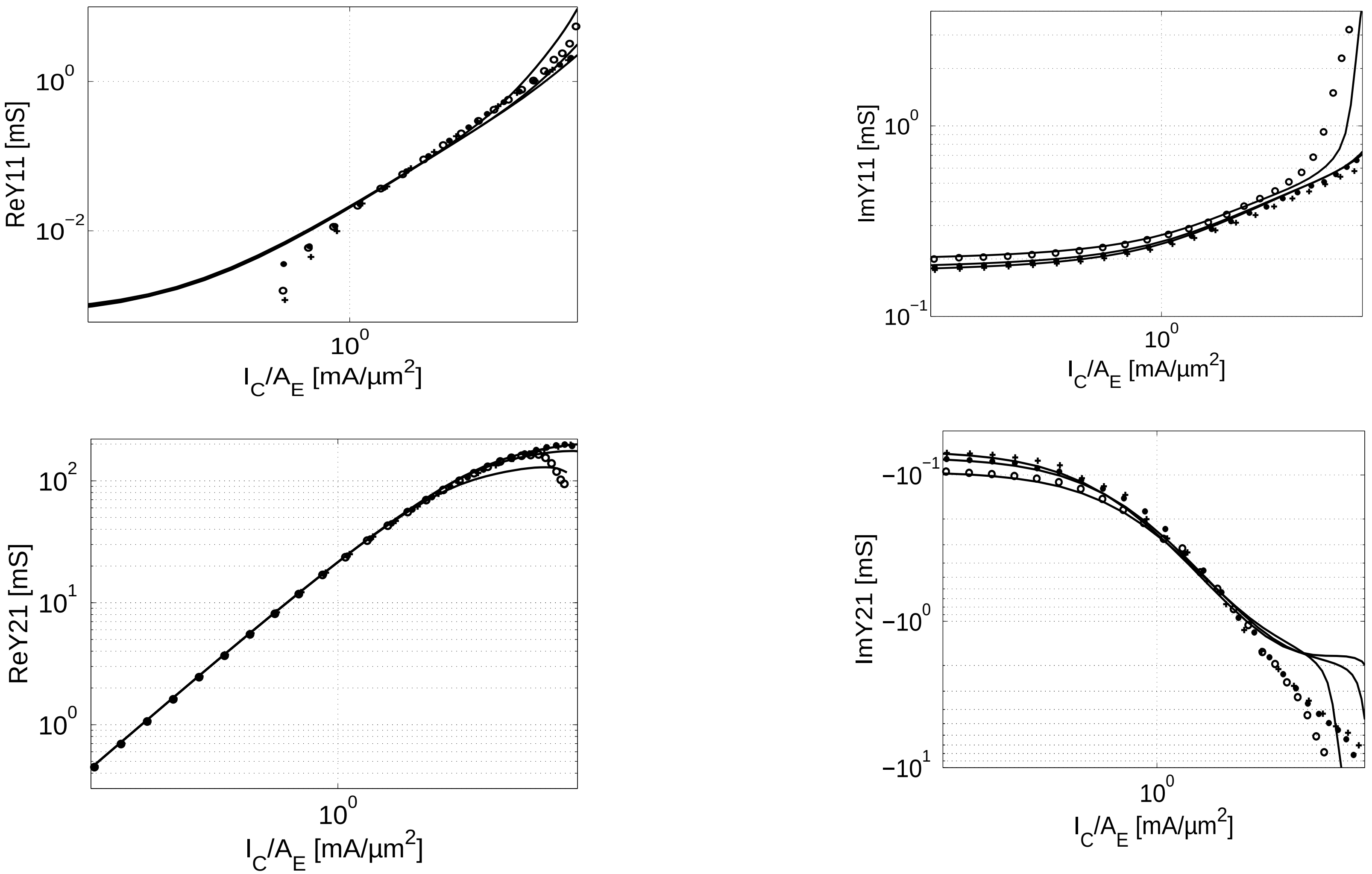
- various procss technologies: ST, IFX, IHP
- Selected results for advanced 250GHz (f_T) SiGe HBTs (from ST)
  - for more results see other presentations and upcoming publications
- Emitter area $A_E = 0.582\mu m^2$
- Results are for V_{BC} = {0.5, 0 , -0.5}V
- Verification for different temperatures: {-40, 27, 125} ^{o}C
- Symbols: Measured data, Lines: Hicum/L2v2.30

HICUM/L2 v2.30 verification @-40°C

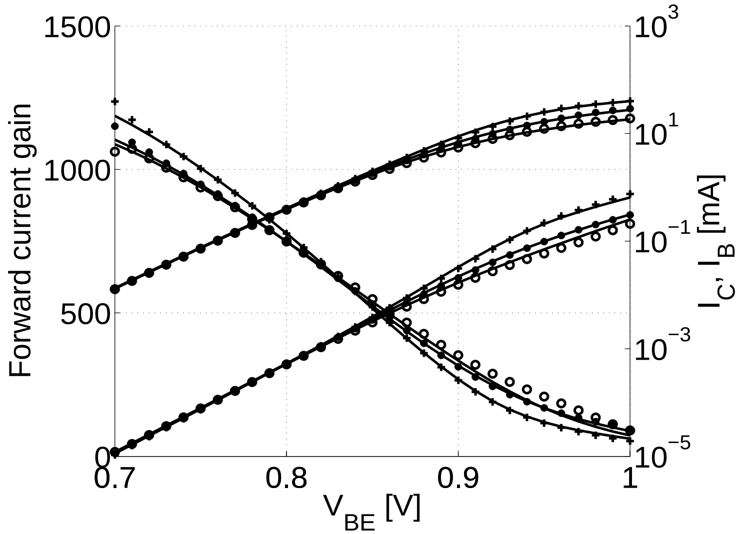


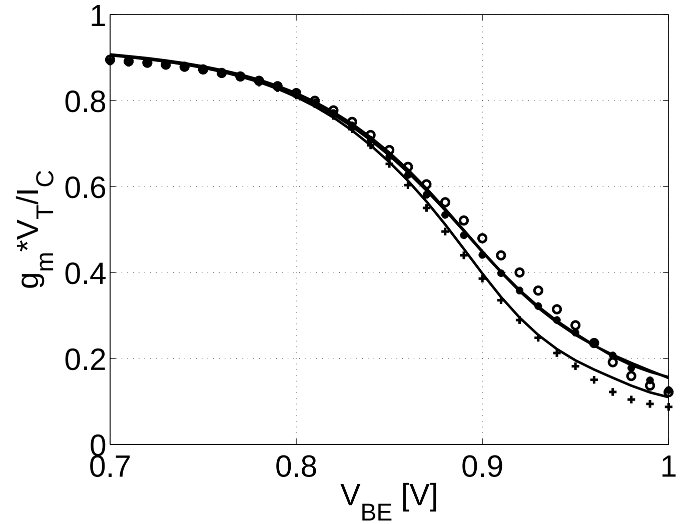
HICUM/L2 v2.30 verification (cont'd.) @-40°C

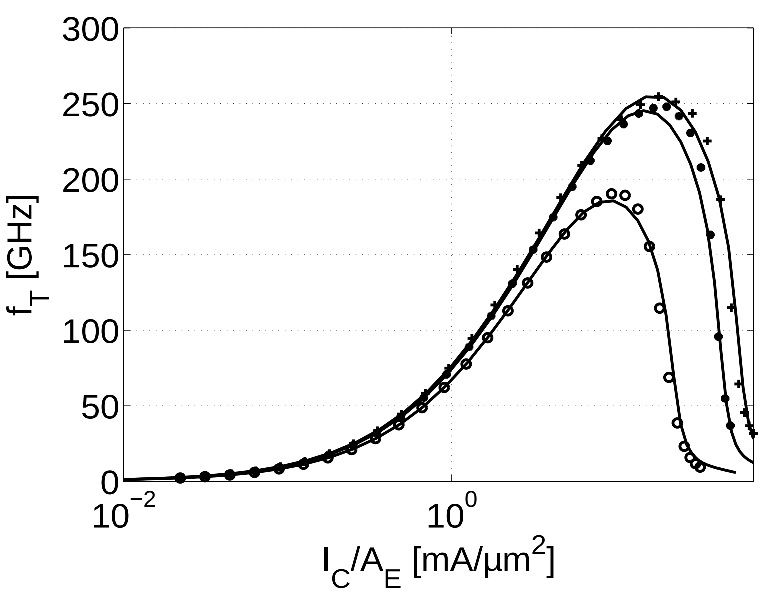
y-parameters @1GHz



HICUM/L2 v2.30 verification (cont'd.) @27 ^oC

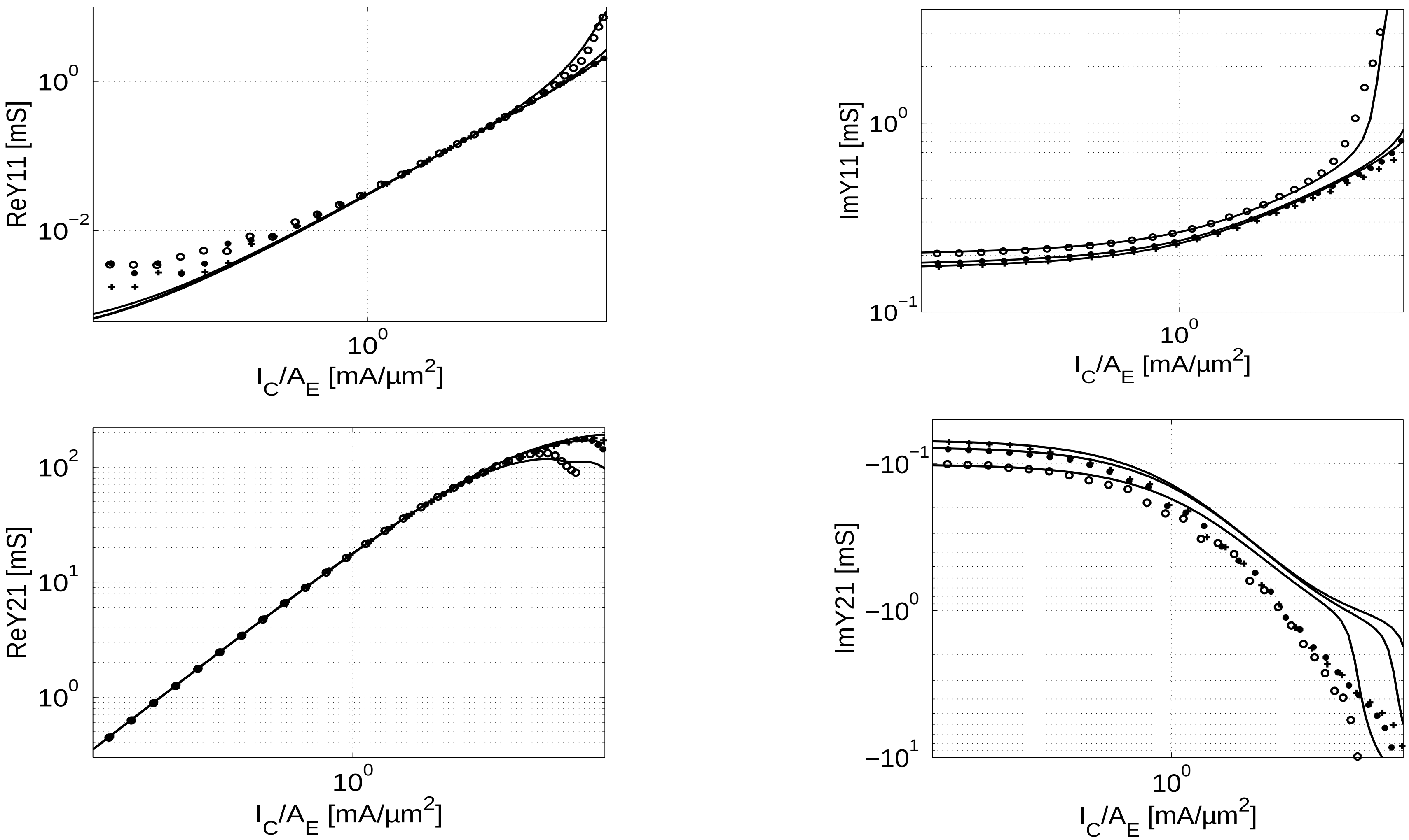




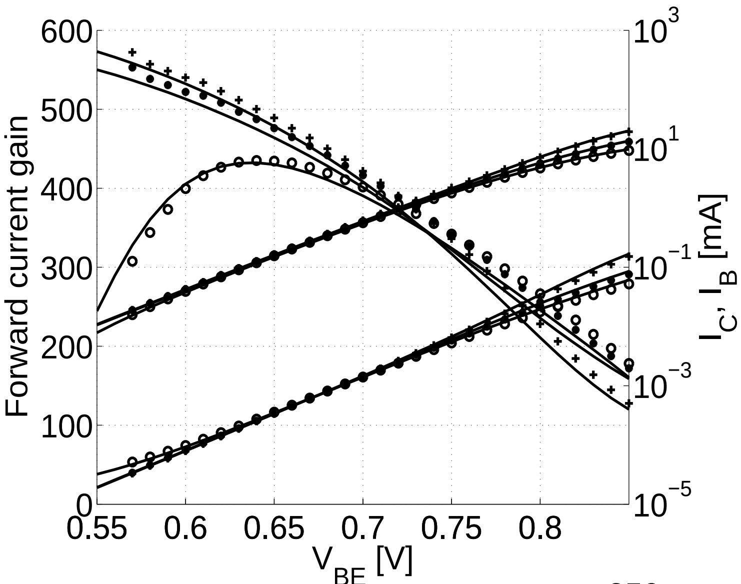


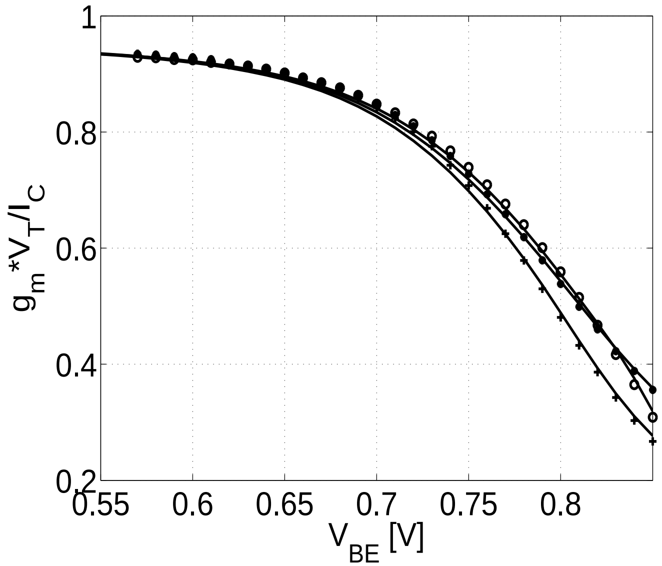
HICUM/L2 v2.30 verification (cont'd.) @27 °C

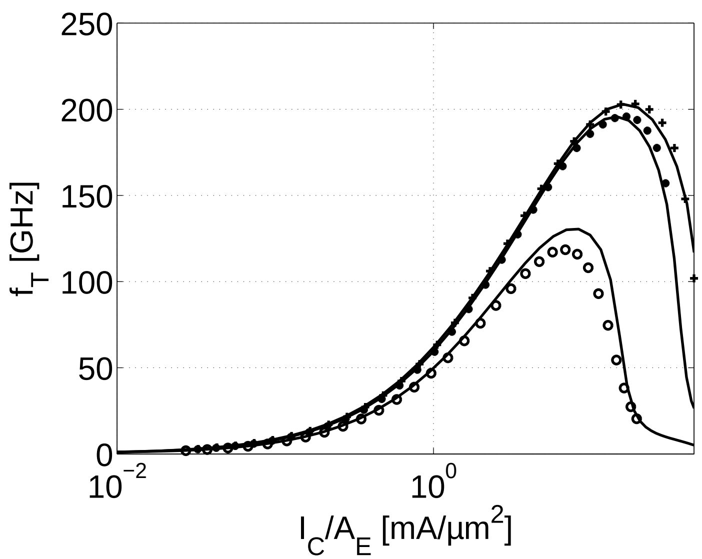
y-parameters @1GHz



HICUM/L2 v2.30 verification (cont'd.) @125 °C

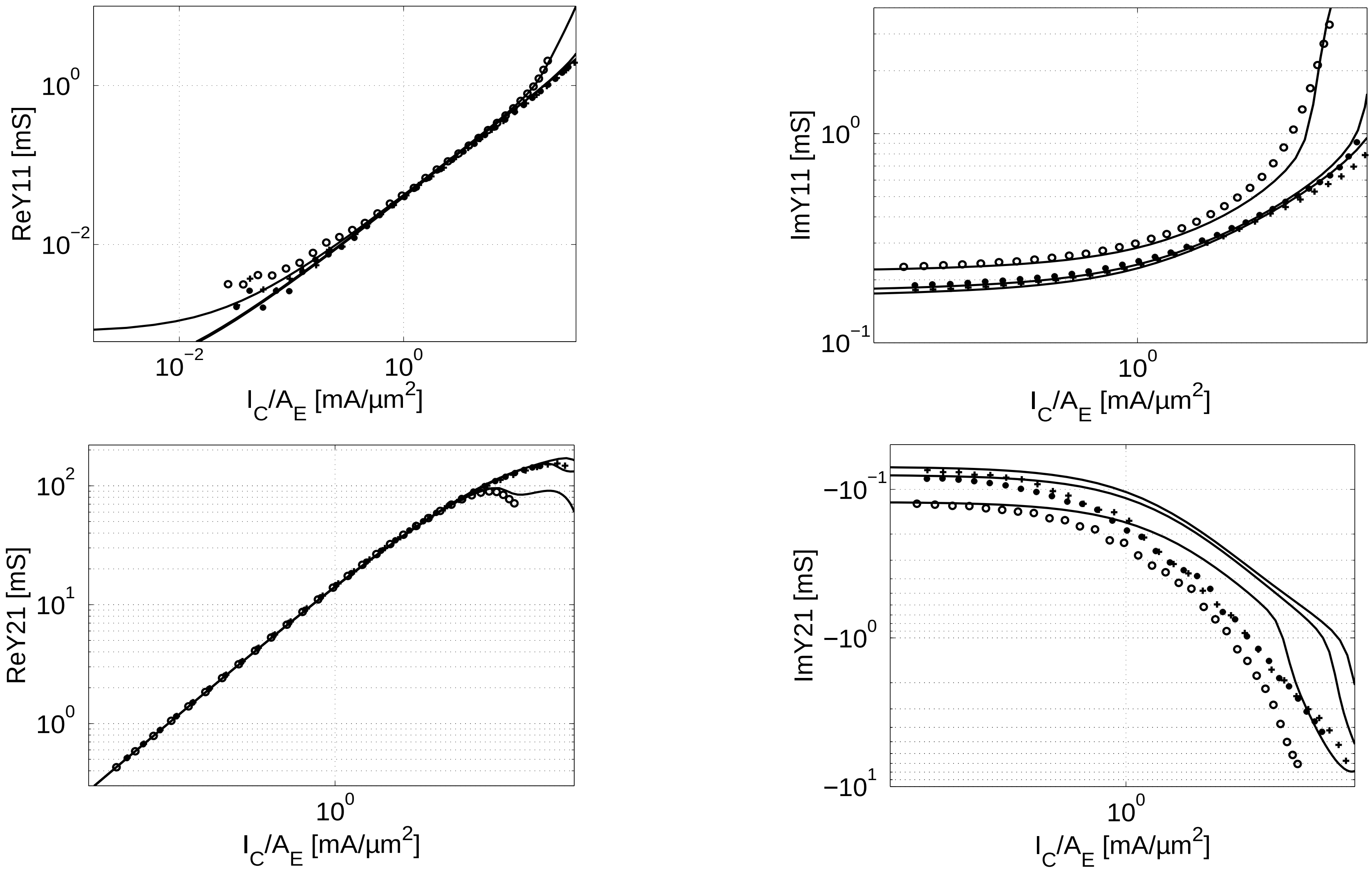






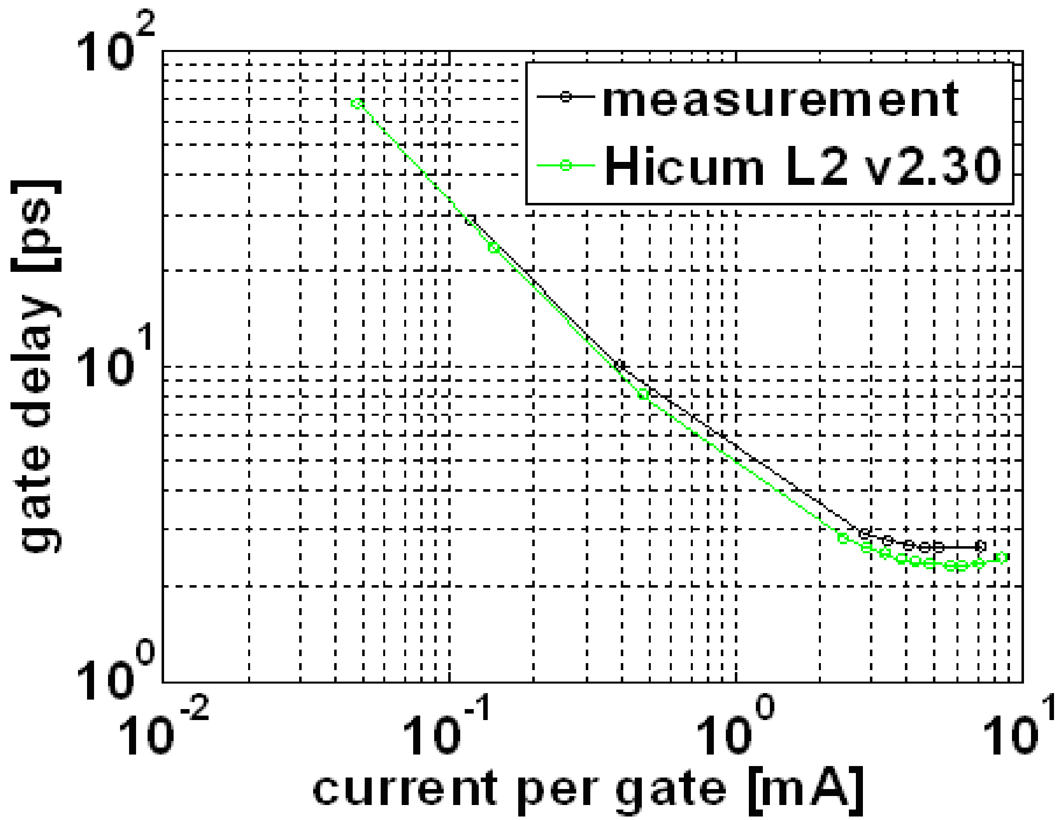
HICUM/L2 v2.30 verification (cont'd.) @125 °C

y-parameters @1GHz



HICUM/L2 v2.30 verification (cont'd.)

- CML Ring-Oscillator
  - HBT with 0.25 x 2.8 μm^2 emitter mask size (CEB contact configuration)



Ref: DotFive Deliverable report4.1.3

Model Run-Time Comparison

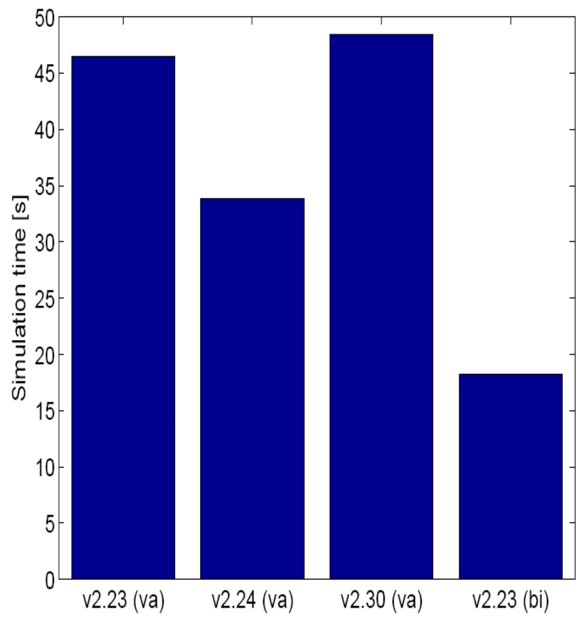
- Test bench:
  - DC-simulation: 20 devices in parallel, 17600 operating points
  - AC-simulation: 1 device, 187 operating points, 1500 frequency points
  - Transient simulation: ring-oscillator with 31 CML stages with two transistors

- HICUM versions tested:
  - HICUM Level 2, version 2.23 (Verilog-A code)
  - HICUM Level 2, version 2.24 (Verilog-A code)
  - HICUM Level 2, version 2.30 (Verilog-A code)
  - HICUM Level 2, version 2.23 (latest available ADS & Spectre built-in version)

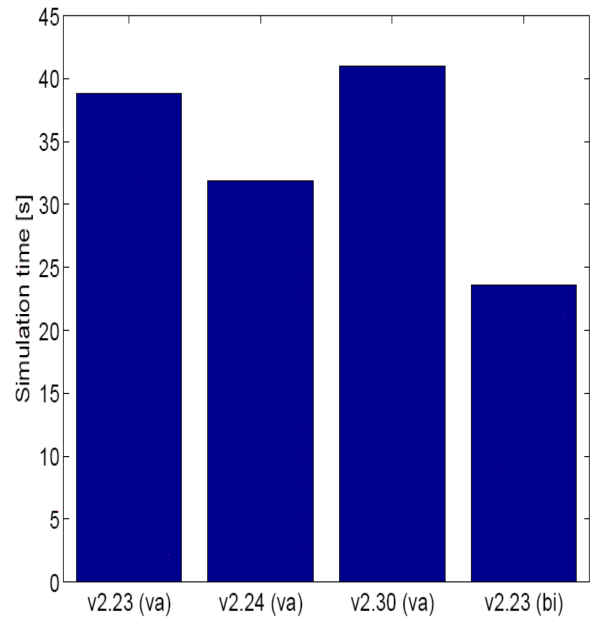
- All newly implemented effects in Hicum/L2v2.30 are turned-off to obtain meaningful comparisons (need to use identical parameter sets with v2.23 as the least common denominator!!)

Model Run-Time Comparison (cont'd.)

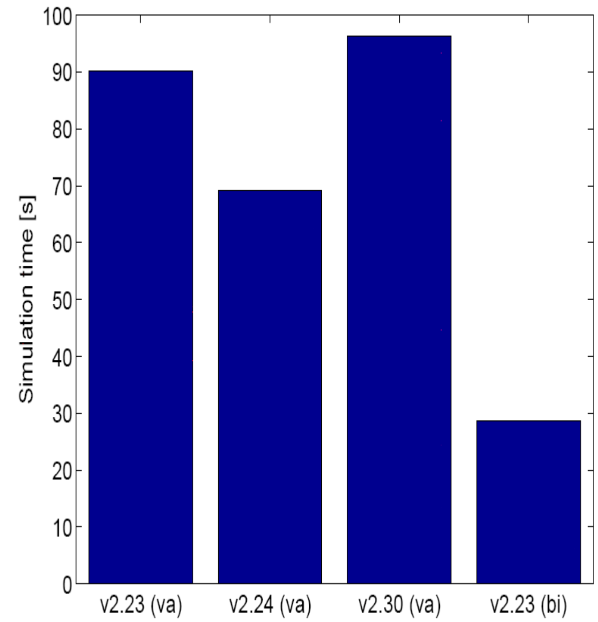
- Simulator: ADS (ADS2009U1), time in (s)



DC



AC



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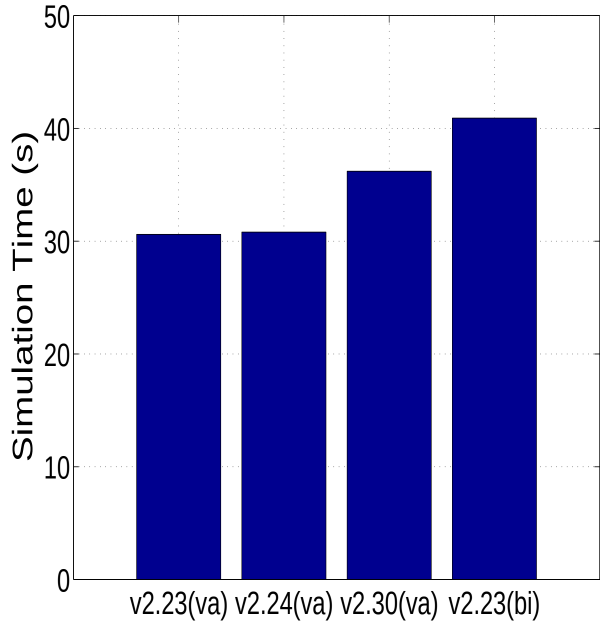
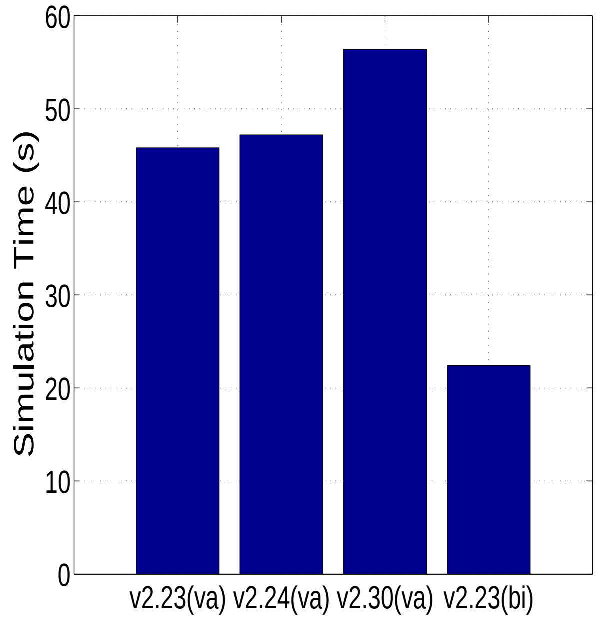
- Observation
  - The ADS built-in model runs ~50% faster except for AC simulation
  - Less time taken by V2.24 clearly shows absence of *"ddx"* operator

Model Run-Time Comparison (cont'd.)

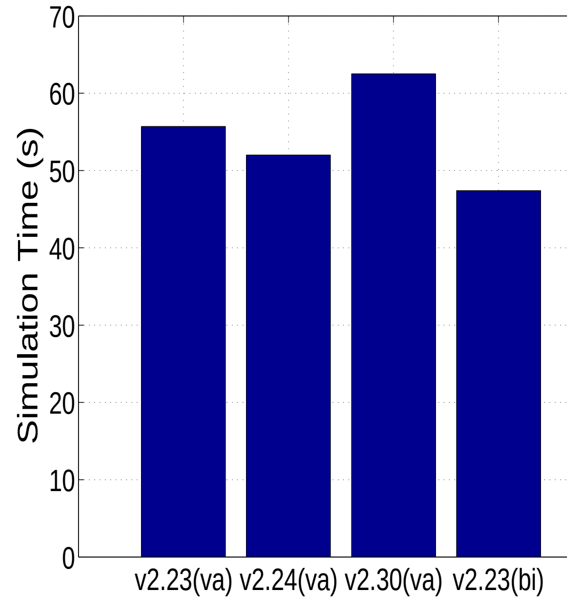
- Simulator: Spectre (MMSIM 7.2), time in second



DC



AC



Tran

- Observation
  - Spectre built-in version takes 30% more time than Verilog-A code in DC case => may be optimization problem during implementation

HICUM/L0 Support Activities

- Released new HICUM/L0 v1.3 => available on website since Feb. 2011
  - Developed primarily in cooperation with ST
- Access of source code restricted to users providing *support for model development and implementation (not CMC "regulations" restricted)*
  - Cadence received the code for implementation
- Primary features of HICUM/L0 v1.3
  - *"Gmin (=1e-12)"* implemented between collector and emitter node
  - *AHQ*, *ZETAIQF* changed to their proper names
  - Low-injection (junction related) base charge *qj* is now limited to positive value
  - Implementation of direct solution for transfer current
    - Cardano's method used for solving third order charge equation
    - *it_mod=0* turns-off & brings back previous model (v1.2) equations
  - Temperature dependence of emitter transit time *tef0* removed (= new default)
    - setting *tef_temp=1* makes former equations (v1.2) available

Conclusions

new version HICUM/L2 v2.3

- includes relevant effects in advanced HBTs through physics-based formulations
- applied to several advanced process technologies
  => excellent accuracy obtained
- was publicly released in May
- planned to be applied to a variety of different technologies (incl. HV HBTs)

runtime comparisons for v2.23: VA vs built-in

- DC results
  - VA: ADS ***50% slower*** than SPECTRE
  - built-in: ADS ***3 times faster*** than SPECTRE
- TR results for built-in: ADS ***50% faster*** than SPECTRE