Mextram 504

Jeroen Paasschens
Willy Kloosterman
Philips Research Laboratories, Eindhoven

Introduction

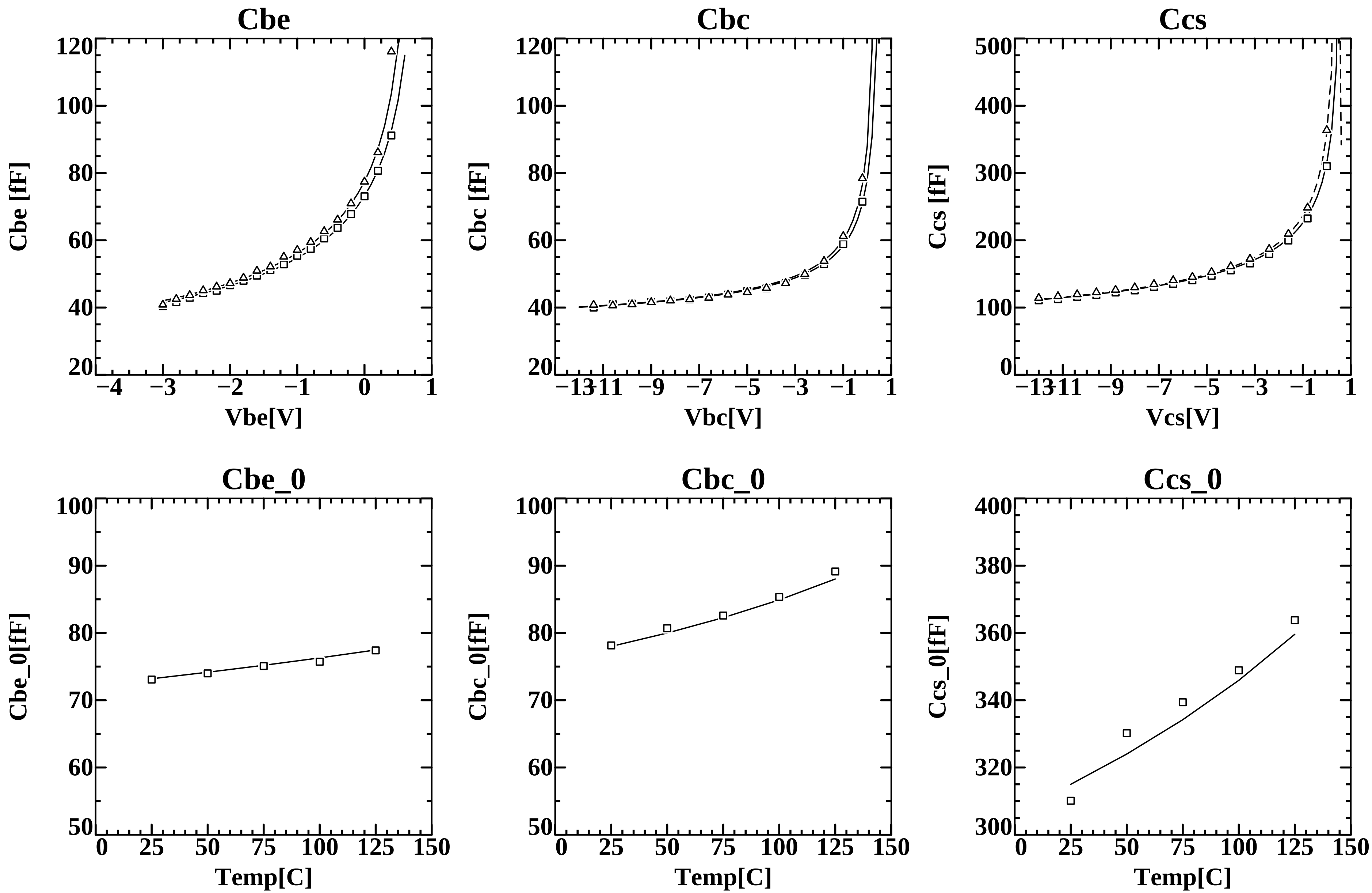
- Previous CMC: Mextram 503 gives generally good results.

- Why Mextram 504
  - — Modelling of SiGe processes
  - — Easier and hence better parameter extraction
  - — Better monotony in (higher) derivatives.

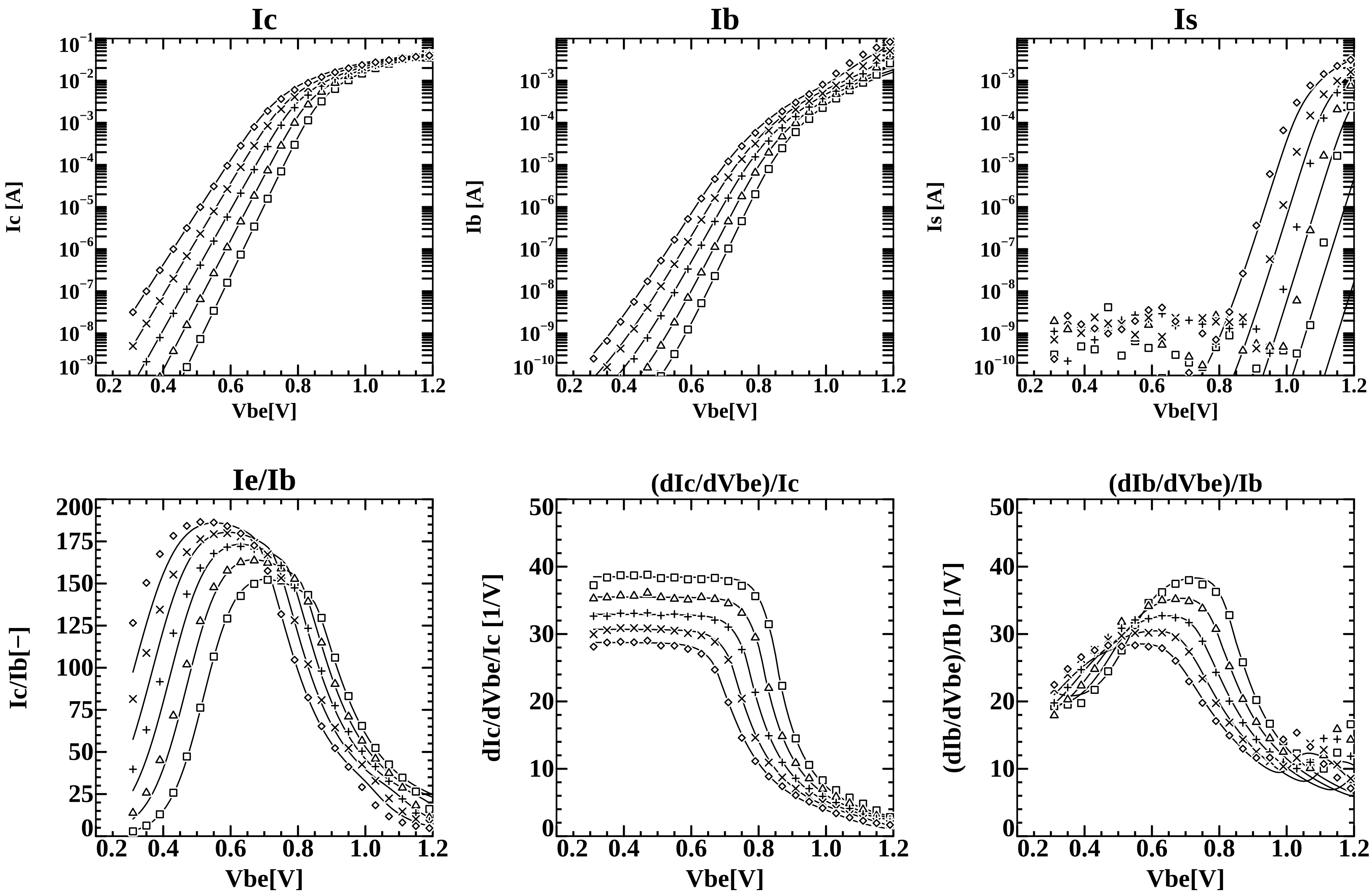
- We have tested Mextram 504 on five CMC data sets

- New parameter extraction only for process A

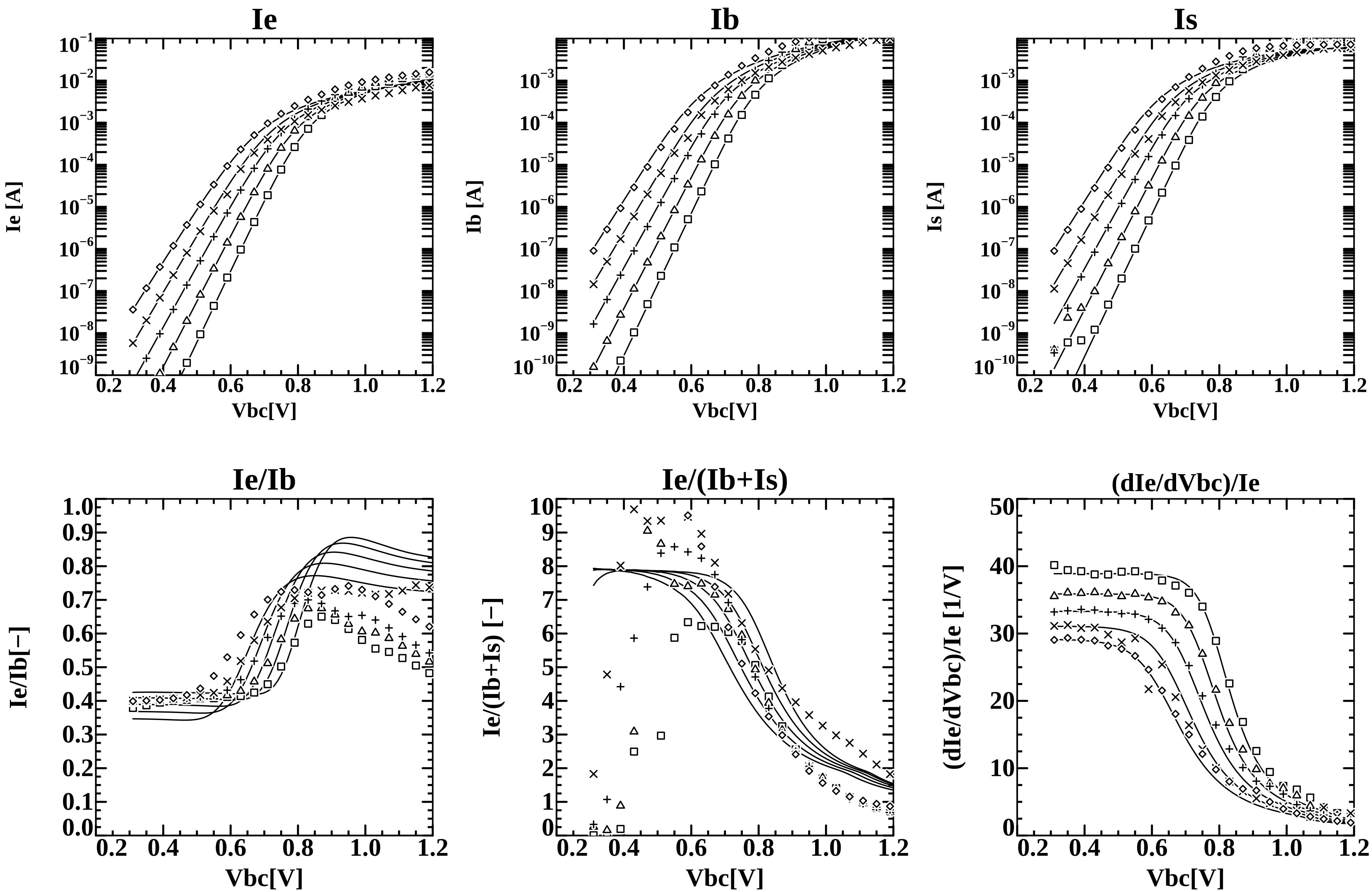
Process A: Cap Temp=25, 125 Mextram 503.2



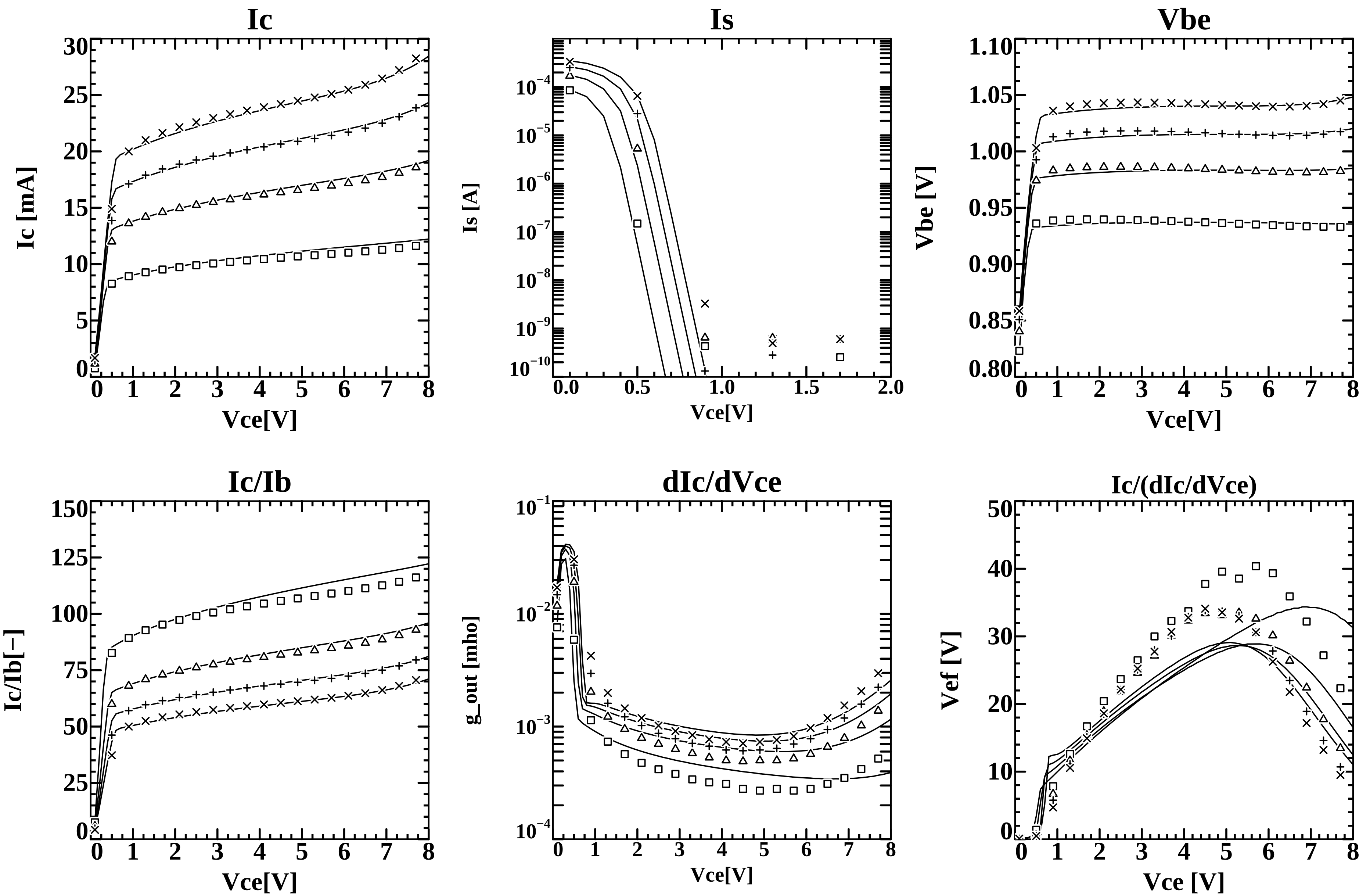
Process A: fgummel Vbc=0 Temp=25, 50, 75, 125, 150 Mextram 503.2 (3)



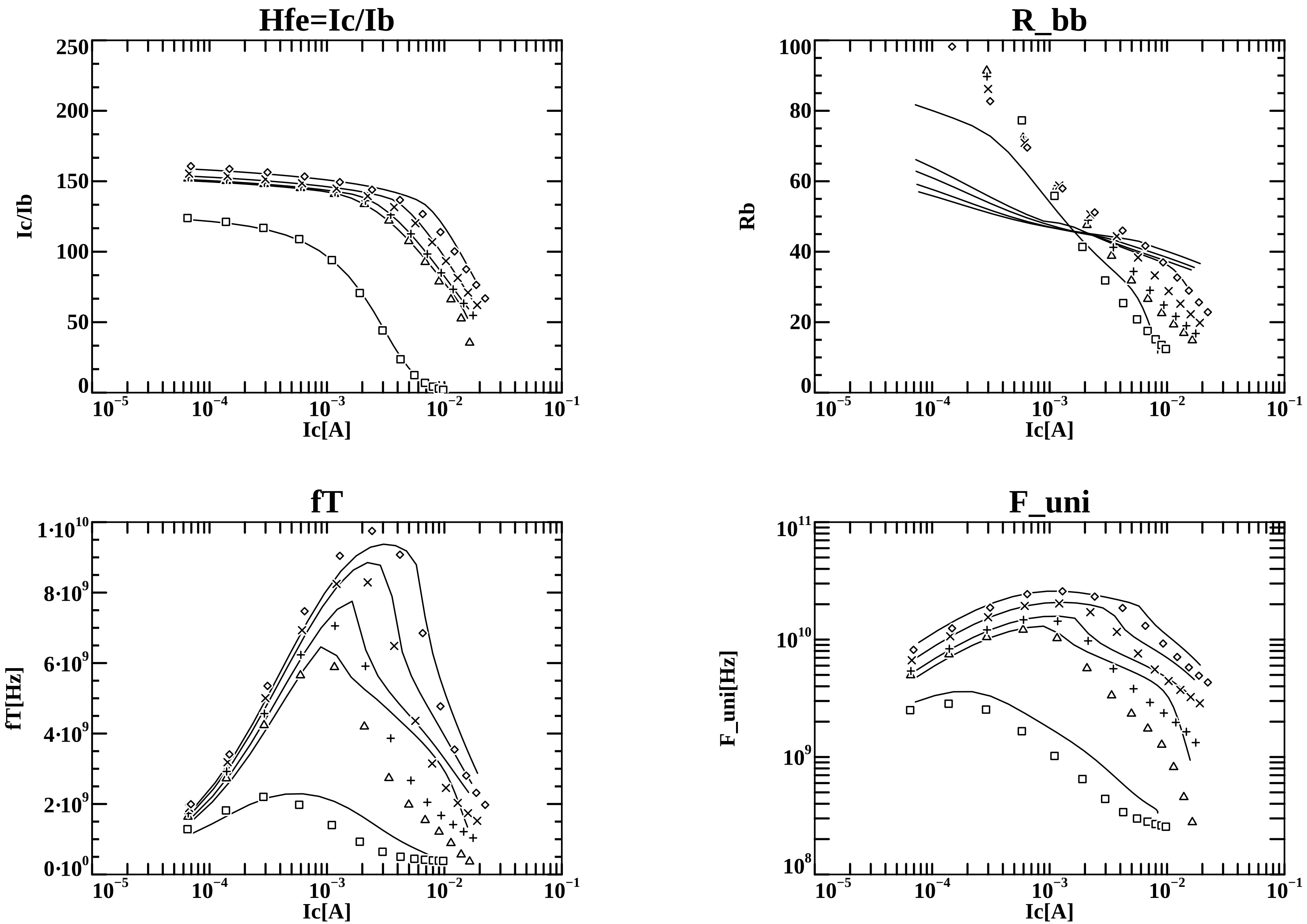
Process A: rgummel Vbe=0 Temp=25, 50, 75, 125, 150 Mextram 503.2 (4)



Process A: foutput-ib Temp=25 Ib=100, 200, 300, 400 uA Mextram 503.2 (5)



Process A: Temp=25 f=1 GHz, Vce =0.2, 0.5, 0.8, 2, 5 V Mextram 503.2 (6)



Outline

- Introduction and previous Mextram 503 results
- Reformulation of the epilayer model
- Results
- Conclusions

Process A

Single Poly BiCMOS process

Emitter size: $0.6 \times 5.4\,\mu\text{m}$

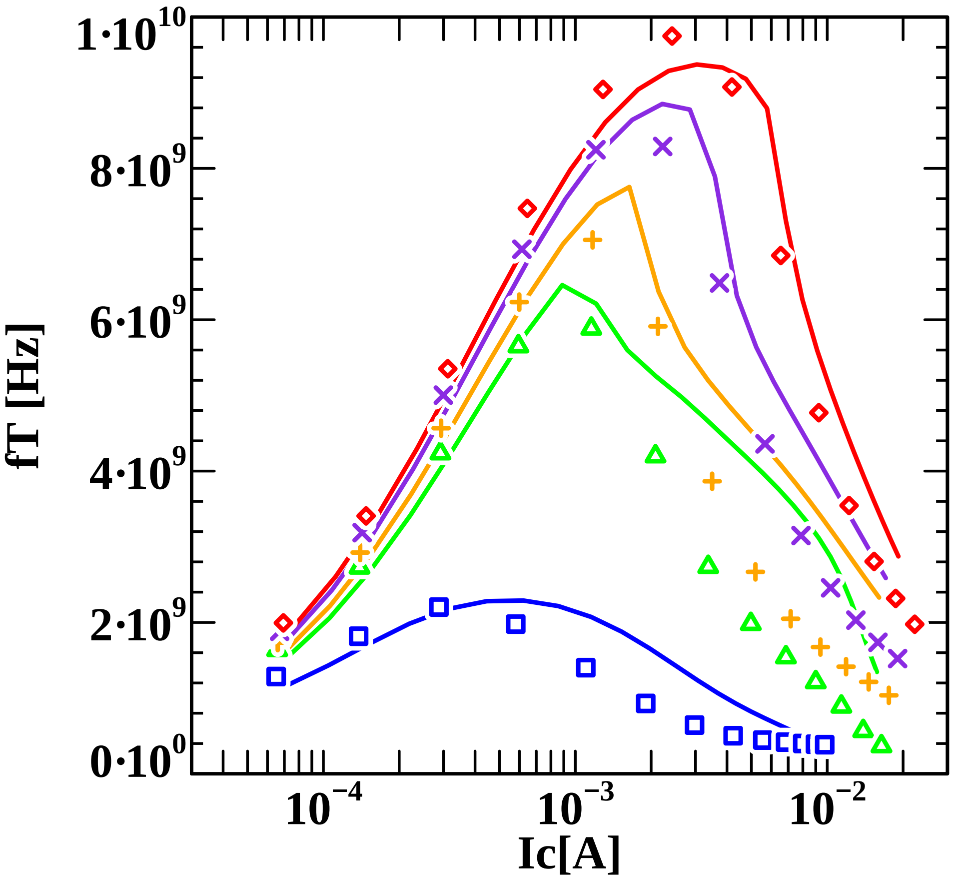
Double base contact: $r_p = 10\,\text{k}\Omega$

Maximum cut off frequency f_T

f_T: **10 GHz @** $V_{CE} = 5\,\text{V}$

f_T: **6 GHz @** $V_{CE} = 0.5\,\text{V}$

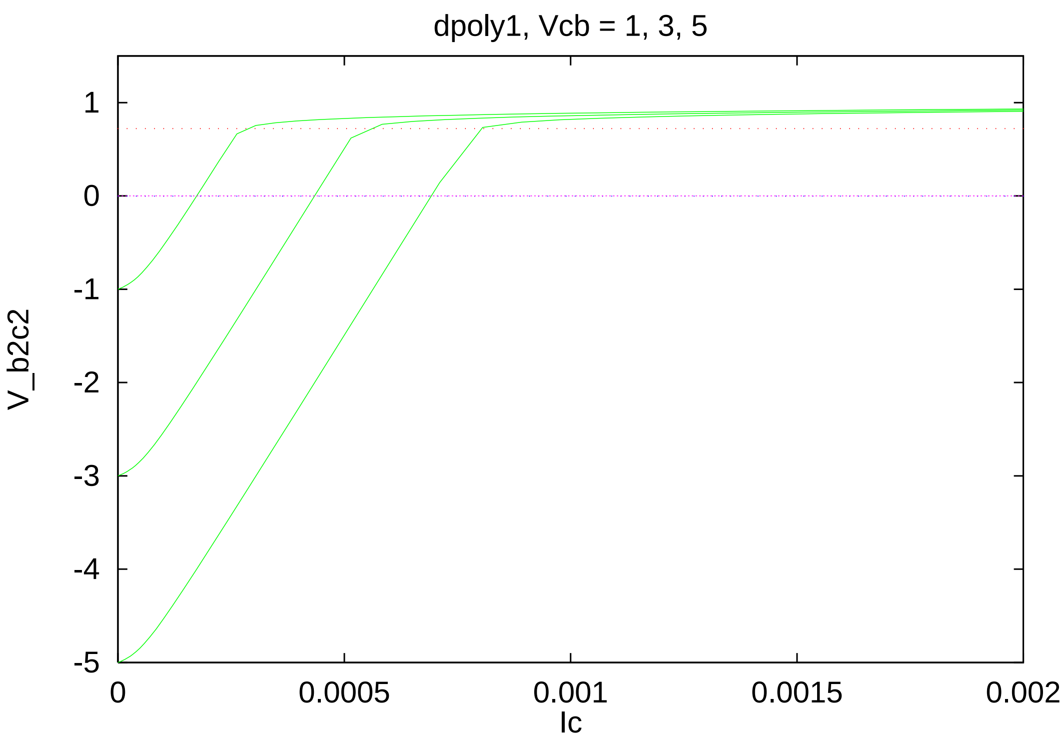
$V_{CE} =$ **0.2, 0.5, 0.8, 2.0, 5.0**

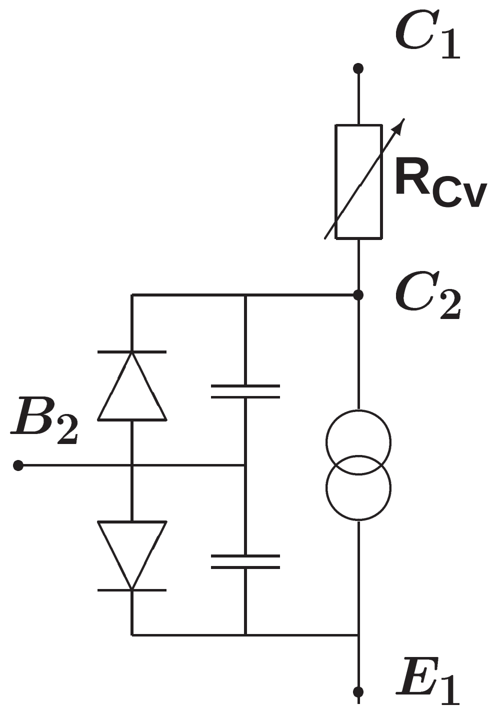


The internal base-collector bias increases strongly due to the (variable) epi-layer resistance.

When $\mathcal{V}_{B_2C_2} > V_{d_C}$ the junction is open. The bias increases only slightly .

This happens quite abrupt.



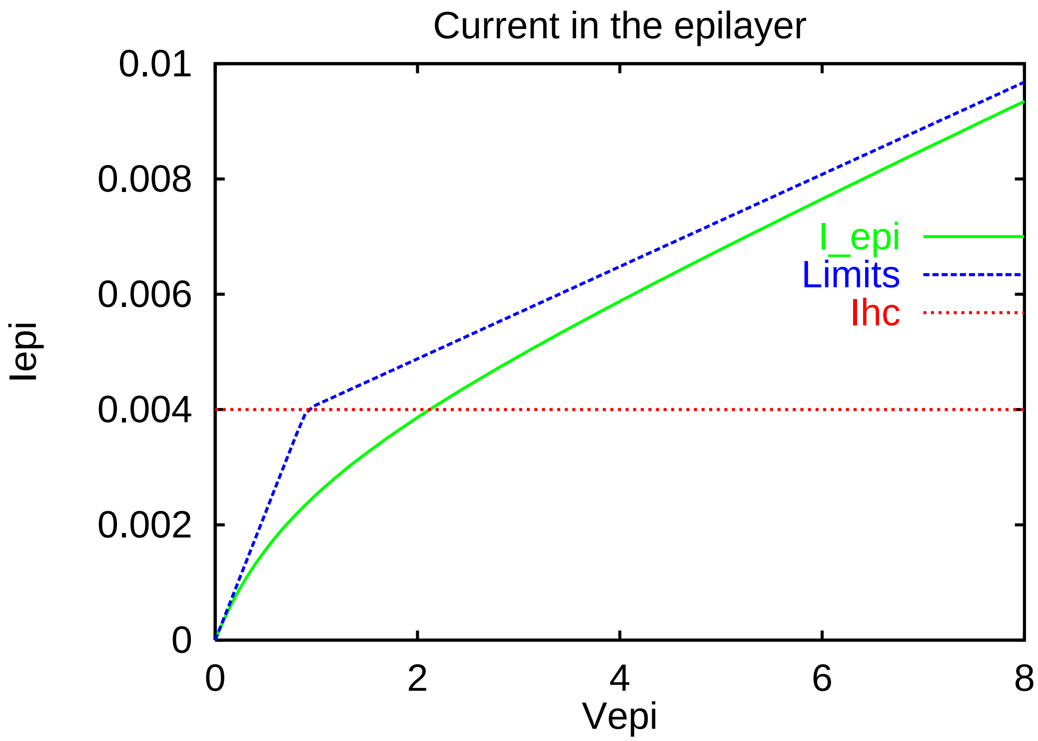


When there is no injection into the epilayer: ($\frac{x_i}{W_{\mathrm{epi}}} = 0$)

$$V_{\mathrm{epi}} = \mathcal{V}_{\mathrm{B_2C_2}} - \mathcal{V}_{\mathrm{B_2C_1}}$$

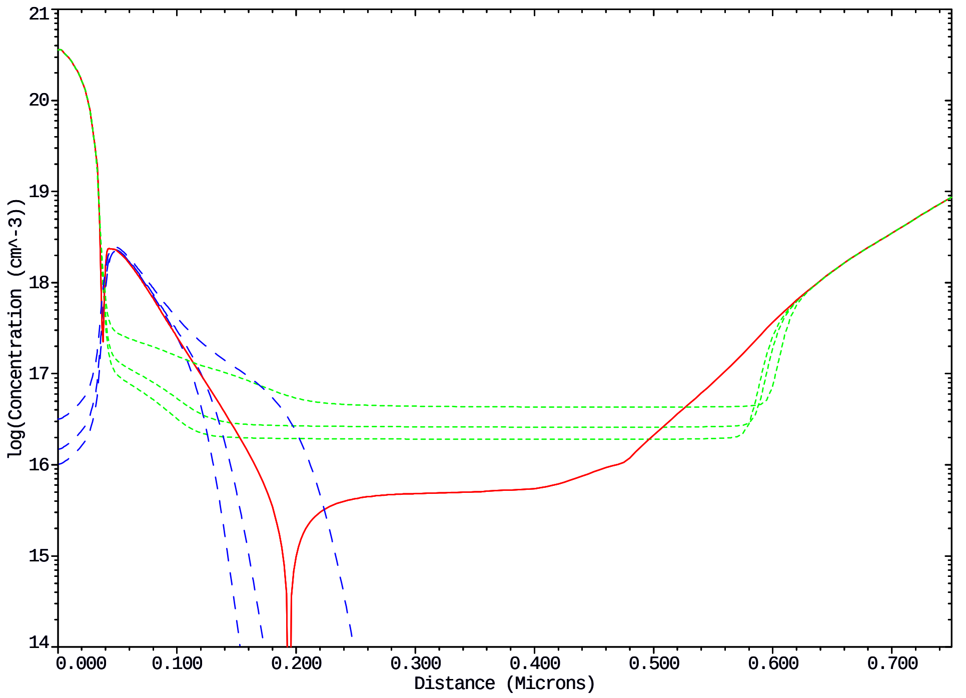
and

$$I = \frac{V_{\mathrm{epi}}}{\mathrm{SCR_{Cv}}} \, \frac{V_{\mathrm{epi}} + \mathrm{I_{hc}}\ \mathrm{SCR_{Cv}}}{V_{\mathrm{epi}} + \mathrm{I_{hc}}\ \mathrm{R_{Cv}}}$$



Basics of the epilayer model

Vce = 5V; ,Vbe = 0.87, 0.88, 0.90V; Ic = 0.32, 0.44, 0.74 mA



In case of injection ($\frac{x_i}{W_{epi}} > 0$)

$$V_{epi} \simeq \mathrm{V_{d_C}} - \mathcal{V}_{B_2C_1}$$

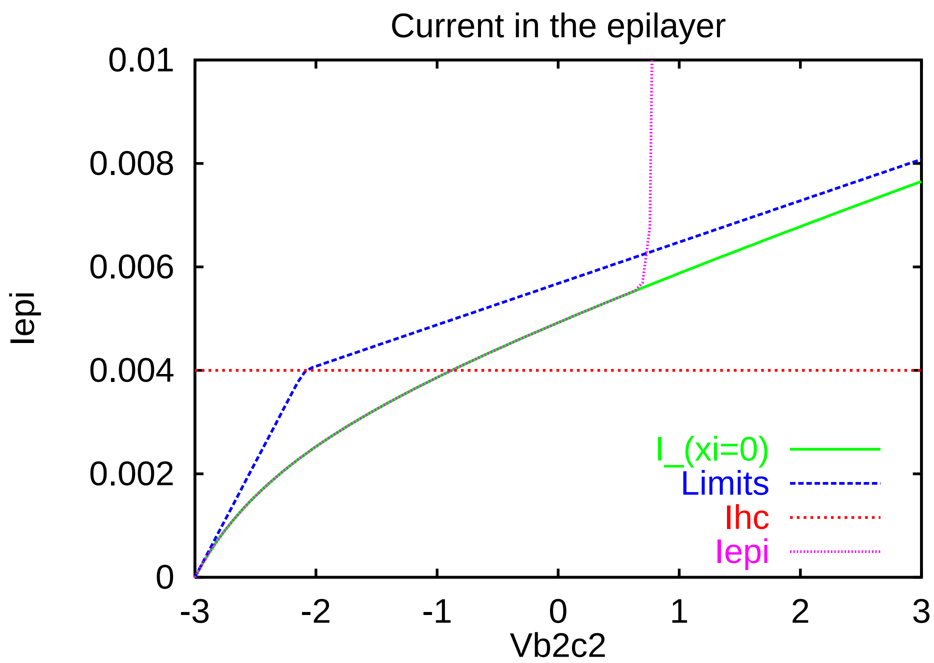
Injection thickness is given by (Kull model)

$$\frac{x_i}{W_{epi}} = \frac{f(\mathcal{V}_{B_2C_2}) - f(\mathcal{V}_{B_2C_1})}{I_{C_1C_2}\,\mathrm{R_{Cv}}}$$

$$I_{C_1C_2} = \frac{V_{epi}}{\mathrm{SCR_{Cv}}\,(1-\frac{x_i}{W_{epi}})^2}\;\frac{V_{epi} + \mathrm{I_{hc}}\,\mathrm{SCR_{Cv}}\,(1-\frac{x_i}{W_{epi}})^2}{V_{epi} + \mathrm{I_{hc}}\,\mathrm{R_{Cv}}\,(1-\frac{x_i}{W_{epi}})}$$

Voltages $\mathcal{V}_{\mathrm{B_2C_2}}$ and $\mathcal{V}_{\mathrm{B_2C_1}}$ are given.

Combine the equations to find a third order equation for $I_{C_1C_2}$.



From $\mathcal{V}_{\mathrm{B_2C_2}}$ calculate

- Reverse current I_r
- Reverse base charge Q_{BC}
- Epilayer charge Q_{epi}

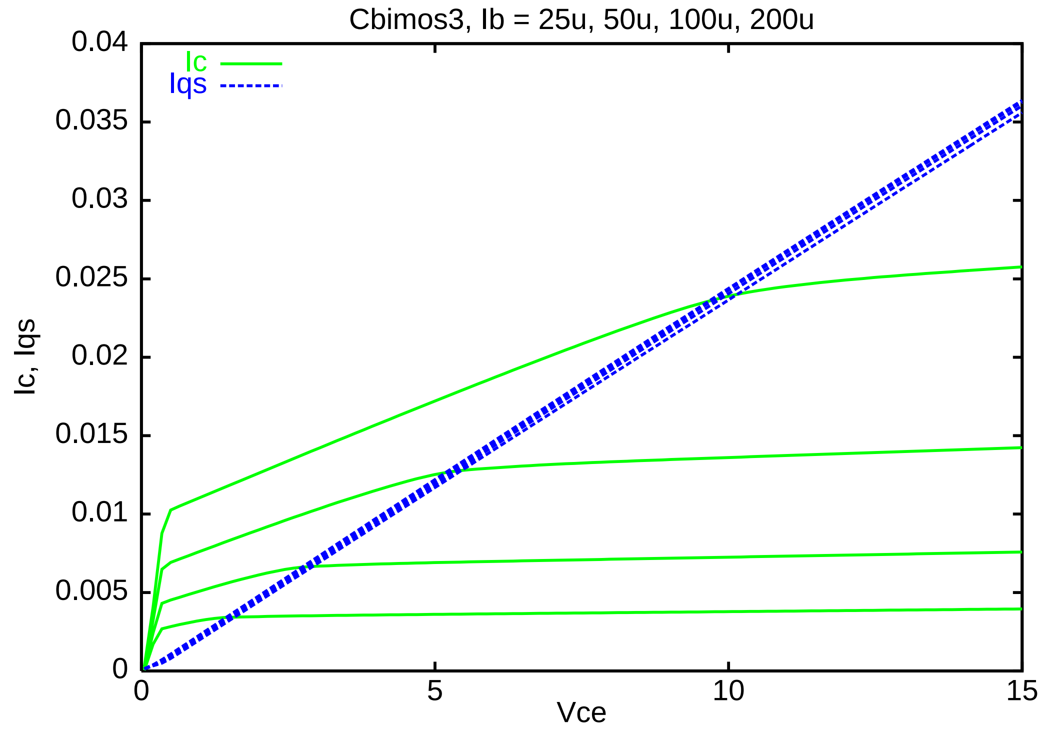
  (from charge control relation)

  Uses also $\mathcal{V}_{\mathrm{B_2C_1}}$ and $I_{C_1C_2}$)

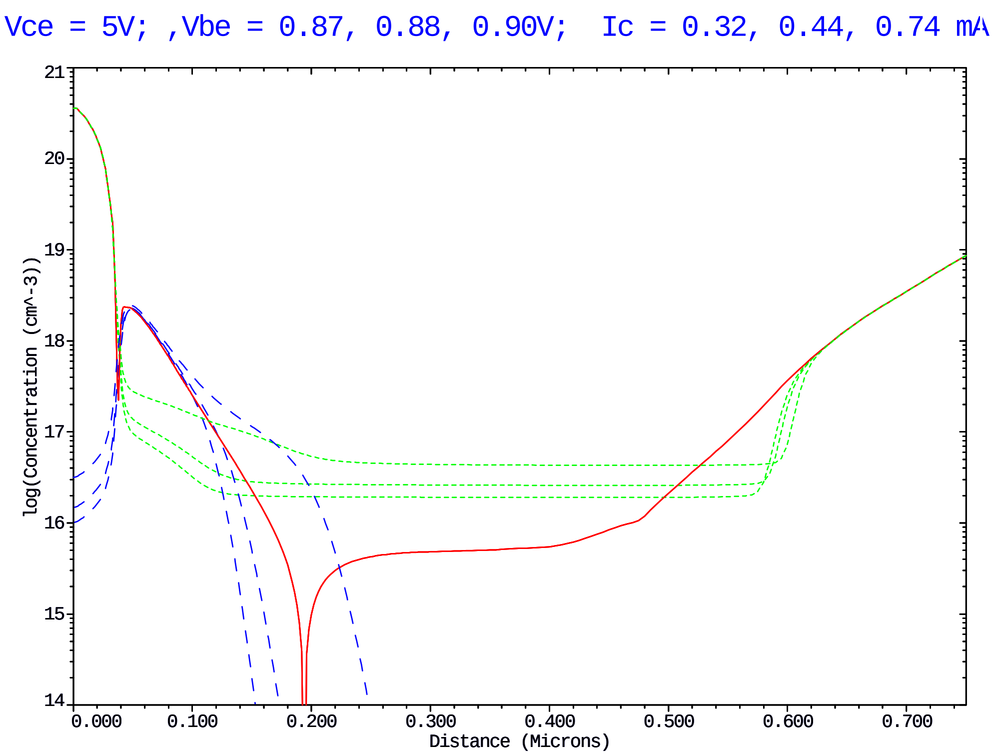
Injection starts when $\mathcal{V}_{B_2C_2} \simeq V_{dC}$:

$$V_{qs} \equiv V_{dC} - \mathcal{V}_{B_2C_1}$$

$$I_{qs} \equiv \frac{V_{qs}}{SCR_{Cv}} \frac{V_{qs} + I_{hc}\, SCR_{Cv}}{V_{qs} + I_{hc}\, R_{Cv}}$$



Example without velocity saturation



In case of injection ($\frac{x_i}{W_{\text{epi}}} > 0$)

$$V_{\text{epi}} \simeq \mathsf{V}_{\mathsf{d_C}} - \mathcal{V}_{\mathrm{B_2C_1}}$$

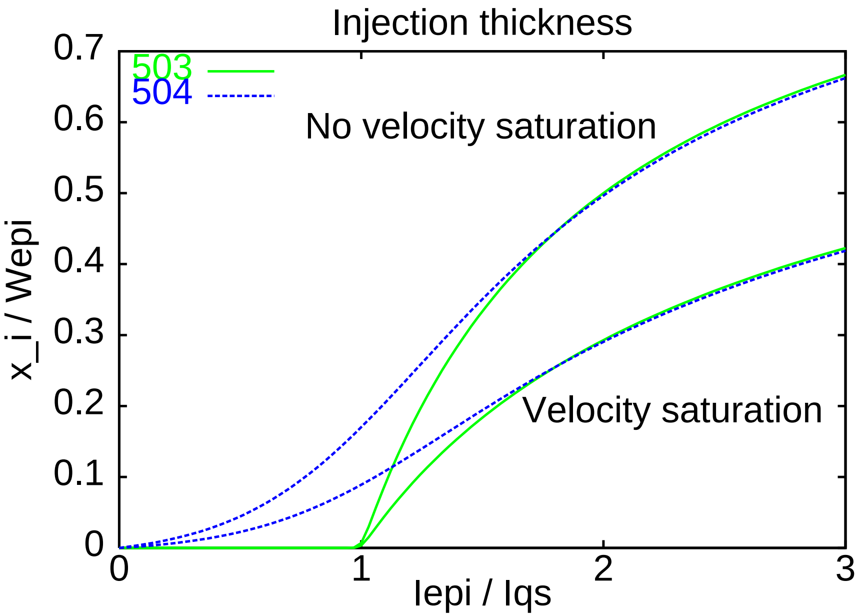
Injection thickness is given by (Kull model)

$$\frac{x_i}{W_{\text{epi}}} = \frac{f(\mathcal{V}_{\mathrm{B_2C_2}}) - f(\mathcal{V}_{\mathrm{B_2C_1}})}{I_{C_1C_2}\,\mathsf{R_{Cv}}}$$

$$I_{C_1C_2} = \frac{V_{\text{epi}}}{\mathsf{SCR_{Cv}}\,(1 - \frac{x_i}{W_{\text{epi}}})^2}\;\frac{V_{\text{epi}} + \mathsf{I_{hc}}\,\mathsf{SCR_{Cv}}\,(1 - \frac{x_i}{W_{\text{epi}}})^2}{V_{\text{epi}} + \mathsf{I_{hc}}\,\mathsf{R_{Cv}}\,(1 - \frac{x_i}{W_{\text{epi}}})}$$

calculate $\frac{x_i}{W_{\text{epi}}}$ from $I_{C_1C_2}$ and $\mathcal{V}_{\text{B}_2\text{C}_1}$ (third order equation)

$$\frac{x_i}{W_{\text{epi}}} = \begin{cases} 1 - \dfrac{I_{qs}}{I_{C_1C_2}} & \text{no velocity saturation} \\ 1 - \sqrt{\dfrac{I_{qs}}{I_{C_1C_2}}} & \text{velocity saturation} \end{cases}$$



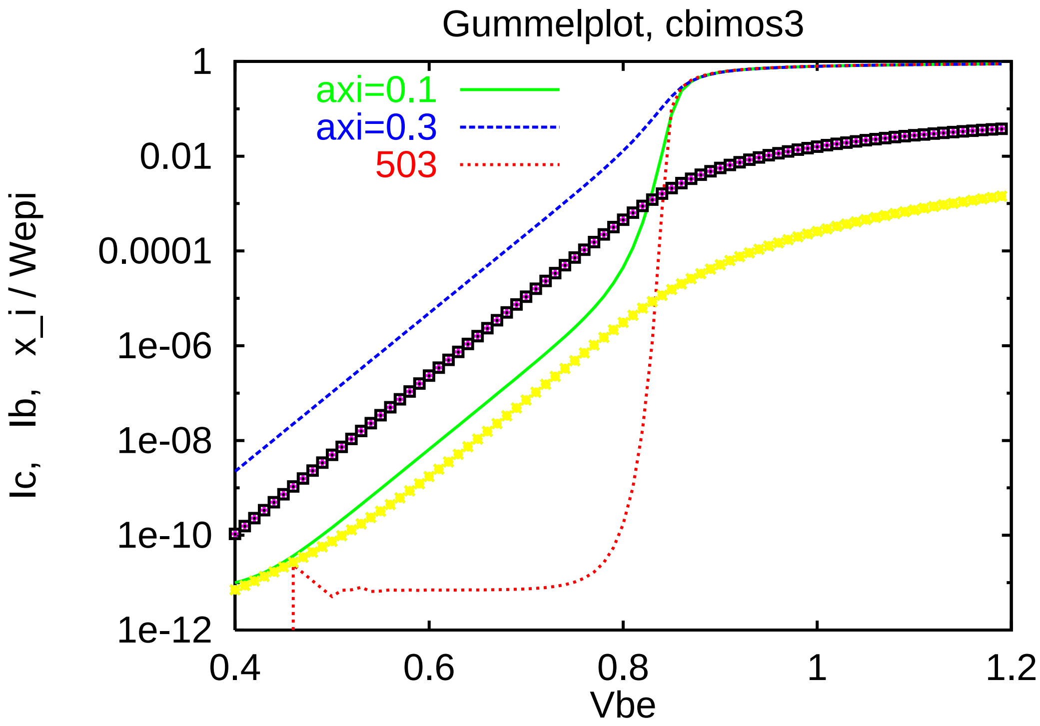
Calculate $\mathcal{V}^*_{\mathrm{B_2C_2}}$ from the equation for $\frac{x_i}{W_{\mathrm{epi}}}$ (Kull model approximated):

$$\frac{x_i}{W_{\mathrm{epi}}} = \frac{f(\mathcal{V}^*_{\mathrm{B_2C_2}}) - f(\mathcal{V}_{\mathrm{B_2C_1}})}{I_{C_1C_2}\,\mathsf{R_{Cv}}}$$

From $\mathcal{V}^*_{\mathrm{B_2C_2}}$ calculate

- Reverse current I_r
- Reverse base charge Q_{BC}
- Epilayer charge Q_{epi}

This describes also charge in hard saturation ($I_{C_1C_2} \simeq 0$)



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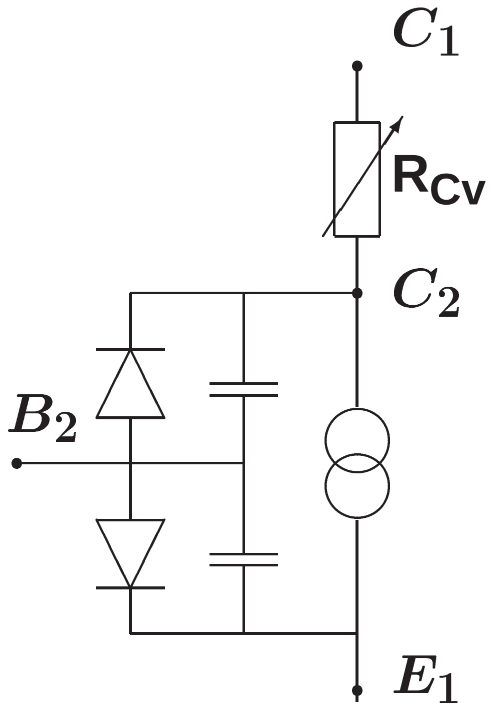
Current definition

Question: How do we find $I_{C_1C_2}$?



Use the epilayer resistance as a *current sensor*.

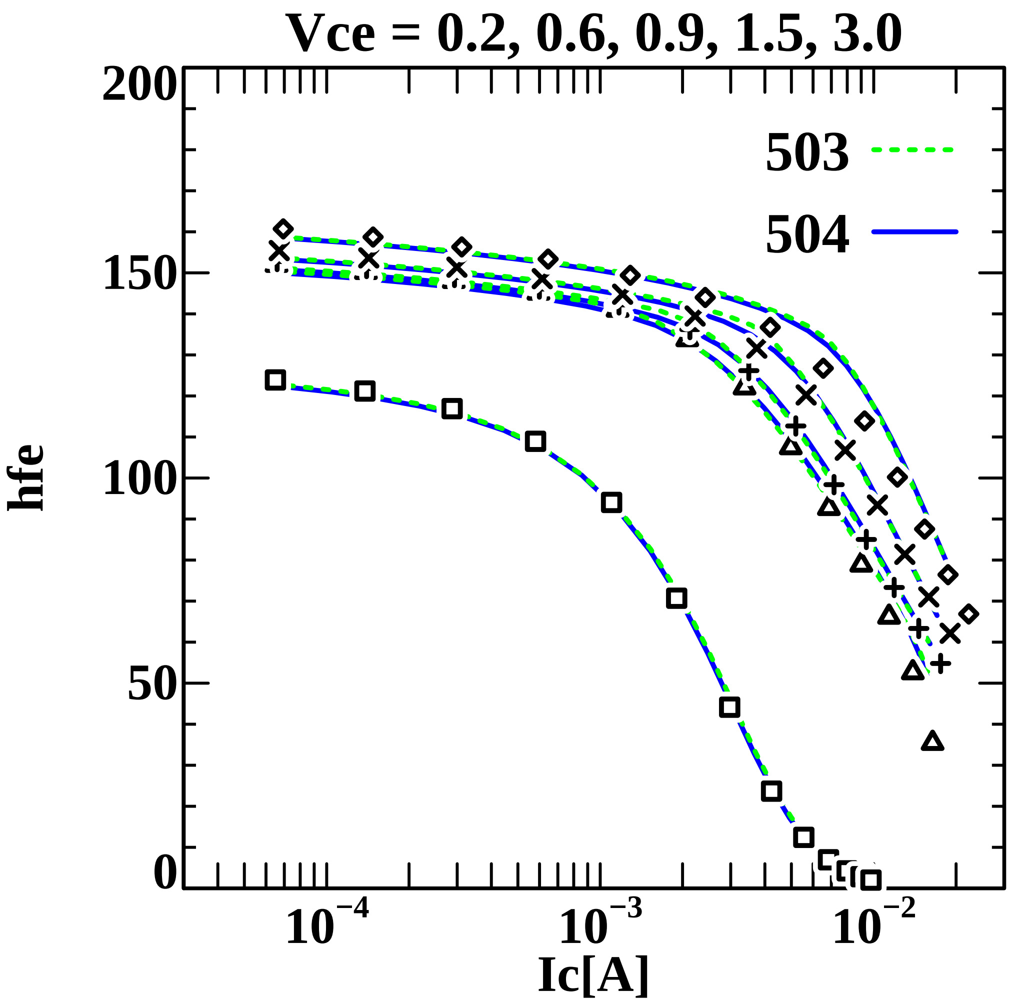
Node voltage $\mathcal{V}_{\mathrm{B_2C_2}}$ is *only* used to define the current:

$$I_{C_1C_2} = \frac{f(\mathcal{V}_{\mathrm{B_2C_2}}) - f(\mathcal{V}_{\mathrm{B_2C_1}}) + \mathcal{V}_{\mathrm{C_1C_2}}}{\mathrm{R_{Cv}}}$$

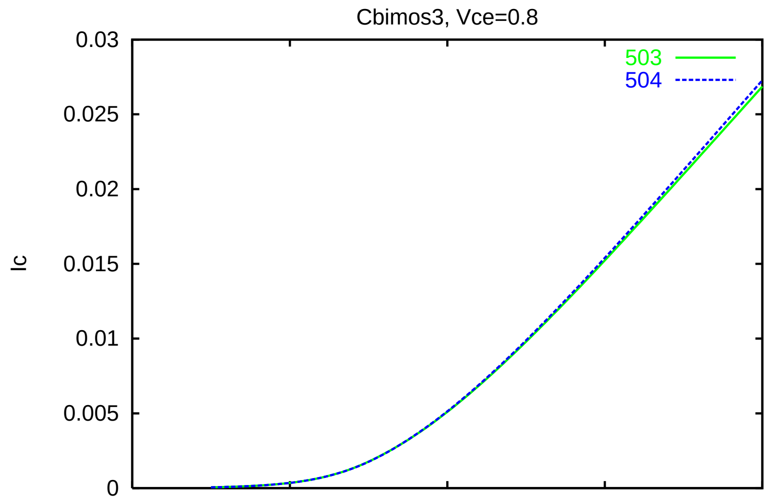
(Kull model; also used in reverse)

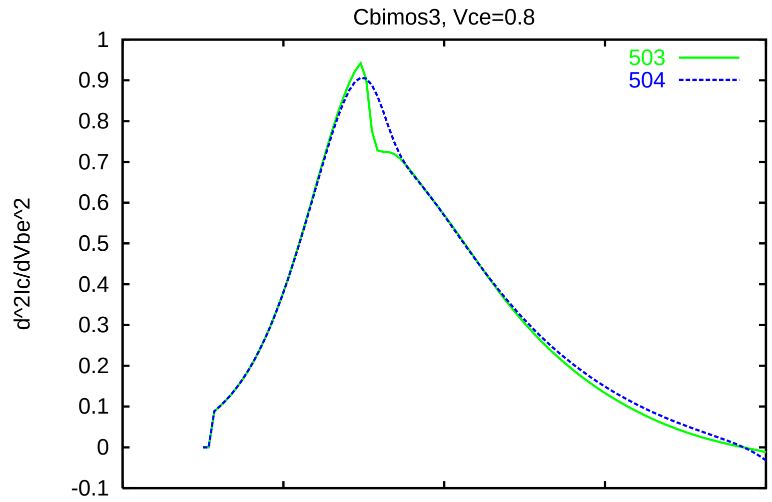
$\Longrightarrow$ **$\mathcal{V}_{\mathrm{B_2C_2}}$ is always reasonably physical.**

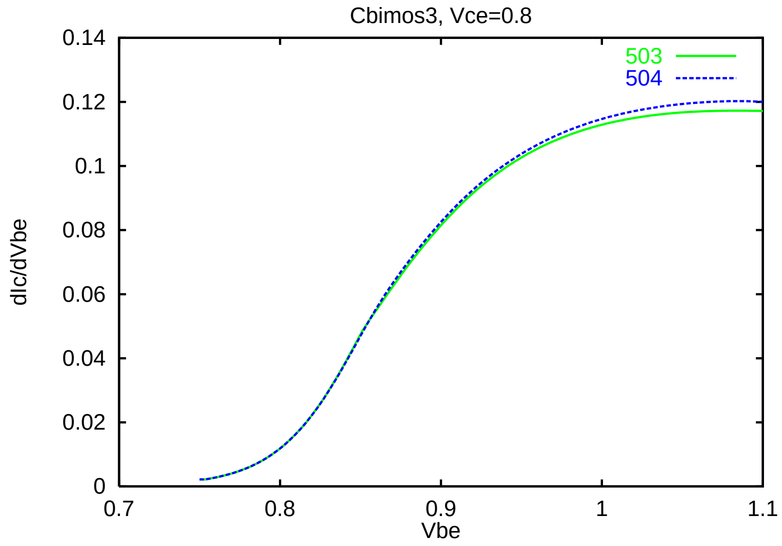
Process A: h_{fe}

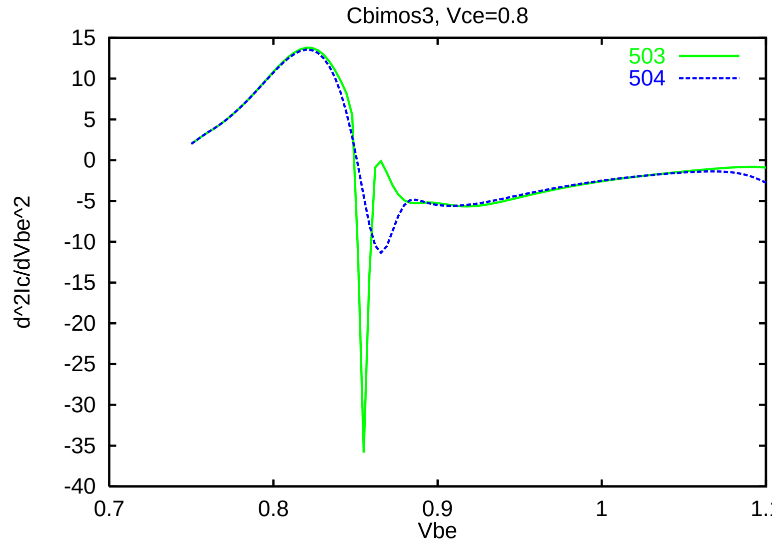


Current and derivatives

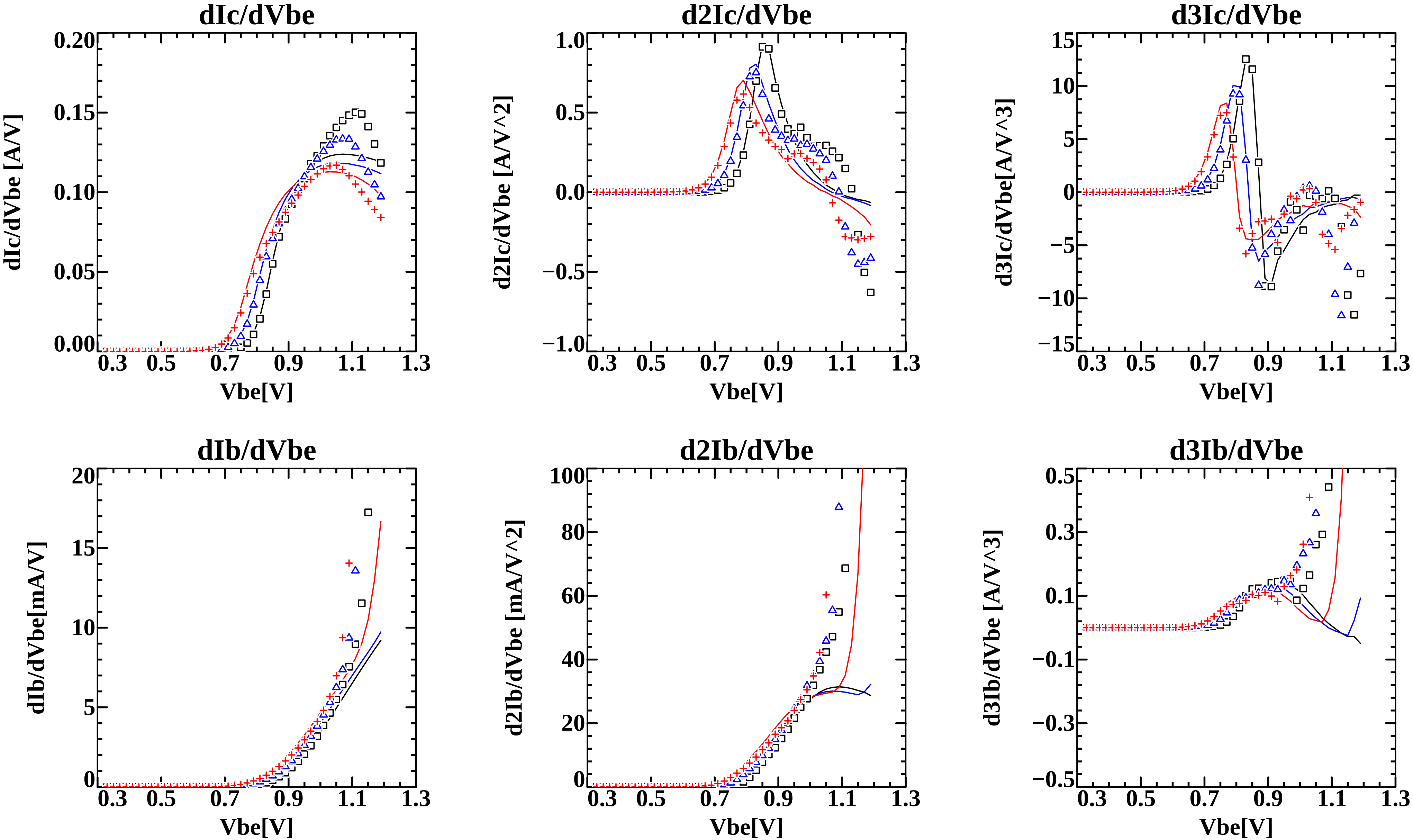




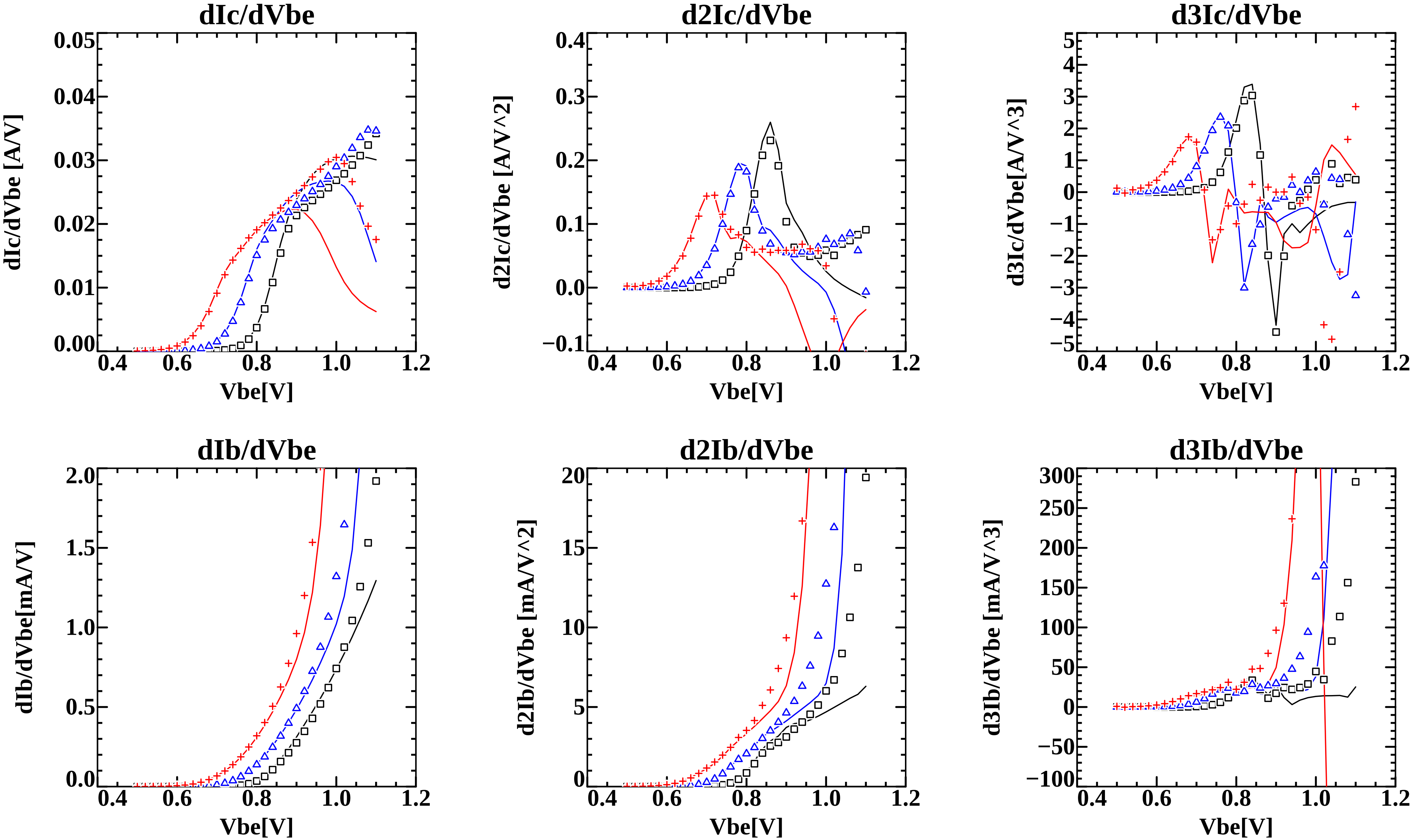




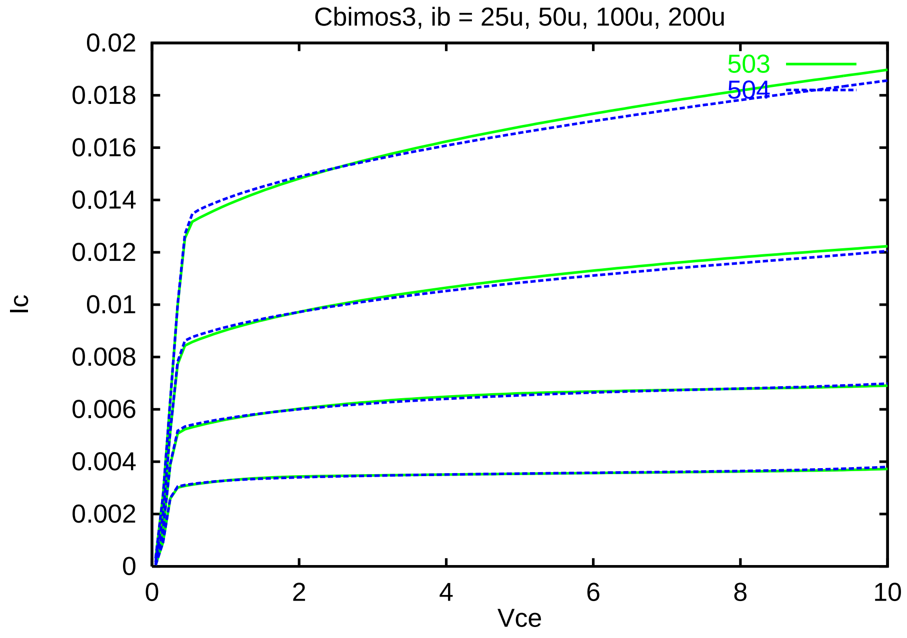
Process A: fgummel Vbc=0 Temp=25,50,75 Mextram 504 (20)

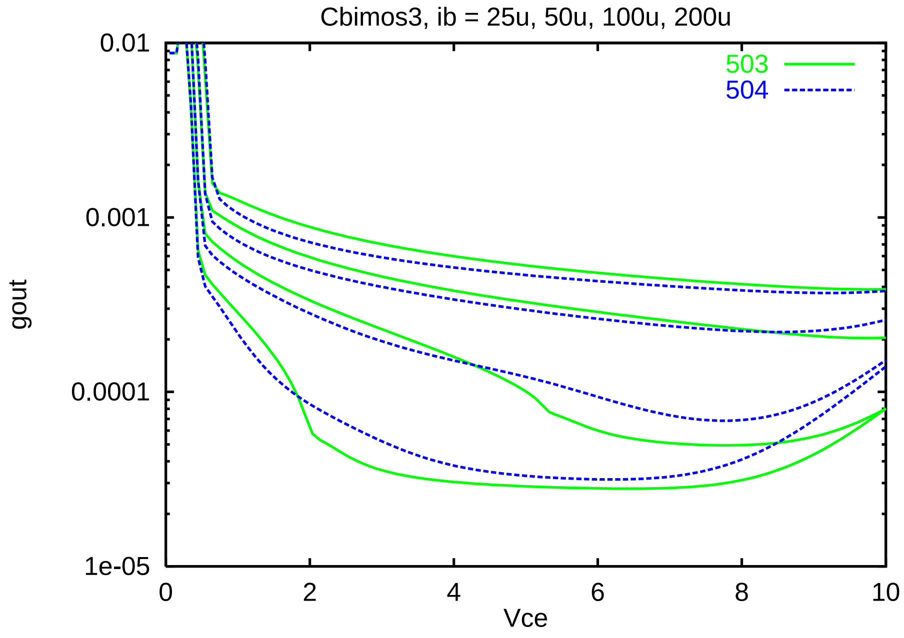


Process C: fgummel Vbc=0 Temp=25, 75, 125 Mextram 504 (21)

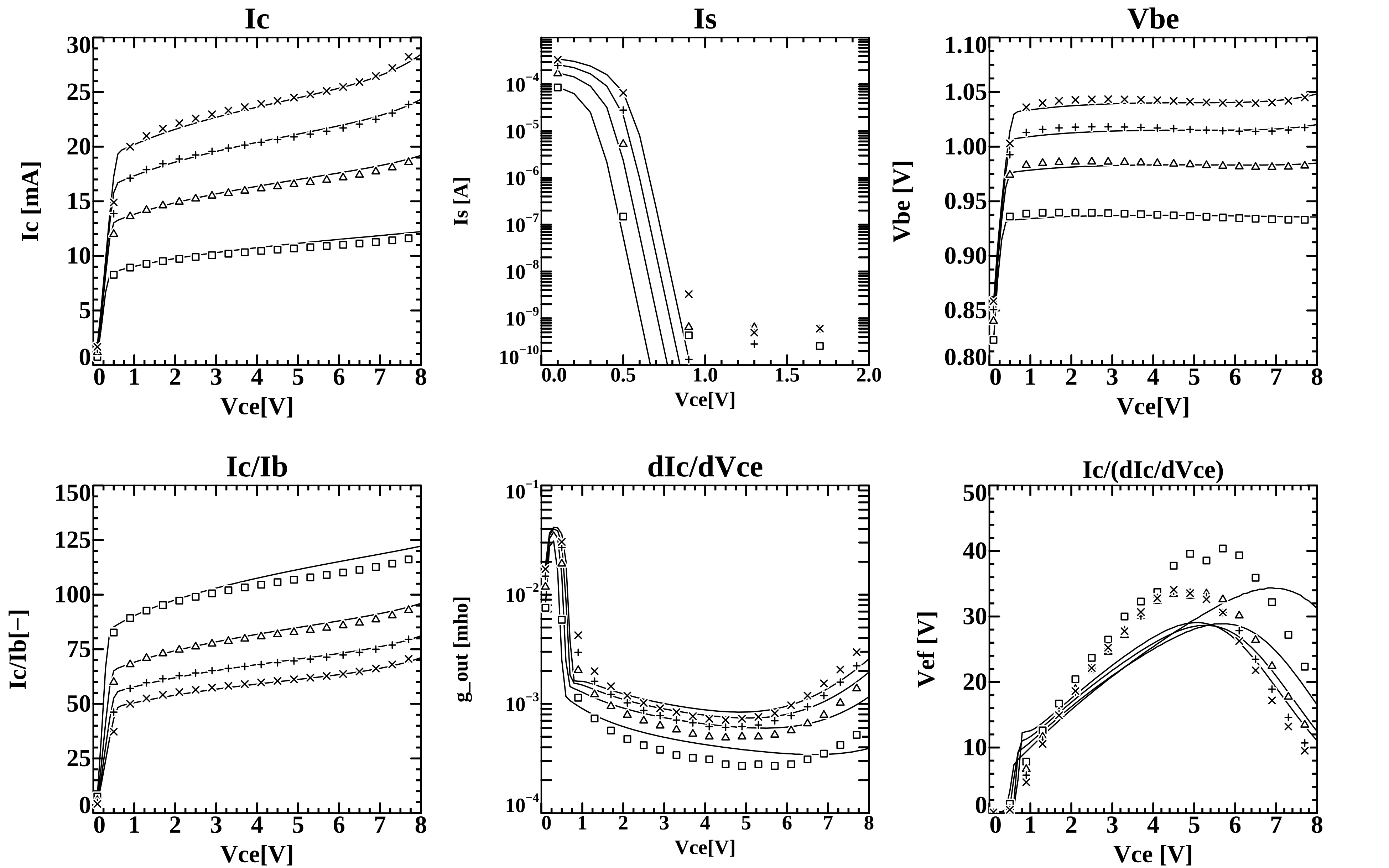


Output characteristics

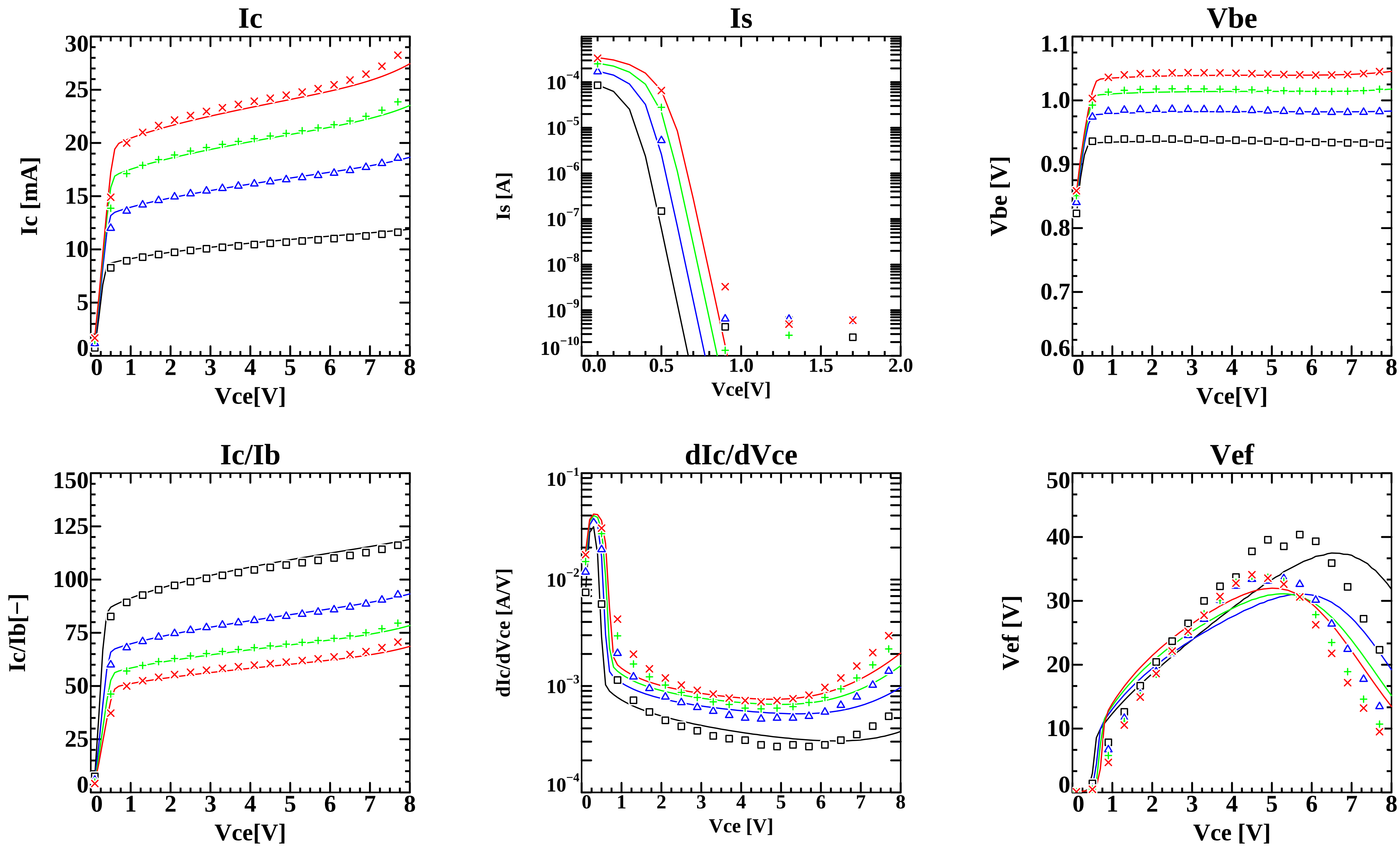




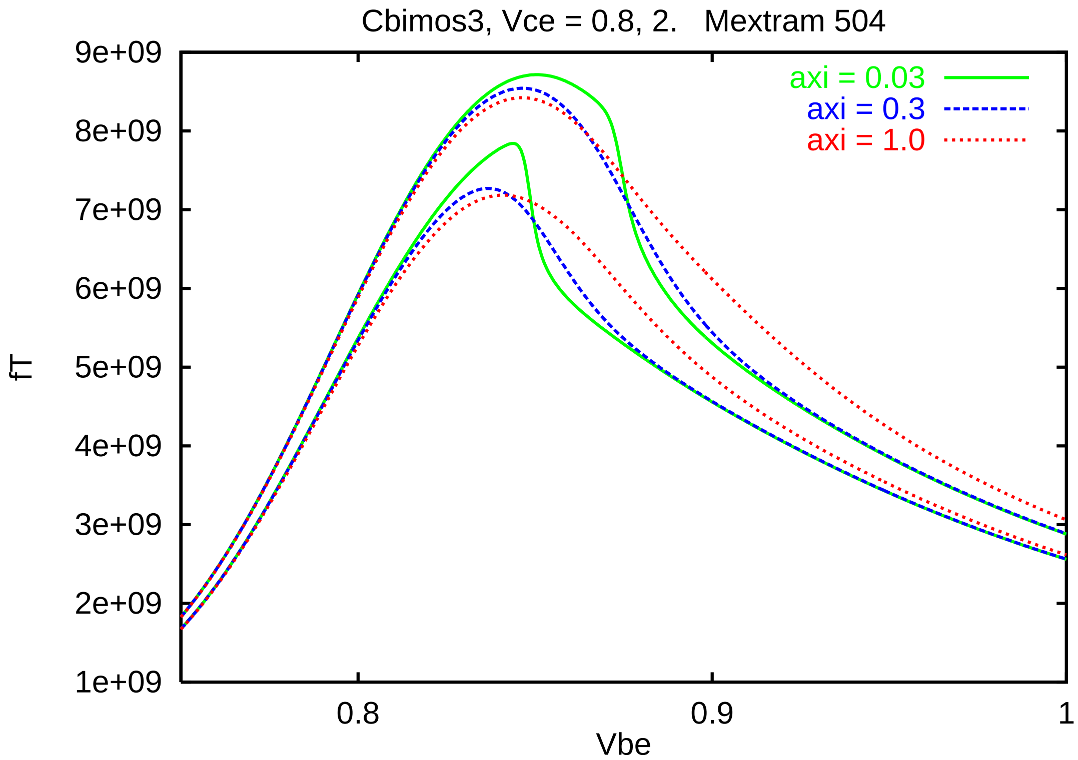
Process A: foutput-ib Temp=25 Ib=100, 200, 300, 400 uA Mextram 503.2 (23)



Process A: foutput-ib Temp=25 Ib=100, 200, 300, 400 uA Mextram 504 (24)



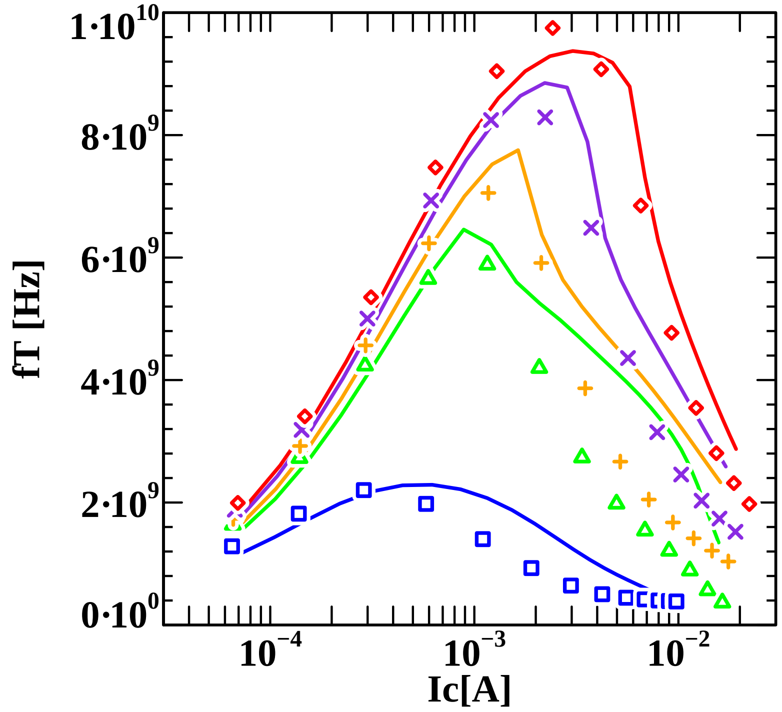
Basically we only need one new parameter: a_{x_i}



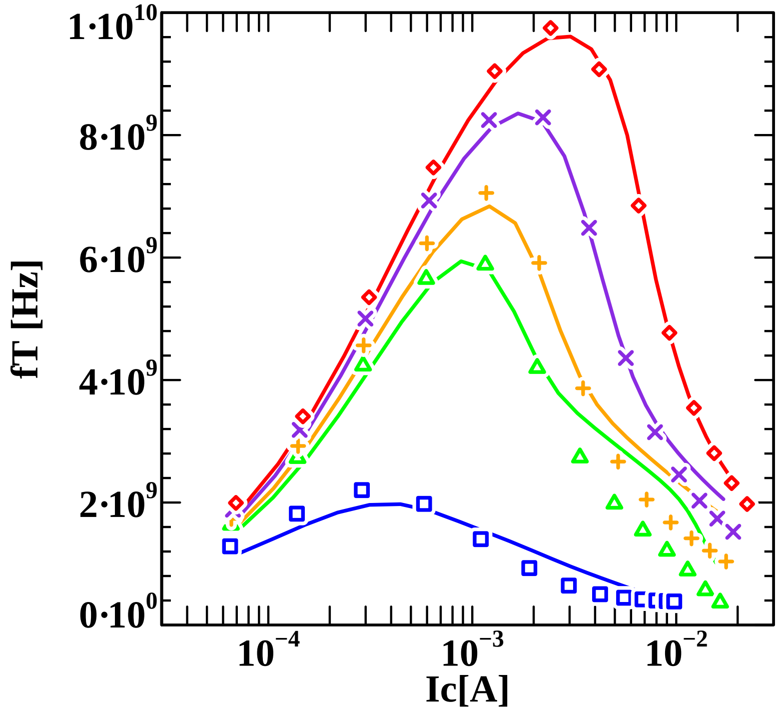
We also add the transit time parameters τ_B, τ_{epi}, and τ_R.

(In Mextram 503 these are calculated from DC parameters)

Mextram 503



Mextram 504



Conclusions

- Mextram 504 has much smoother characteristics

- Better description of measurements,
  improved parameter extraction features must still be demonstrated.

- SiGe modelling:
  — Mextram 503 results are reasonable.
  — Physical description and geometric scaling better with Mextram 504
  — Not enough experience (yet) with SiGe (e.g. not tested in production)

- Mextram 504 will contain self-heating network

- Mextram 504 model equations are ready except for details

Further testing mainly within Philips