HICUM/L0: Improvement of the injection width description

Never stop thinking

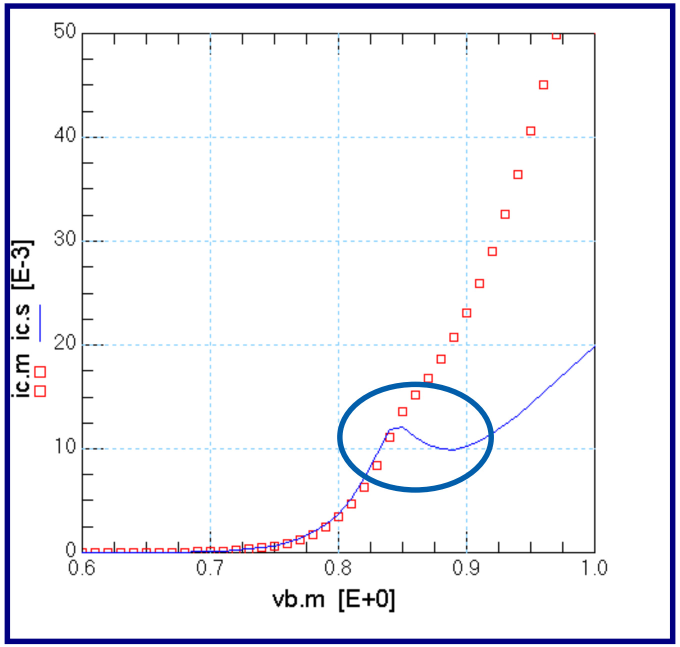
Outline

- Improvement of the transfer current modeling (Review)
- Investigation of quasi saturation modeling
- Improvement of the injection width description
- Modeling results
- Summary

Improvement of the transfer current modeling

Motivation:

Avoidance of negative slope in the simulated collector current of the HICUM/L0 model



Reason for negative slope:

Usage of the low transfer current I_{tfl} for the calculation of the injection width w and the normalized hole charge $q_{pT,T}$

Improvement of the transfer current modeling

Development of improved model equations for $q_{pT,T}$ and w:

- Do not need $Itfl$
- Have a non-iterative solution

$$q_{pT,T} = \frac{q_j}{2} + \sqrt{\left(\frac{q_j}{2}\right)^2 + q_{m\,new}}$$

$$q_j = \frac{qjci}{VEF} + 1$$

$$q_{m\,new} = \frac{Itfi}{IQF} + \frac{Itri}{IQR} + \frac{Itfi}{IQFH} \cdot w^2 + \left(\frac{Itfi^2}{Ick}\frac{TFH}{IQFH}\right)^{2/3}$$

$$a_{new} = 1 - \frac{Ick}{Itfi}\sqrt{q_{m\,new}(a)}$$

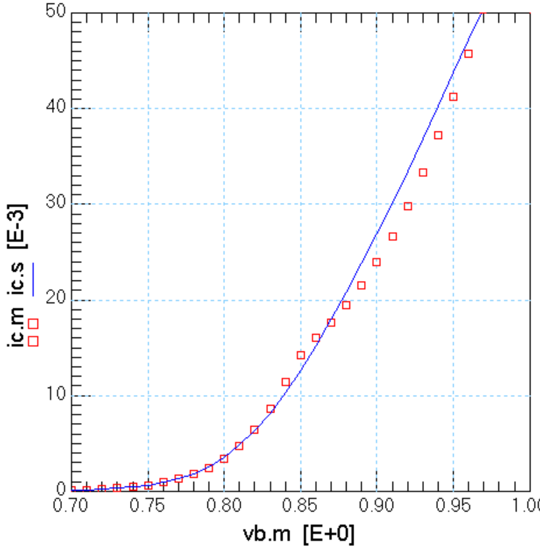
$$a_{new} = \frac{1}{(1 + Ick / \sqrt{Itfi \cdot IQFH})}$$

$$w_{new} = \frac{a_{new} + \sqrt{a_{new}^{\;2} + AHC}}{1 + \sqrt{1 + AHC}}$$

Improvement of the Transfer Current Modeling

Using the improved model equations:

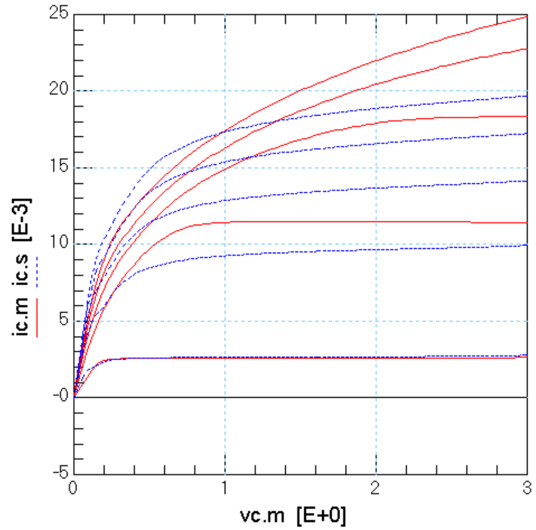
- The collector current can be modeled sufficient using IQFH and TFH
- In no case a negative slope occurs in the collector current



However:

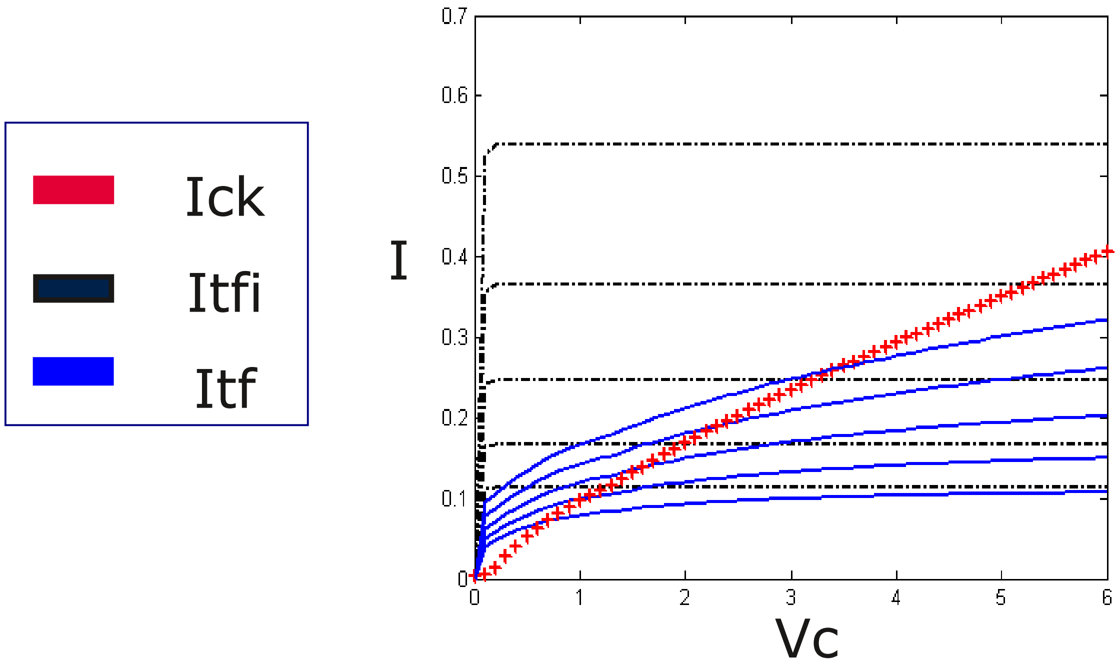
The modeling of the quasi saturation is not sufficient

→ Further investigation is necessary



Investigation of the quasi saturation modeling

As in HICUM/L2, also in HICUM/L0 the quasi saturation should be modeled by the critical current *Ick*. Where *Ick* should act as a limit to the high current range.



Using the improved model equations:

- *Ick* is directly reflected on the output characteristic.
- In particular for the collector-base-charge term: $Itf\_cb = \sqrt{Itfi \cdot IQFH} + Ick$

Investigation of the quasi saturation modeling

Reason for this behavior:

The intersection between $q_{pT,T}$ and w, was not regarded at the calculation of $q_{pT,T}$. w was regarded as a constant.

$$q_{pT,T} = 1 + \frac{q_{jCi}}{VEF} + \frac{Itf}{IQF} + \frac{Itr}{IQR} + \frac{Itf \cdot w(Itf)^2}{IQFH} + \frac{Itf^2}{Ick}\frac{TFH}{IQFH}$$

Taking into account the intersection between w and $q_{pT,T}$ by inserting the unlimited injection width $a=1-Ick/Itf$ for w, leads to:

$$q_{pT,T} = 1 + \frac{q_{jCi}}{VEF} + \frac{Itfi}{IQF \cdot q_{pT,T}} + \frac{Itri}{IQR \cdot q_{pT,T}} + \frac{Itfi}{IQFH \cdot q_{pT,T}}\left(1 - \frac{ick}{itfi}\cdot q_{pT,T}\right) + \frac{Itfi^2}{Ick}\frac{TFH}{IQFH \cdot q_{pT,T}^2}$$

Solvable for $q_{pT,T}$, but:

- the solution is not unique
- poles and nulls can appear

⇒ Not usable for a implementation

Improvement of the injection width description

Therefore the calculation of $q_{pT,T}$ stays the same:

$$q_{pT,T} = \frac{q_j}{2} + \sqrt{\left(\frac{q_j}{2}\right)^2 + q_{m\,new}} \qquad q_j = \frac{qjci}{VEF} + 1$$

$$q_{m\,new} = \frac{Itfi}{IQF} + \frac{Itri}{IQR} + \frac{Itfi}{IQFH} \cdot w^2 + \left(\frac{Itfi^2}{Ick}\,\frac{TFH}{IQFH}\right)^{2/3}$$

But, calculation of w is improved:

$$a_{new} = 1 - \frac{Ick}{Itfi}\sqrt{q_{m\,new}(a)} \quad \Rightarrow \quad a_{new} = 1 - \frac{Ick}{Itfi} \cdot q_{pT,T\_cb}$$

q_{pT,T_cb} takes into account the interaction of w and $q_{pT,T}$

Improvement of the injection width description

For derivation the new assumption for q_{pT,T_cb}, simplified only the collector-base charge term is regarded.

$$q_{pT,T\_cb} = 1 + \frac{Itfi}{IQFH \cdot q_{pT,T}} \cdot w^2 \approx 1 + \frac{Itfi}{IQFH \cdot q_{pT,T\_cb}} \cdot w^2$$

Inserting the unlimited injection width a, makes it possible to consider the dependence from w on $q_{pT,T}$

$$q_{pT,T\_cb} = 1 + \frac{Itfi}{IQFH \cdot q_{pT,T\_cb}} \left(1 - \frac{ick}{itfi} \cdot q_{pT,T\_cb}\right)^2$$

➡ However, by using the unlimited injection width again nulls an pols can occur in the solution

Improvement of the injection width description

Therefore the following conversion for w is done :

- to limit the injection width
- to be able to isolate the variable $q_{pT,T(\_cb)}$

$$a = 1 - \frac{ick}{itfi} \cdot q_{pT,T\_cb} = 1 - \frac{ick}{itfi} \cdot q_{pT,T\_cb} - q_{pT,T\_cb} + q_{pT,T\_cb} = 1 + q_{pT,T\_cb} \underbrace{\left(1 - \frac{ick}{itfi}\right)}_{ai} - q_{pT,T\_cb}$$

Inserting the limited ideal injection width w_i for a_i in w,

$$a_i = 1 - \frac{Ick}{Itfi} \quad \Longleftrightarrow \quad w_i = \frac{a_i + \sqrt{a_i^2 + AHC}}{1 + \sqrt{1 + AHC}}$$

Leads to:

$$w^* = q_{pT,T} \cdot w_i + 1 - q_{pT,T} = 1 + q_{pT,T}(w_i - 1)$$

Improvement of the injection width description

Inserting this assumption of w^* in q_{pT,T_cb}, makes it possible to isolate $q_{pT\_T\_cb}$

$$q_{pT,T\_cb} = 1 + \frac{Itfi}{IQFH \cdot q_{pT,T\_cb}} \left(1 + q_{pT,T\_cb}(w_i - 1)\right)^2$$

And leads to a quadratic assumption for q_{pT,T_cb} with the following unique solution:

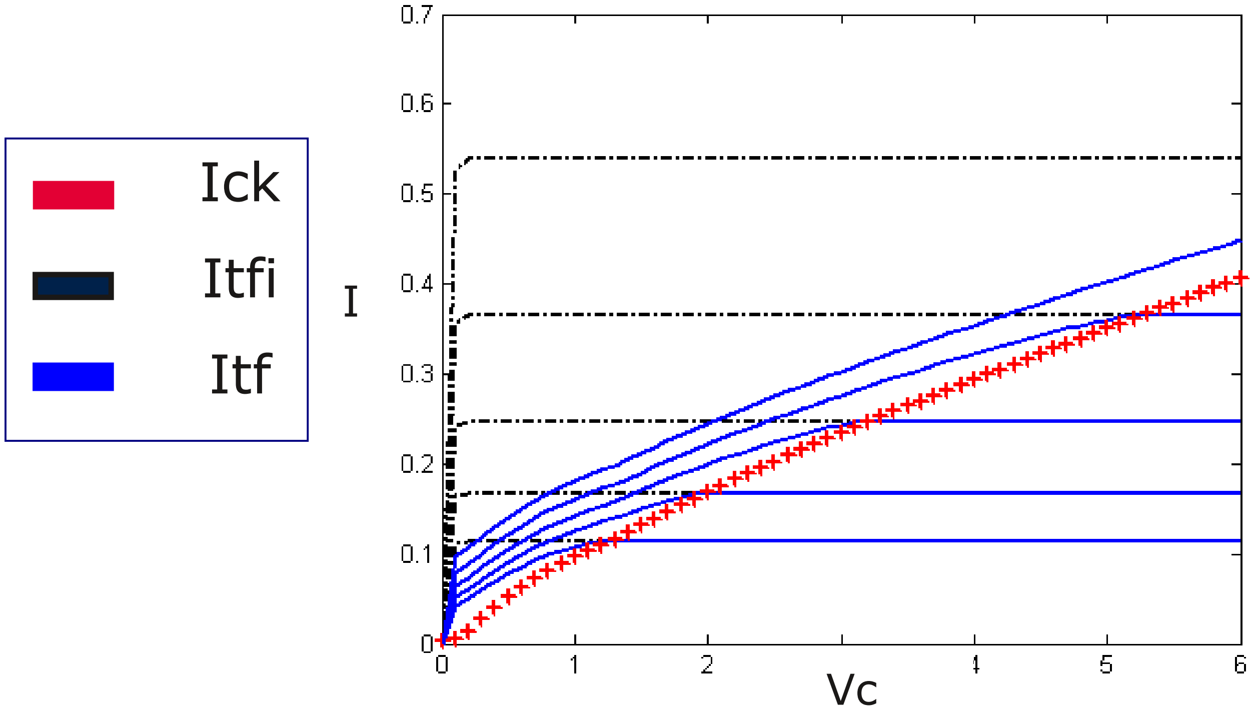
$$q_{pT,T\_cb} = \frac{1 + 2 \cdot (1 - w_i) \cdot \frac{Itfi}{IQFH} + \sqrt{1 + 4Itfi \cdot w_i}}{2\left(1 - \frac{itf}{IQFH}(w_i - 1)^2\right)}$$

This solution can be implemented in a simulator and therefore is usable for the calculation of w_{new}

$$a_{new} = 1 - \frac{Ick}{Itfi} \cdot q_{pT,T\_cb} \qquad w_{new} = \frac{a_{new} + \sqrt{a_{new}^{\;2} + AHC}}{1 + \sqrt{1 + AHC}}$$

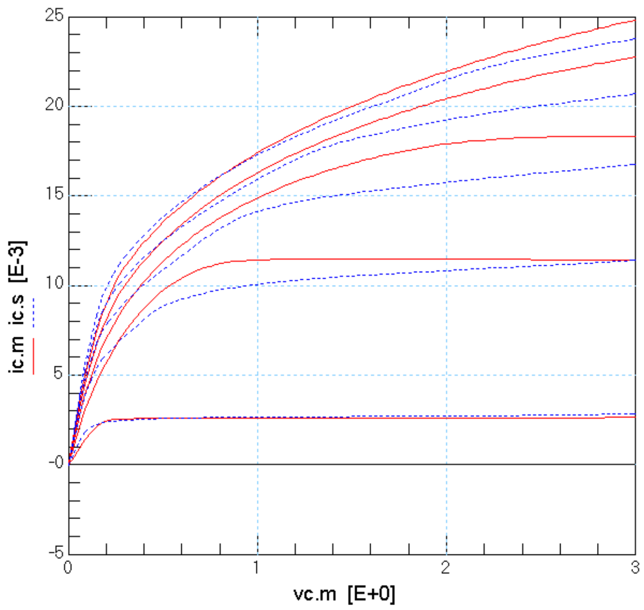
Improvement of the injection width description

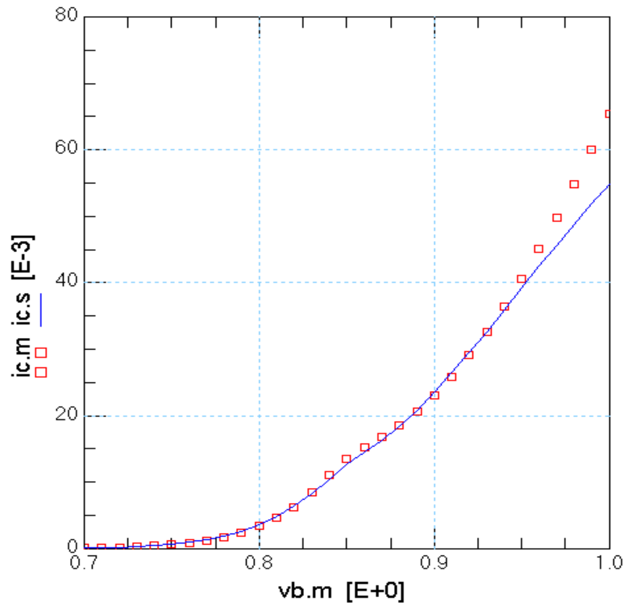
Quasi saturation characteristic using the improved injection width description



The critical current Ick behaves as expected as a limit between the high and low current range.

Modeling results

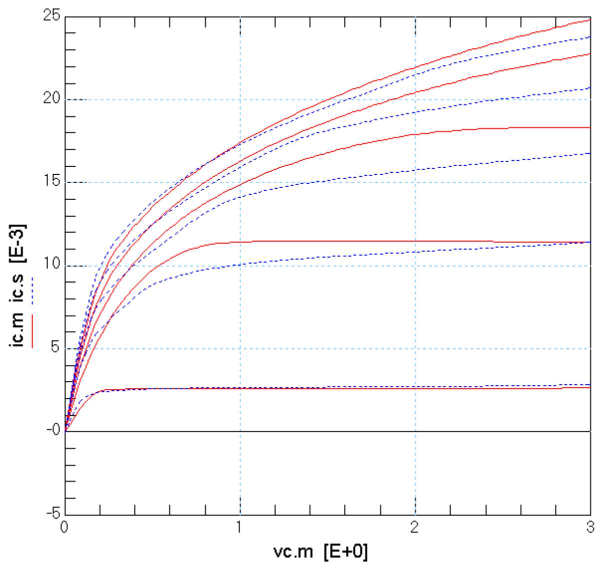


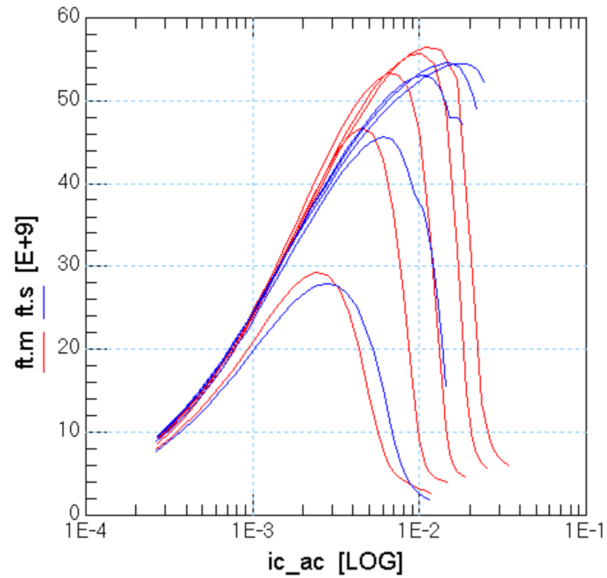


Using the improved injection width description the collector current and the quasi saturation can be modeled well.

Modeling results

However, the ac- and dc- modeling is mostly decoupled in HICUM/L0 by *Ick* still a coupling exists.



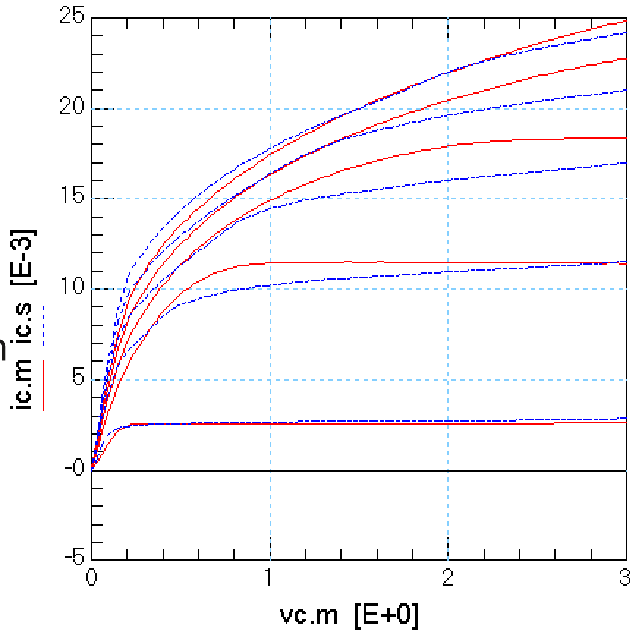


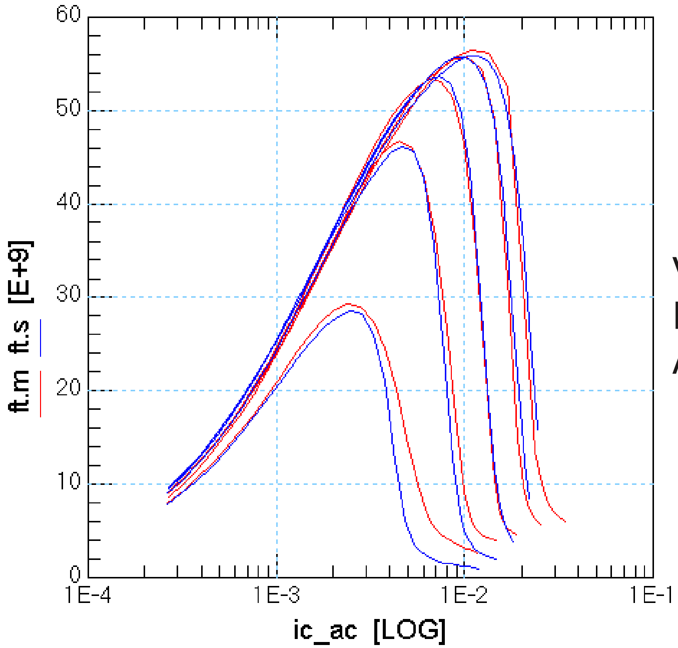
Therefore it is difficult to get a fit sufficient fit for the <u>ft-characteristic</u> and the <u>quasi saturation</u> in parallel at a single transistor extraction

➡ Suggestion: Doubling of the parameters VLIM,RCI0 and AHC

Modeling results

VLIM_dc:1.528
RCI0_dc:21.64
AHC_dc: 28.0m





VLIM:745.4m
RCI0:38.07
AHC:77.07m

With the doubled parameter set the quasi saturation and the ft-characteristic can be modeled sufficient.

But further question to investigate:

What is the reason for the difference in the model parameters?

Summary

- The transfer current modeling is improved to avoid the appearance of a negative slope
- Non–iterative equations for the injection width w and the normalized hole charge $q_{pT,T}$ are developed
- Using this improved equation the collector current can be modeled sufficiently and in no case a negative slope occurs
- However, the quasi saturation modeling is not sufficient
- Therefore a improved description of the injection width is derived, which takes into account the intersection between $q_{pT,T}$ and w
- Using this equations a good fit of the quasi saturation is possible
- However, the dc- and ac-modeling is still coupled by Ick and makes it difficult to get a sufficient fit of the quasi saturation and the ft-characteristic in parallel
- Therefore a doubling of the parameters RCI0, VLIM and AHC is suggested