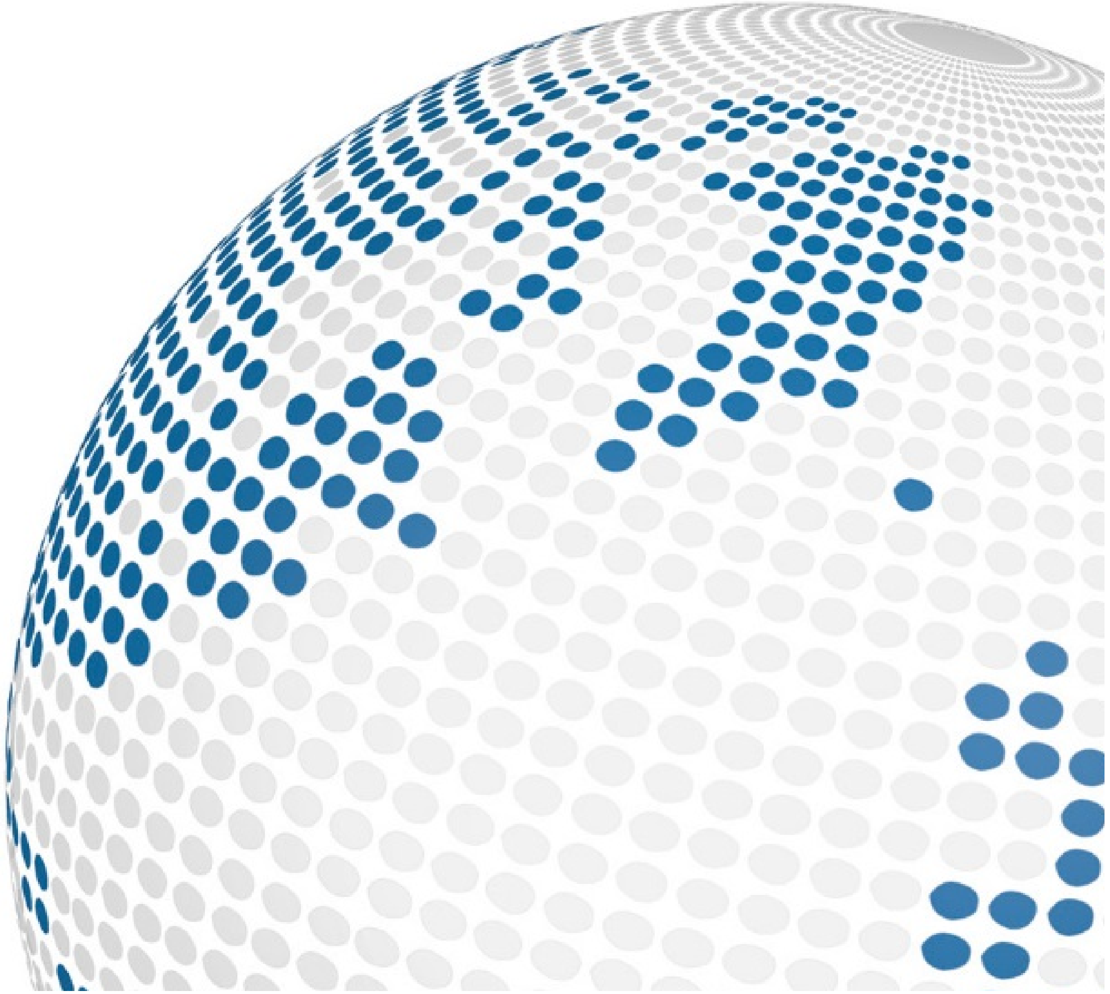
Revisiting the Extraction of γ_C

33th BipAK Workshop at Infineon Munich, Germany, 4&5 November 2021

Letter Session



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Outline

Revisiting the Extraction of γ_C

- overview of the scaling formulations
- the concept of the effective emitter area
- analogy to the SGP area scaling
- unweighted and weighted regressions
- confirmation of the bias dependence using Ic as a regression basis
- proposing an alternative γ_C extraction providing bias independent values
- examples

Scaling

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The fundamental technique introduced in SGP is the „area” scaling. It is based on the intuitive law that a current is proportional to the surface it flows through

$$X = X_A \cdot A \qquad (1)$$

X can be a current, X_A its area component, A is the (emitter) area. This simple rule worked well for large disk or square shaped emitters but provided too small currents for oblong emitter stripes.

The problem was thouroughly investigated in [1], [2]. The total current I is the sum of an internal (area) and a peripheral current

$$I = I_A + I_P = J_A \cdot A + J_P \cdot P \qquad (2)$$

A and P are known for each geometry hence the specific current densities can be obtained from a two-variable linear regression. If the emitter is immersed in a homogeneous media J_P and J_A are proportional to each other. Their ratio is γ_C.

Weighting, effective area

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$$\gamma_C = \frac{J_P}{J_A} = const. \qquad (3)$$

Multiplying (2) by a weight *w* a weighted regression scheme is obtained. Particularly if w=1/A the popular P/A or PoA scaling is obtained

$$\frac{I}{A} = J_A + J_P \cdot \frac{P}{A} \qquad (4)$$

When the current densities are known one can write

$$\frac{I}{J_A} = A_{eff}\,; \quad A_{eff} = A\left(1 + \gamma_C \cdot \frac{P}{A}\right) \qquad (5)$$

With the concept of the effective area we have arrived back to the fundamental SGP area scaling (1).

Conventional extraction

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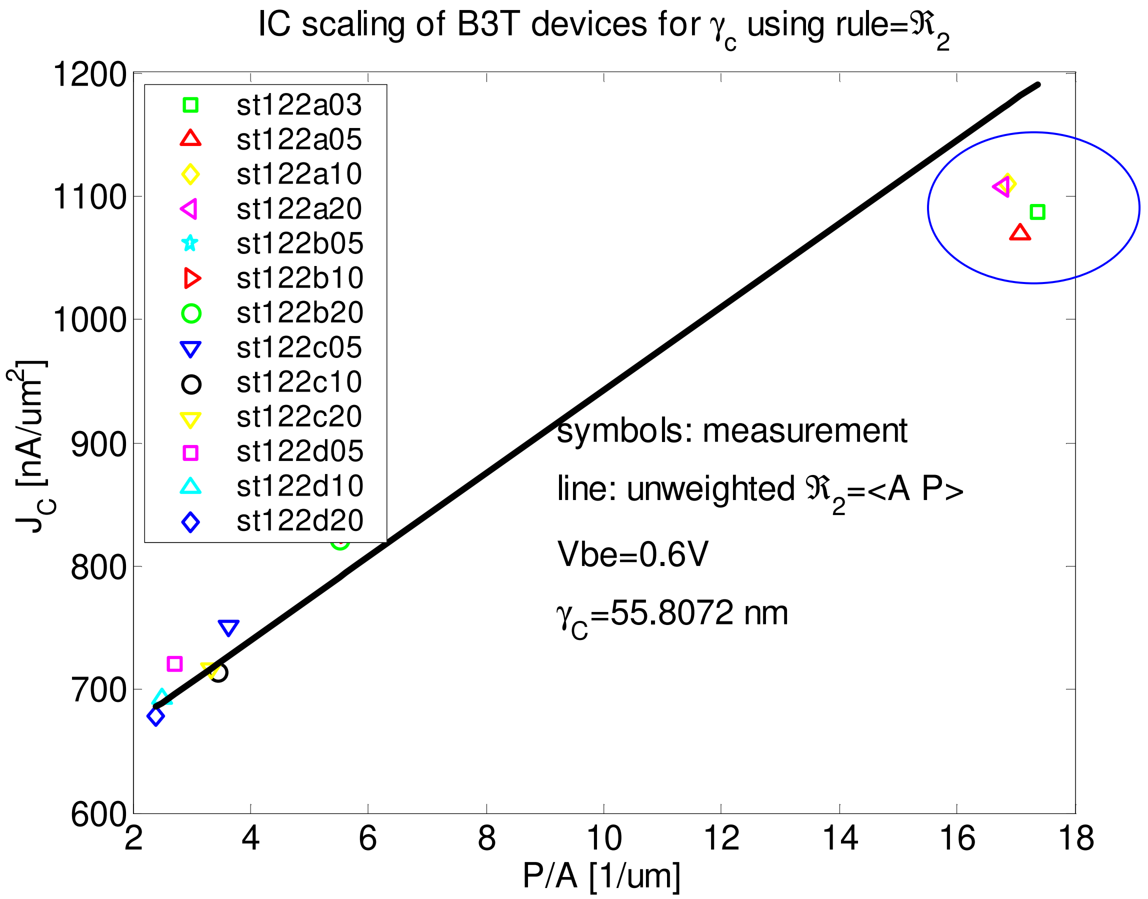
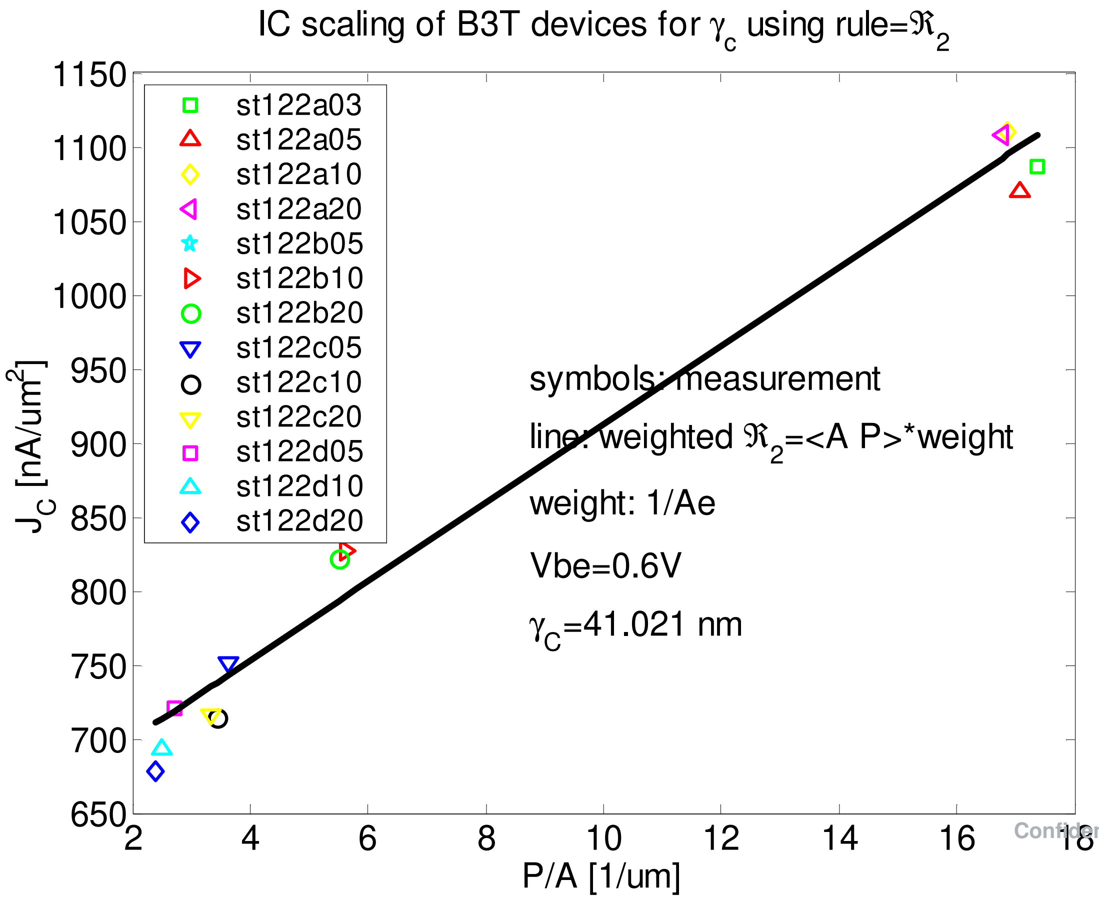
We need to obtain J_A and J_P for the determination of γ_C (3) and consequently the effective area (5). Weighted regression (right) provides a more uniform fit across the device sizes. Unweighed (left) loses hold of the smaller geometries.





Typical extraction result

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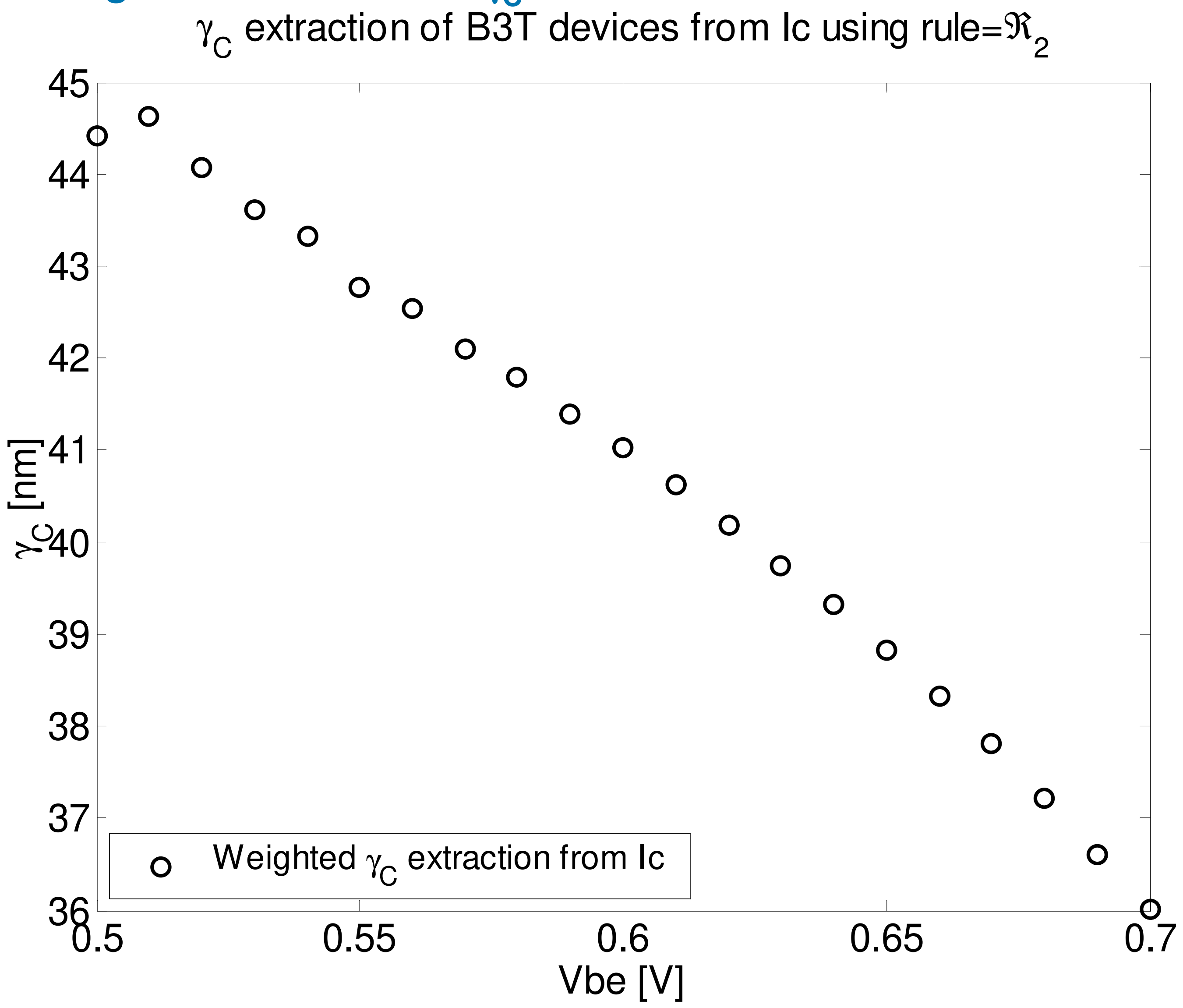

A marked bias dependence can be observed as predicted by [1] adapting different ideality factors to the area and perimeter currents.

Equivalently, [3] provided an explanation of the bias dependence in terms of the different reverse Early effects in the two directions.

Phenomenon explained but

„Which value of γ_C to use?" [4]

An alternative approach

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[5] tabulated the scaling rules $c_{10} = c_{10A} \cdot A_{eff}^2 \quad q_{p0} = q_{p0A} \cdot A_{eff} \quad is = \frac{c_{10}}{q_{p0}} = is_A \cdot A_{eff} \quad \ldots$

In principle each of the three equations is suitable for an alternative extraction of A_{eff}. However a feasible selection is only *is* due to its ease of extraction. [6] suggests two ways for doing so

$$\left(\frac{Q_{p0}}{c_{10}}\right) + \left(\frac{h_{jEi} C_{jei0}}{c_{10}}\right) B(u(ahjei, Vbiei)) q_{jEi}(Vbiei) + \left(\frac{h_{f0}\tau_0}{c_{10}}\right) I_T = \frac{\exp\left(\frac{V_{biei}}{V_T}\right) - \exp\left(\frac{V_{bici}=0}{V_T}\right)}{I_T} \quad \text{or} \quad \frac{1}{is_H} + Hjei \cdot early(ahjei) + Hf0 \cdot I_T = M_0 \qquad \text{I.}$$

I. is a 3-variable linear regression minimized in *ahjei*. Alternatively [6] proved the identity

$is_H = \frac{is}{nf}$ between the SGP extracted *is* and the HICUM (HL2) related is_H

$$is - \frac{is}{var} V_{biei} - \frac{is}{ikf} I_T = \frac{I_T}{\exp\left(\frac{V_{biei}}{nf \cdot V_T}\right) - 1} \qquad \text{II.}$$

This linear regression is minimized in *nf* but it is enough to fix *nf=1*. As opposed to I. it is independent of the *Cjei* parameters making it particularly suitable for extraction.

Determination of is_SGP

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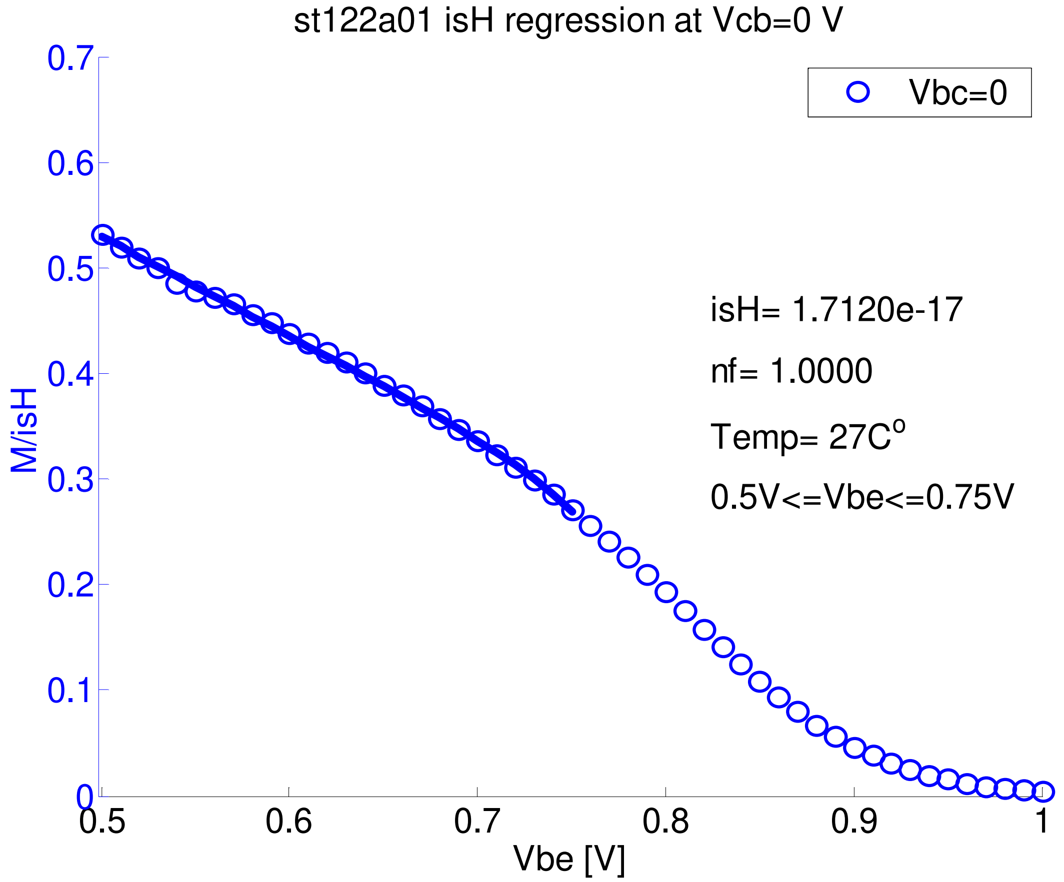
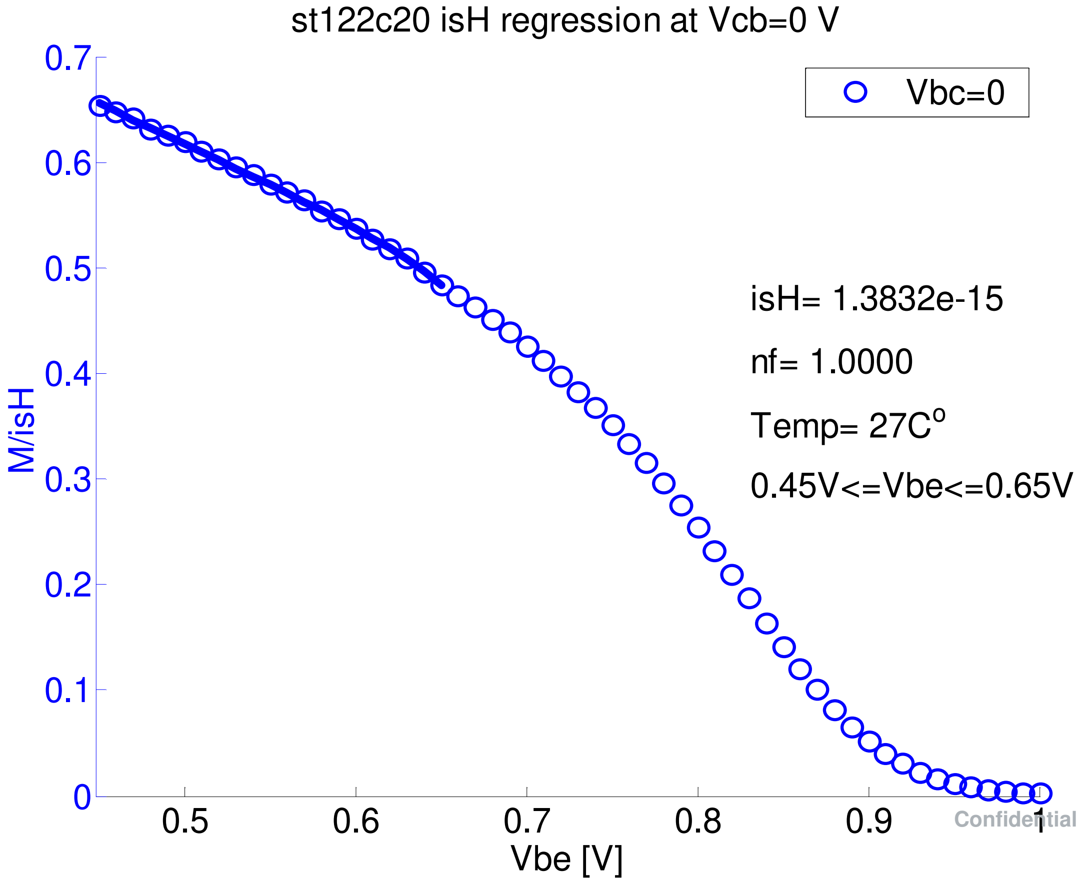
There is a conveniently wide range avaliable for the 3-variable linear regressions. Note the I_T term on the LHS of II. which acts as an accuracy enhancer. The regressed curve is bent with bias otherwise as a stright line the regression interval should be reduced.





γ_C from is_SGP

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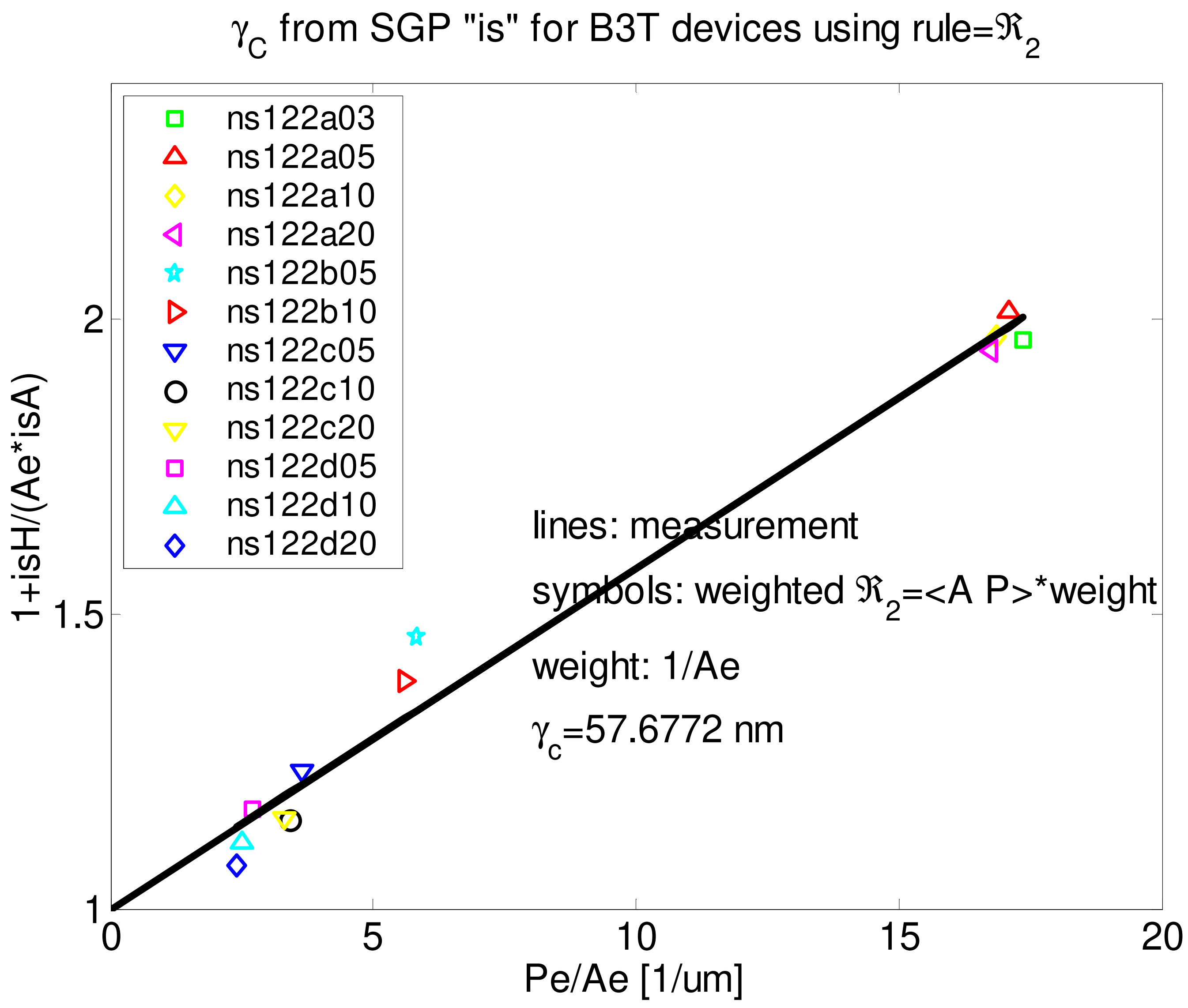

Comparing to the bias dependent curve of slide#6 the obtained value is larger. This appears to be in agreement with [4] where γ_{C0} extrapolated from the reverse Early theory exceeded measurements.

γ_C from experimental devices

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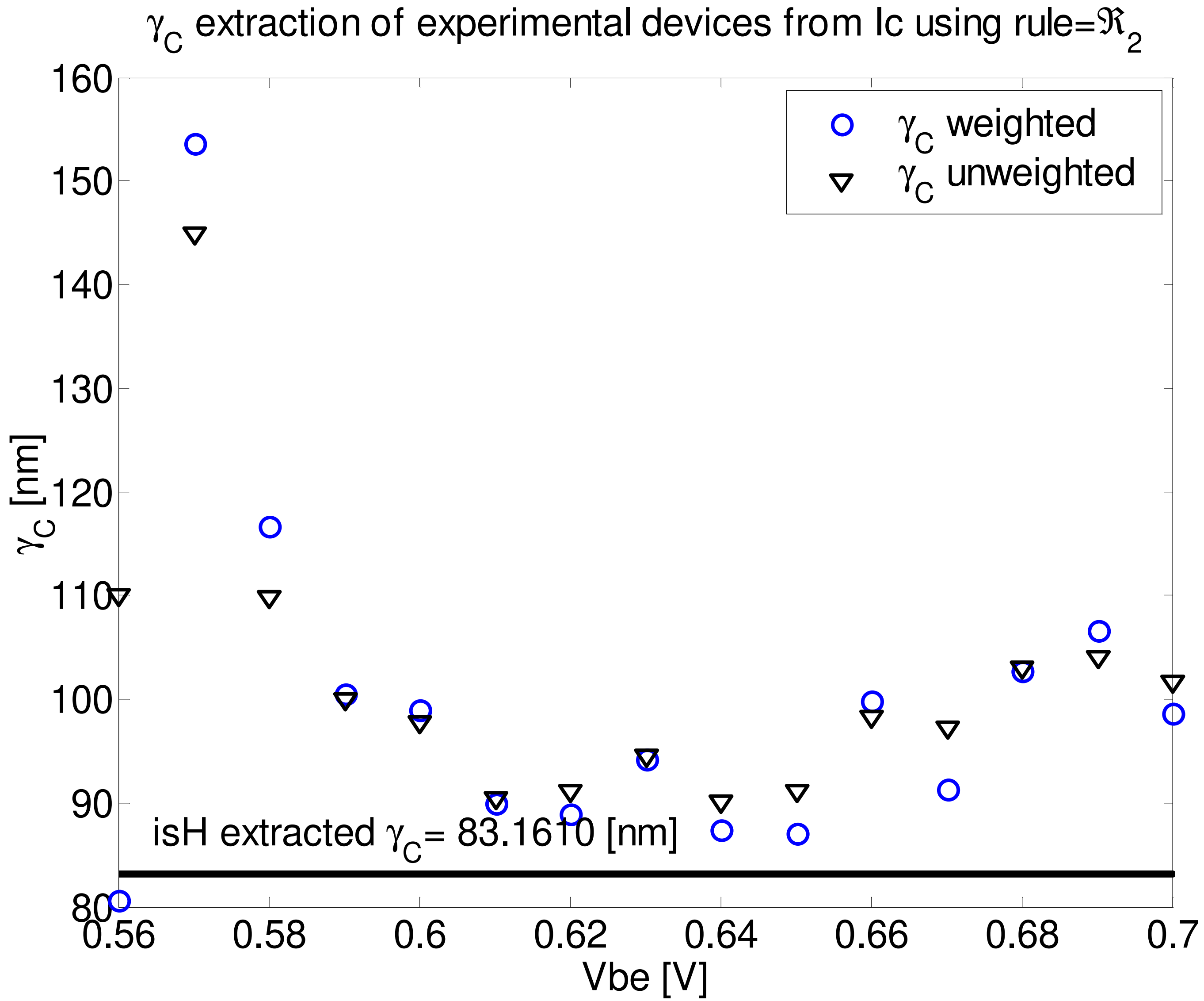

Extractions were performed on a set of experimental devices with robust dimensions compared to the B3T process. Both unweighted from (2) and weighted regressions from (4) were performed. Interestingly the value pairs showed random γ_C sequences. This is in contrast to B3T where the unweighted values were consistently larger.

The is_H parameter was extracted both from the HL2 (I.) formula and from the SGP equation (II.). Both data resulted in the same γ_C value under the population obtained from Ic.

Summary

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- the bias dependence of the conventionally extracted effective area has been confirmed
- it has been demonstrated that the bias dependence is an extraction related issue
- an alternative method has been proposed using the HICUM related saturation current
- two examples have been demonstrated showing the relation between the conventional and proposed regression results
- the existing model libraries had to be prepared by using some average of the obtained bias dependent effective area values
- the proposed method is free of such heuristic considerations
- on the other hand no accumulated experience can support these findings yet
- future recalculation of γ_C for existing libraries with the new methodology might be decisive

Acknowledgment

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The former unique work of Didier Celi (STM) in the subject matter is highly appreciated as forming the starting point of the present investigations.

References

A Solution to the Qp0 Issue in Hicum Parameter Extraction

[1] H.-M. Rein, “A Simple Method for Separation of the Internal and External (peripheral) Currents of Bipolar Transistors“, Solid-State Electron., vol. 27, pp. 625-635, 1984.

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[5] D. Celi, „Review of Some HICUM Geometry Scaling Laws: Isssue and Proposal,” 7th HICUM Workshop at TU Dreseden, Germany, June 2007

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Thank you!

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