An Improved Impact Ionization Model for SOI Circuit Simulation

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ABSTRACT

The impact ionization (II) model accuracy issue in industry standard SOI MOSFET is discussed in the paper. Based on Medici 2D simulation study, an improved impact ionization model is proposed which can capture the voltage and geometry dependence for impact ionization current contributed by the parasitic BJT collector current. The model is implemented into the BSIMSOI infrastructure in HSPICE. A reasonably good fit of the model to the 2D simulation results is obtained.

Keywords: impact ionization, SOI MOSFET model, parasitic BJT effect.

1 INTRODUCTION

Generally the device substrate current arising from the impact ionization process near the drain edge can provide important guidance in estimating device reliability [1]. In the floating body SOI (Silicon-On-Insulator) device, impact ionization current plays an important role in determining the floating body potential [2-4]. Therefore, an accurate impact ionization model is very crucial, especially for advanced technology where thin gate oxide, short channel length, etc, which increase the electric field near drain region, hence substrate current significantly.

State-of-the-art impact ionization compact model[2] has been validated over various biases, and geometry range, and has been successfully applied to digital/analog CMOS/SOI IC design. However, in the recent interest on single transistor memory, such as Z-RAM [5-6] that utilizes the often detrimental floating body effect for charge storage, impact ionization effect contributed by the parasitic BJT collector current becomes important in determining memory state where device operates in subthreshold region. Our research found that impact ionization model in the standard BSIMSOI model shows a deviation from 2D device simulation in this operation region.

In this paper, Medici 2D simulation is used to study the impact ionization behavior in all the operation ranges. Model accuracy issue in industry standard SOI MOSFET is discussed and an improved model is proposed to capture the voltage/geometry dependence for impact ionization current contributed by the parasitic BJT collector current. The model is then verified using 2D simulation results and a good agreement is achieved.

2 EXISTING MODEL STUDY

In the industrial standard BSIMSOI model [2], impact ionization current components due to MOSFET and parasitic BJT are both considered, where a same bias dependence for impact ionization rate was used for these two components. This approximation generally won't cause accuracy problem since the majority of impact ionization current in the interested operation regions is contributed by MOSFET drain current. Fig.1 gives the total impact ionization current 2D simulation result for device channel length of 90nm, 65nm, 45nm SOI MOSFETs. As shorter length can significantly increase BJT current and therefore the II current due to BJT, data show that for worst case of 45nm, II current contributed by parasitic BJT is more than one order lower than that of MOSFET contribution when device operates in strong inversion region, so it is negligible.

When SOI MOSFET device operates in subthreshold to accumulation regions, parasitic BJT effect starts to dominant nodal drain current at high drain bias. Medici 2D simulation shows that the impact ionization current in these regions has a near linear dependence on SOI body thickness (Fig.2). From modern BJT model studies [7-8], when BJT characteristics is dominated by emitter area, its collector current is proportional to this effective emitter area. In the case of parasitic BJT in MOSFET structure when using unit width in the simulation, the parasitic BJT collect current should then be proportional to silicon thickness for SOI MOSFET, hence the same dependence for its impact ionization current. The 2D simulation result here indicates that the impact ionization current so generated in subthreshold and/or accumulation regions comes from parasitic BJT current contribution.

Regarding the impact ionization current bias dependence, from 2D simulation results, this II current has very weak dependence on Vgs in subthreshold to accumulation regions (Fig.2), where existing BSIMSOI II model tends to give a strong Vgs dependence for parasitic BJT contributed impact ionization current. As to the model drain bias dependence, parasitic BJT contributed impact ionization current should be explicit function of Vdb rather than the voltage difference between source and drain (Vds), as was the case in BSIMSOI where it is included through

Vdiff. A new model is proposed in the following section to overcome these issues.

3 IMPROVED MODEL DEVELOPMENT

In the new model derivation, Vgs dependence of II current is ignored for simplicity and reasonable accuracy. Impact ionization is well studied in BJT device which generates electron-hole pairs in the depletion layer of the reverse biased drain-substrate (collector/base) junction due to the high electrical field and weak avalanche model is developed in BJT [7-8] to address this effect. We modified the weak avalanche model used in [7] with special consideration of the parasitic BJT effect in MOSFET. Due to the lateral nature of this parasitic BJT, channel length dependency of the impact ionization rate is incorporated in the model. The temperature dependence is also improved. The equations are:

$$I_{ii\_BJT} = \frac{CBJTII + EBJTII \cdot L_{eff}}{L_{eff}} \cdot I_C \cdot \left(Vbci - V_{bd}\right) \cdot \exp\left(-ABJTII \cdot (Vbci - V_{bd})^{(MBJTII-1)}\right) \quad (1)$$

$$Vbci = VBCI \cdot \left(1 + TVBCI \cdot \left(\frac{T}{TNOM} - 1\right)\right) \quad (2)$$

This model has been implemented into the BSIMSOI infrastructure in HSPICE. The model parameters and their default values are listed in table I.

4 MODEL VERIFICATION AND DISCUSSION

The model is verified over several geometries and bias range with 2D Medici simulation and proved to be able to present the correct physics of parasitic BJT impact ionization effect. To obtain the pure impact ionization current, 2D simulation was applied twice where one model turns off the impact ionization model and the other turns it on. The body current difference from these two simulations will then be calculated which turns out to be the pure impact ionization current. Impact ionization rate is then calculated as the ratio of impact ionization current vs. total drain current for simplicity. Fig. 3 shows the II rate against drain voltage at Vgs=-1V for L=45nm. Both linear and logarithm curve are given. A good agreement is obtained. Fig. 4 shows the results for L=65nm. And Fig. 5 gives the results for L=32nm. By using the same set of parameters, but keeping the term $\left(\frac{CBJTII + EBJTII \cdot L_{eff}}{L_{eff}}\right)$ as another variable for parameter extraction, the length dependence of this variable can be captured by the proposed expression in equation (1) with result shown in Fig. 6.

5 CONCLUSION

An improved impact ionization model for SOI circuit simulation has been developed and implemented into standard BSIMSOI in HSPICE, which facilitates the BSIMSOI application into deep subthreshold to accumulation regions where accurate II model is a prerequisite for novel memory circuit simulation.

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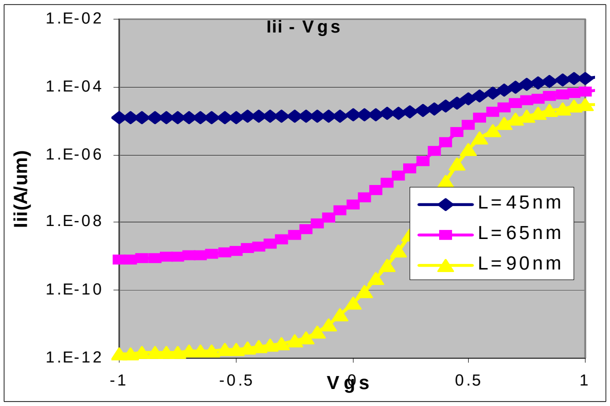


Fig.1 Iii vs. Vgs at various channel length

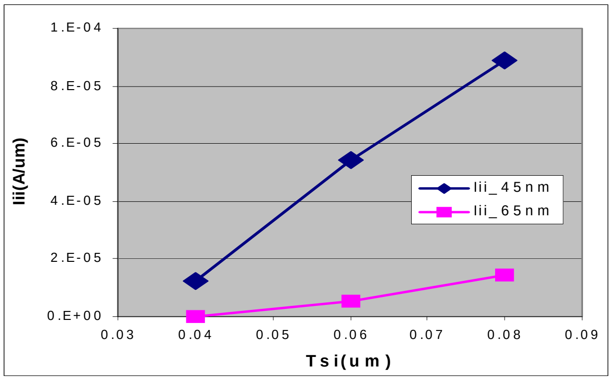


Fig.2 Iii vs. Tsi at various channel length

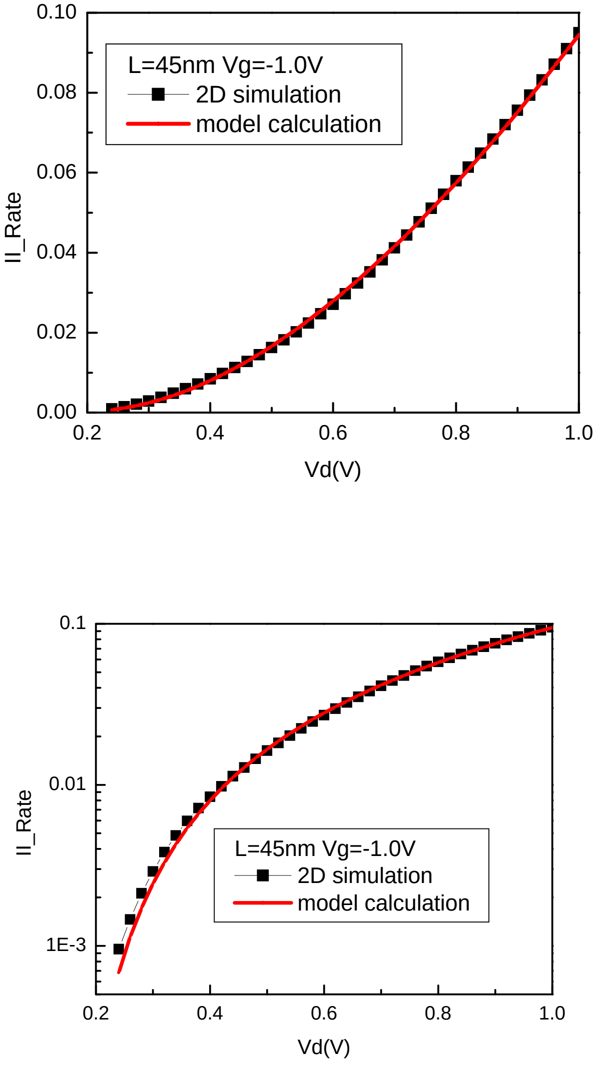


Fig.3 II rate vs. Vd at Vb=0.4V for L=45nm

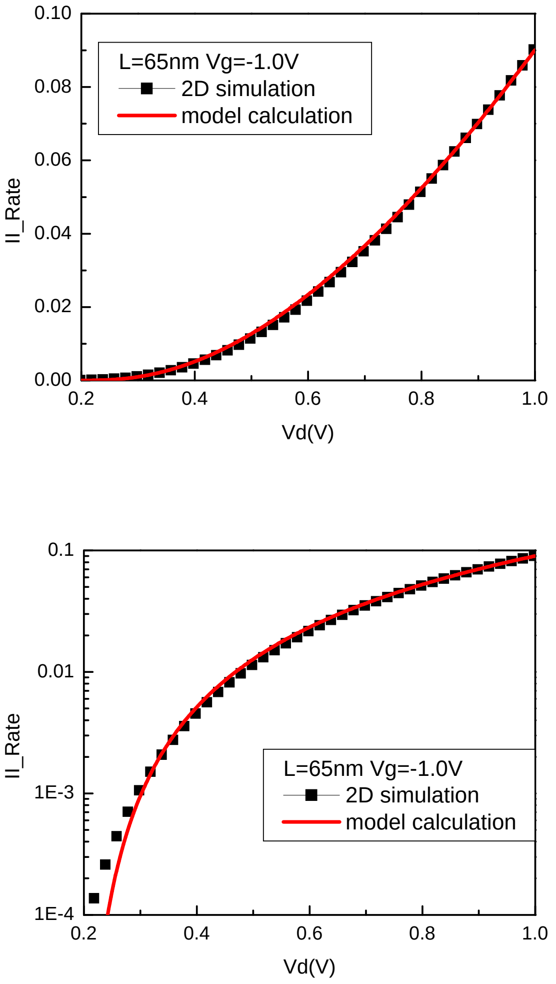
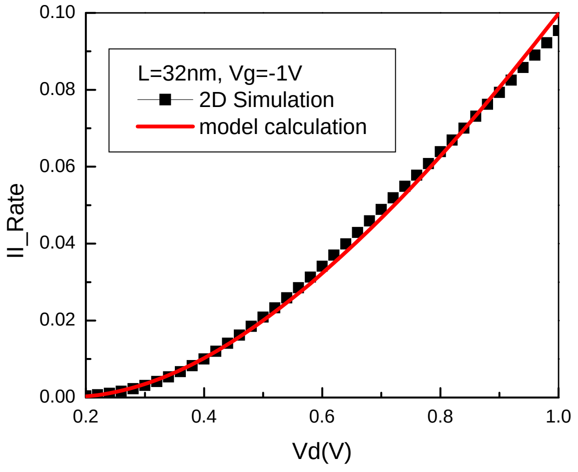


Fig.4 II rate vs. Vd at Vb=0.4V for L=65nm



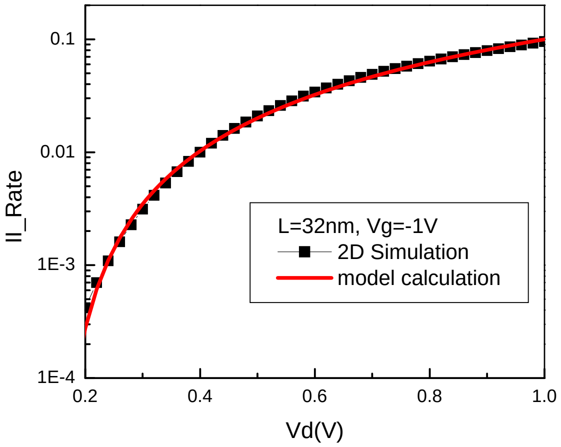


Fig. 5 II rate vs. Vd at Vb=0.4V for L=32nm

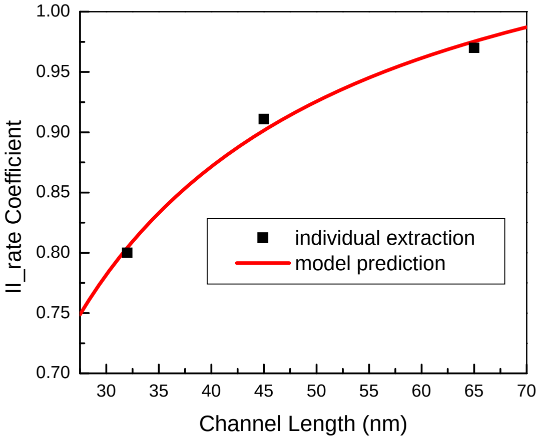


Fig. 6 II Rate channel length dependence

Parameter	Description	Unit	Default
IIMOD	impact ionization model selector	-	0 (original II model)
EBJTII	impact ionization parameter for BJT part	1/V	0.0
CBJTII	Length scaling parameter for II BJT part	m/V	0.0
VBCI	Internal B-C built-in potential	V	0.7
ABJTII	Exponent factor for avalanche current	-	0.0
MBJTII	Internal B-C grading coefficient		0.4
TVBCI	Temperature coefficient for VBCI		0.0

Table I: New parameters enhanced in the new II model