Study of the Bipolar Amplification Effect in FDSOI Caused by Heavy Ion Strike

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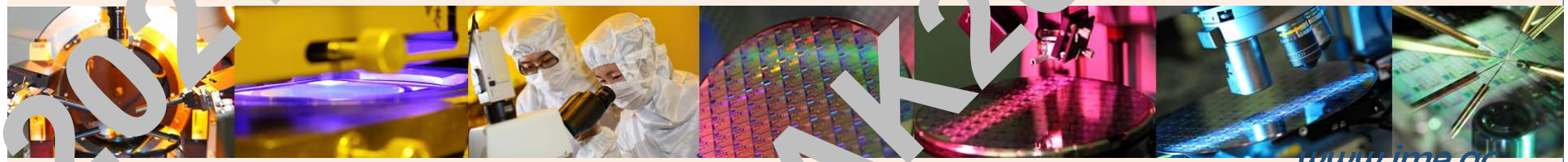


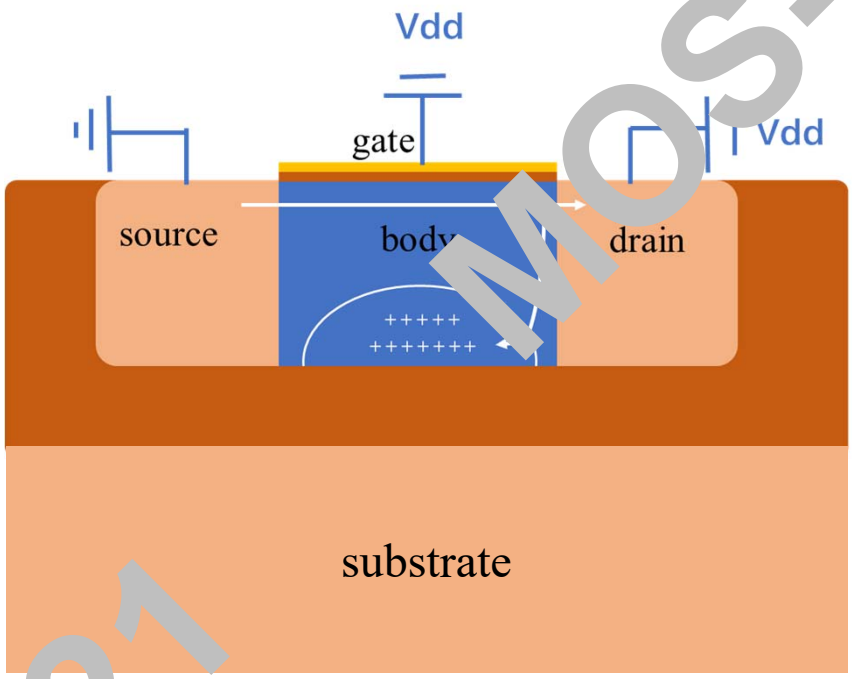
1.Introduction of the bipolar amplification effect in SOI

2. TCAD simulation of the single event effect in FDSOI

3.FDSOI SET model

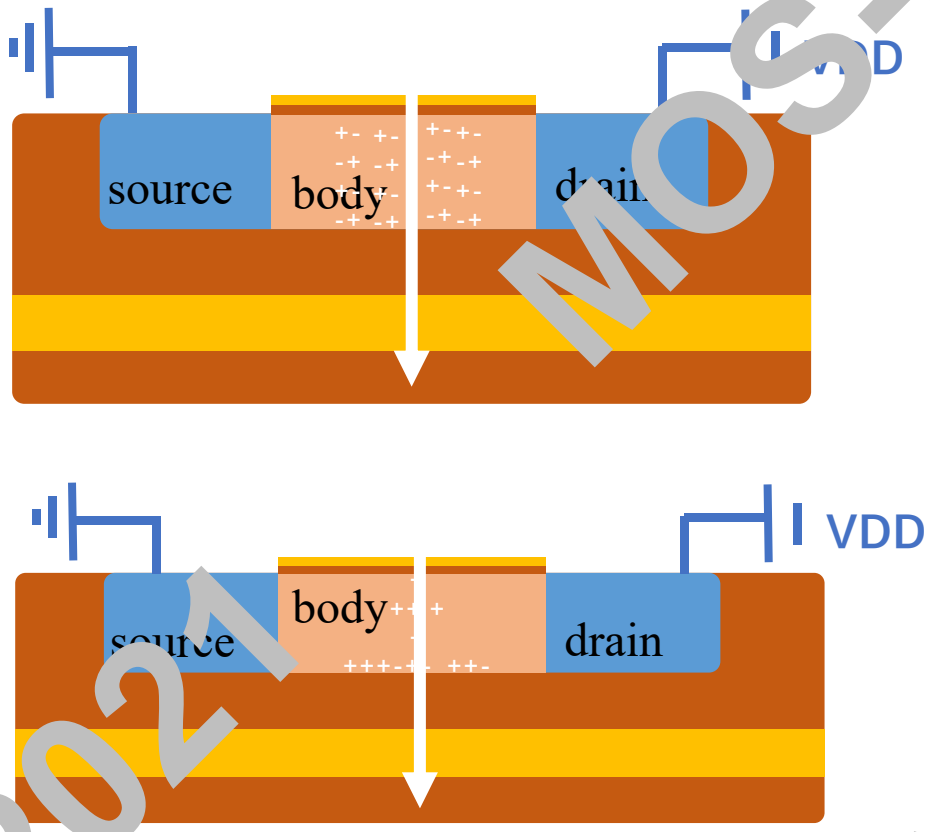
4. Summary

Floating body effect in SOI device



- For PDSOI, because of the neutral body region, the holes caused by impact ionization will accumulate in it and rise the body potential.
- For FDSOI, there is not floating body effect in normal conditions because the silicon film is fully depleted.

Floating body effect in FDSOI



- A large amount of ehps will be generated immediately after ion strike.
- Some electrons will be quickly collected by electrode, the remaining holes will rise the body potential.
- The rising of the body potential will decrease the threshold voltage. The parasitic bipolar may be turned on and result in the bipolar amplification effect.
- Floating body effect in FDSOI is a temporary phenomenon caused by ion strike.

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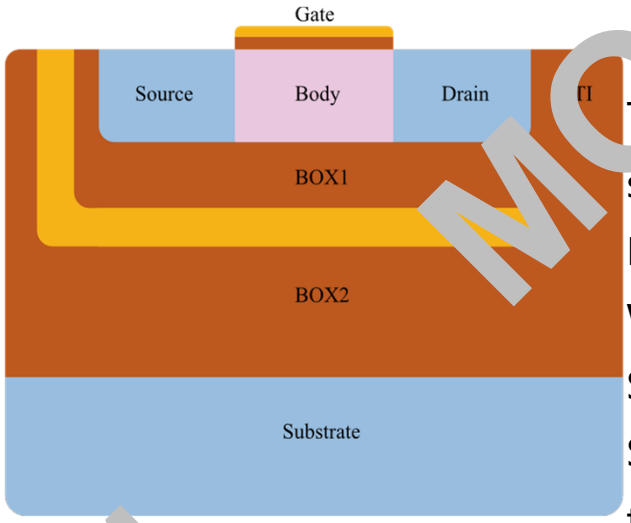
TCAD simulation condition



Double-SOI structure

type：NMOS
Channel length：0.18μm
Thickness of SOI：60nm
state： OFF
LET ： 0.4pC/μm
Width if the track：0.07μm
Strike time： 0s
Strike position：perpendicula
through the middle of the gate

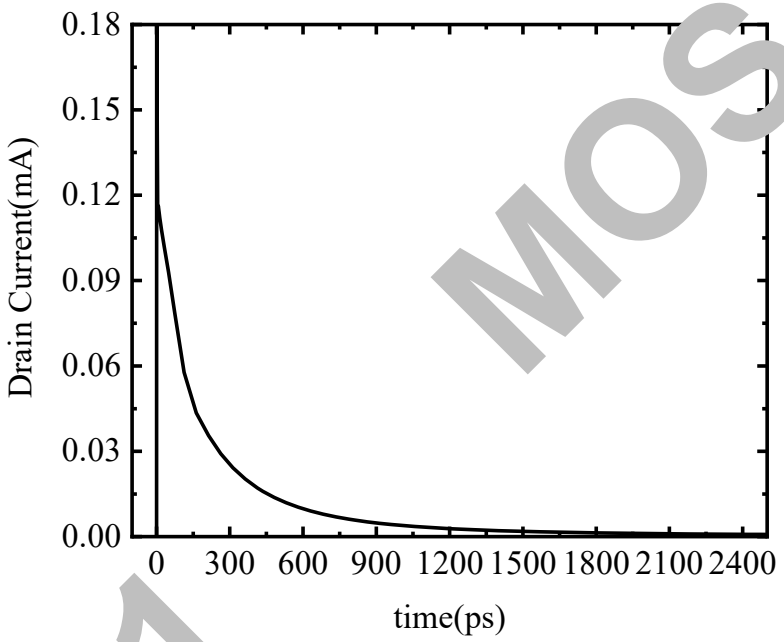
TCAD set

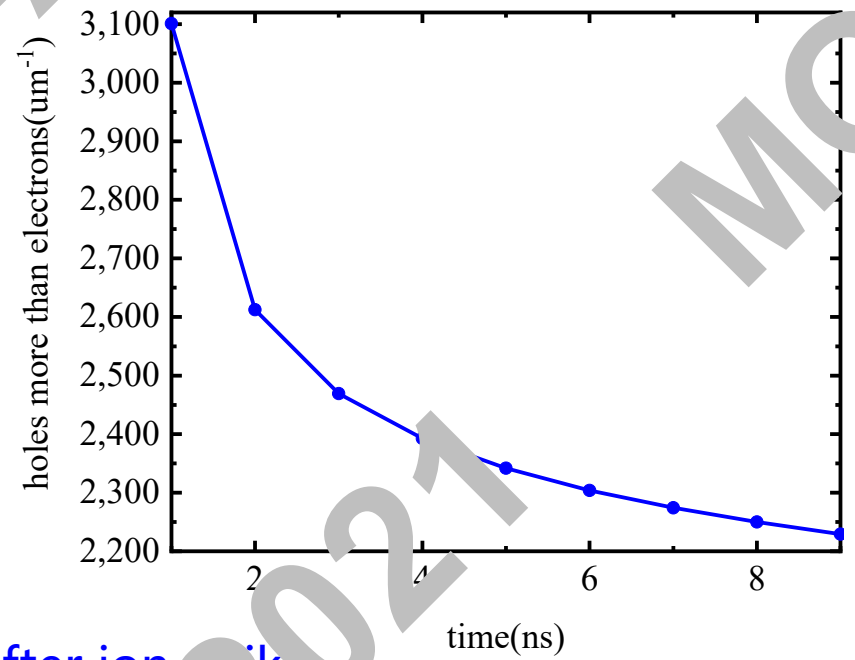
Mobility:
DopingDependence
Enormal
HighFieldSaturation
Recombination:
SRH(DopingDependence)
Auger(WithGeneration)
Radiative
Avalanche

✓ DSOI has a wider back-gate voltage range with independent electrode

✓ DSOI could have excellent anti-radiation performance by applying appropriate back-gate voltage.

Accumulation of holes in the body

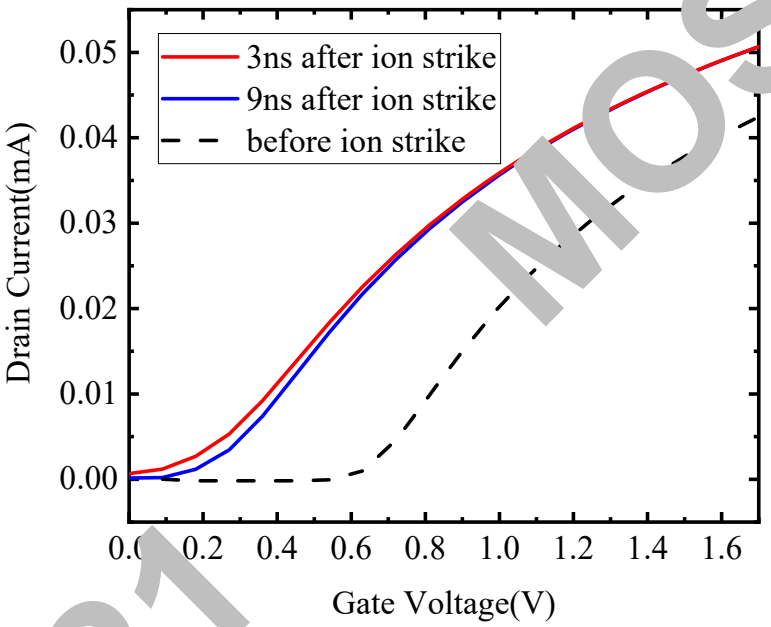




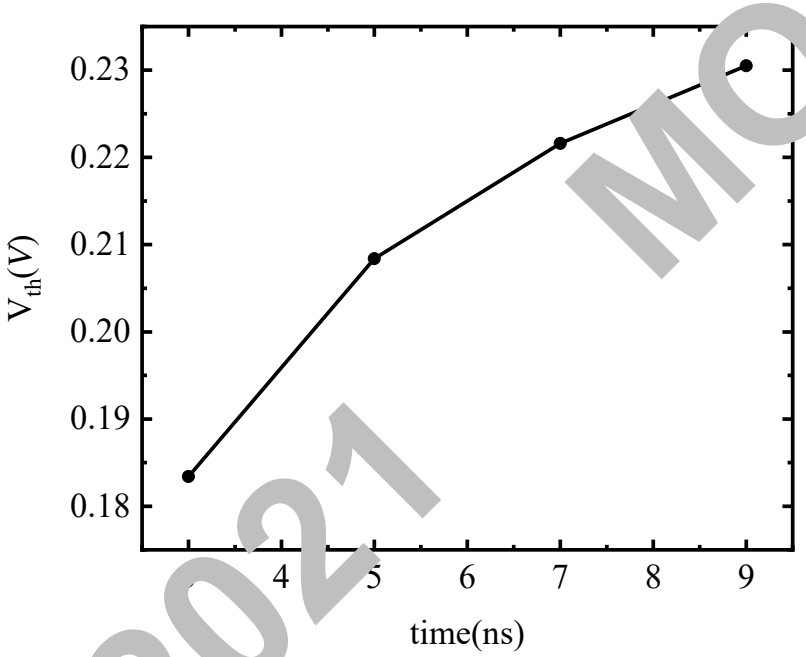
- SET current is close to zero at 2ns after ion strike
- There is still many holes remaining in the body at 9ns after ion strike

Holes will remain in the body for a relatively long time

Decrease of threshold voltage



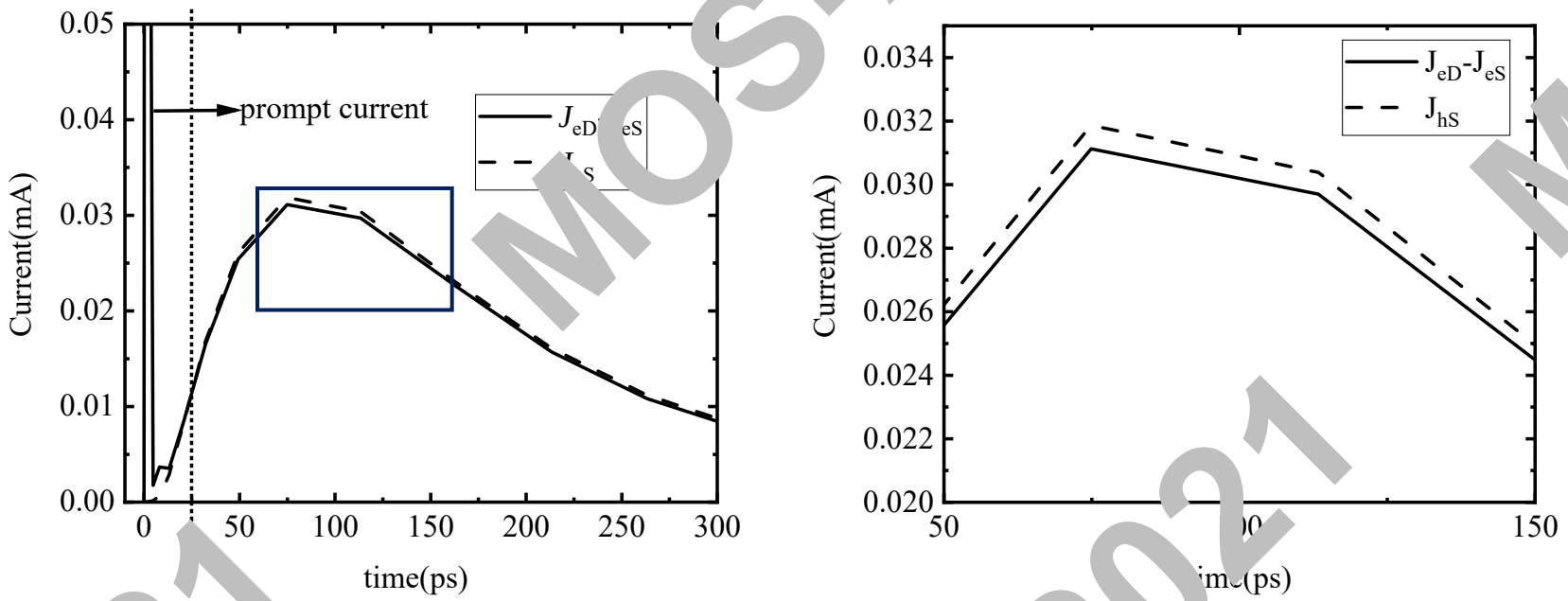
Id-Vg curves from different time after ion strike



The threshold voltage changing with time

The floating body effect lasts for a long time, and it can be predicted that the threshold voltage of the device will not recover to a normal level within a few tens of nanoseconds.

Components of SET



- **Prompt current**: electrons were collected by drift, holes remained in the body .
- **Diffusion current**: hole current is slightly larger than electron current, extra holes are slowly dissipate from the body.

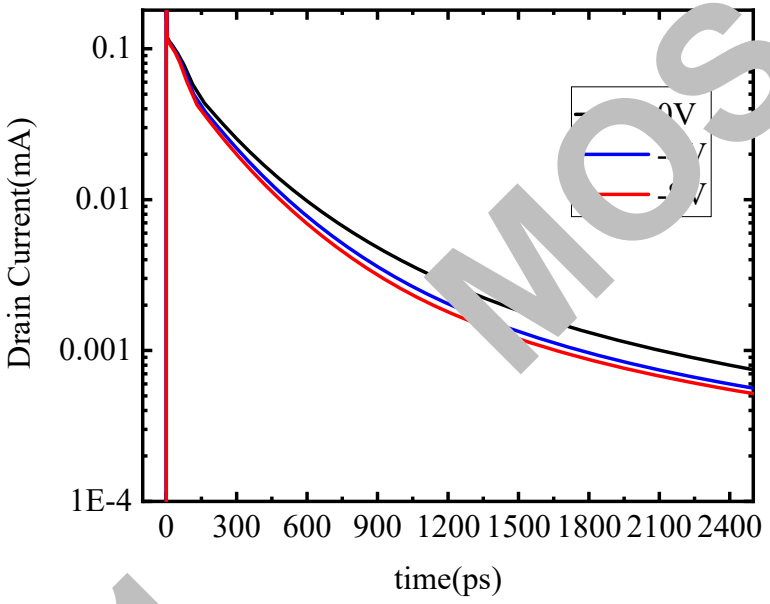
Analysis of diffusion current

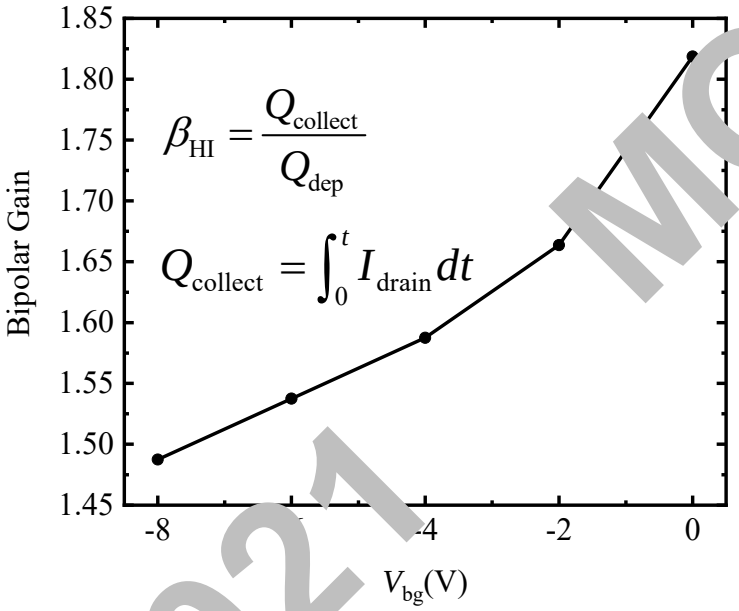
$$D_a = \frac{(n+p)D_n D_p}{nD_n + pD_p}$$

$$\mu_a = \frac{|n-p|\mu_n\mu_p}{n\mu_n + p\mu_p}$$

In high injection condition, diffusion is the main transport mode. Electrons and holes will share the same diffusion coefficient and mobility because the separation of the holes and electrons will form a electronic field and then influent the behavior of carriers. This makes the SETs in PMOS and NMOS are similar.

Influence of the back-gate voltage

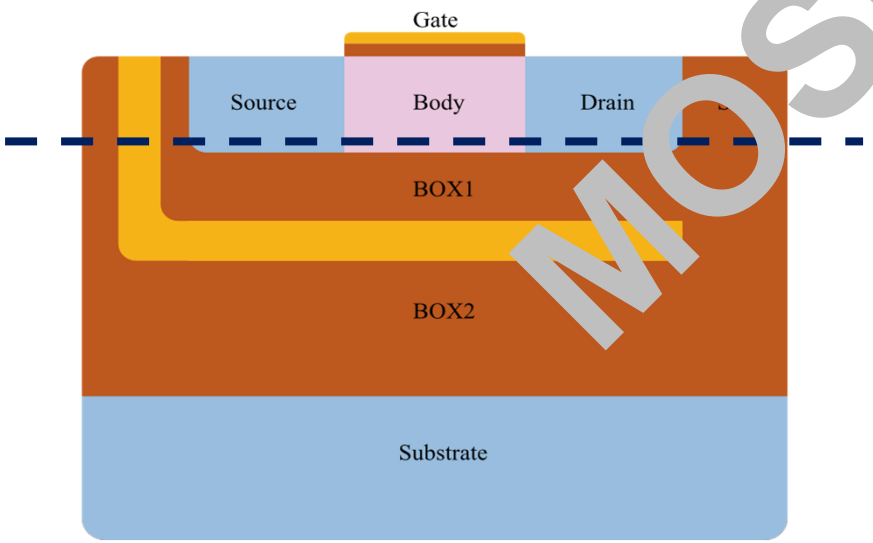


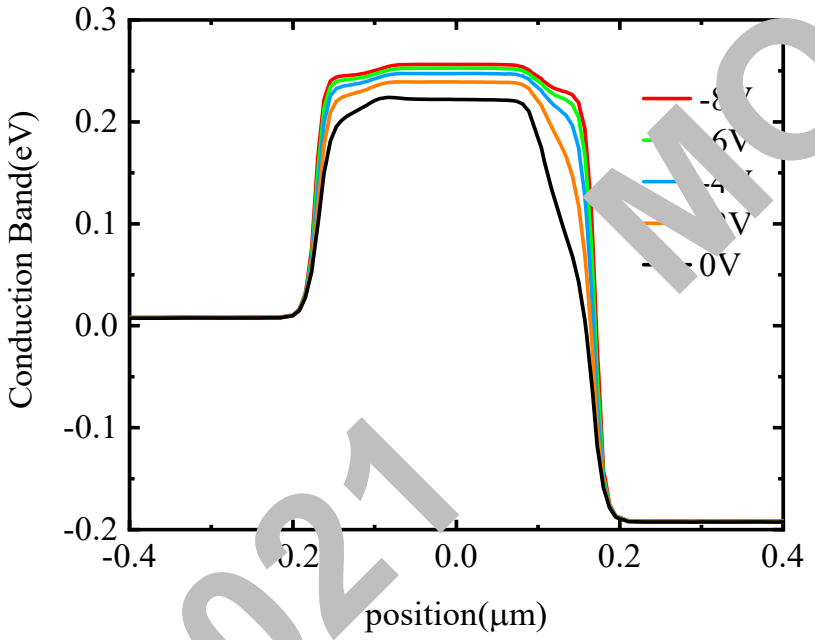


SET under different back-gate voltage condition

- For NMOS, the current in the fall period is decreased by negative back-gate voltage
- The bipolar gain of the NMOS decreased under negative back-gate voltage.

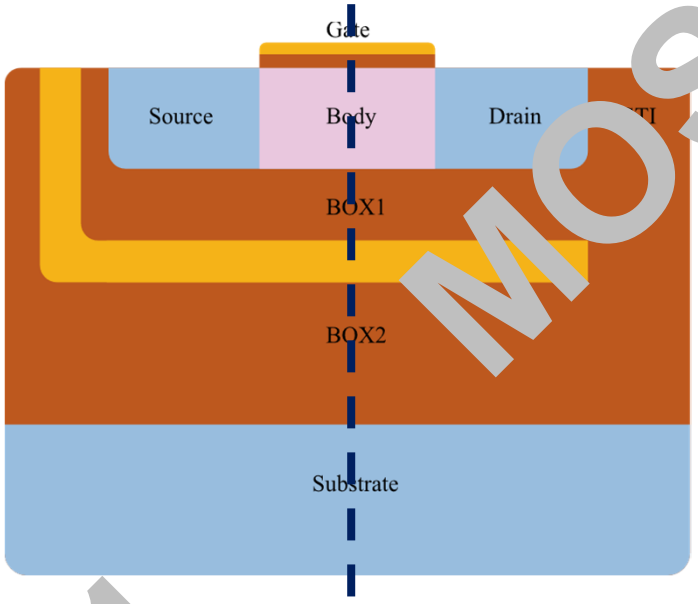
How the back-gate voltage works

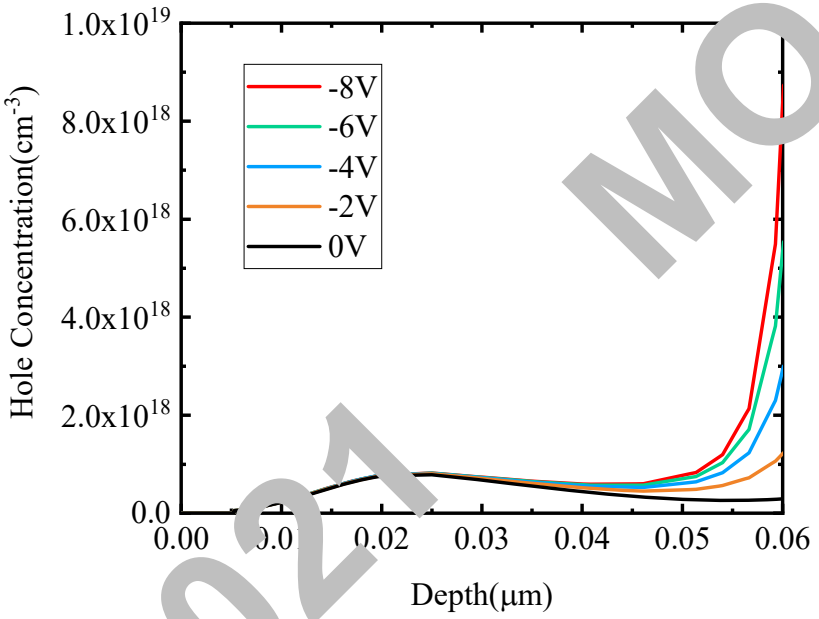




- As the back-gate voltage increases in the negative direction, the conduction band energy at the back interface rises (the body potential drops)
- The body potential can be reduced by applying a negative back-gate voltage, thereby suppressing the floating body effect

Hole concentration with different back-gate bias





- Negative back gate voltage will increase the concentration of holes in the body
- Holes in the body are attracted by the back gate potential and move to the back interface. The positive potential generated by the hole charges will be offset by the negative back-gate voltage.

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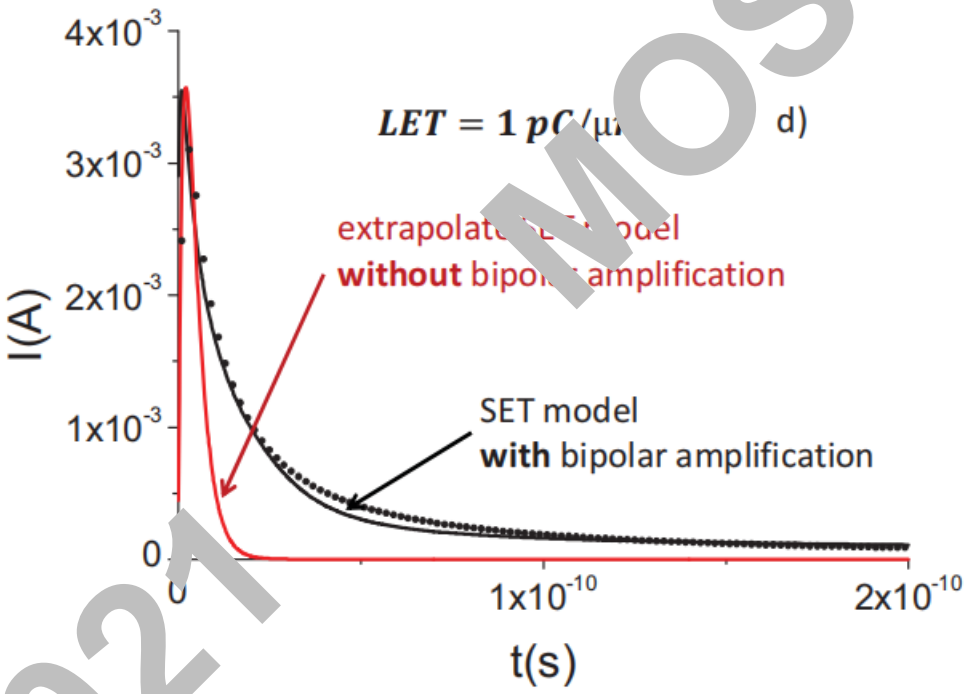
Shortcoming of existing model

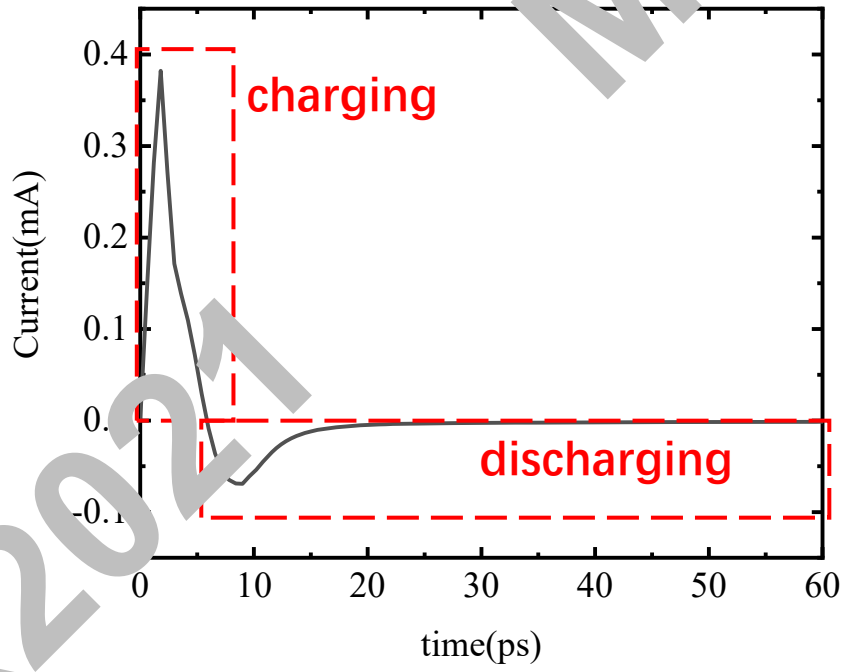


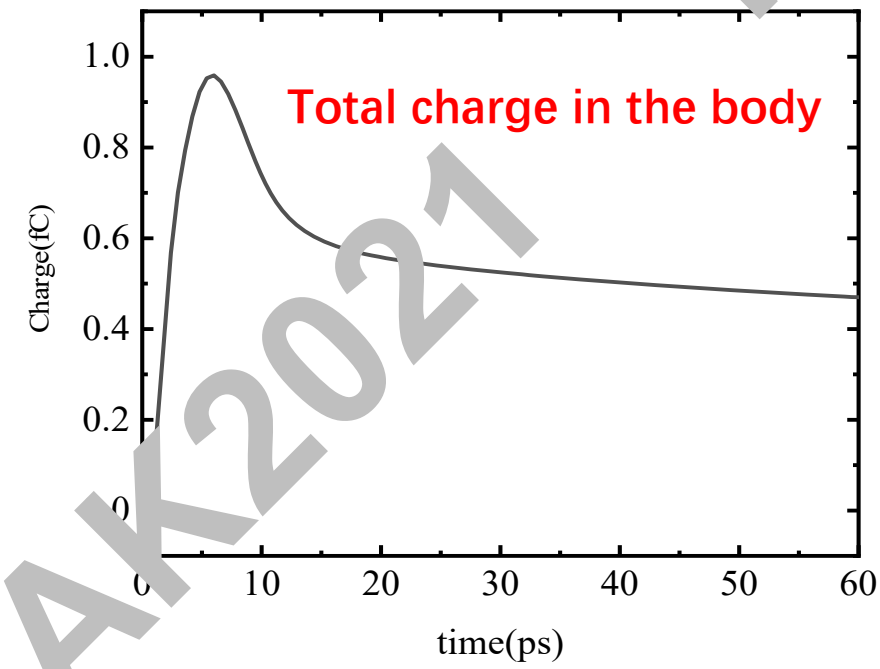
Existing model has difficulty in rebuilding the SET curve because of the bipolar amplification effect.

Three components of SE Current

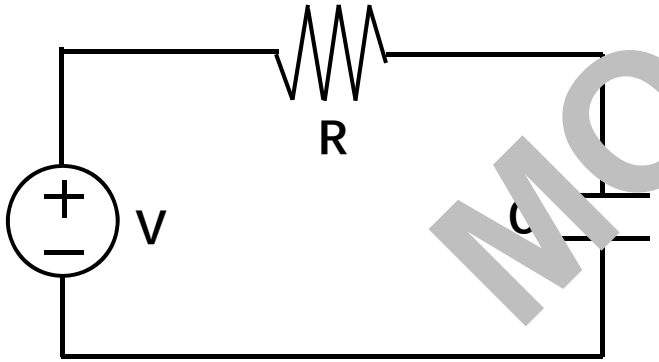
1. Prompt current (electrons).
2. Diffusion current (holes and electrons).
3. Bipolar amplification current (electrons).

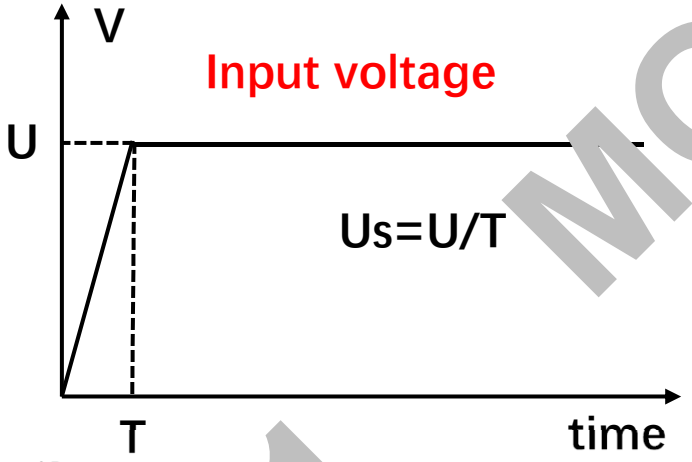
Charging and discharging of the capacitance





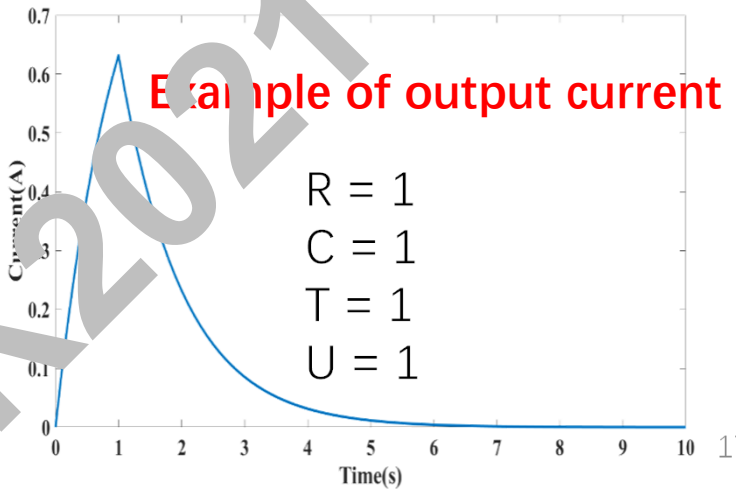
RC circuit model



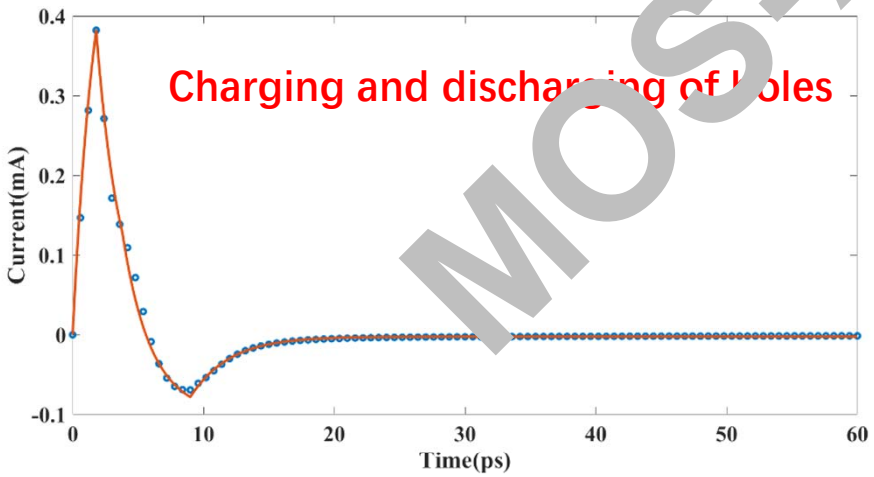


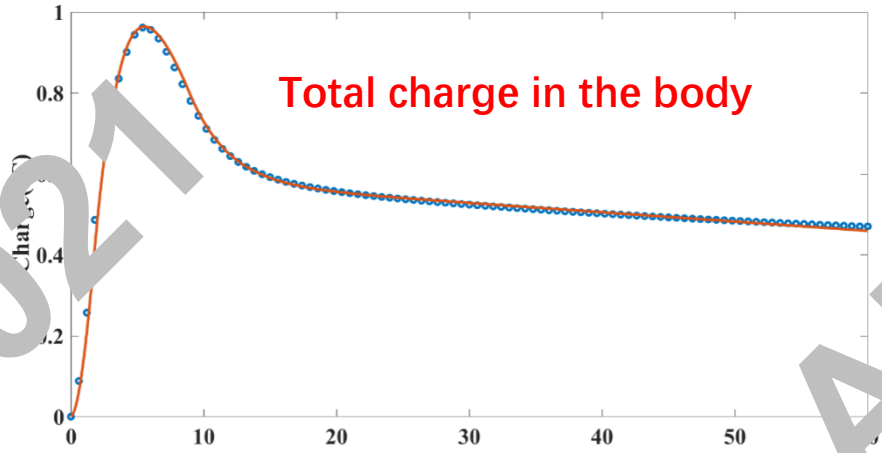
$$I = \begin{cases} I = CUs - CUs\exp\left(\frac{-t}{\tau}\right) & t < T \\ Cl\ s\exp\left(\frac{T}{\tau}\right) - CUs\right)\exp\left(\frac{-t}{\tau}\right) & t \geq T \end{cases}$$

$$\tau = RC$$



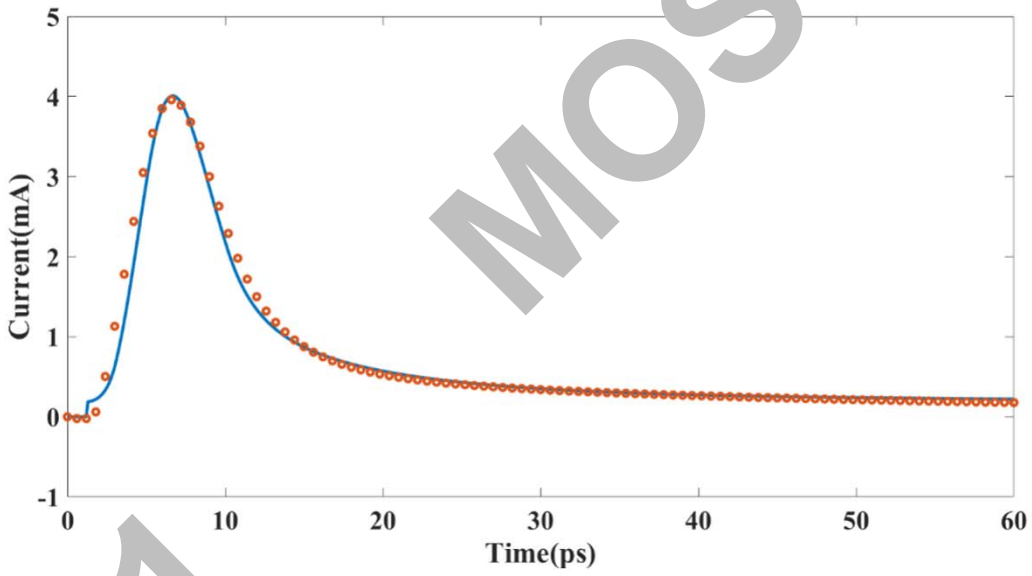
fitting results





R and total charge(Q=CU) of the prompt current were extracted.

Electron current from the sou

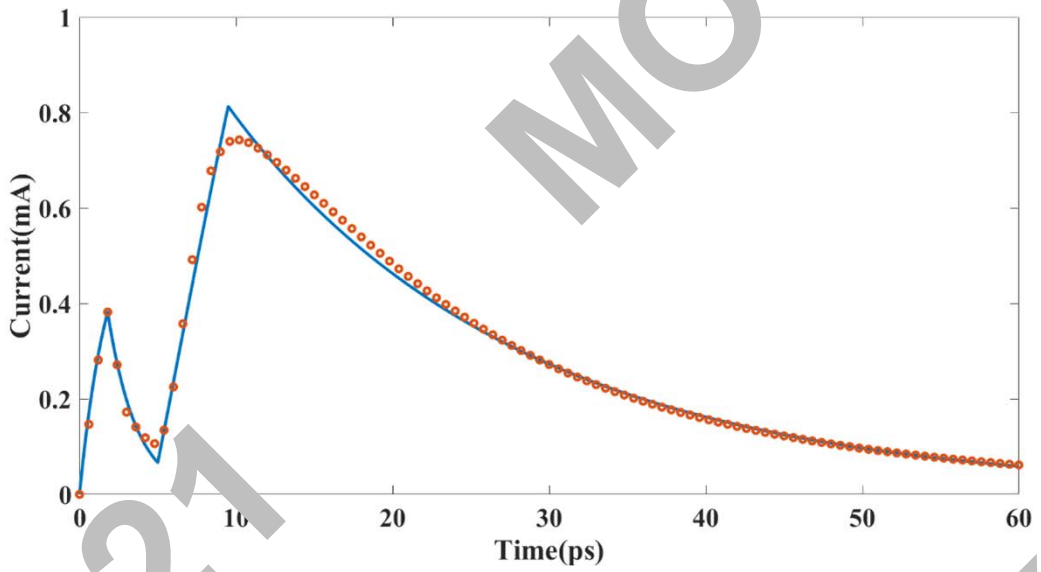


$$\phi(t) = \frac{Q(\quad)}{C_b(t)}$$

$$I_{am} = I_0\left(e^{\frac{q\phi(t)}{kT}} - 1\right)$$

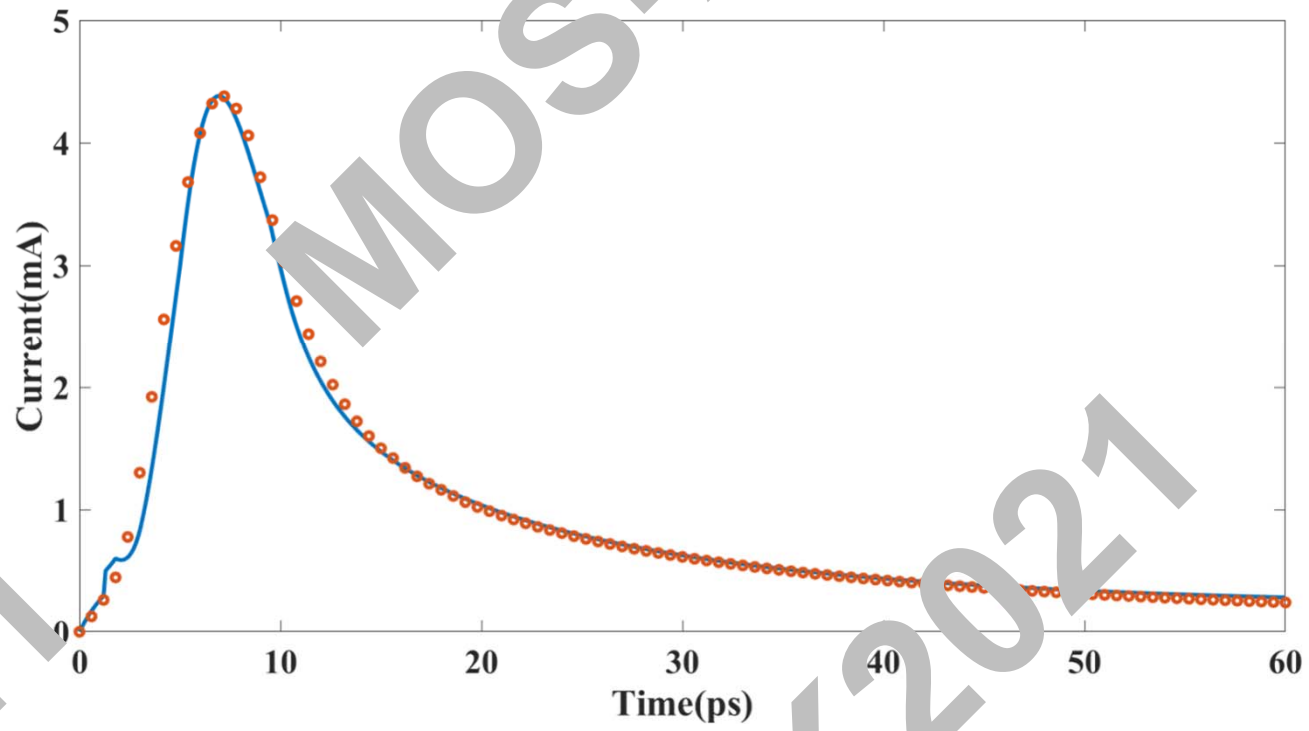
Bipolar amplification Current

Electron current from the body



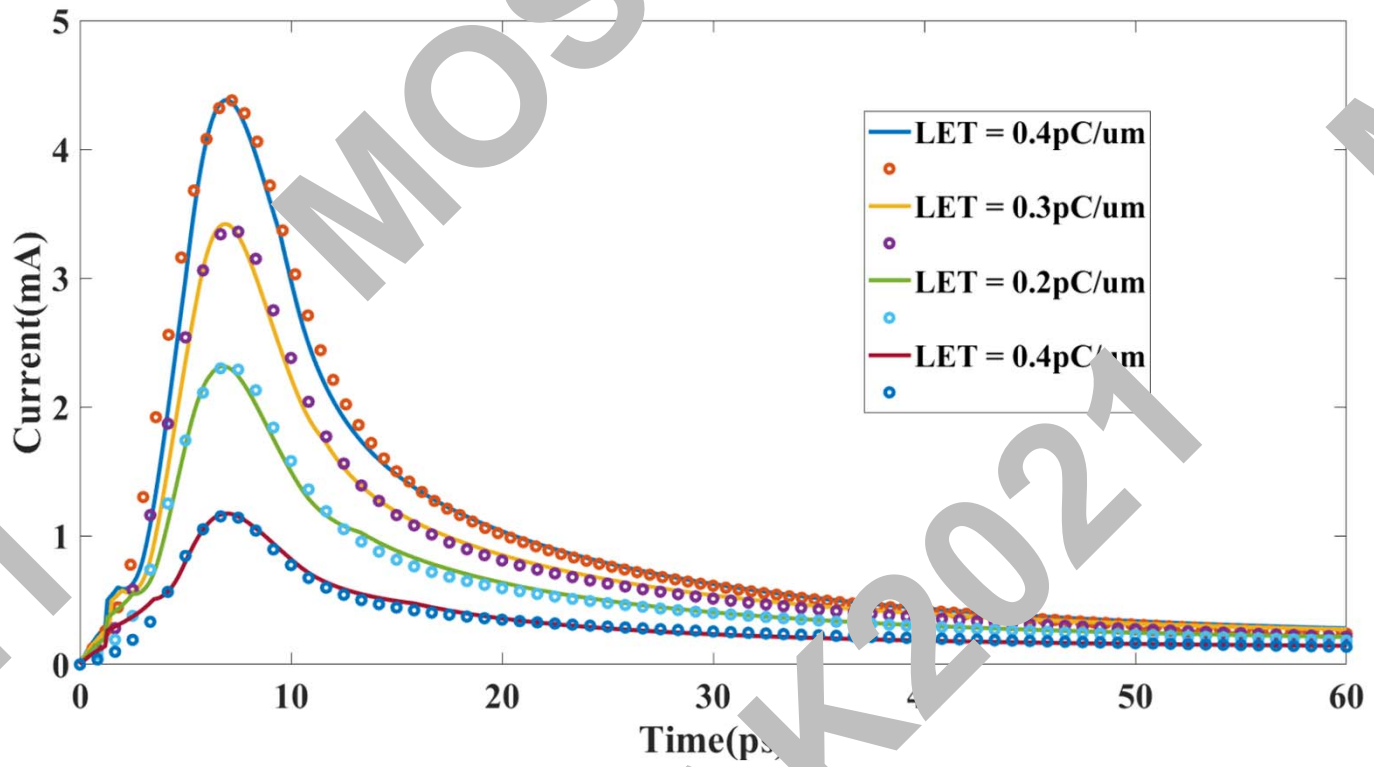
The electron current consists the prompt current and the diffusion current, it can be modeled with another two RC circuit combination.

Final results



SET current = electron current from the source - electron current from the body

Simulation results with different LET



Discuss of this model

- **Advantage** : this model restores the SET current by modeling every components of it. Every step has very clear meaning in physics and has a good fitting.

- **Disadvantage**: this model has too many parameters. Some of them have clear physics meanings, but some of them is not much clear or hard to be got by calculation.

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Summary

- ✓ For FDSOI devices, some electrons generated by heavy ion strike quickly drift to the electrode, causing accumulation of holes in the body region, leading the bipolar amplification effect.
- ✓ Because of bipolar diffusion and drift, the loss of holes accumulated in the body area is relatively slow, and the floating body effect will last for a long time.
- ✓ The negative back gate bias can decrease the body potential, effectively suppressing the bipolar amplification effect.
- ✓ A SOI NET model is proposed. It rebuilts the transient curve by model every components of it.

Thank you!