# Scaling Effects on Single-Event Transients in InGaAs FinFETs

Huiqi Gong[1], Kai Ni[1], En Xia Zhang[1], Andrew L. Sternberg[1], Kaitlyn L. Ryder[1], Ryan F. Keller[1], Landen D. Ryder[1], Sharon M. Weiss[1],
Robert A. Weller[1], Michael L. Alles[1], Robert A. Reed[1], Daniel M. Fleetwood[1],Ronald D. Schrimpf[1],
John A. Kozub[2], Alon Vardi[3], and Jesús A. del Alamo[3]
[1]Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN 37235, USA
[2]Department of Physics and Astronomy, Vanderbilt University, Nashville, TN 37235, USA
[3]Microsystems Technology Laboratories, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

VANDERBILT
UNIVERSITY

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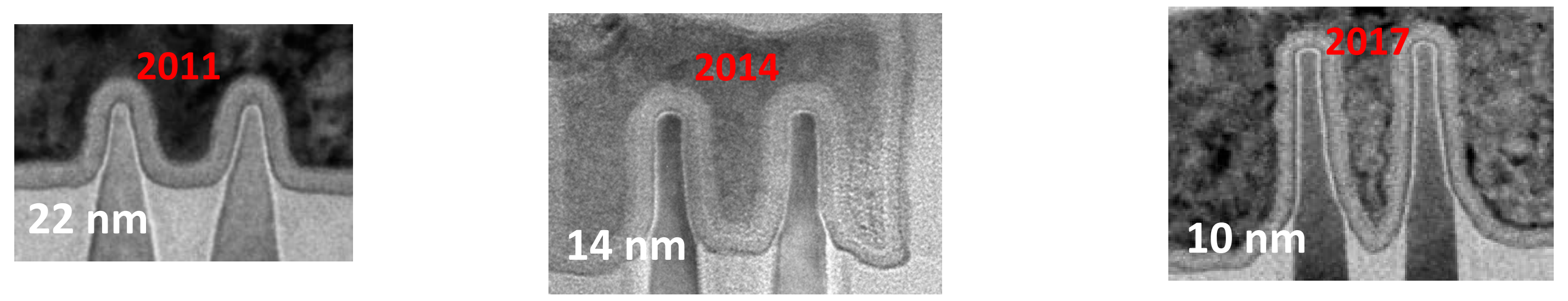
## Abstract

The single-event-transient response of InGaAs FinFETs with different fin widths is examined using pulsed-laser and heavy-ion irradiation. Devices with wider fins collect more charge in both environments. Quantum-well structures confine charge collection in the channel, and determine the sensitive volume. Charge accumulated in the buffer and substrate layers modulates the body potential, altering the degree of back-gate control, leading to additional effects associated with charge accumulation in the wider fin devices. Optical simulations suggest that the optical intensity is enhanced in narrow fins during laser irradiation due to the confinement of light associated with the metal-dielectric interface inside the fin, and the degree of confinement scales inversely with fin width.

## Motivation

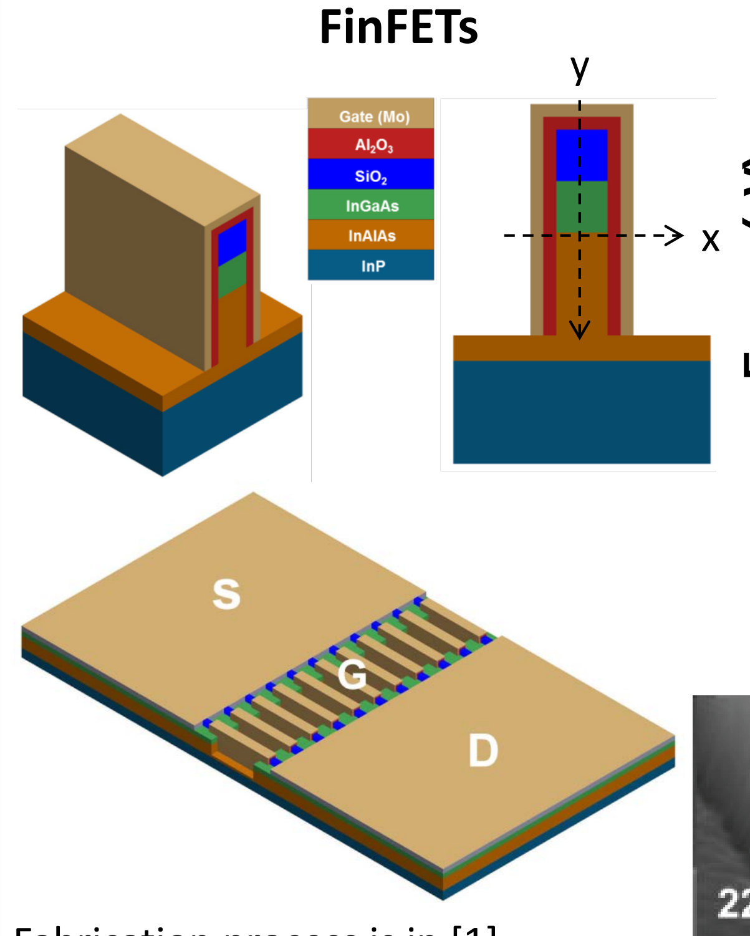
**To explore the fundamental mechanisms of charge collection on III-V MOSFETs for sub-10 nm node CMOS**



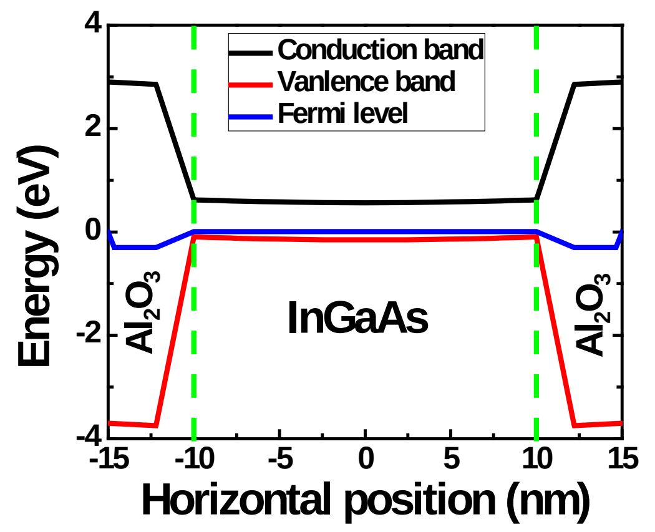
**Fin width scaling from Intel's 22-nm to 10-nm technology**

## Devices

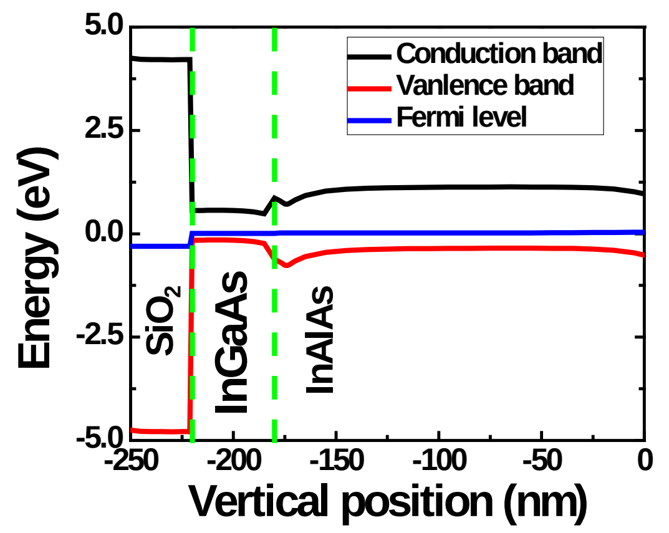
**InGaAs double-gate FinFETs**



**Type-I quantum-well**

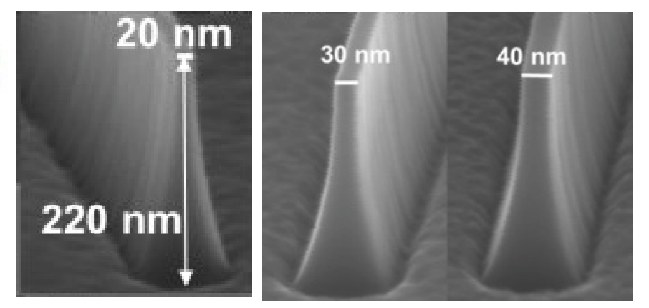


Band structure along x direction



Band structure along y direction

Fabrication process is in [1]

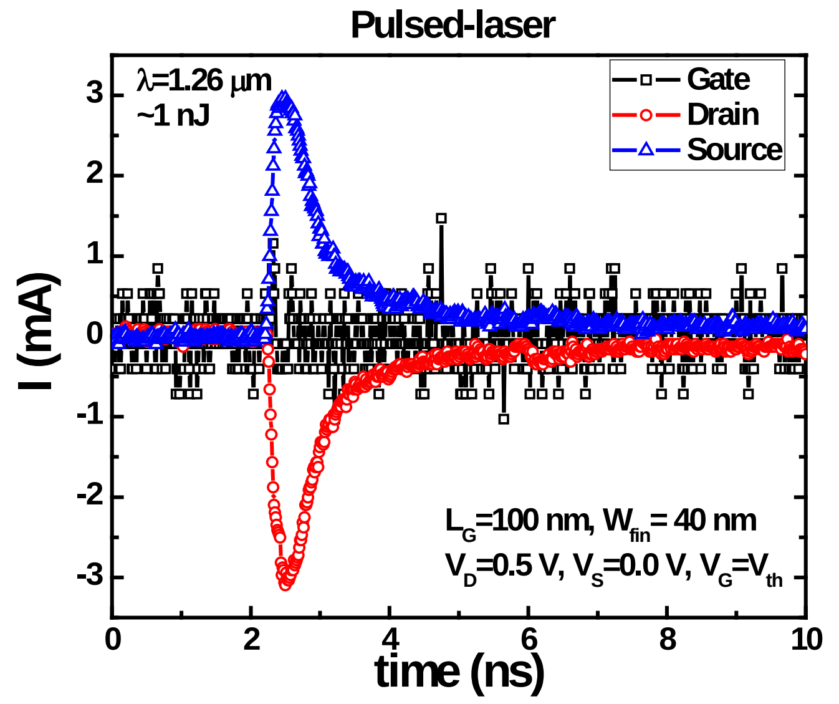


**Device geometry information**
Fin number: 11
Pitch (fin to fin): 0.8 µm
Gate length: 100 nm
Fin width: 20 nm , 30 nm, 40 nm
Fin height: 220 nm
Channel height (InGaAs layer): 40 nm

[1] Vardi, et al. *IEEE IEDM,* 2015

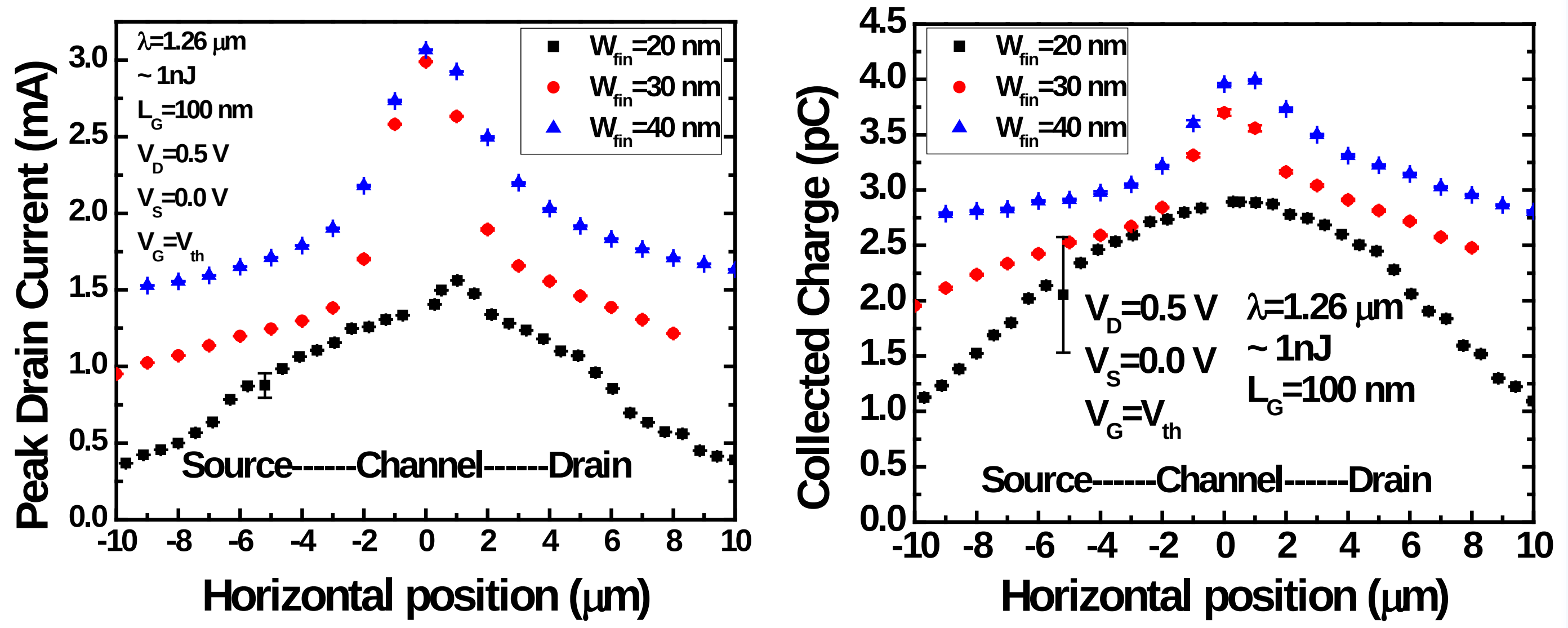
## Pulsed-laser irradiation

Pulsed-laser experiments were performed at Vanderbilt University, a detailed experimental setup for laser testing are reported in [2].



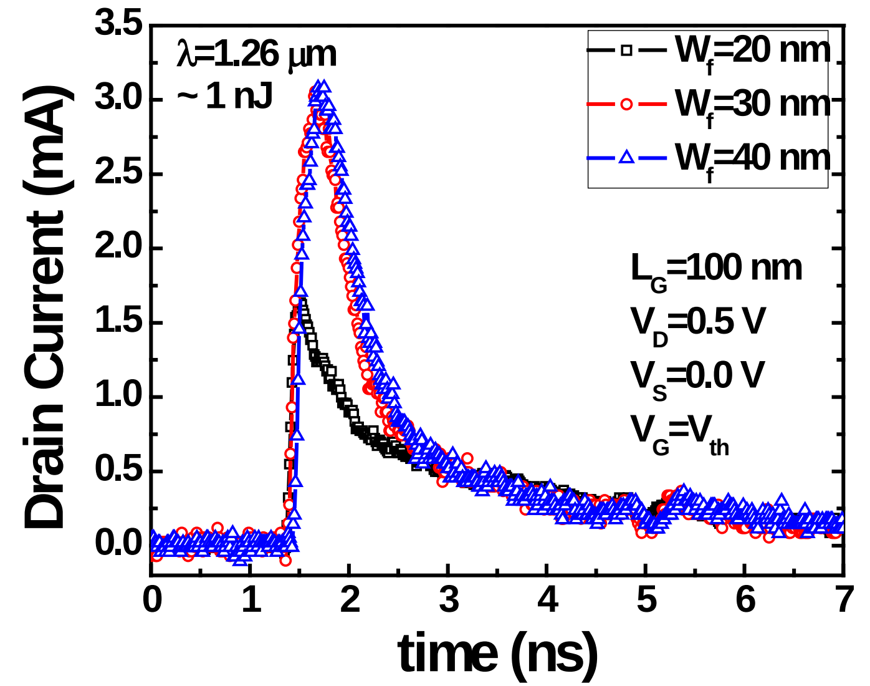
**Pulsed-laser induced SET**

- ☐ Symmetric source and drain transient currents
- ☐ Gate current is negligible
- ☐ Carriers confined in channel layer by type-I quantum-well
- ☐ Peak current: charge collection from channel, prompt process
- ☐ Tail current: charge collection from substrate, slow process



Peak drain current and drain collected charge along a line scan from source to drain for InGaAs FinFETs of different fin widths during pulsed testing

- ☐ SET intensity scales with fin width
- ☐ Spatial asymmetry: peak drain current is higher on the drain side, due to the higher electric field on the drain side
- ☐ The tails of the transients overlap for all three devices, because all devices have the same substrate material and geometry

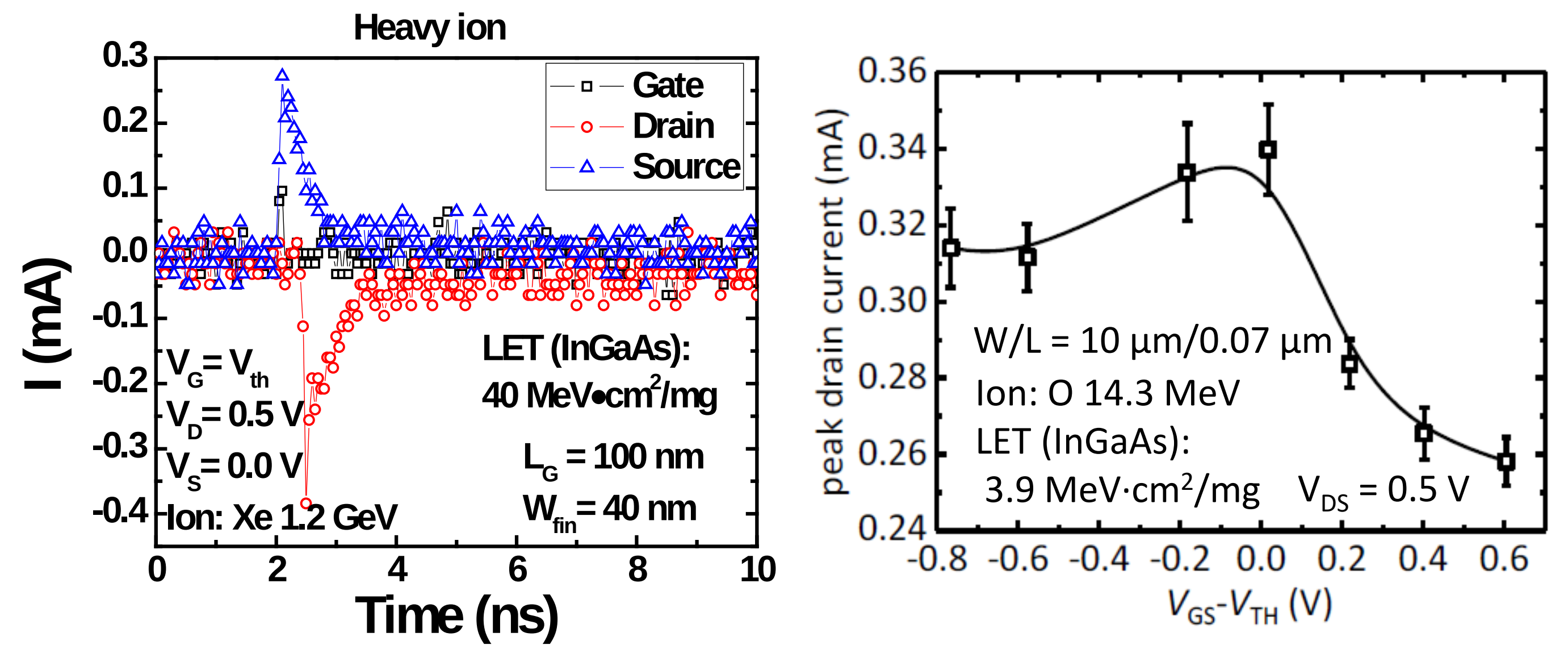


Drain current transients for InGaAs FinFETs of different fin widths

[2] Ni, et al. *IEEE TNS,* 2017

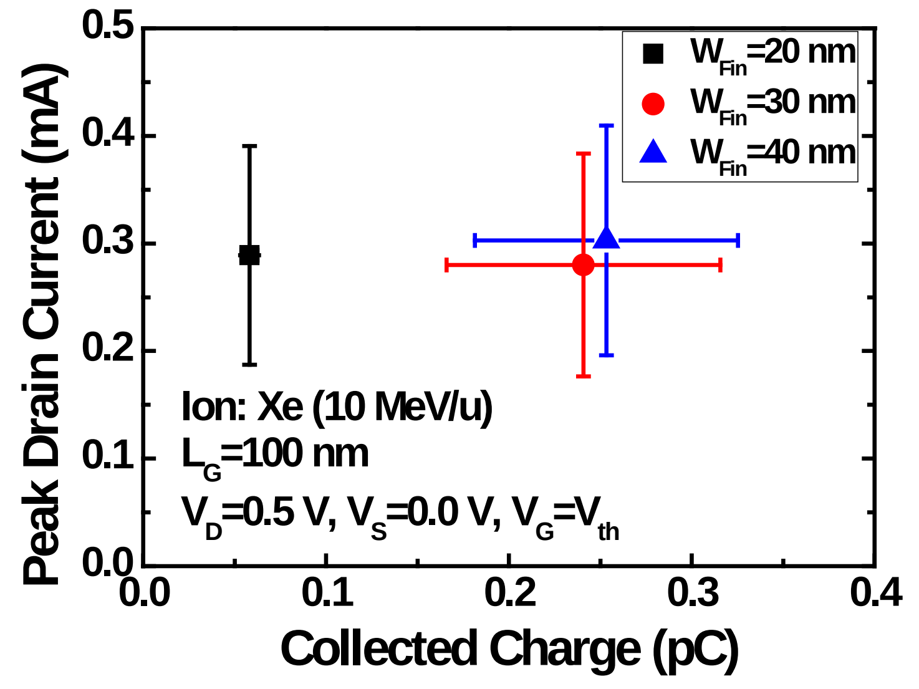
## Heavy-ion irradiation

Heavy-ion experiments were performed with the 88 inch cyclotron at Lawrence Berkeley National Laboratory (LBNL).



Heavy-ion induced SET in InGaAs FinFETs vs. planar InGaAs MOSFETs [3]

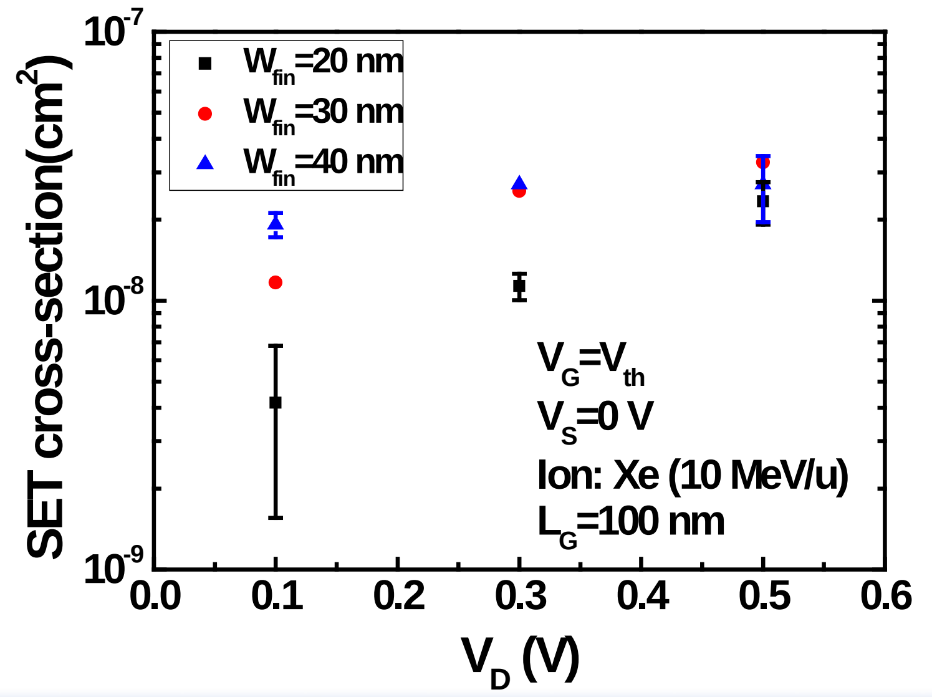
- ☐ Less charge collection compared to laser induced SET
- ☐ Planar InGaAs MOSFETs under lower LET ion irradiation shows similar peak current to InGaAs FinFETs under higher LET ion irradiation
- ☐ Larger sensitive volums for planar devices than for FinFETs



- ☐ Collected charge scales with fin width, consistent with pulsed-laser results
- ☐ Peak current is independent of fin width, which is different from pulsed-laser results, due to:
  - ✓ Ion track structure effects
  - ✓ Diffusion current from substrate
  - ✓ Device to device variations

SET cross-section: $\sigma = \dfrac{N}{\phi \cdot t}$

- ☐ SET cross-section scales with fin width: narrow fin devices show smaller cross-sections compared with wider fin devices

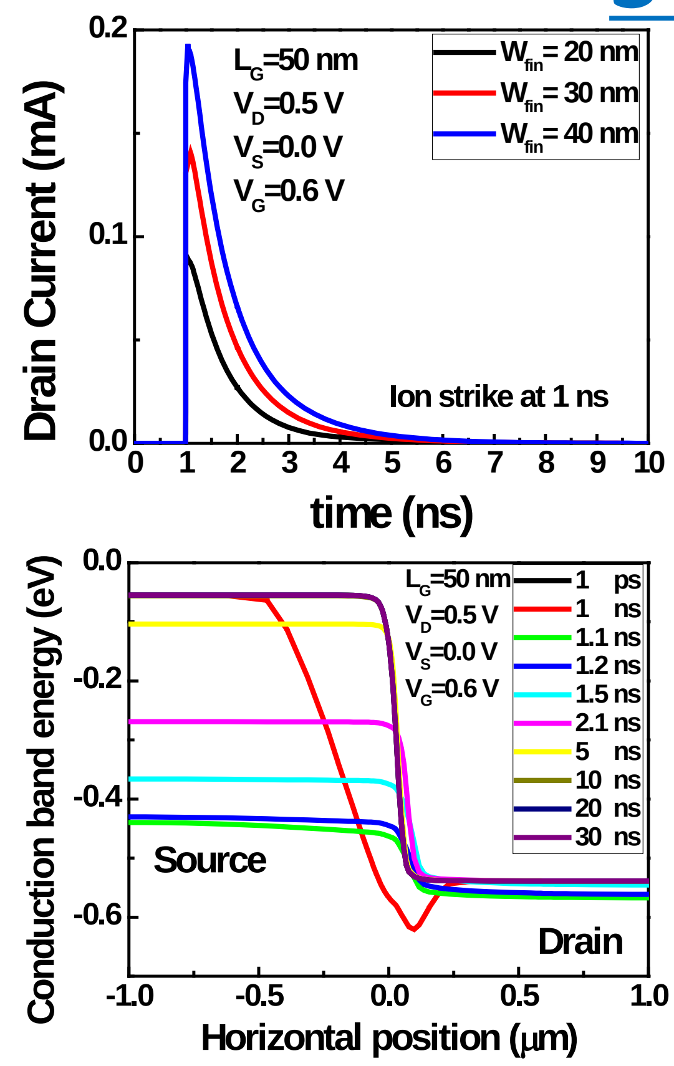


[3] Ni, et al. *IEEE TNS,* 2014

## Conclusion

- ➢ Charge collection and SET cross-section in InGaAs FinFETs scale with fin width.
- ➢ 3D TCAD simulations suggest the enhanced charge collection of wider fin devices is mainly due to larger geometric volumes.
- ➢ Charge accumulated underneath channel functions as back gate, which also produces stronger channel modulation effects for wider fin devices.
- ➢ Optical simulation shows the optical field is enhanced inside the fin due to the confinement of light associated with the metal-dielectric interface.

## 3-D TCAD simulation



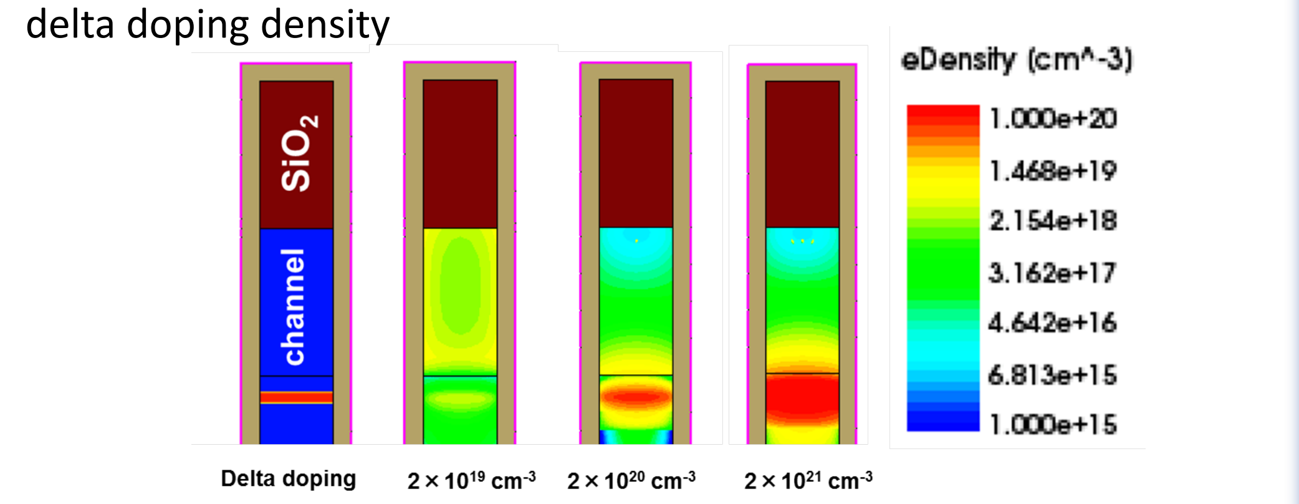
Barrier lowering on source side

Ion with LET of 3.9 MeV·cm²/mg (InGaAs) injected from the top of the gate to the substrate, centered at the middle of channel

- ☐ Peak current scales with fin width: geometric effects
- ☐ Barrier lowering due to hole accumulation at the source side

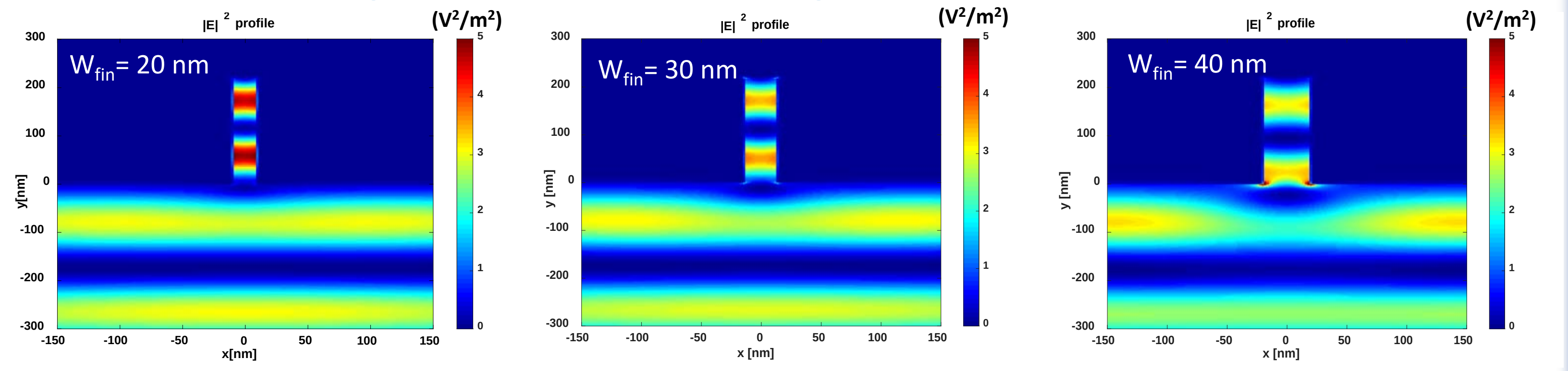
### Channel modulation by substrate

Simulating effects of charge accumulation in substrate by changing delta doping density



- ☐ Charge underneath channel acting as back gate
- ☐ Narrower fin suggests shorter back gate length, less likely modulated by the back gate

## Optical intensity enhancement



- ☐ Confinement of light associated with the metal-dielectric interface inside the fin