Total Dose and Single Event Effects in Strained Si Technologies

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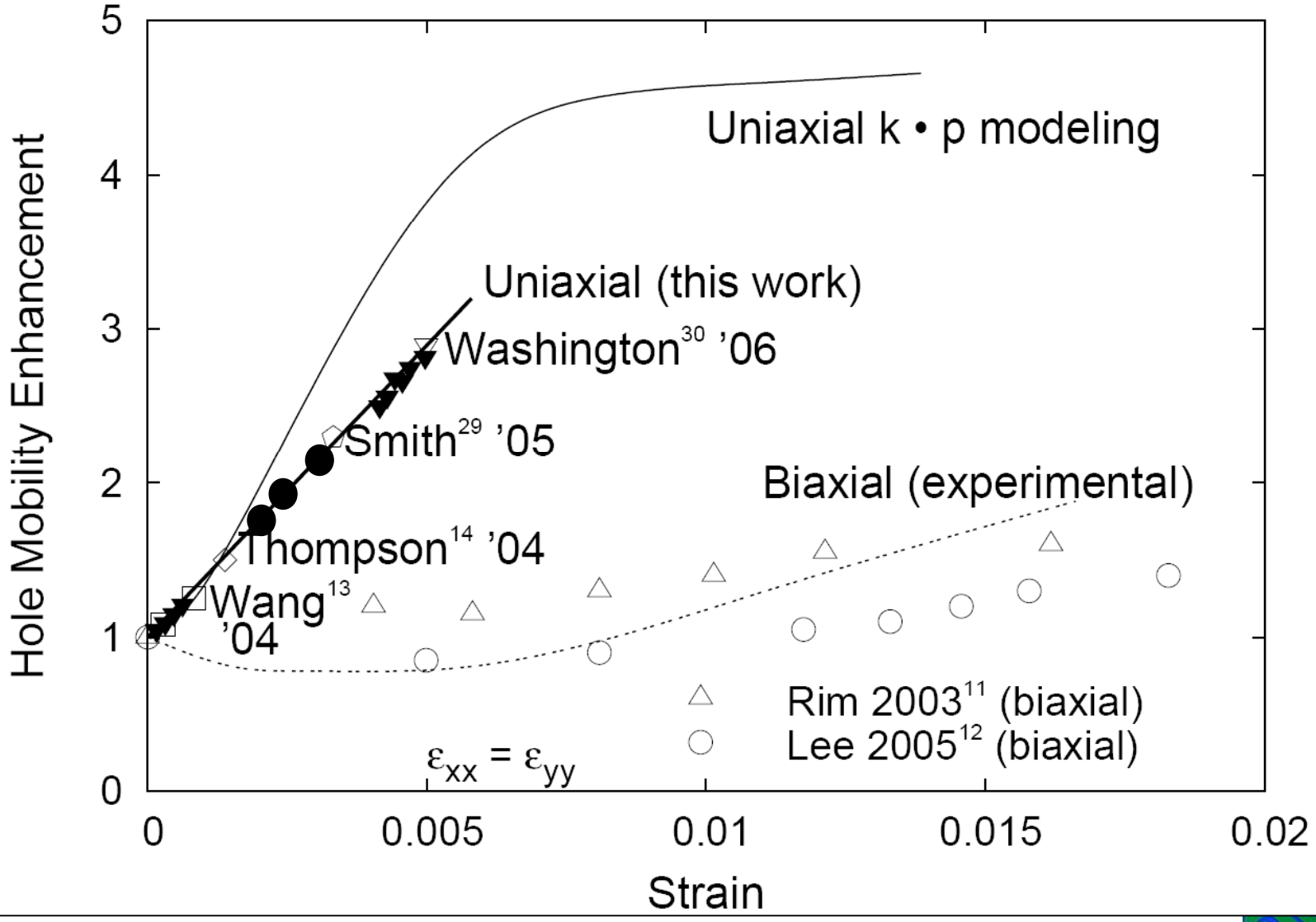
Strained Si Hole Mobility Higher than Ge



Outline

- Single Event Transient in Strained Si Diode
- Total Ionizing Dose Effects on Strained HfO_2-based nMOSFETs
- Future Planes

1GPa Stress Video: Flexure Jig

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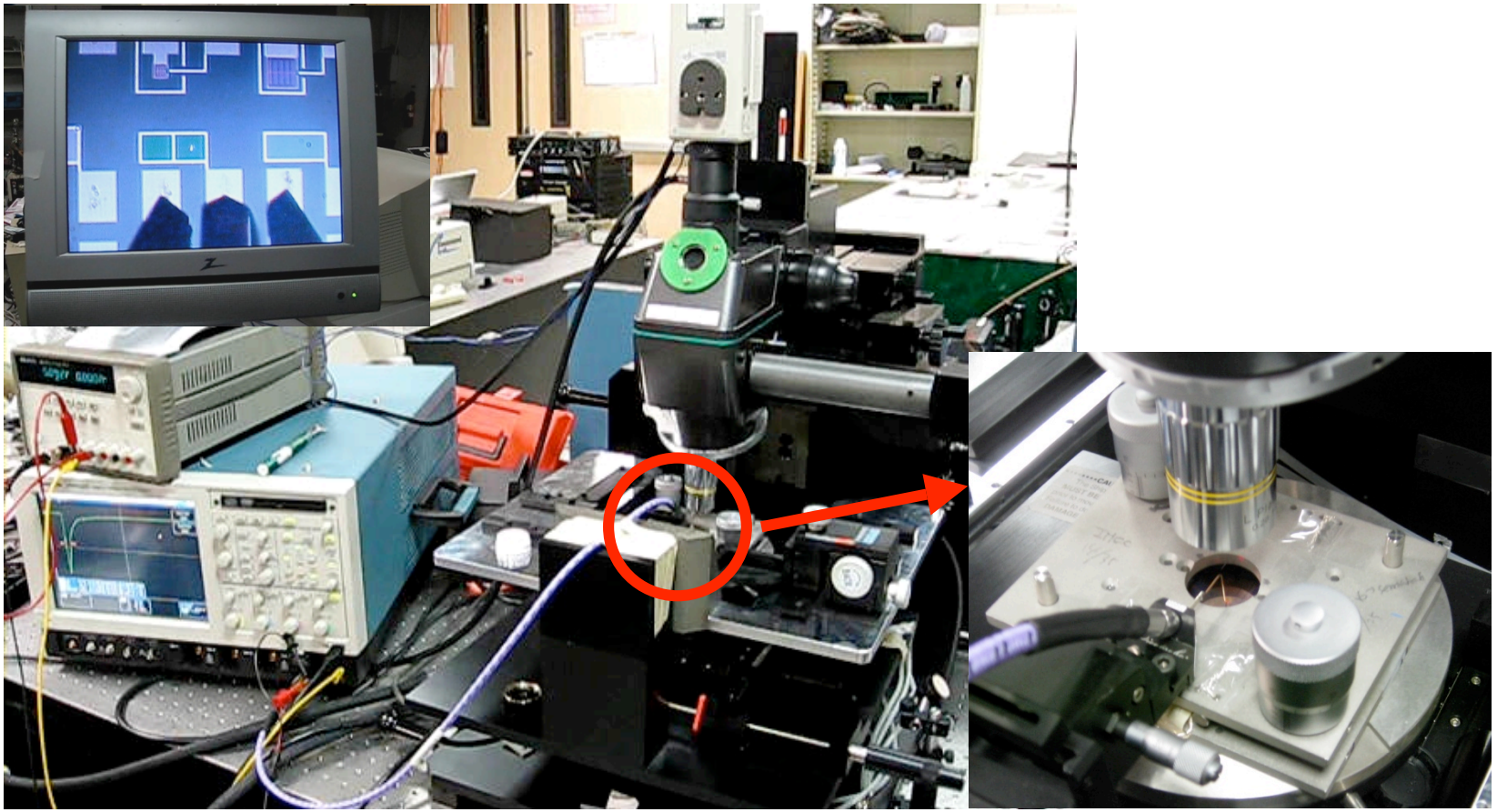
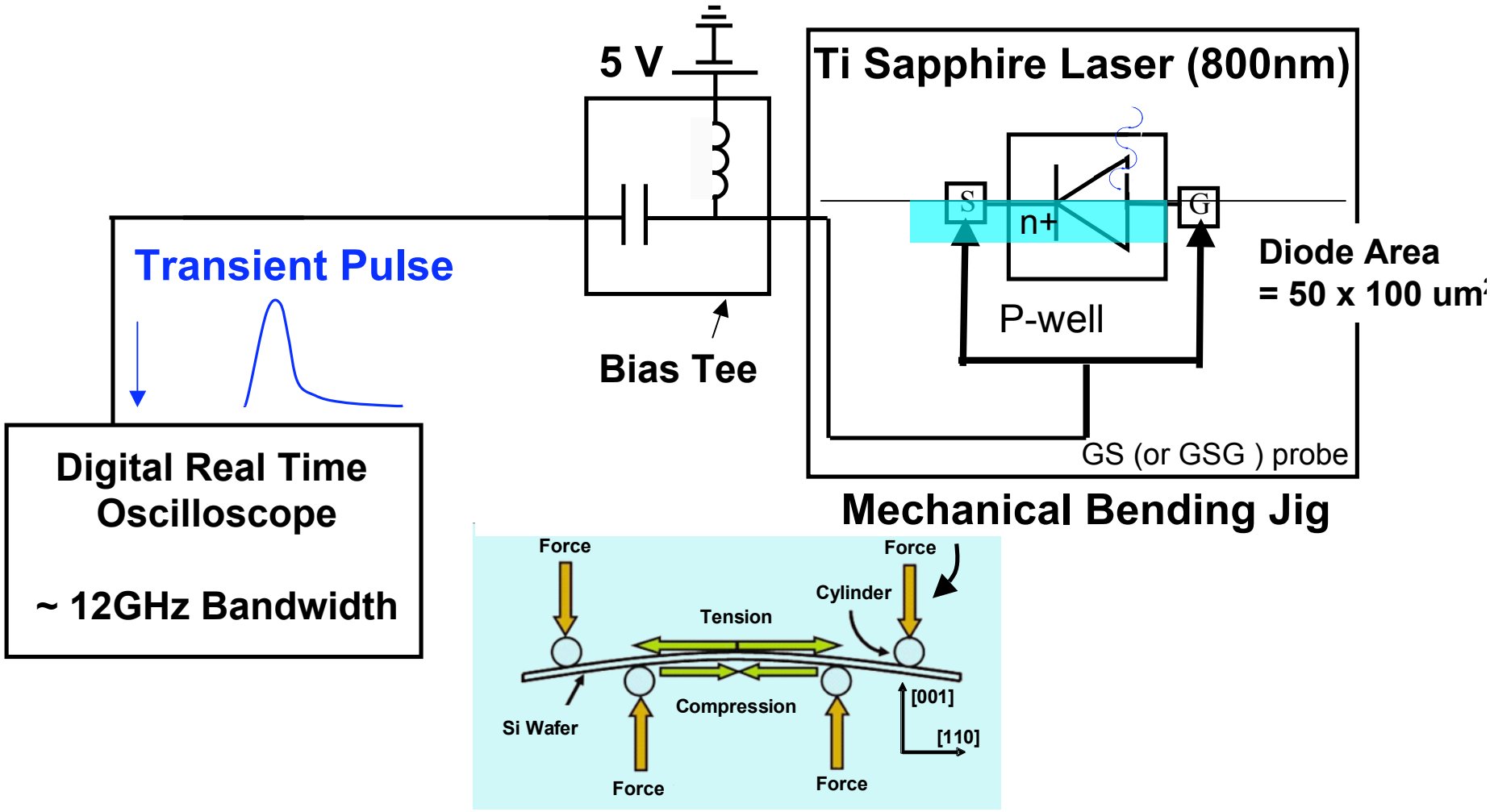
Single Event Transient (SET) Measurement Set Up

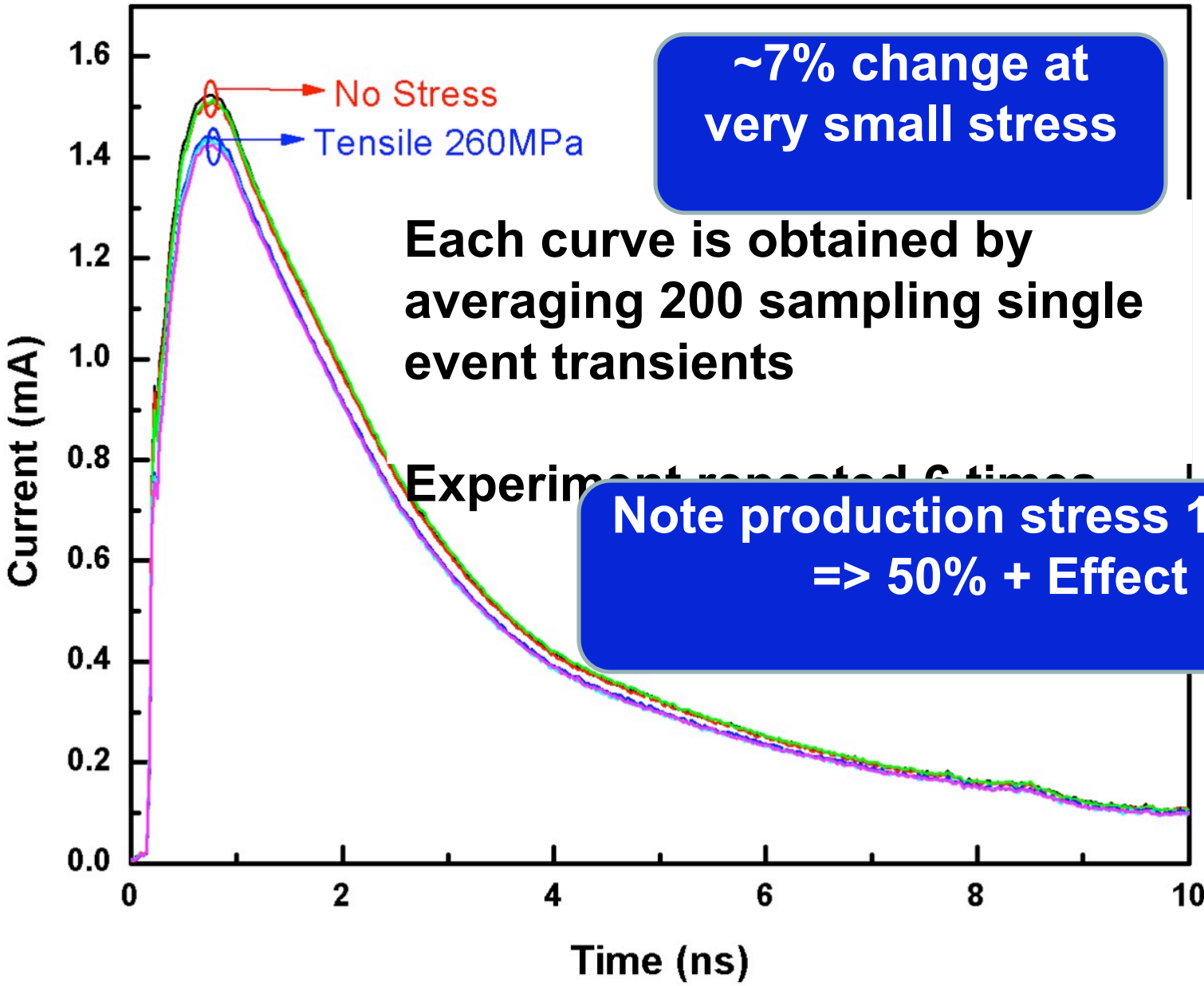


SET setup / Robert A. Reed[2]

Single Event Transient (SET) Measurement System



Electron Single Event Transient Pulse



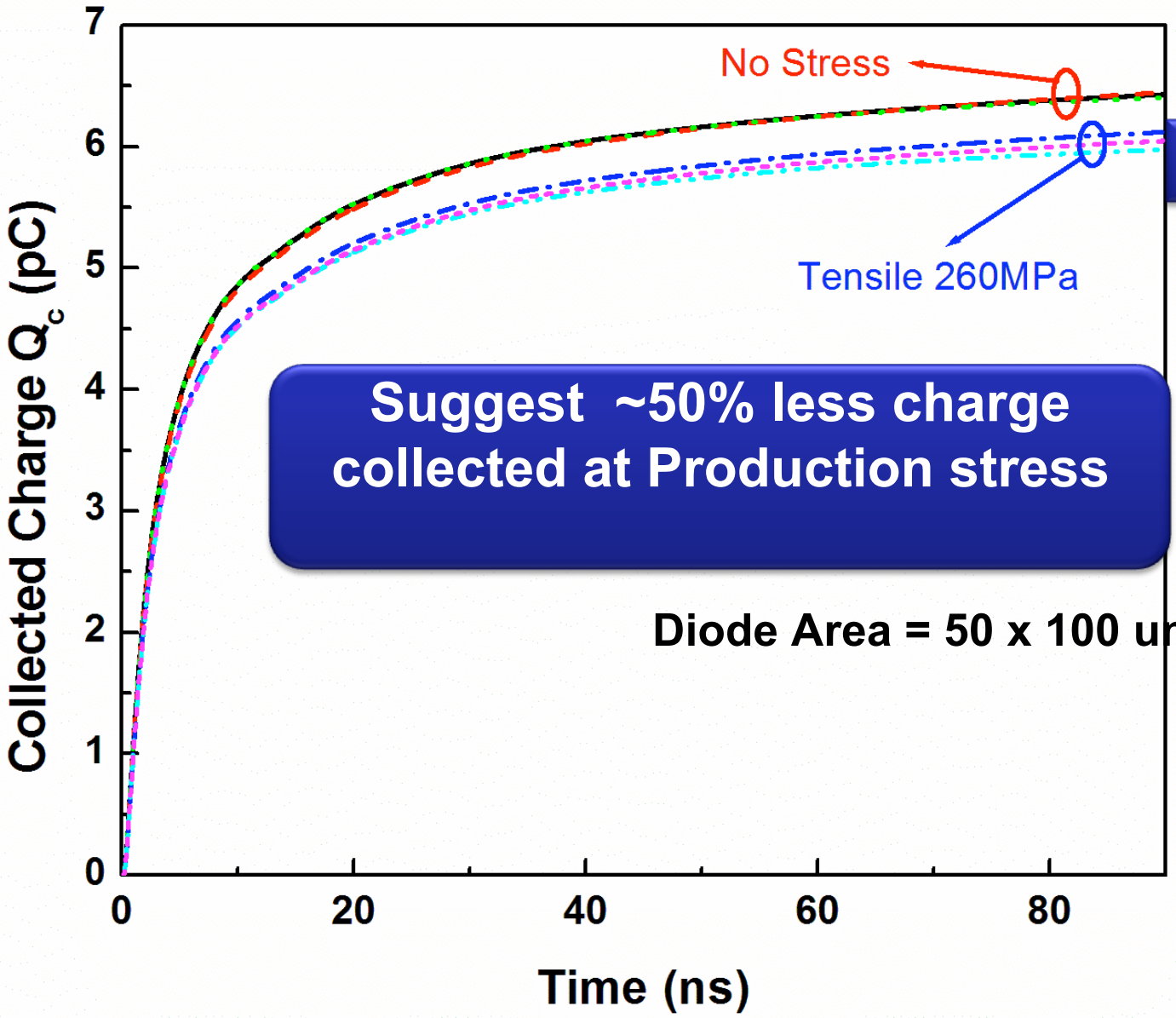
~7% change at very small stress

Each curve is obtained by averaging 200 sampling single event transients

Experim

Note production stress 1 to Gpa => 50% + Effect

Total Charge Collection in Diode

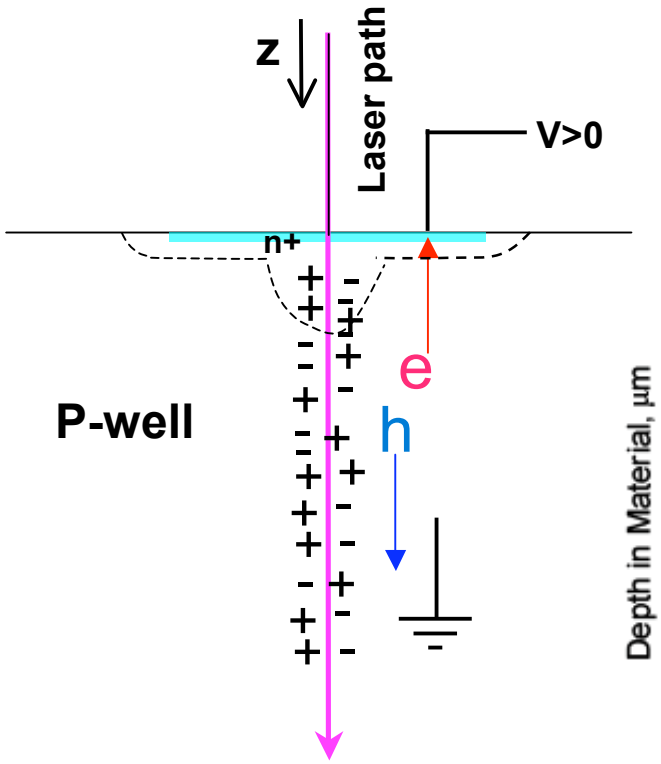


6. 3 % decreas

Suggest ~50% less charge collected at Production stress

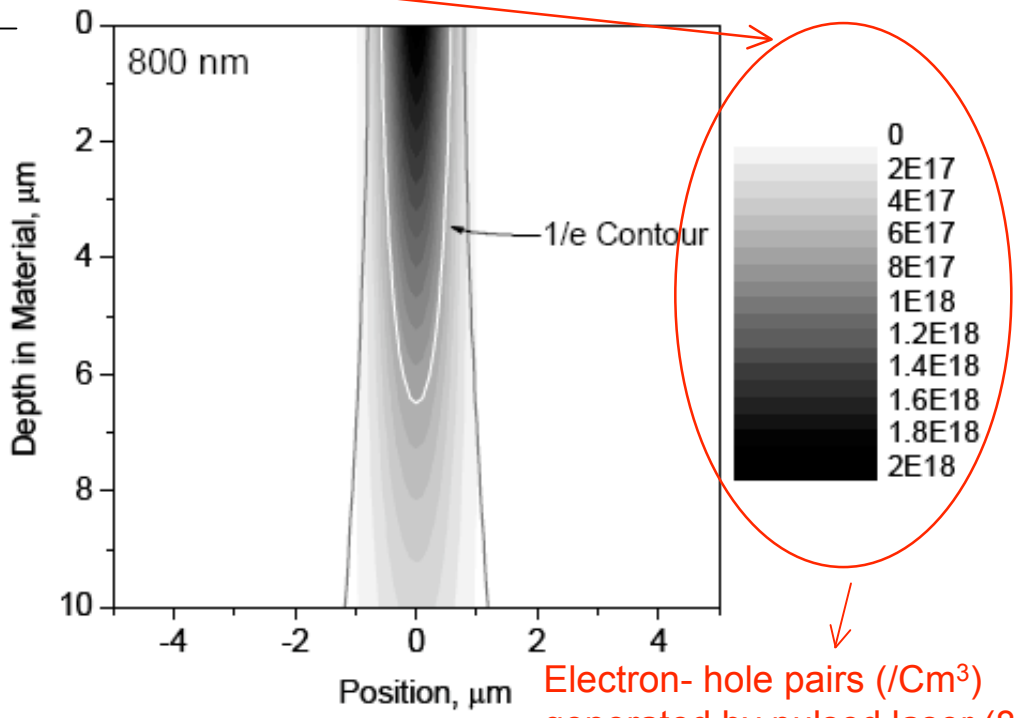
Diode Area = 50 x 100 um^2

Single Event Transient on pn Diode
Pulsed Laser (Single Photon Absorption)



Absorption coefficient

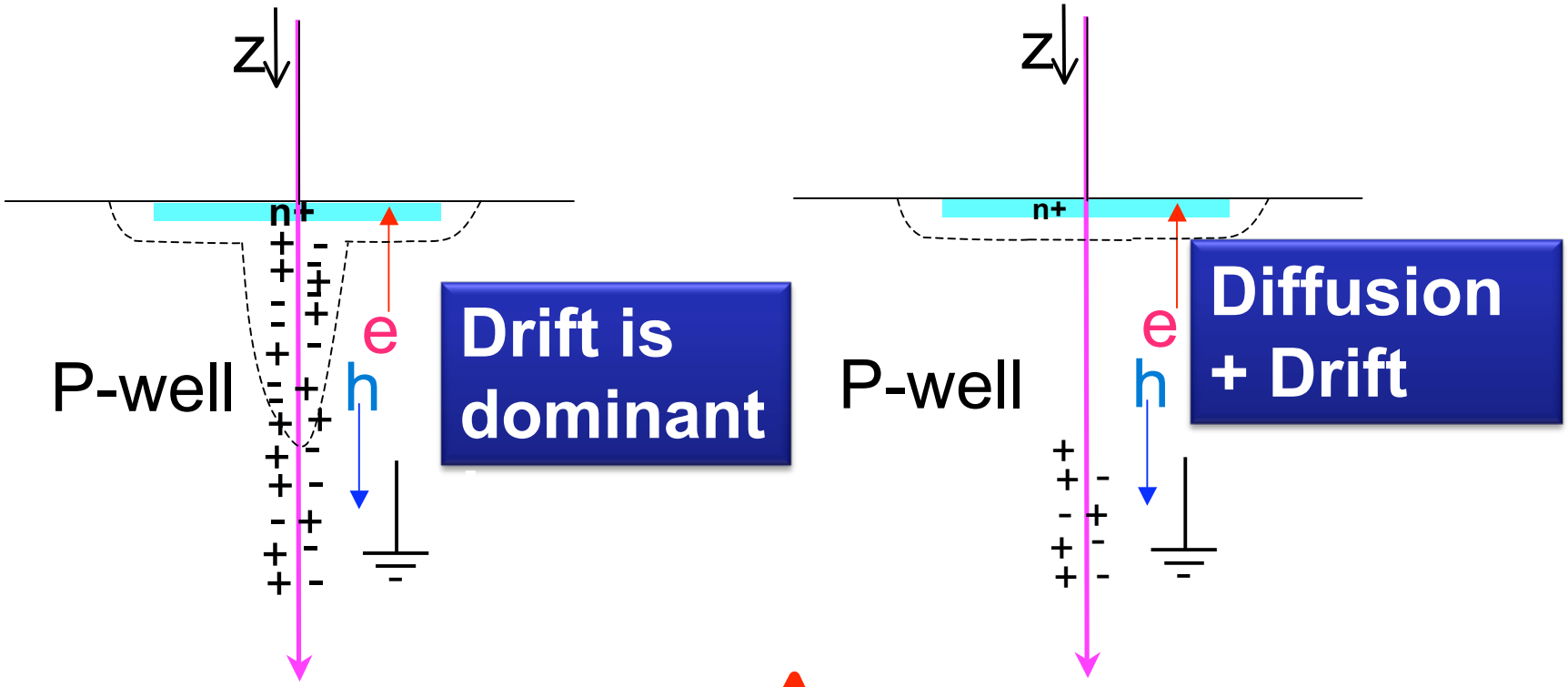
$$N_{1p}(z) = \frac{\alpha}{\hbar\omega}\exp(-\alpha z)\int_{-\infty}^{\infty} I_0(z,t)dt$$



Electron- hole pairs (/Cm^3) generated by pulsed laser (800nm)

McMorrow , NSREC Short Course, 2005

Single Event Transient due to Time Domain



Rise time (0 ~ 700 ps)

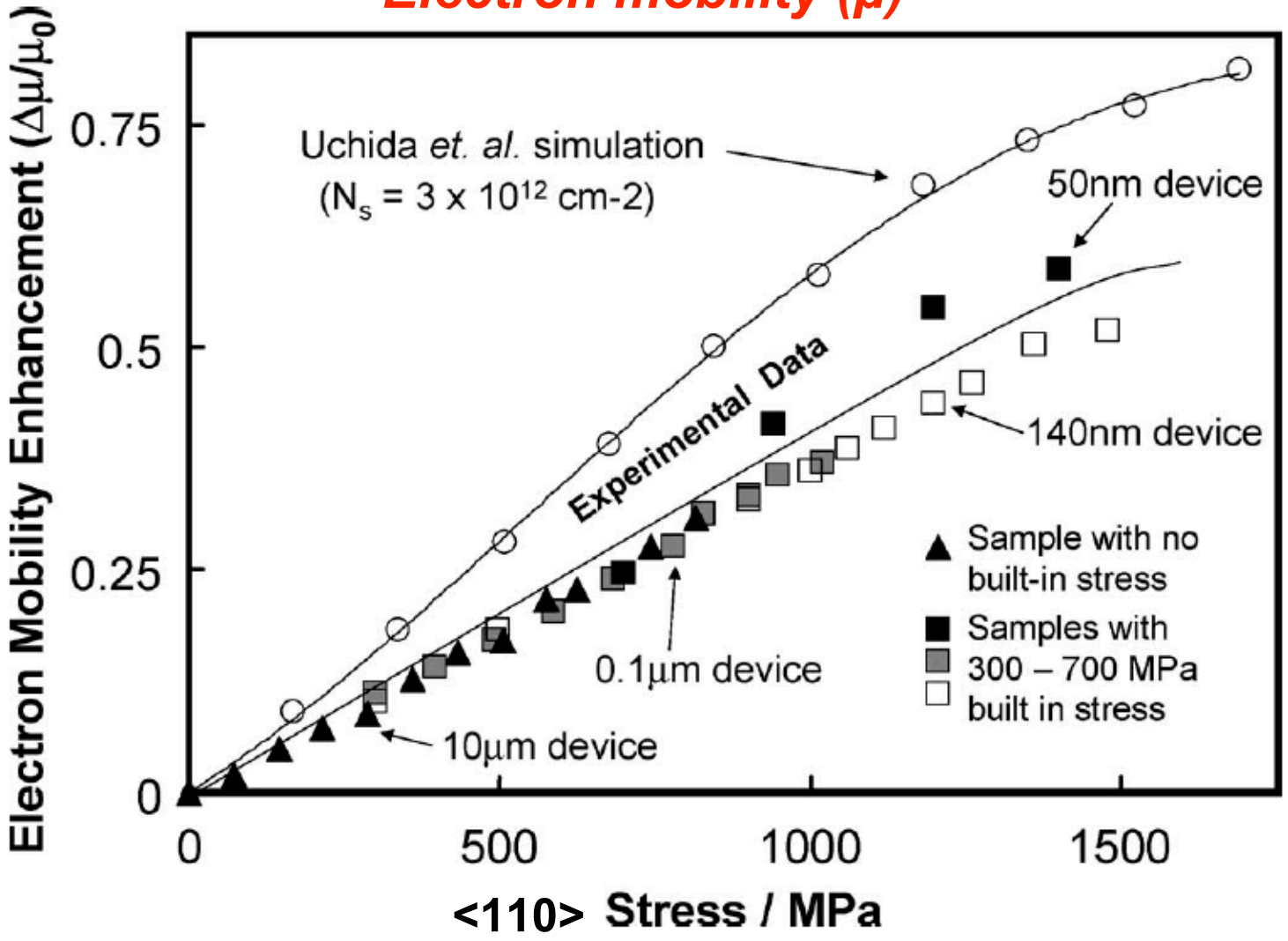
Fall time (20 ~ 85ns

$u_{\perp}$ **-4%/100MPa**

$u_{\parallel}$ **+3%/100MPa**

Strain Alters Mobility / Charge Collection

Electron mobility (μ)

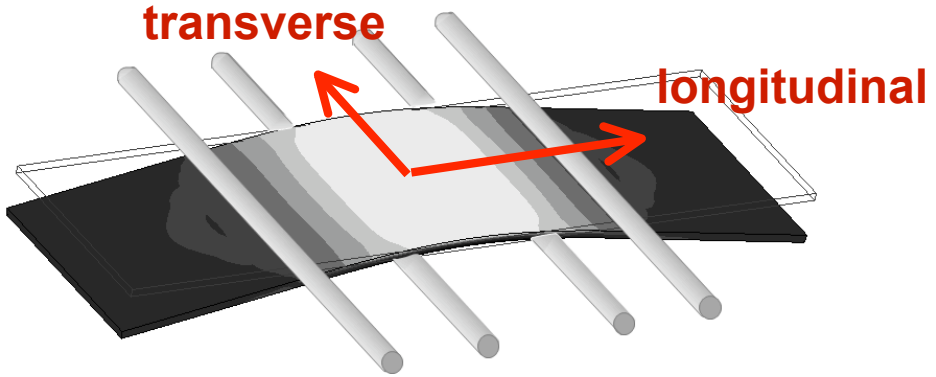


UF Group, EDL, 2007

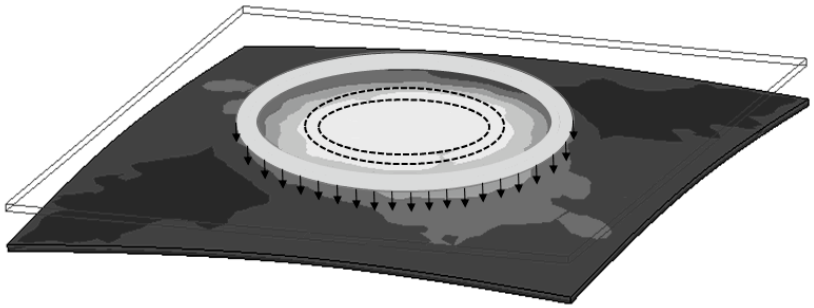
Complete Set of Piezoresistance Coefficients

Measurement includes:

- ✓ In-plane longitudinal pi-coefficient
- ✓ In-plane transverse pi-coefficient
- ✓ In-plane biaxial pi-coefficient
- ✓ Out-of-plane uniaxial pi-coefficient (using biaxial setup)



schematic for applying uniaxial stress



schematic for applying biaxial stress

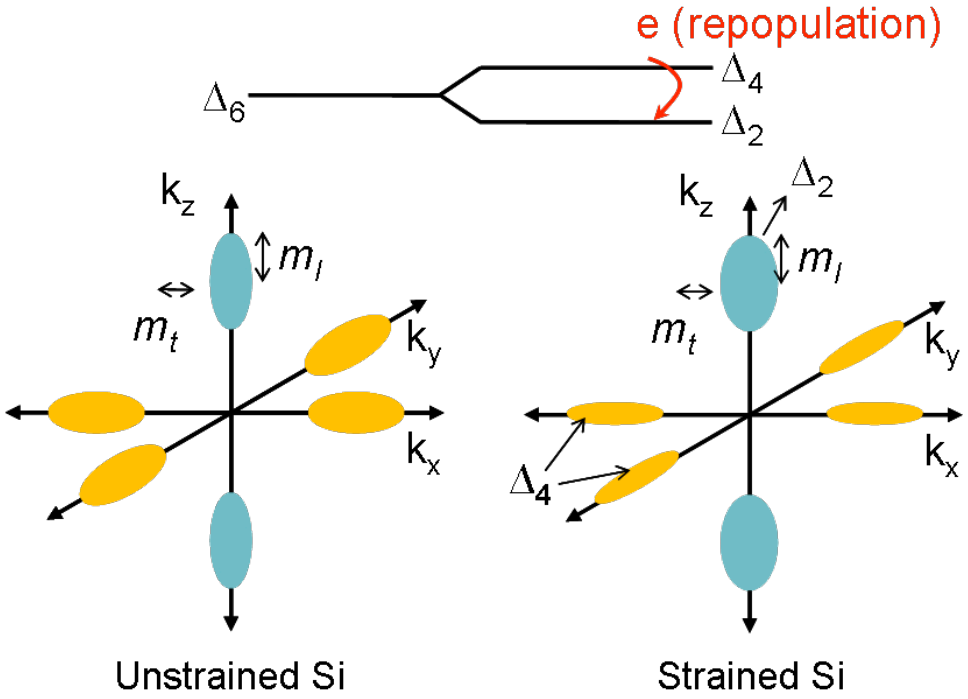
n-MOSFET Piezoresistance Coefficients

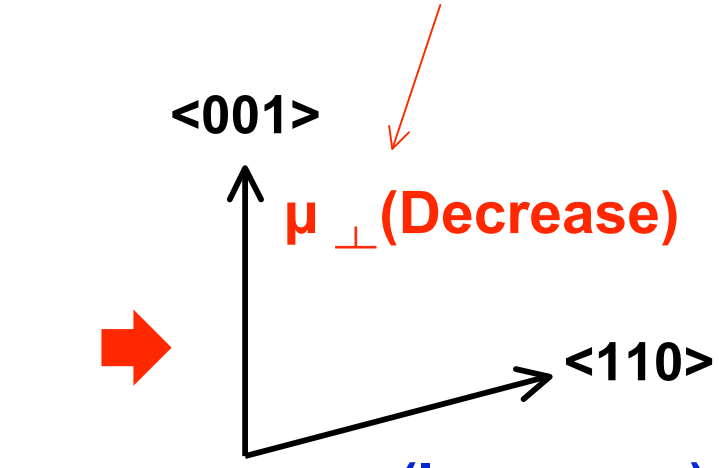
14

			π_l	π_t	π_B
(001) wafer	<100> channel	n-MOSFET	-47 (7.7)	-22 (4)	-50 (2.3)
		Smith bulk Si	-102	53	-49
	<110> channel	n-MOSFET	-32 (7.4)	-15 (6.4)	-47 (3.2)
		Smith bulk Si	-31	-18	-49
(110) wafer	<100> channel	n-MOSFET	-24 (1)	25 (1)	10 (2.4)
		Smith bulk Si	-102	53	-49
	<110> channel	n-MOSFET	-17 (1.8)	11 (2.4)	-7 (3.9)
		Smith bulk Si	-31	53	-49

Strain Effect on Electron Mobility

Significant in Single Event Transient!!

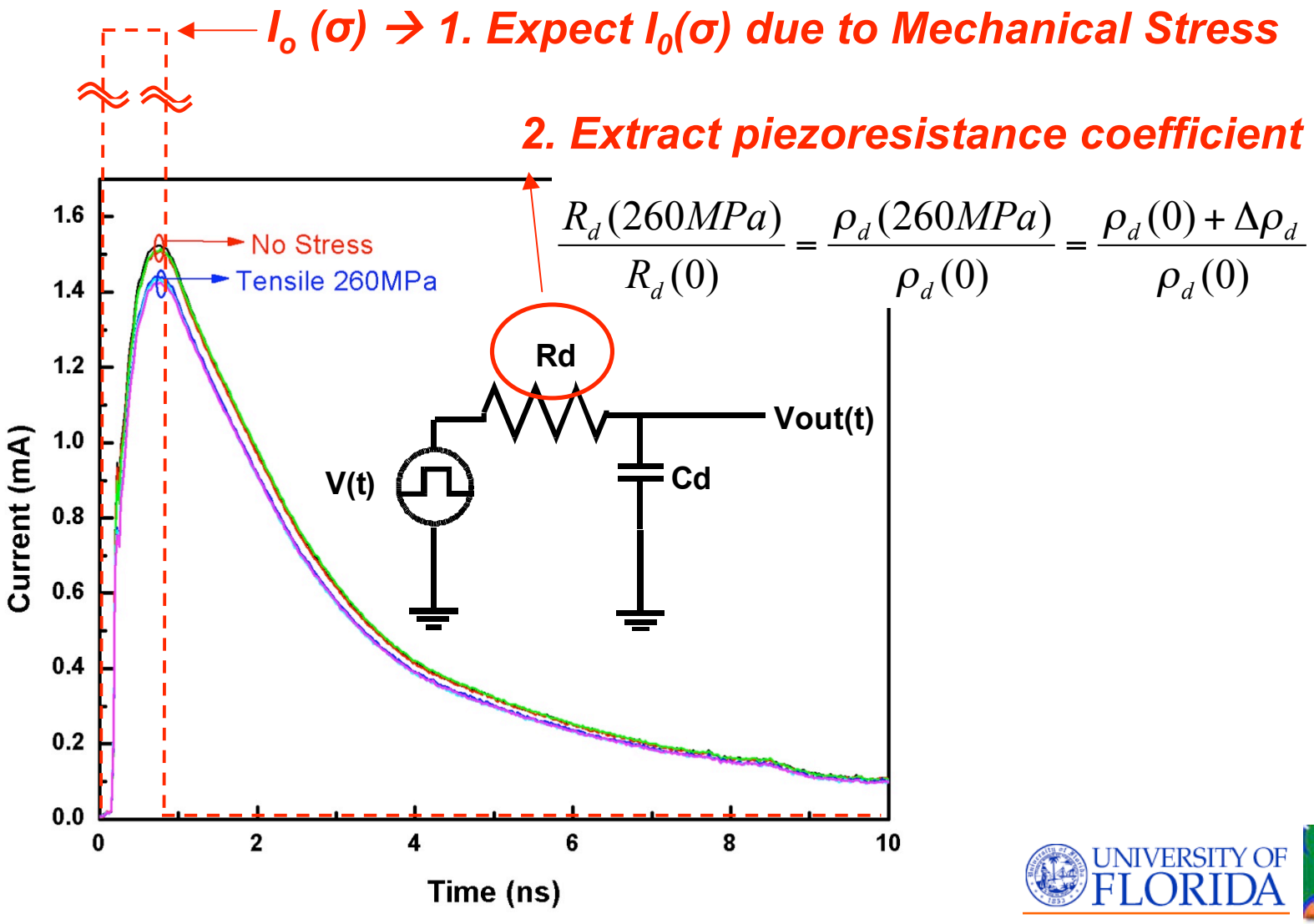




$$\mu \prec \frac{1}{m}$$

<Tensile Stress>

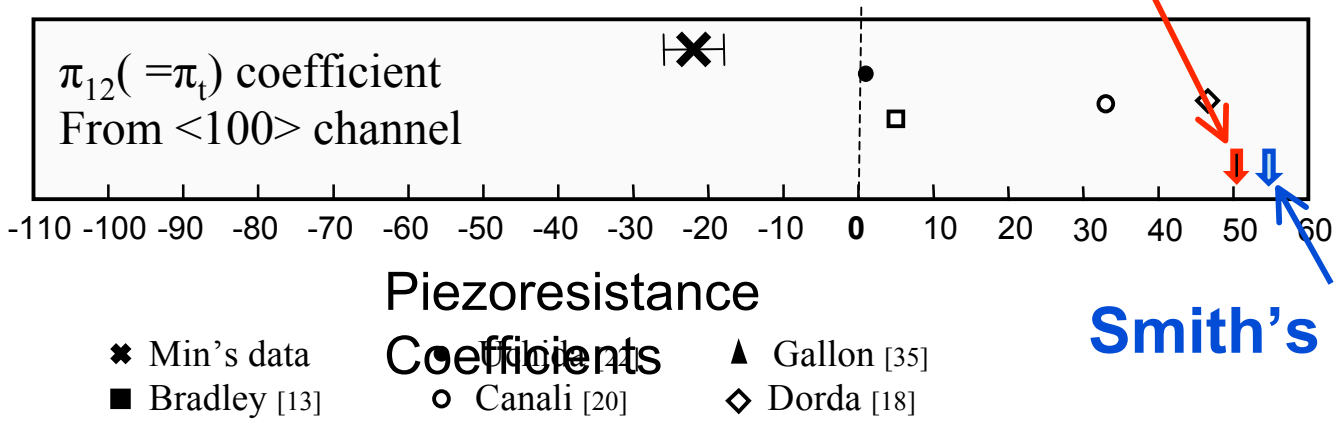
Extract Piezoresistance Coefficient
(Simple RC delay Circuit Model)



Compare with other Piezoresistance Coefficients

Extracted piezoresistance coefficient (bulk)

$$\frac{\Delta\rho_d}{\rho_d} = \pi_d \sigma = 0.13 \longrightarrow \pi_d = 50\times10^{-5}\ /\ MPa$$



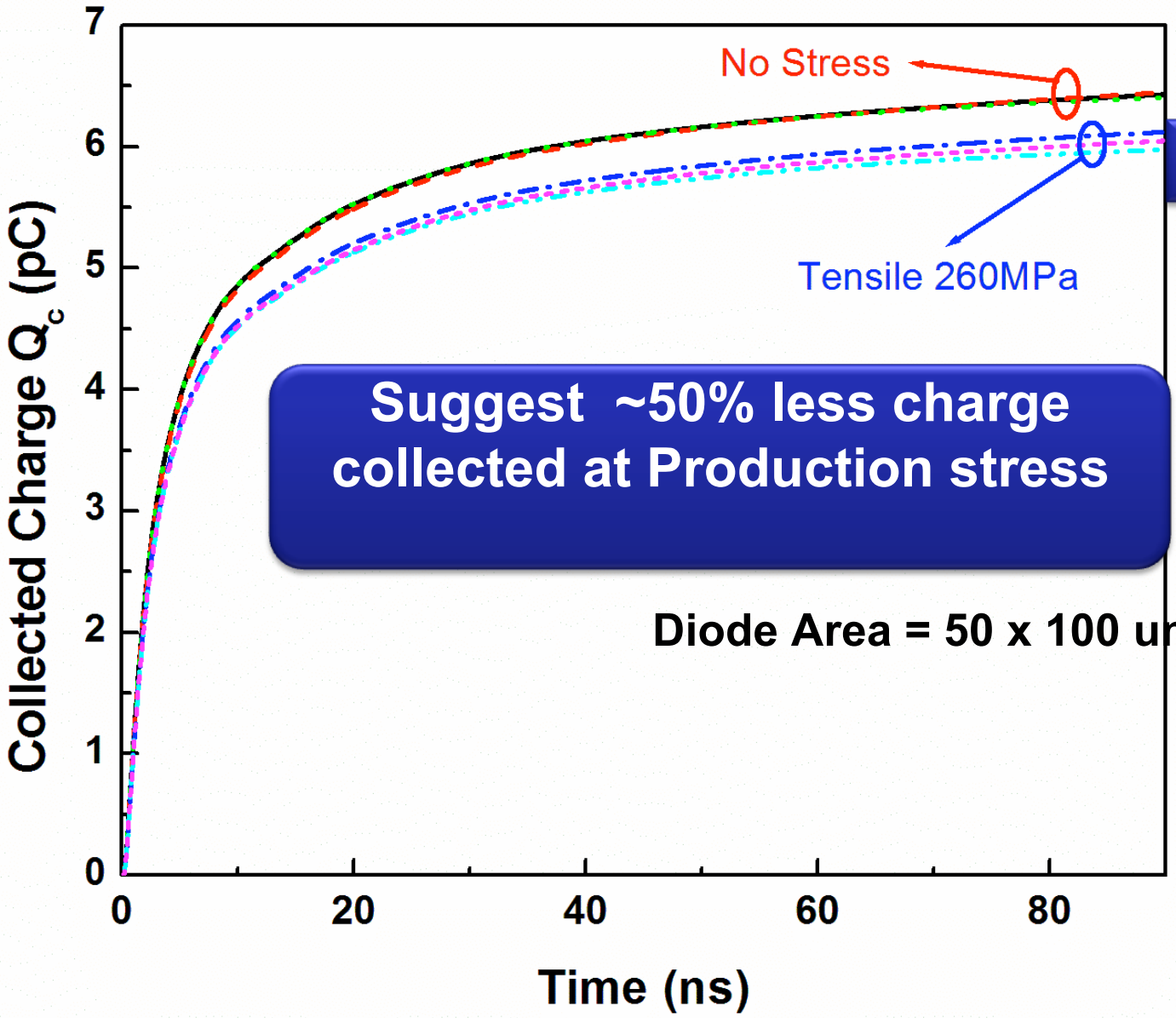
Smith's bulk value

- ✖ Min's data
- ■ Bradley [13]
- □ Hiroake [16]
- ● Fischetti [17]
- ○ Canali [20]
- △ Smith [12]
- ▲ Gallon [35]
- ◇ Dorda [18]
- ⇩ Extracted Value from SET pulse (bulk value)

Note: Tensile stress is taken to be positive stress and compression stress is taken to be negative stress. This vaule is compared with nMOSFET's transverse π_t (=π_{12}) coefficient and Smith's bulk π_{12} coefficient.

UF Group, JAP, in press June 2008

Total Charge Collection in Diode



6. 3 % decreas

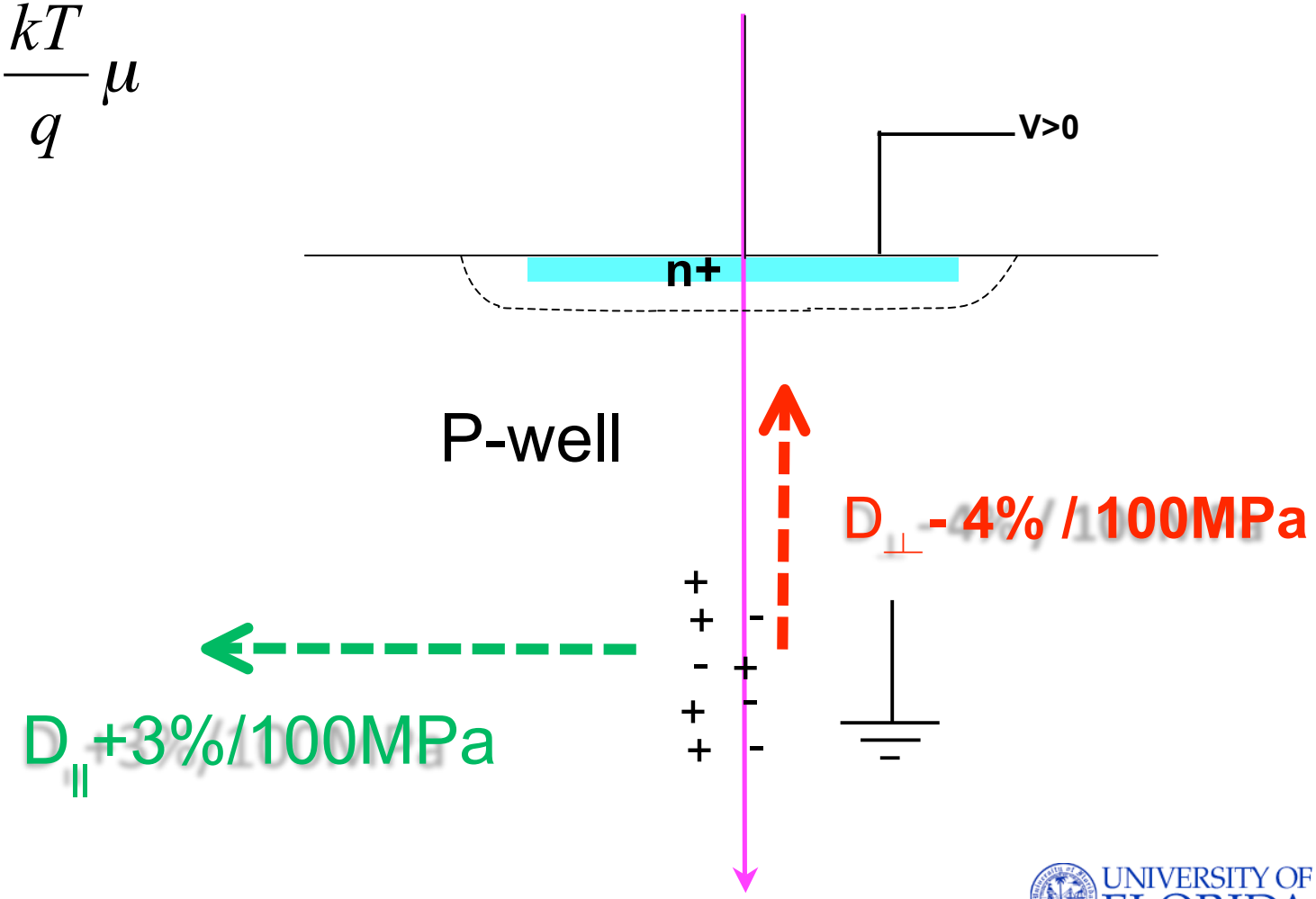
Suggest ~50% less charge collected at Production stress

Diode Area = 50 x 100 um^2

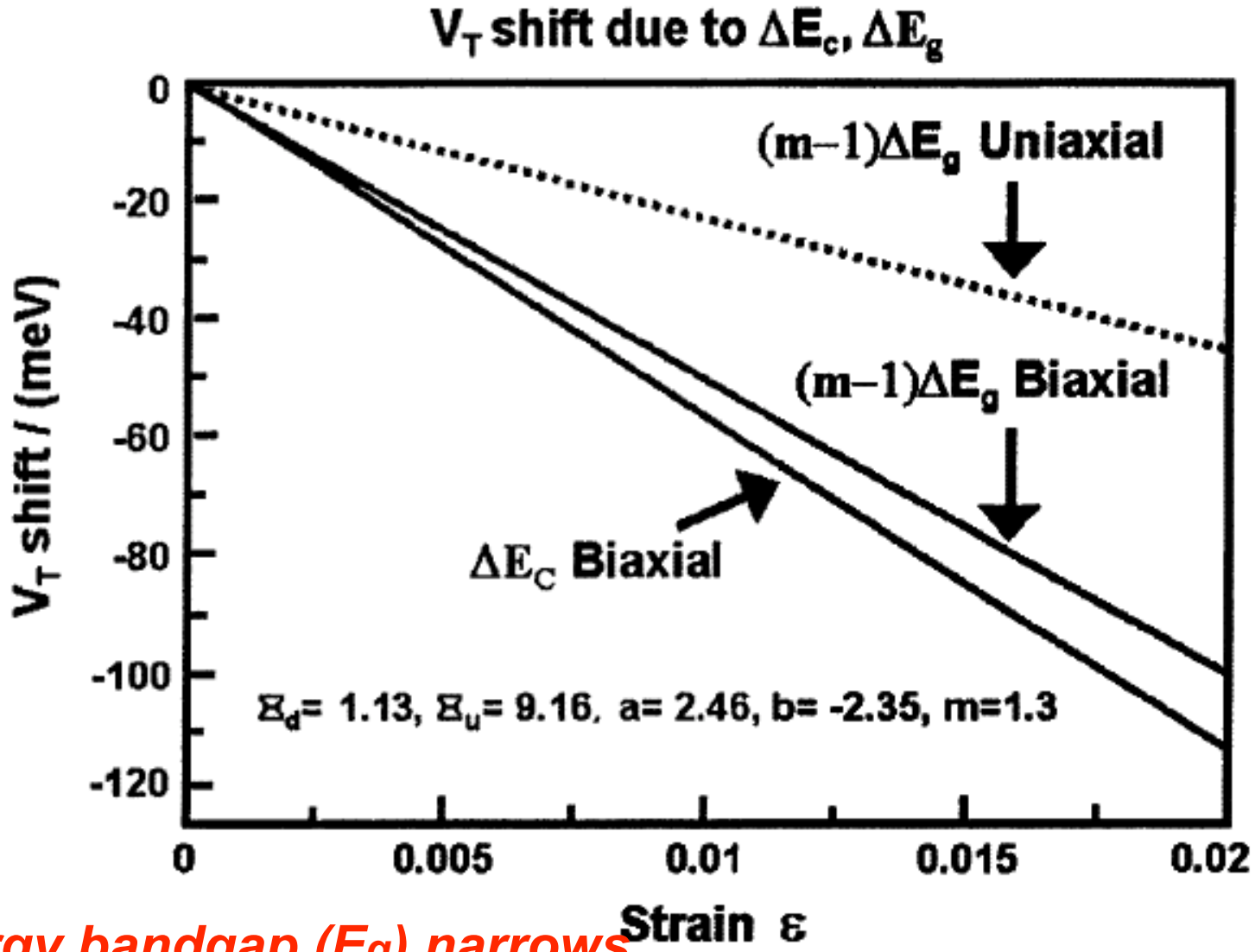
Qualitative Model: Less Charge Collection

Uniaxial Tensile Stressed Silicon

$$D = \frac{kT}{q}\mu$$



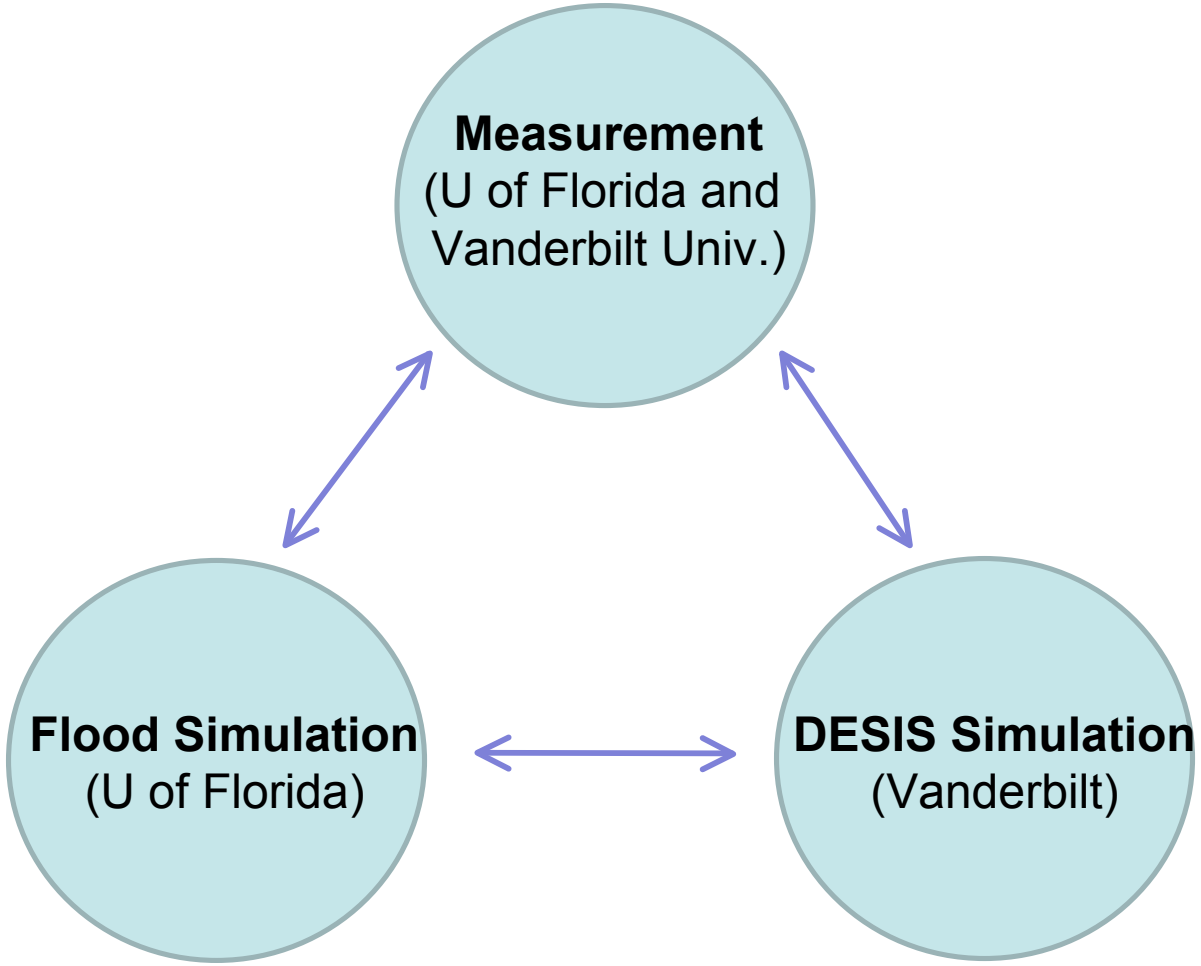
Strain Alters Bandgap: e, h Generation



Energy bandgap (E_G) narrows

UF Group , EDL, 2004

Simulation of SET on Si Diode in Floods/DESIS



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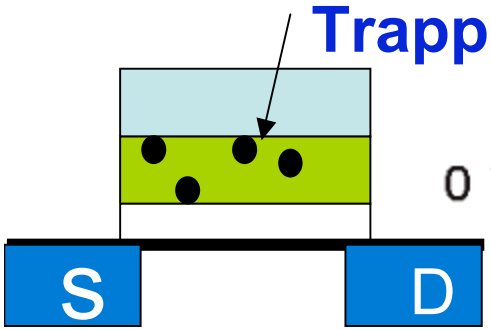
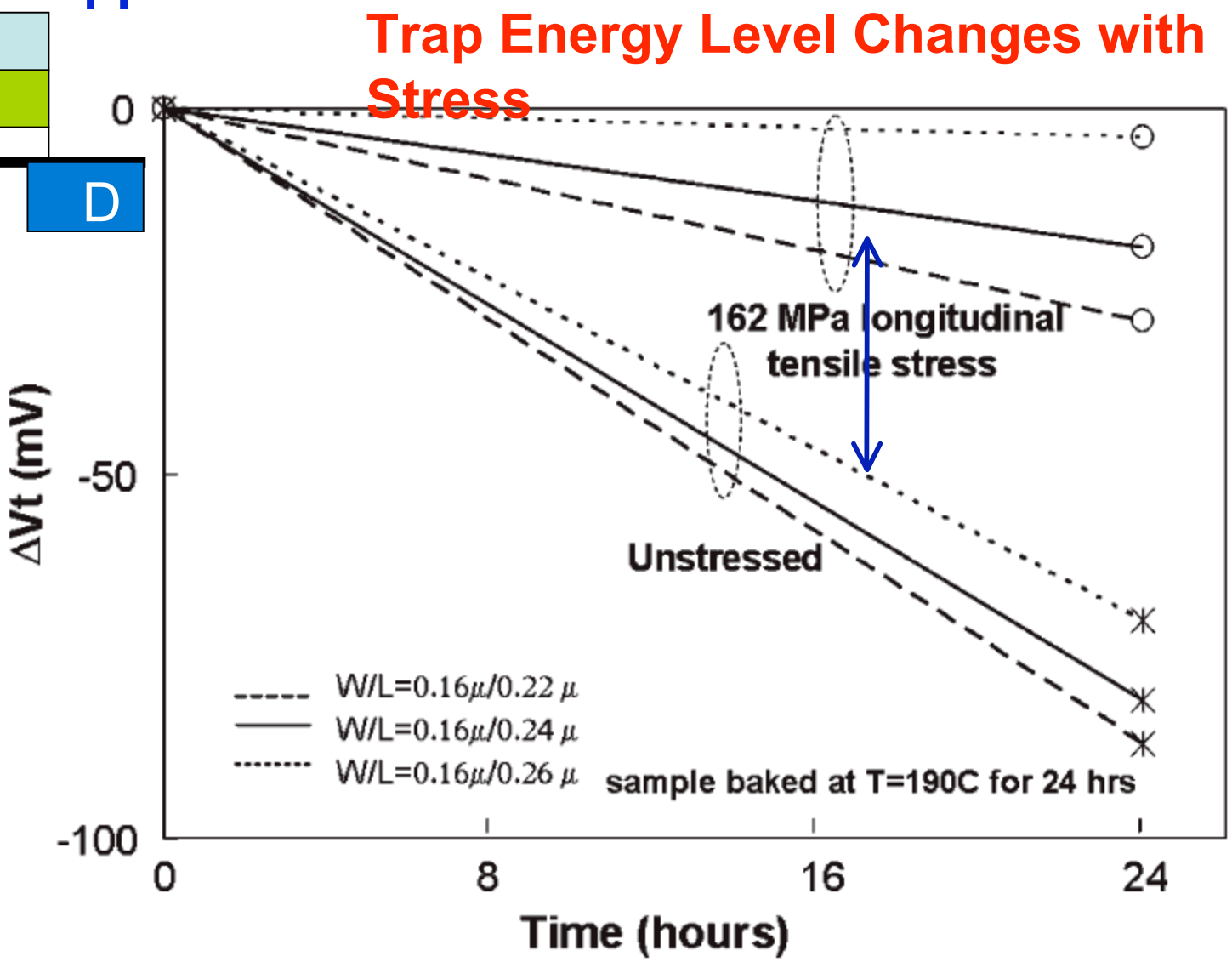
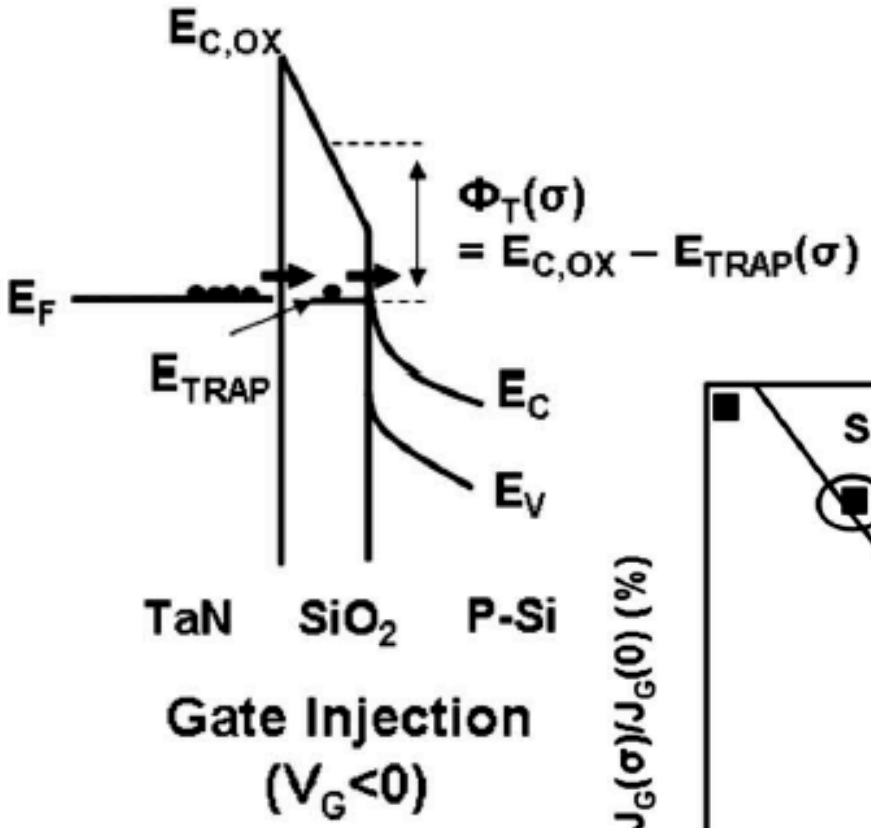
Stress Alters Trap Energy Level



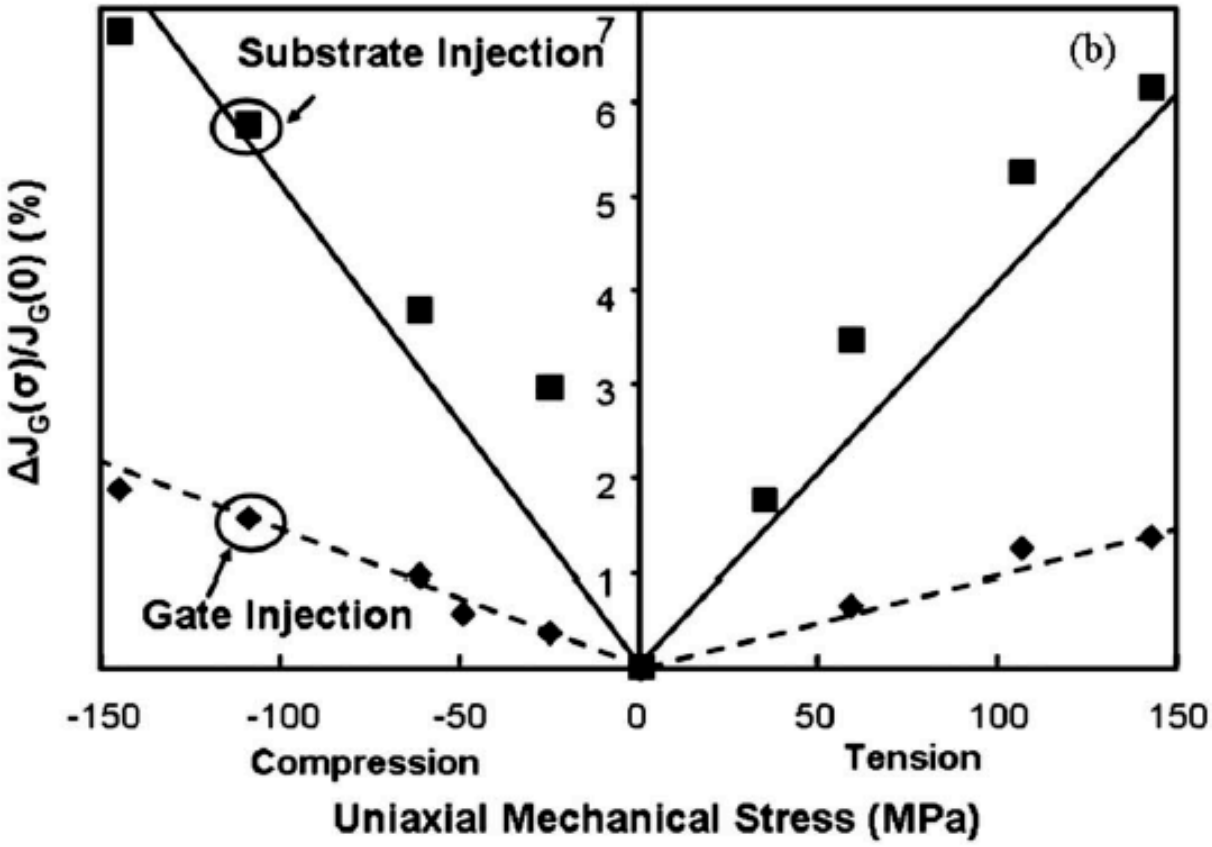


UF Group, TED, 2007

Stress Alters Trap Energy Level

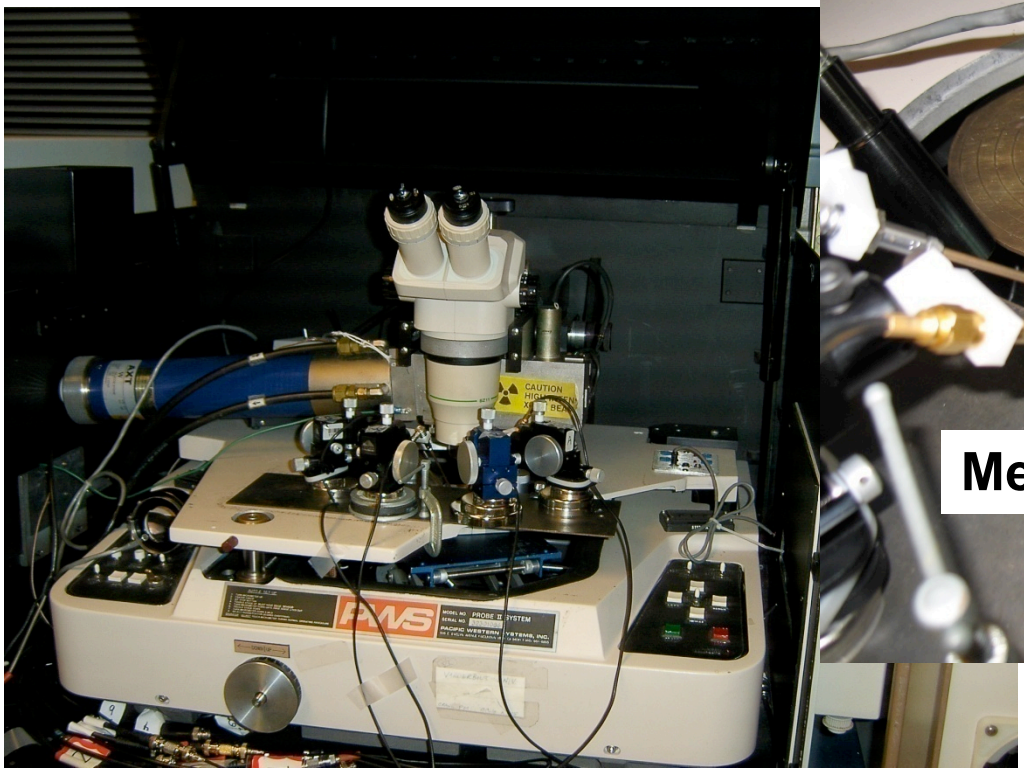


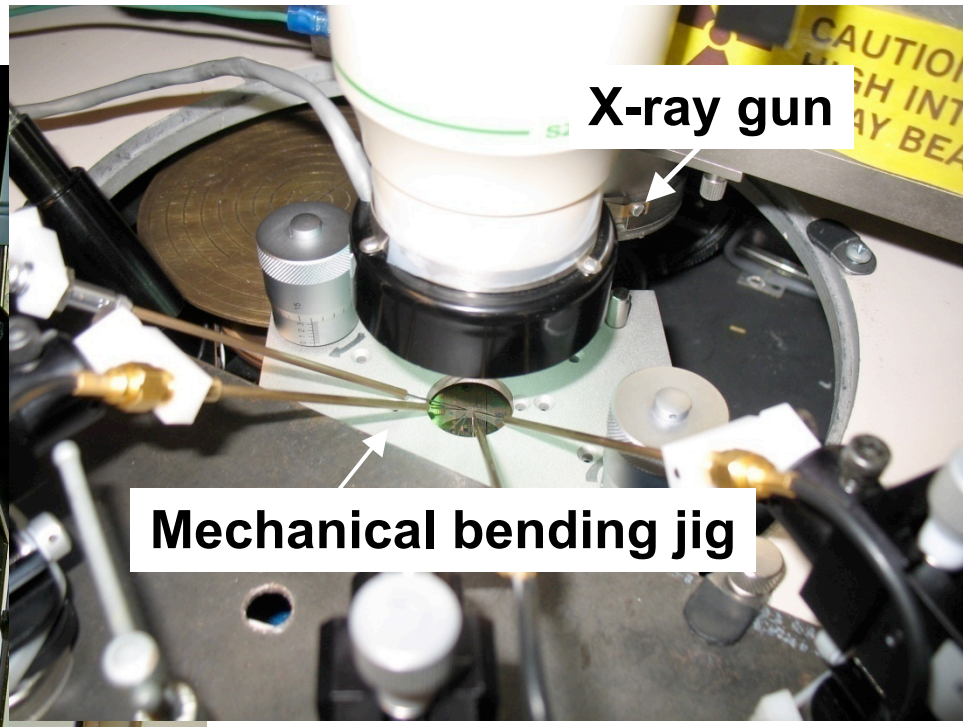
Trap Energy Level Changes with Stress



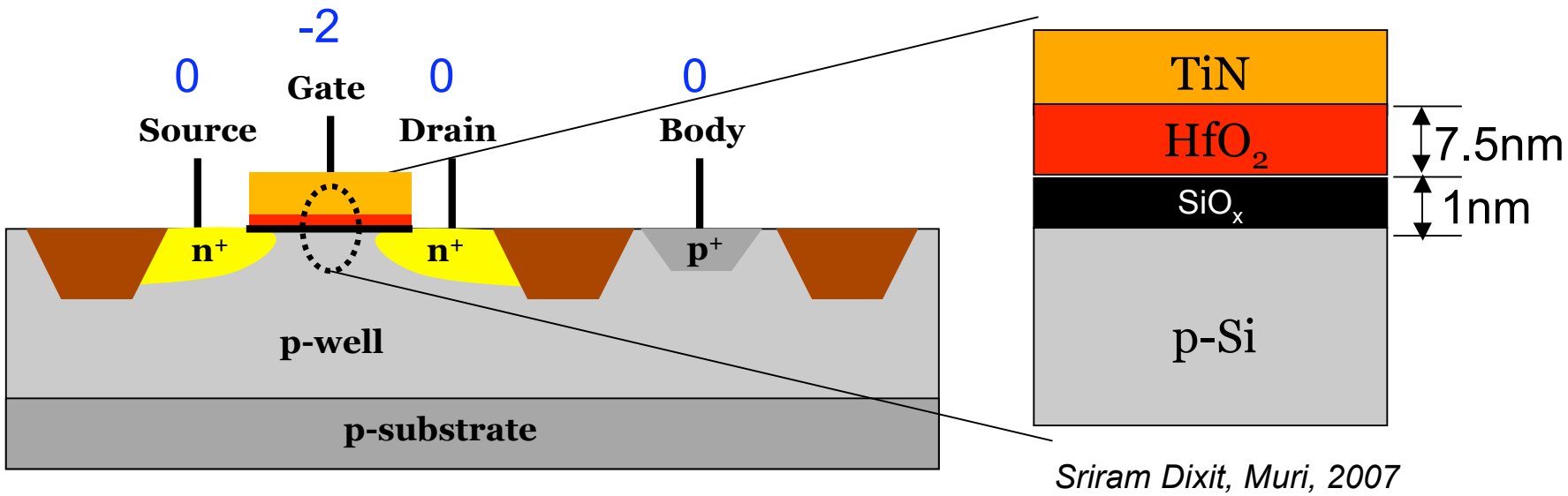
UF Group, APL 2008

Set up in Aracor Machine





Sample

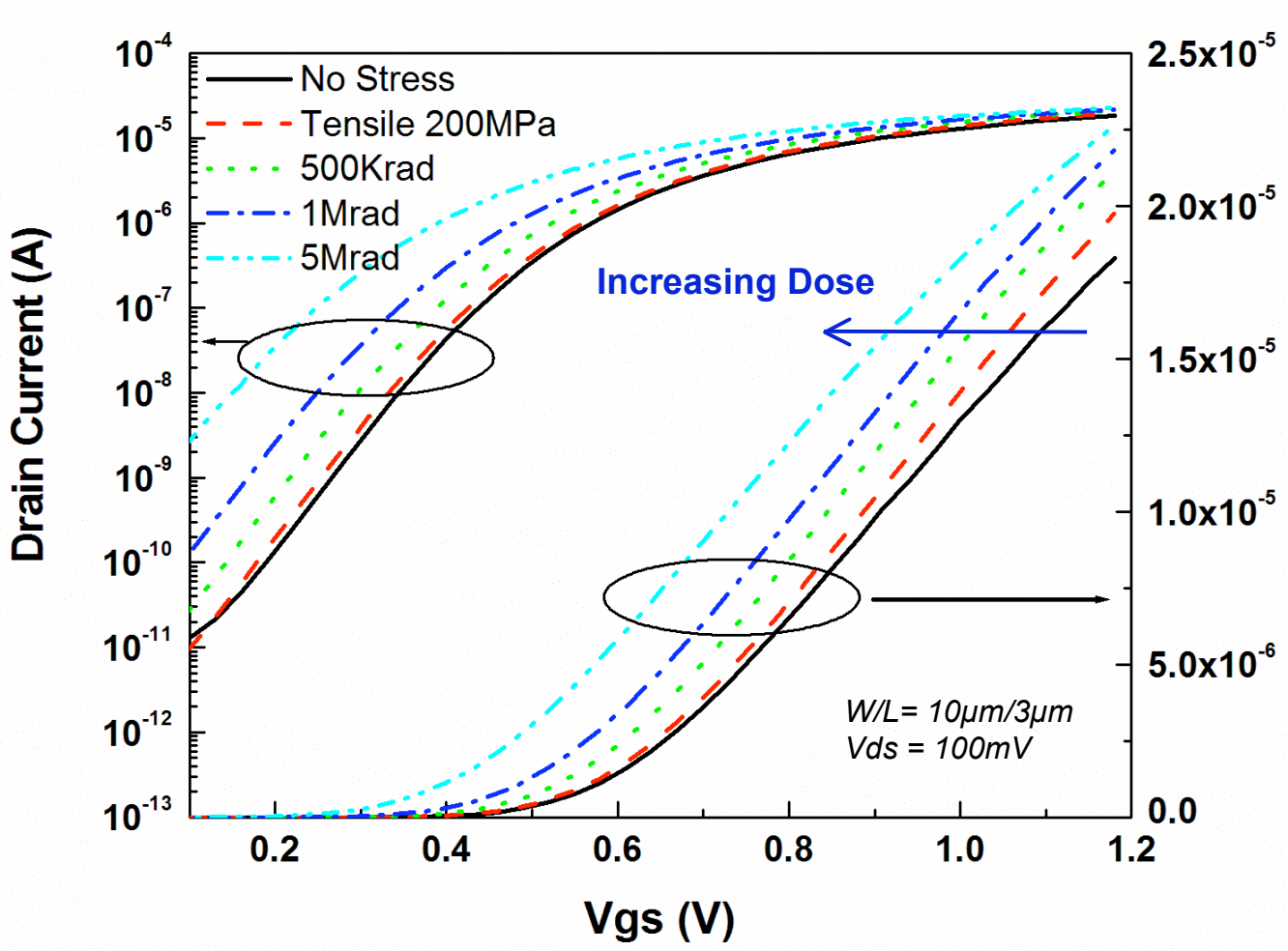


Sriram Dixit, Muri, 2007

HfO_2 based nMOSFET

Note: 65nm technology in Sematech

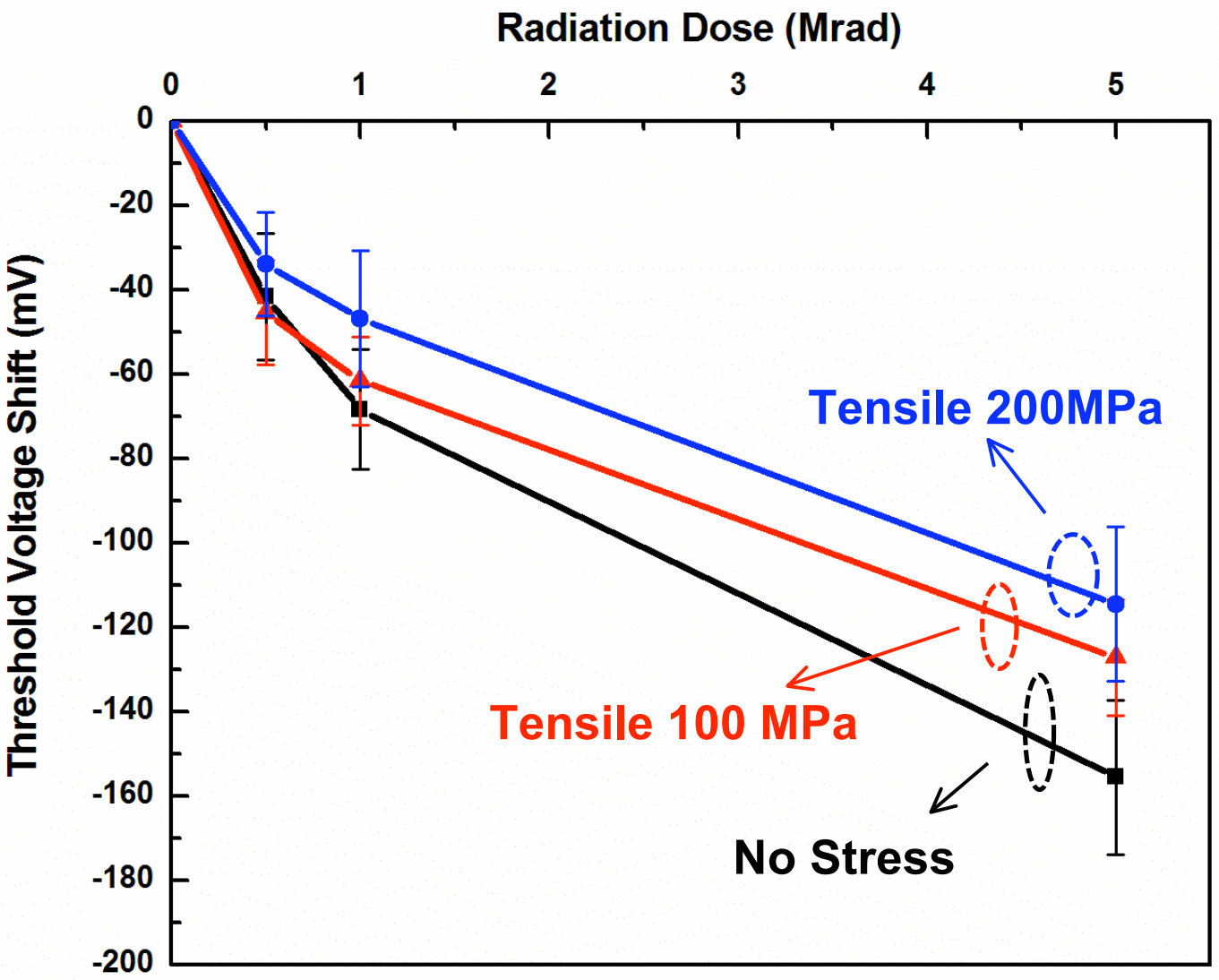
Id_Vgs (Tensile 200MPa)



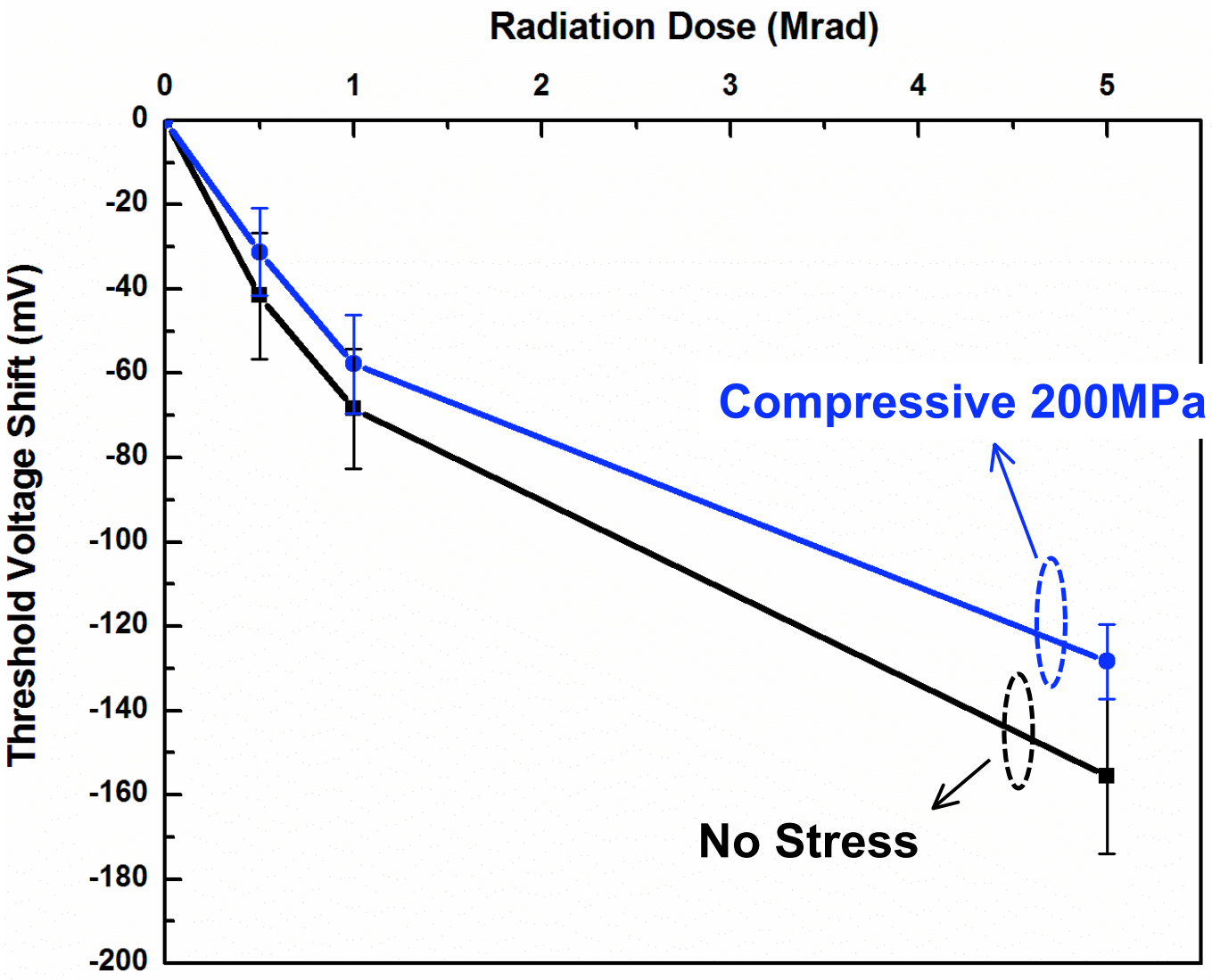
Threshold voltage is decreased by increasing radiation dose.

This trend is seen in other stress cases such as compressive -, No-, and Tensile-St

Threshold Voltage: Tensile Stress



Threshold Shift: Compressive Stress



Conclusions / 2008 Plans

- Significantly less electron charge collection in tensile strained (~50% less charge collected at ~1GPa stress)
- Strain also alters trap energy level in gate insulator
- Future work
  - NRL June, 2008 trip planned
  - Higher stress range
  - Hole P+ / n-well collections
  - Close SET modeling / experimental data gap
  - Develop model for trap energy change with strain