

## Improving the ability of bulk built-in current sensors to detect Single Event Effects by using triple-well CMOS

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## I. Introduction

SET mechanism, BBICS principle

## II. Zhang et al. BBICS architecture

Experimental results & unexpected weakness

## III. Analysis

Experimental measurements

Improving BBICS efficiency: use of triple-well CMOS

## IV. Validation

A new BBICS design

Simulation results

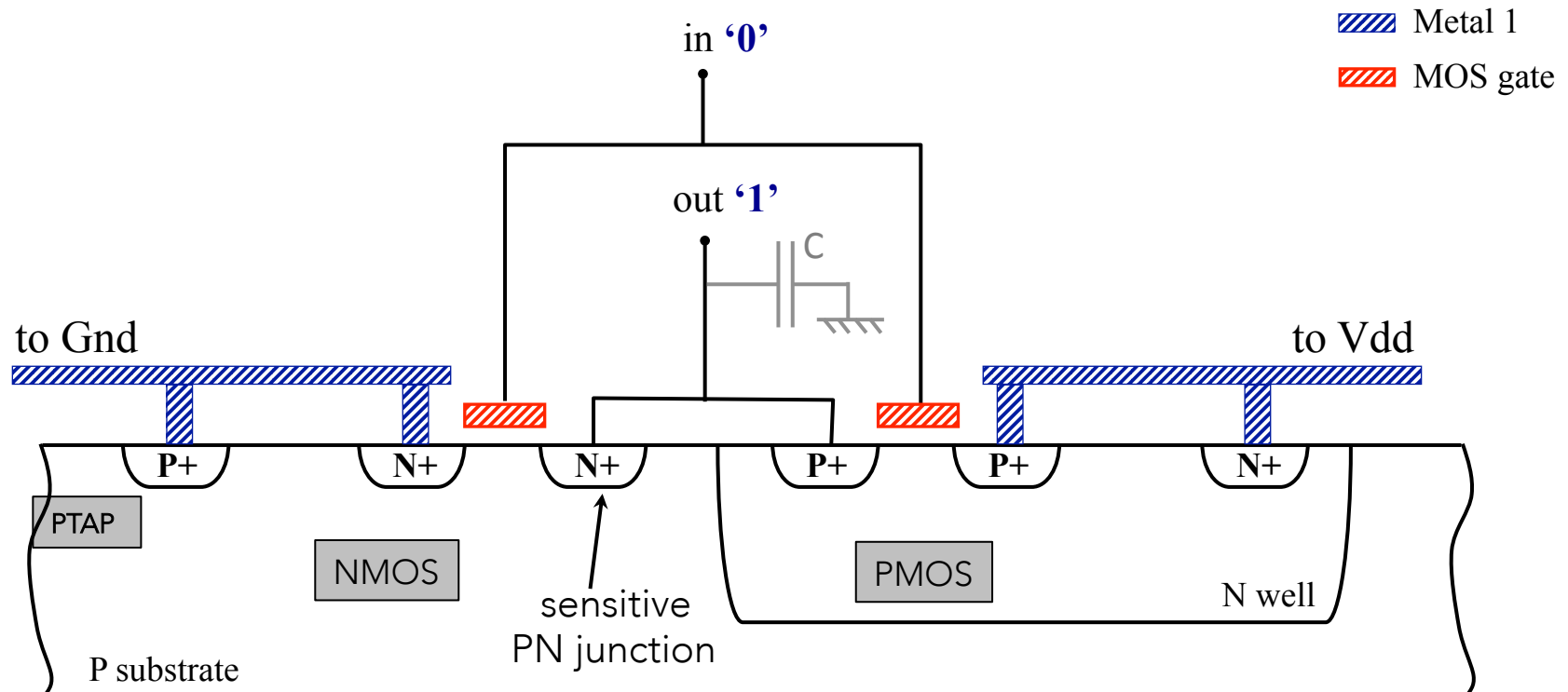
### ❑ Integrated circuits in radioactive environment

- Suffer from various types of Single Event Effects (SEE)
  - Single Event Transient (SET),
  - Single Event Upset (SEU),
  - Single Event Latchup (destructive)
  - Single Event Gate Rupture, etc.

### ❑ Bulk Built-In Current Sensor (BBICS)

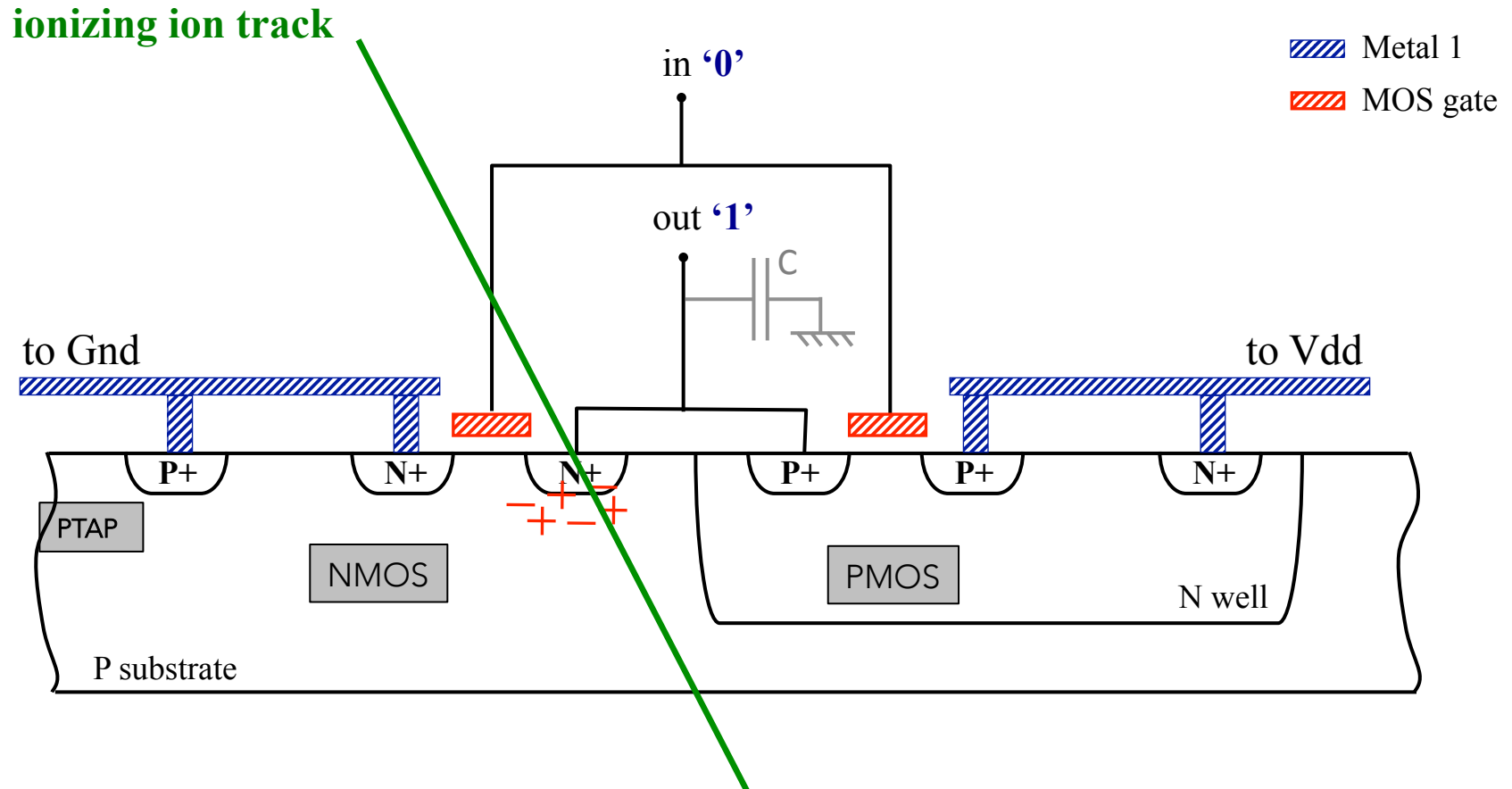
- Design to monitor the advent of SETs and SEUs
- Not to prevent their effects

## □ SET mechanism – The inverter case



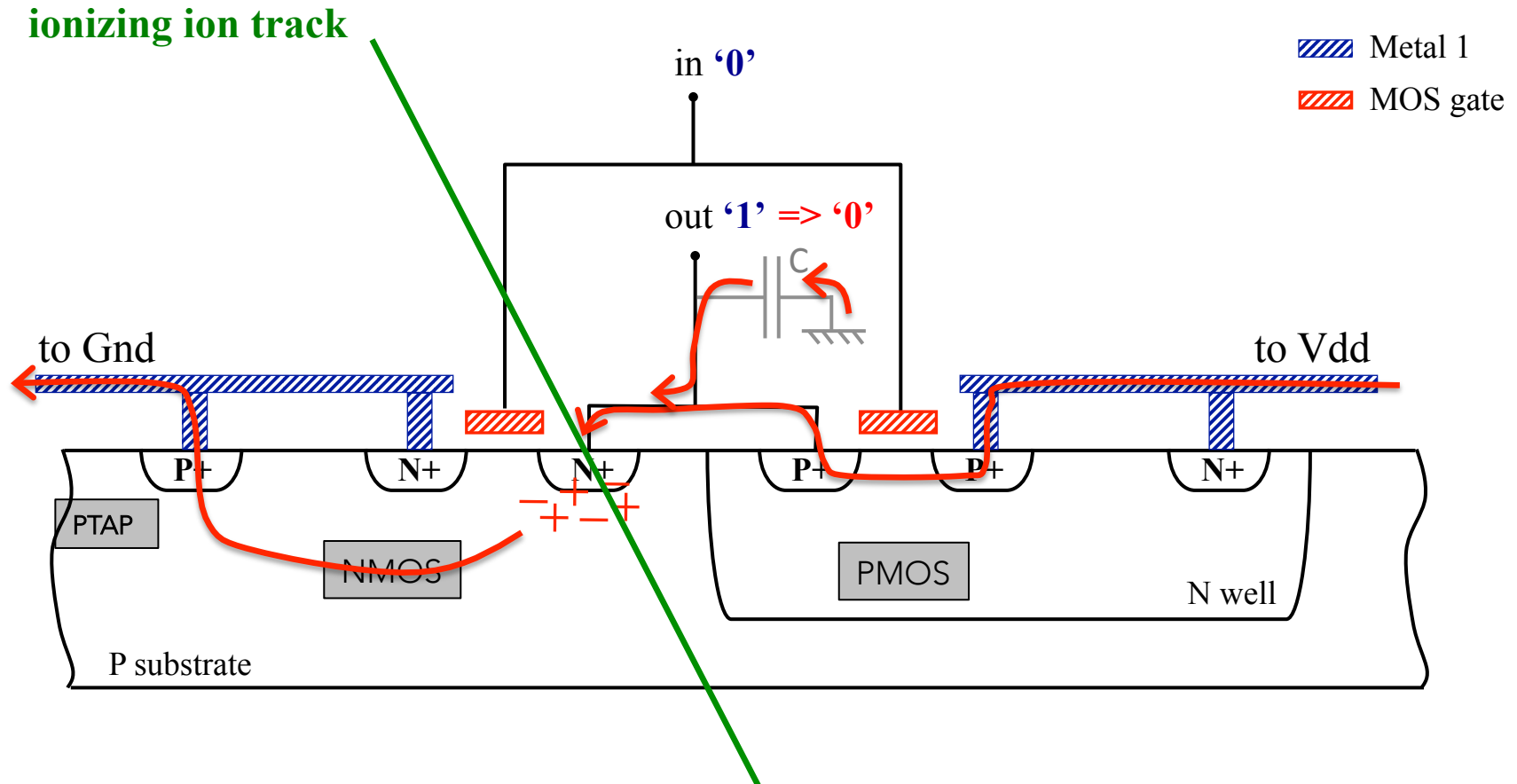
Sensitive area: reverse biased PN junction (drain of the off transistor)

## □ SET mechanism – The inverter case



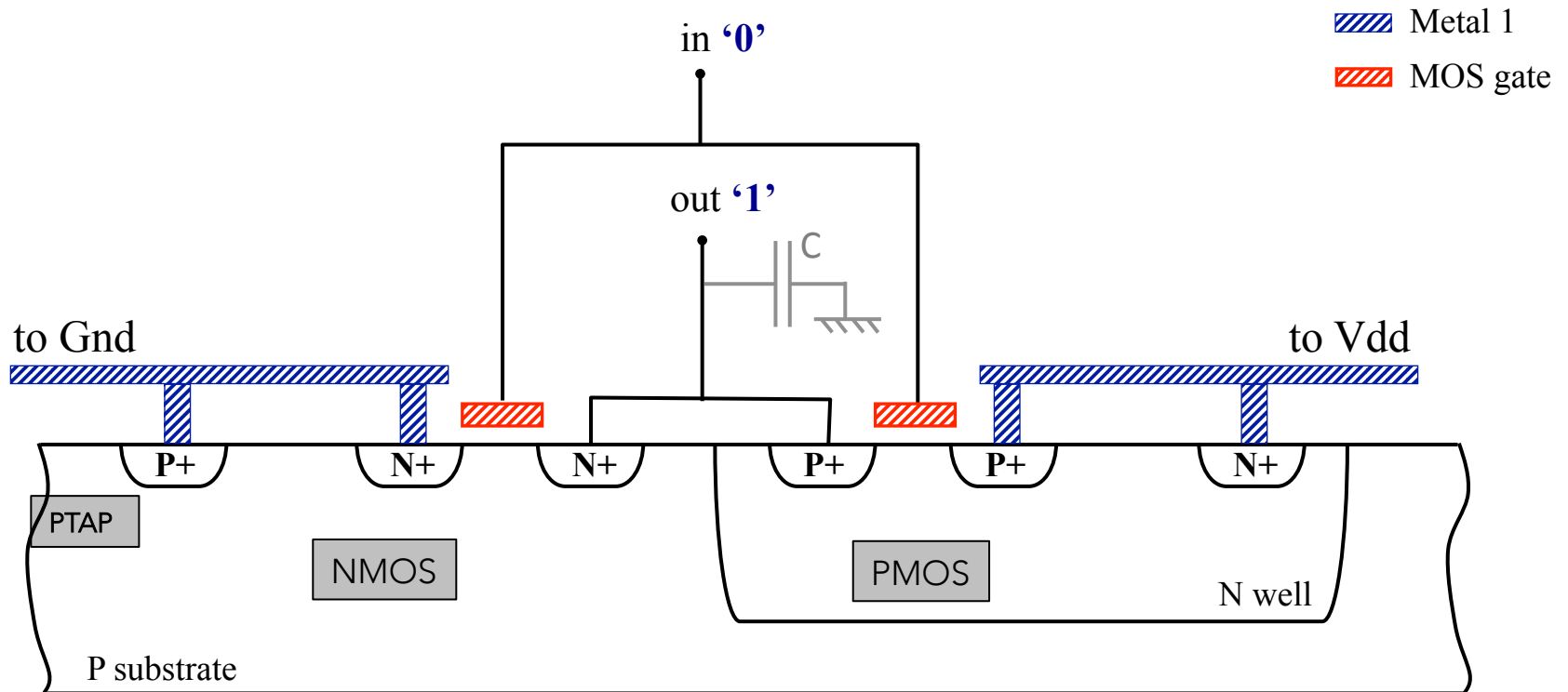
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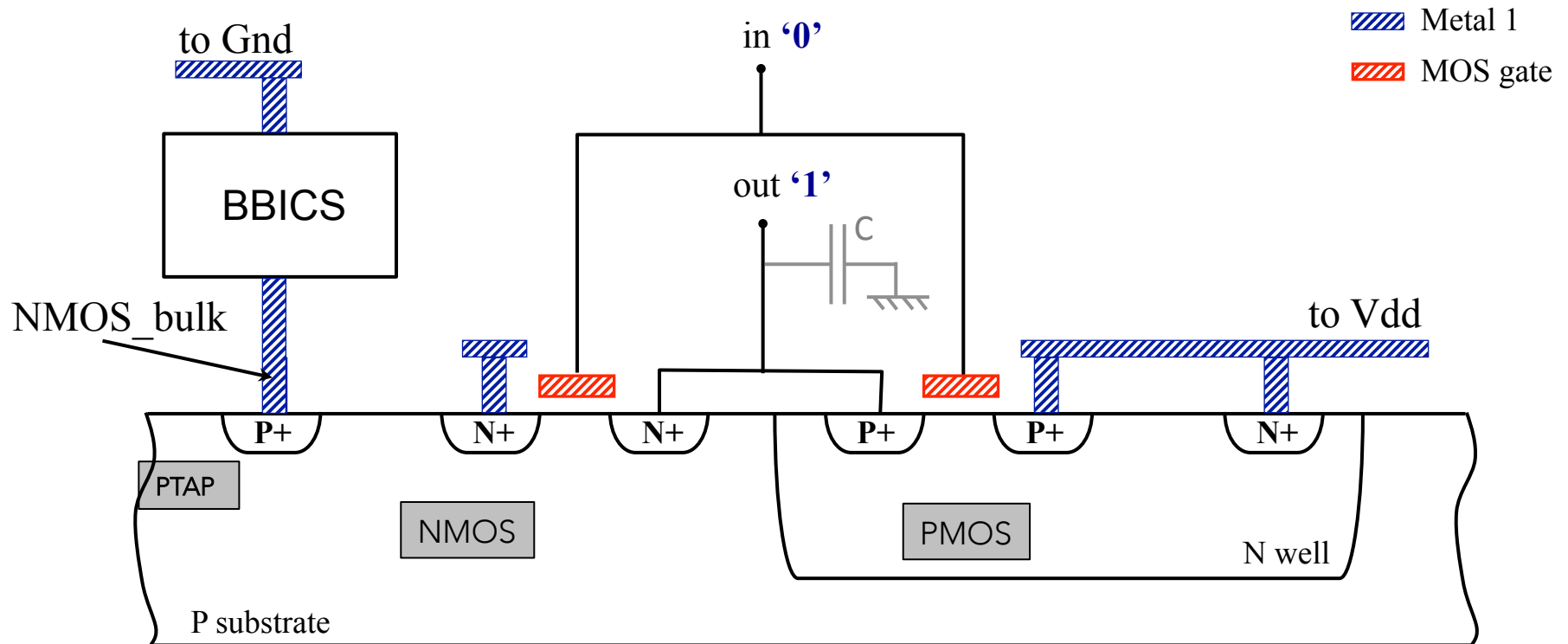
SEE current flows through substrate and its biasing TAPs

□ BBICS principle: monitoring bulk currents



SEE current flows through substrate and its biasing TAPs

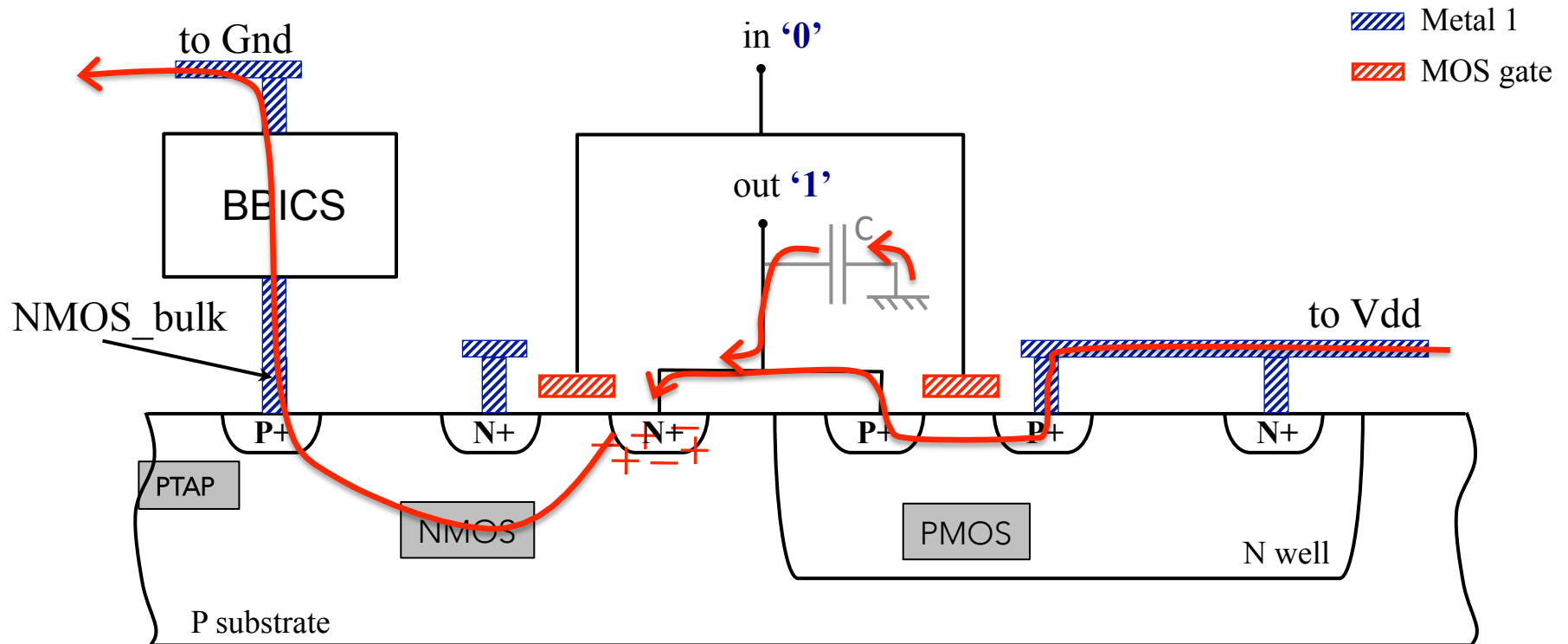
□ BBICS principle: monitoring bulk currents



BBICS: monitor SEE current through node NMOS\_bulk

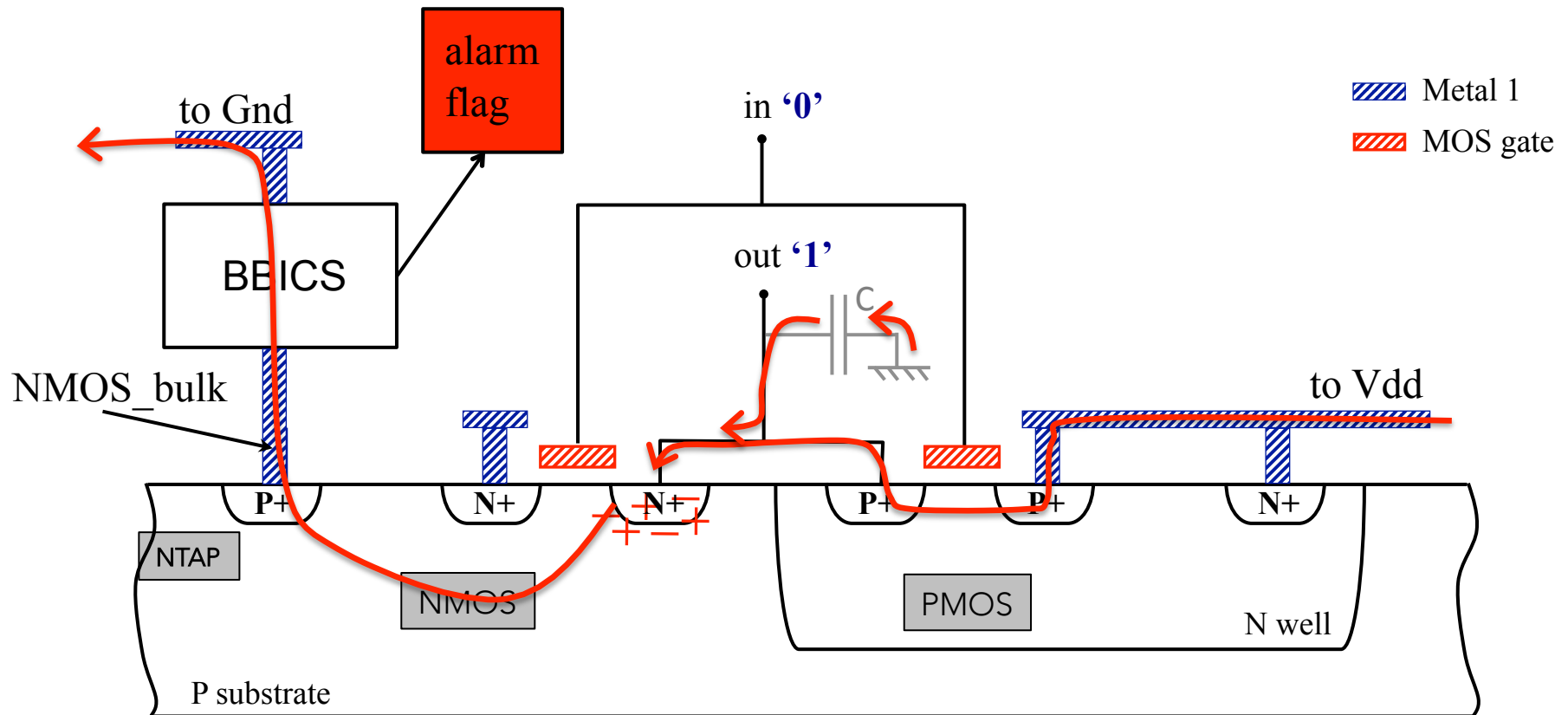


□ BBICS principle: monitoring bulk currents



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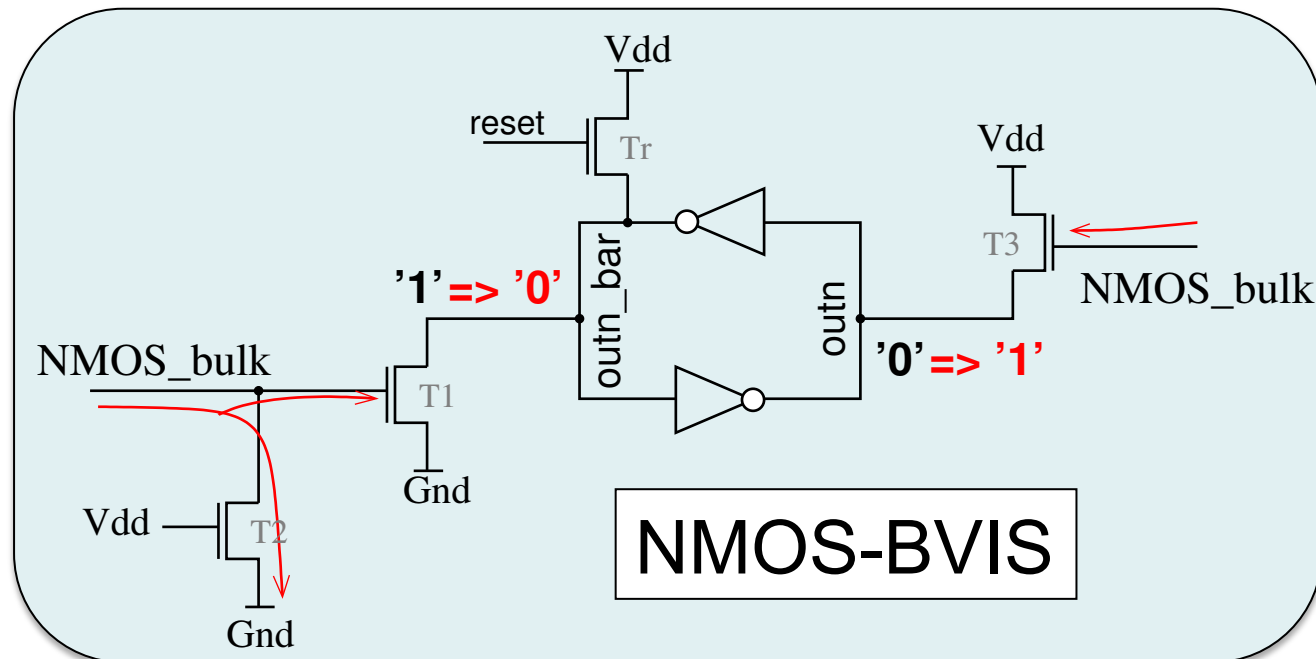
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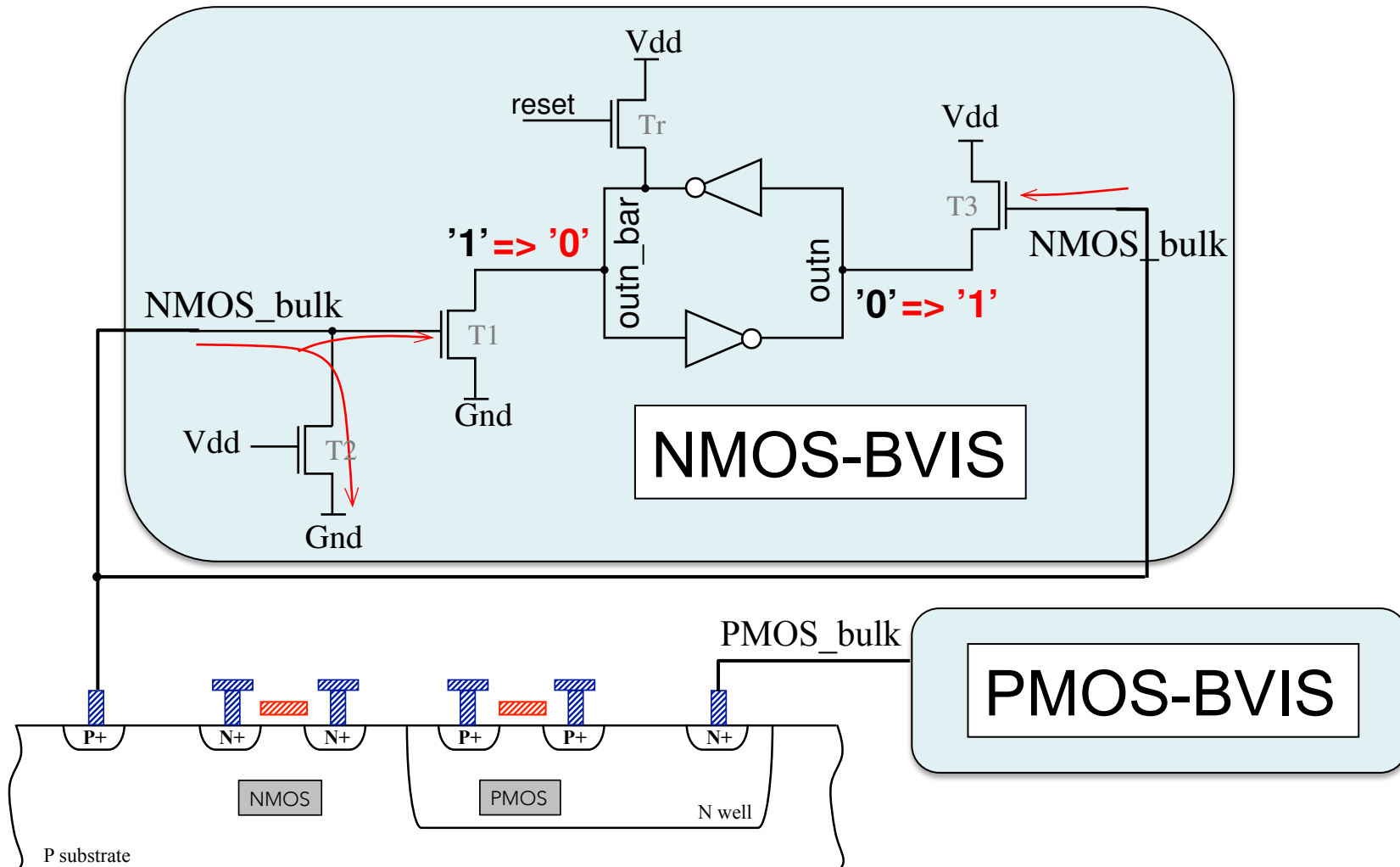
### □ Zhang et al. BBICS architecture [zhang2010]

- Published in 2010, experimental validation reported in 2013  
⇒ NMOS monitoring less effective than expected?!



## II. Zhang et al. BBICS architecture

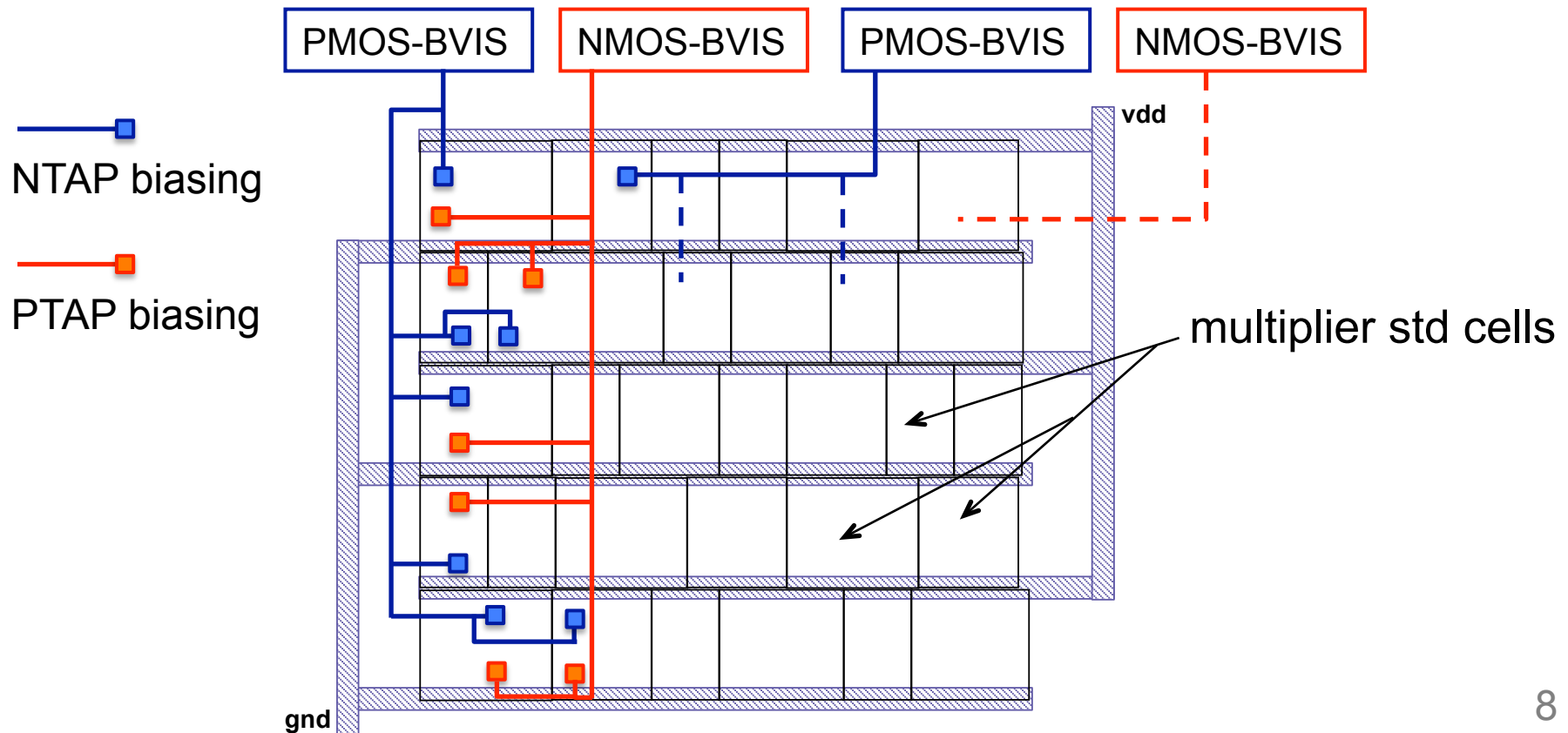
- NMOS-BVIS : NMOS monitoring / PMOS-BVIS : PMOS monitoring



- Experimental testing of NMOS-/PMOS-BVIS [zhang2013]

Test chip CMOS bulk 90 nm:

- many instances of NMOS-/PMOS-BVIS,
- multiplier as a test element.



- Experimental testing of NMOS-/PMOS-BVIS [zhang2013]

Ionizing particle effect emulation with a laser source:

-  $\lambda = 800$  nm, laser spot  $\varnothing = 1.6$   $\mu$ m, pulse duration = 1 ps

# of biasing contact (NTAPs or PTAPs)	10	40	80	160
Multiplier SEE sensitivity threshold	82 pJ	82 pJ	82 pJ	82 pJ
PMOS-BVIS detection threshold	15 pJ	42 pJ	75 pJ	n.d.
NMOS-BVIS detection threshold	110 pJ	149 pJ	n.d.	n.d.

n.d. = not detected

⇒ PMOS monitoring: efficient up to 80 biasing contacts

⇒ NMOS monitoring: **inefficient**  
SEE sensitivity always < BBICS detection threshold

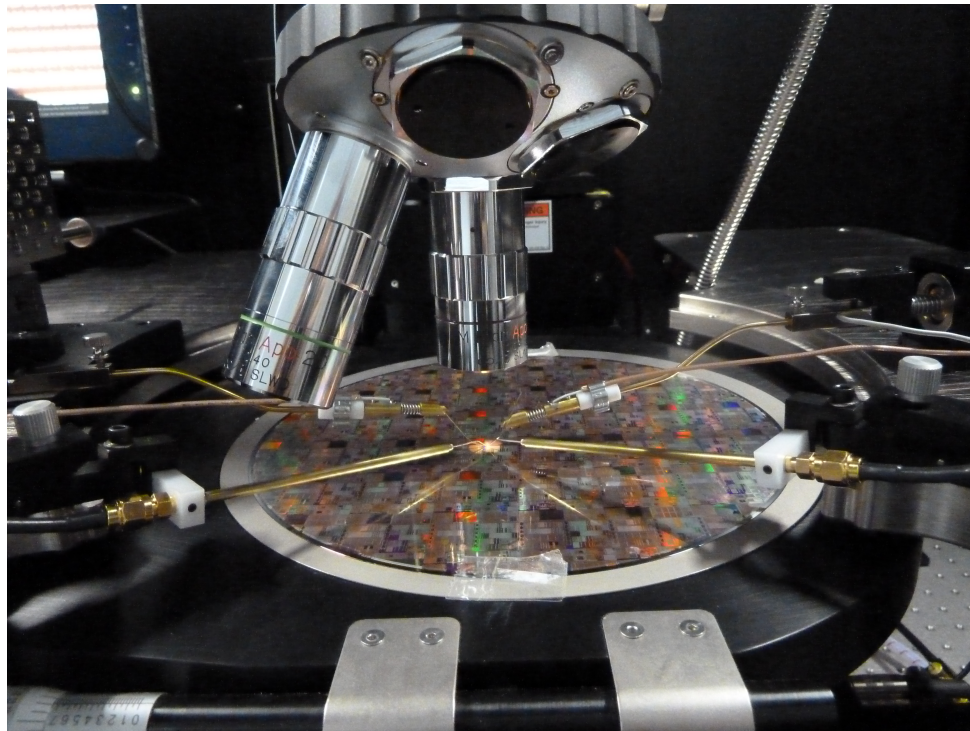
### □ Experimental measurements

- Understanding SEE currents in NMOS/PMOS

Test chip: CMOS 90 nm, bulk and triple-well, single NMOS and PMOS

Experiment settings: measure of laser-induced currents

at  $\lambda = 1064$  nm, laser spot  $\varnothing = 5$   $\mu\text{m}$ , pulse duration = 20  $\mu\text{s}$ , 1.25 W  
(settings outside ionizing particle emulation)



EMSE  
laser facility

## □ Experimental measurements

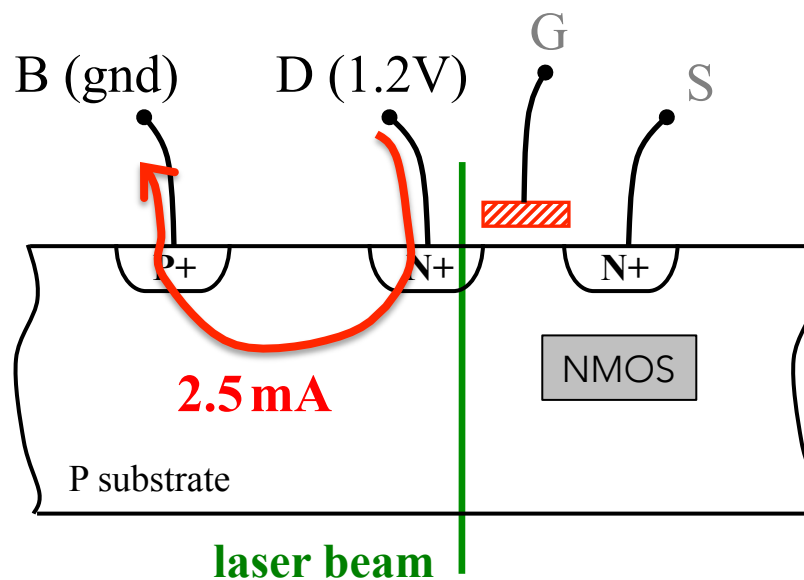
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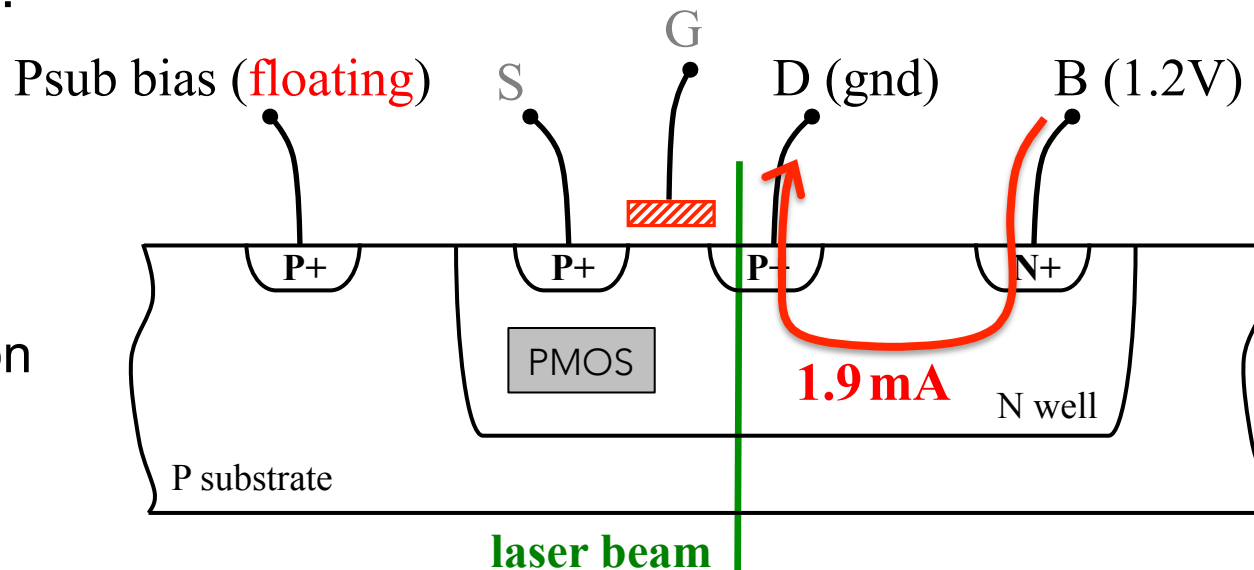
NMOS current:



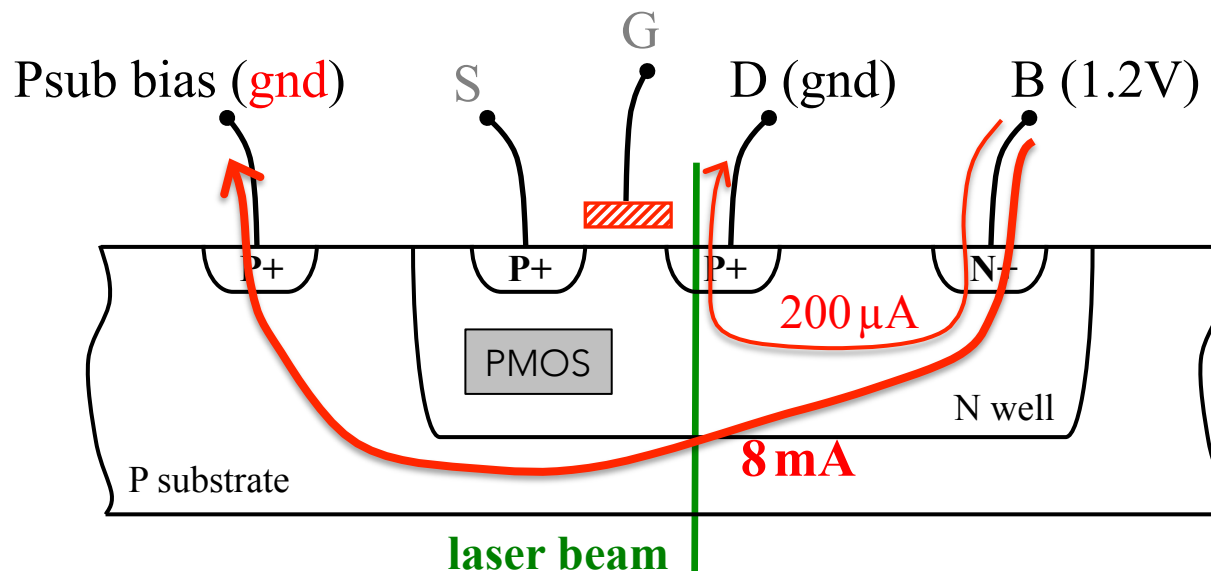


## PMOS current:

Psub-Nwell junction unbiased



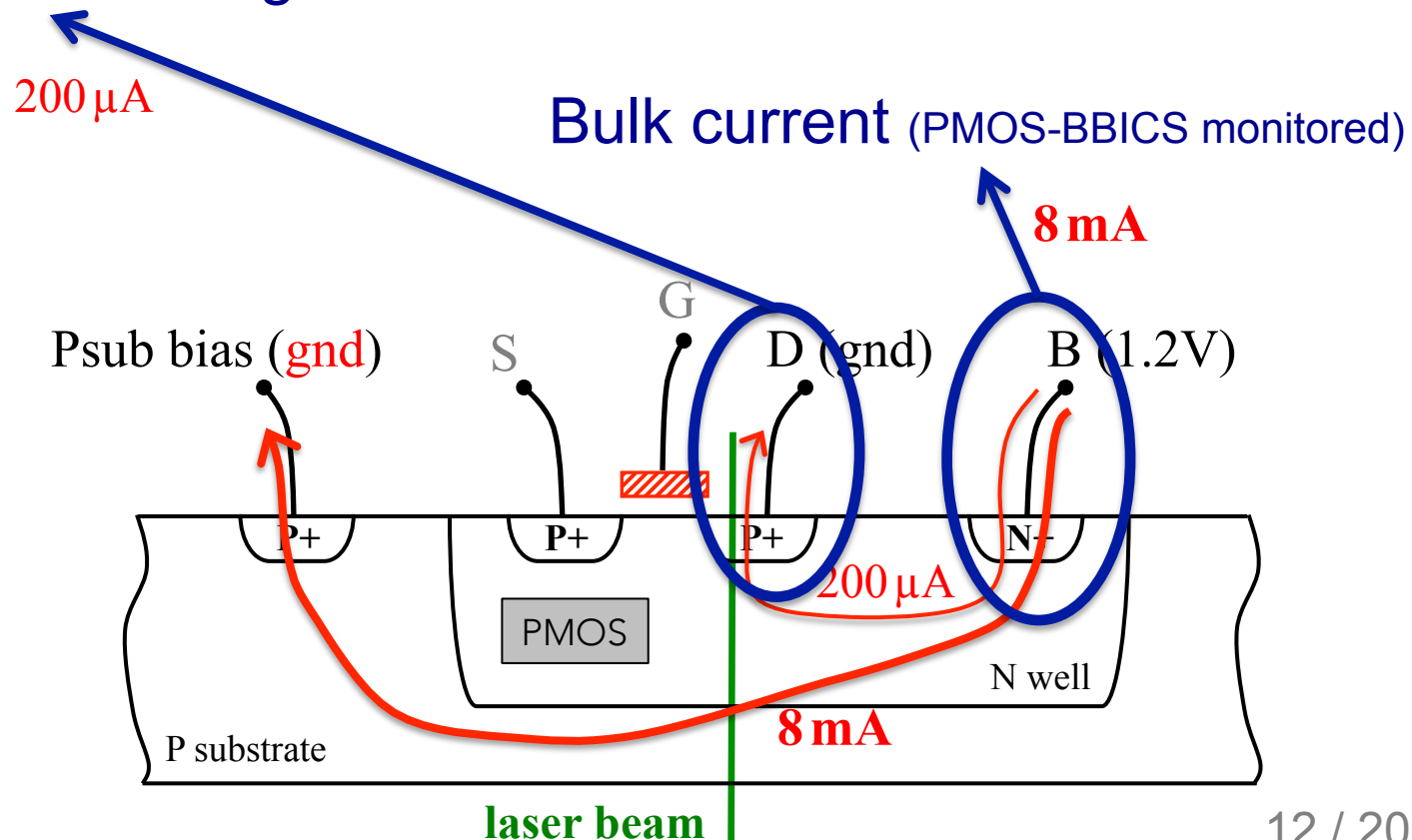
Psub-Nwell junction reverse biased



## Analysis:

- ⇒ Bulk current an order of magnitude above drain current
- ⇒ Promote detection over SEE generation

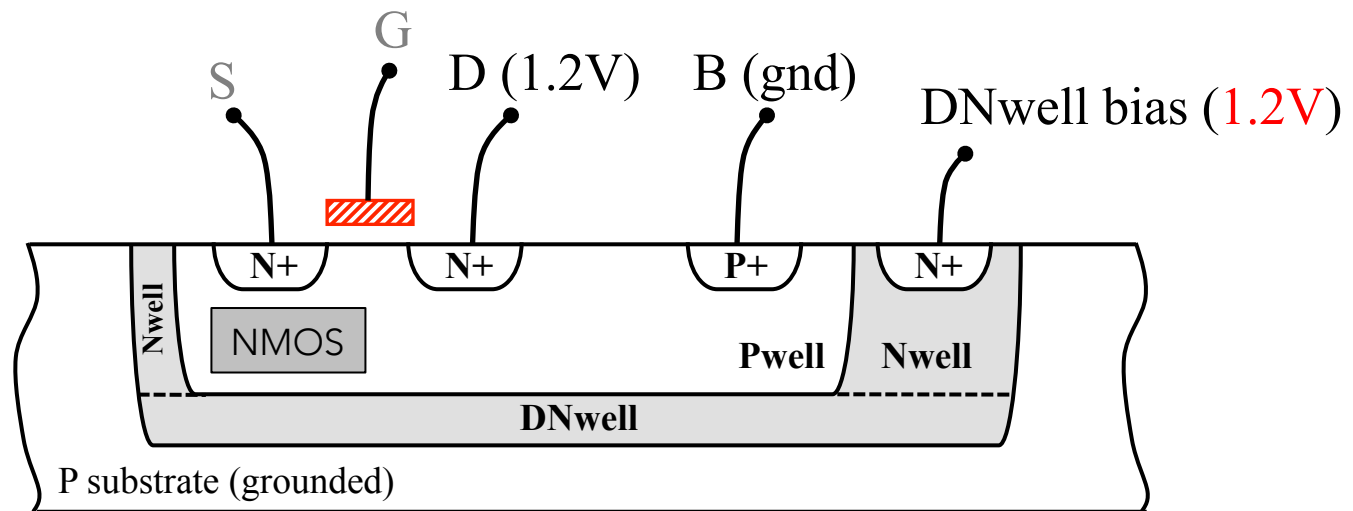
## Drain current contributing to SEE



## □ Improving BBICS efficiency

- Use of triple-well CMOS

⇒ NMOS in Pwell to mimic PMOS properties

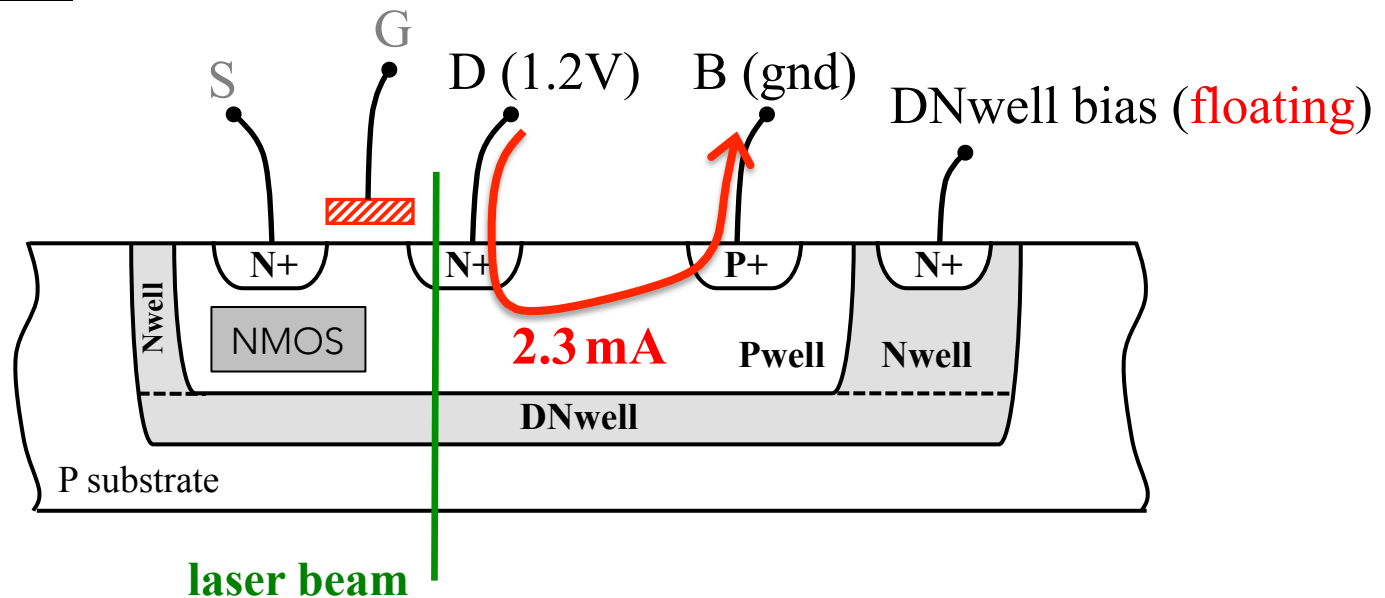


## □ Improving BBICS efficiency

- Use of triple-well CMOS

⇒ NMOS in Pwell to mimic PMOS properties

NMOS current:



Pwell-DNwell junction  
unbiased

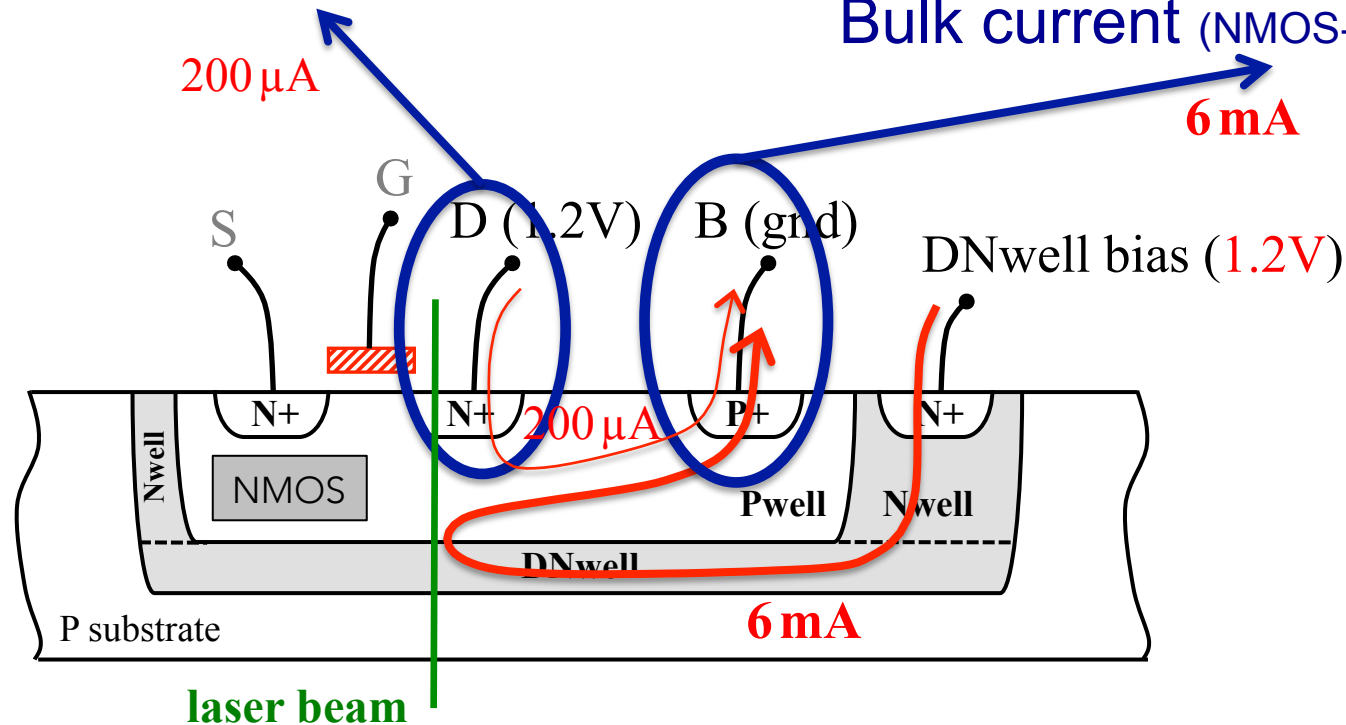
- Use of triple-well CMOS

NMOS current:

Pwell-DNwell junction  
reverse biased

Drain current contributing to SEE

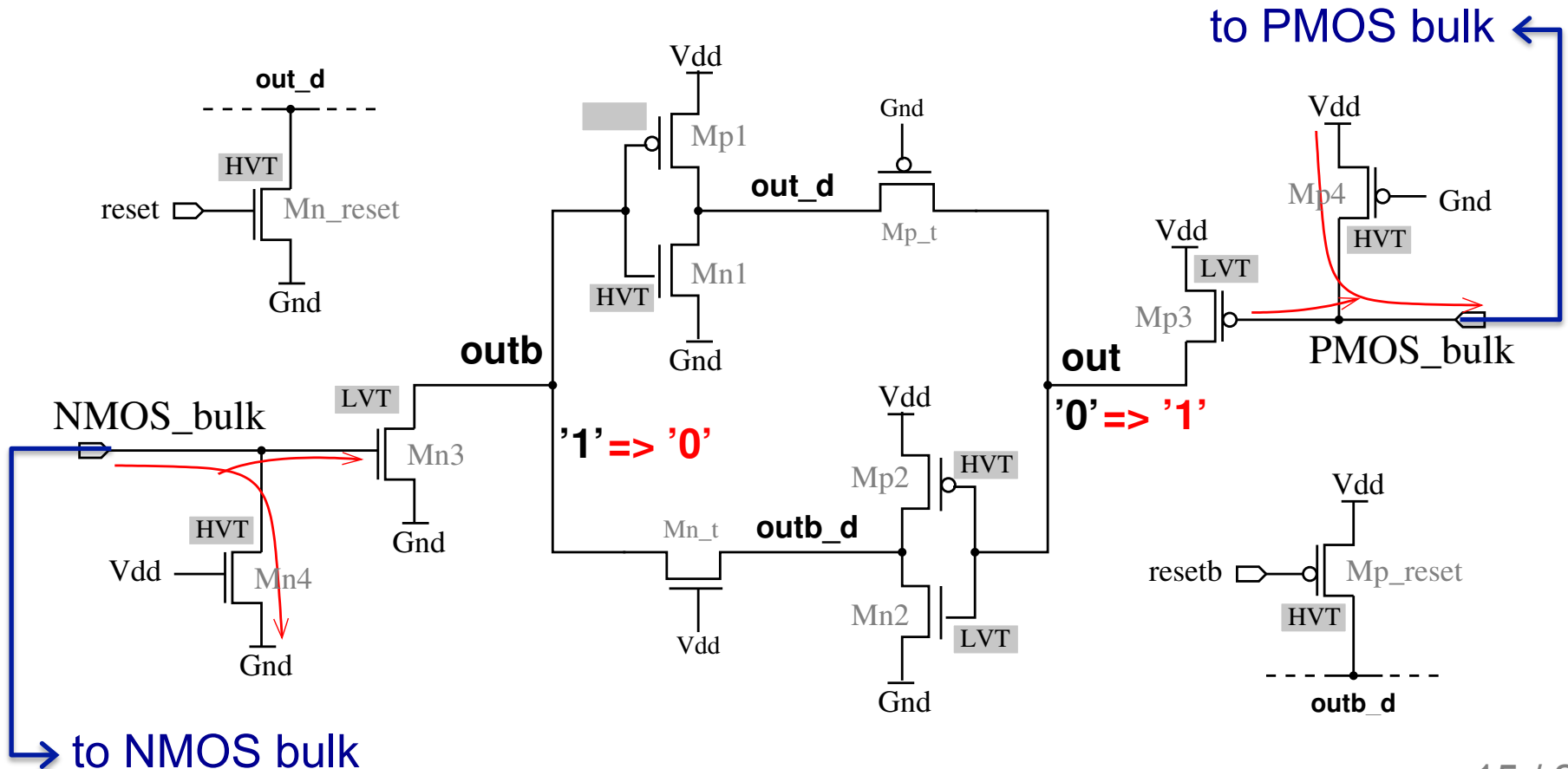
Bulk current (NMOS-BBICS monitored)



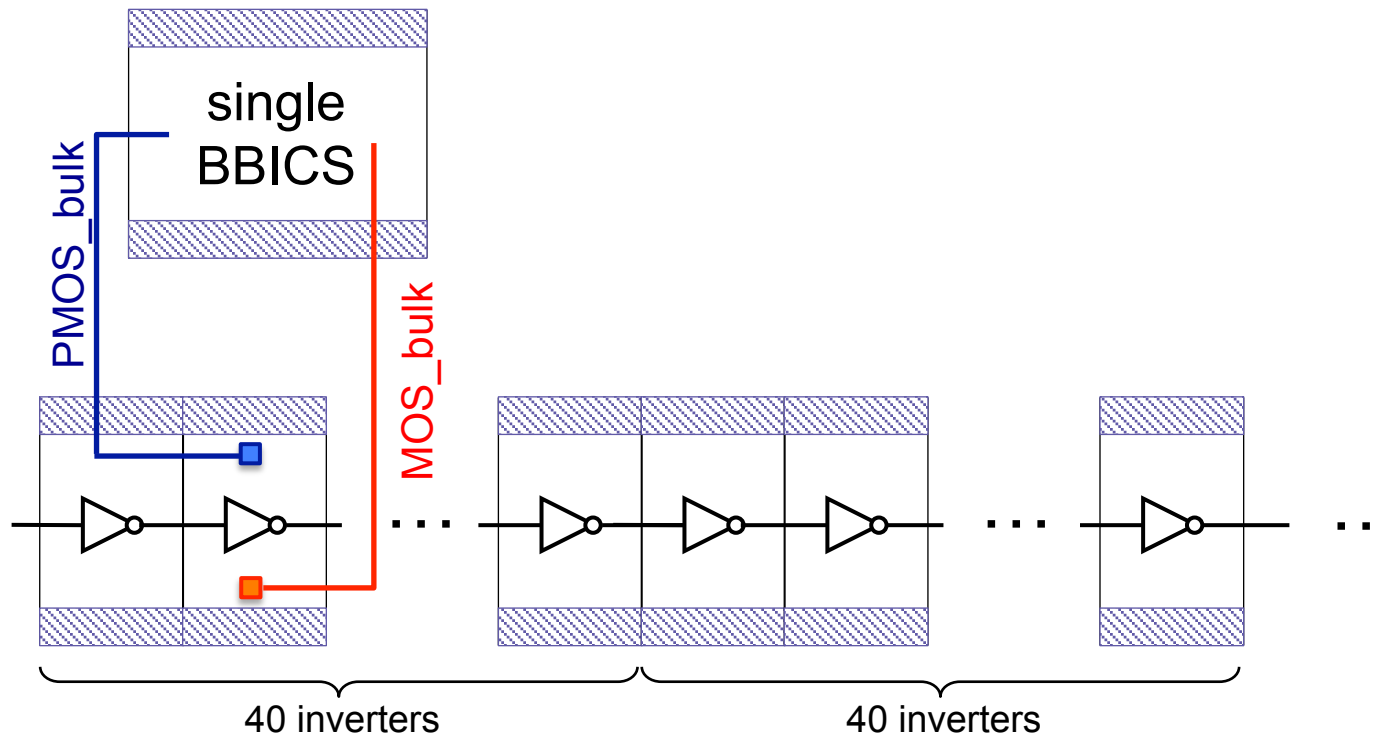
- ⇒ Bulk current an order of magnitude above drain current
- ⇒ Promote detection over SEE generation

## □ Single BBICS architecture

- Design of a test chip: CMOS 65-nm (bulk and triple-well)
- New BBICS architecture: the *single* BBICS (design to bring together NMOS and PMOS monitoring ability)




- Validation on the basis of simulation
  - Post-layout electrical simulation (parasitic R and C extracted)
  - Current source to model SEE currents:
    - current pulse, double exponent, 50 ps rise time, 150 ps fall time,  $\mu\text{A}$  range
  - Investigation of SEE and BBICS detection thresholds



- Validation on the basis of simulation

- CMOS bulk (NMOS on Psub, ie. no triple-well)

# of inverters	40	80	120	200
Threshold of NMOS SET	102 $\mu\text{A}$	104 $\mu\text{A}$	104 $\mu\text{A}$	104 $\mu\text{A}$
Single BBICS detection threshold	56 $\mu\text{A}$	82 $\mu\text{A}$	107 $\mu\text{A}$	155 $\mu\text{A}$


Threshold of PMOS SET	126 $\mu\text{A}$	131 $\mu\text{A}$	134 $\mu\text{A}$	137 $\mu\text{A}$
 corresp. PMOS bulk current	>1.2mA	>1.3mA	>1.3mA	>1.3mA
Single BBICS detection threshold	45 $\mu\text{A}$	67 $\mu\text{A}$	107 $\mu\text{A}$	134 $\mu\text{A}$


⇒ NMOS monitoring weakness confirmed on the basis of simulation



- Validation on the basis of simulation

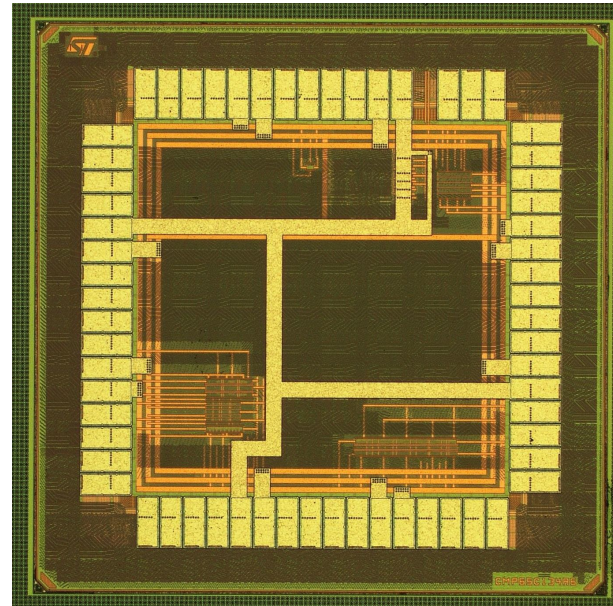
## 2. Triple-well CMOS (NMOS in Pwell)

# of inverters	40	80	120	200
Threshold of NMOS SET	94 $\mu\text{A}$	95 $\mu\text{A}$	98 $\mu\text{A}$	100 $\mu\text{A}$
 corresp. NMOS bulk current	>0.9mA	>0.9mA	>0.9mA	>1 mA
Single BBICS detection threshold	75 $\mu\text{A}$	112 $\mu\text{A}$	147 $\mu\text{A}$	212 $\mu\text{A}$

Threshold of PMOS SET	118 $\mu\text{A}$	125 $\mu\text{A}$	127 $\mu\text{A}$	130 $\mu\text{A}$
 corresp. PMOS bulk current	>1.1mA	>1.2mA	>1.2mA	>1.3mA
Single BBICS detection threshold	84 $\mu\text{A}$	125 $\mu\text{A}$	163 $\mu\text{A}$	237 $\mu\text{A}$

$\Rightarrow$  Triple-well restore NMOS monitoring ability of BBICS

- ❑ Review of BBICS principle
  - Exp. revealed a weakness in monitoring NMOS
- ❑ Analysis and proposal of a solution
  - Use of triple-well CMOS (NMOS in Pwells)
  - Validation on simulation basis (new BBICS architecture)
- ❑ Perspectives
  - Experiments on a CMOS 65-nm test chip



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Thank you for your attention

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[zhang2010], Zhang et al., CCECE 2010

A new bulk built-in current sensing circuit for single-event transient detection

[zhang2013], Zhang et al., Journal of electronic testing 2013

A Bulk Built-In Voltage Sensor to Detect Physical Location of Single-Event Transients