SEE induced by heavy ions and laser pulses in Si Schottky diodes

RADLAS 2017

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(1) TRAD – (2) INSA/LPCNO – (3) CNES – (4) Thales Alenia Space

Context & objectives

- **Context of the study**
  - **First destructive events in Schottky diodes : 2011 [Casey,2014]**
  - **Laser tests for SEE sensitivity prediction or initial sorting**
  - **Derating rules**

- **Funding**
  - **Framework** : CNES (R&T)
  - **Tests & analysis :** TRAD / INSA LPCNO / THALES Alenia Space
  - **Heavy ion beam-time :** CNES / ESA

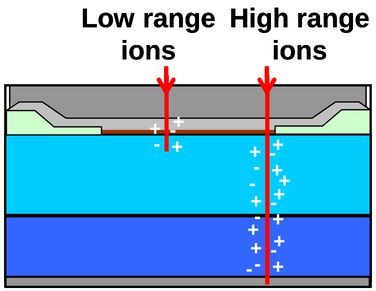
- **Objectives**
  - **Laser / heavy ions comparison in simple structures**
  - **Impact of optical parameters**

- **Outline**

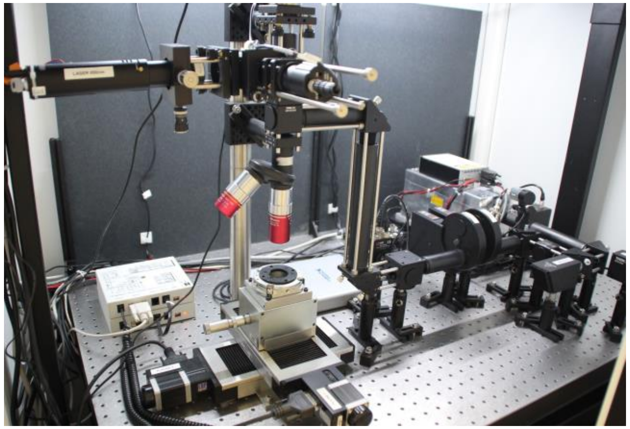
1. Test methods
2. SEB in Schottky diodes
3. Heavy ion tests
4. Laser tests
Conclusion

Tests methods

- **Heavy ion tests performed at UCL and GANIL**
  - **Low range tests: UCL**
    (Université Catholique de Louvain, Belgium)
  - **High range tests: GANIL**
    (Grand Accélérateur Nat. d'Ions Lourds, France)



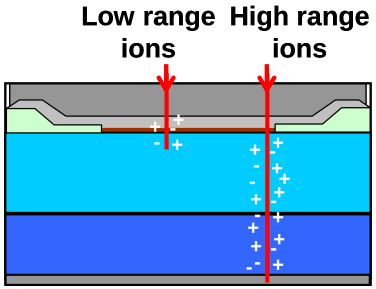
- **Laser tests performed at TRAD laser facility**
  - **Laser**
    - Active Q-switched
    - Wavelength 1.064µm
    - Pulse duration 400ps
    - Single shot to 50kHz
    - Beam waist 0.9µm, **1.3µm**, 4µm
  - **3-axis motorized linear stages**
  - **Visible camera + 850nm positioning laser**



TRAD Laser facility

LISA (Laser Irradiation tool for SEE Analysis)

Tests methods



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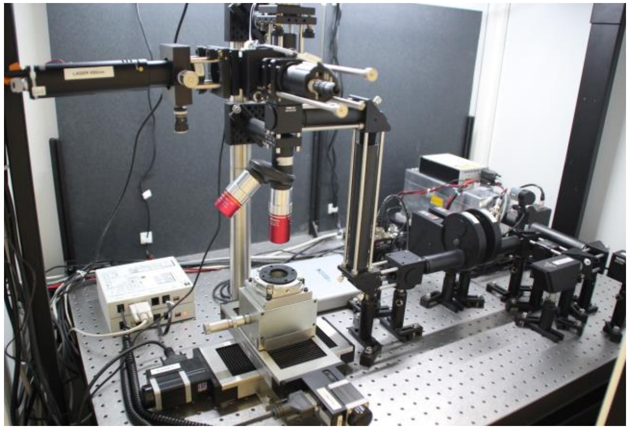


TRAD Laser facility

LISA (Laser Irradiation tool for SEE Analysis)

- **Test set-up**
  - **Single Measure Unit**
    - Polarization and leakage current measurements
    - Resolution : < 250ms
  - **No additional capacitor or resistance**
  - **Identical for both heavy ion and laser tests**

Schottky devices

- **Devices tested : planar and trench Si Schottky diodes from *OnSemiconductor***

MBRF10L60CTG

V_{RRM}=60 V (max reverse voltage)

Planar structure

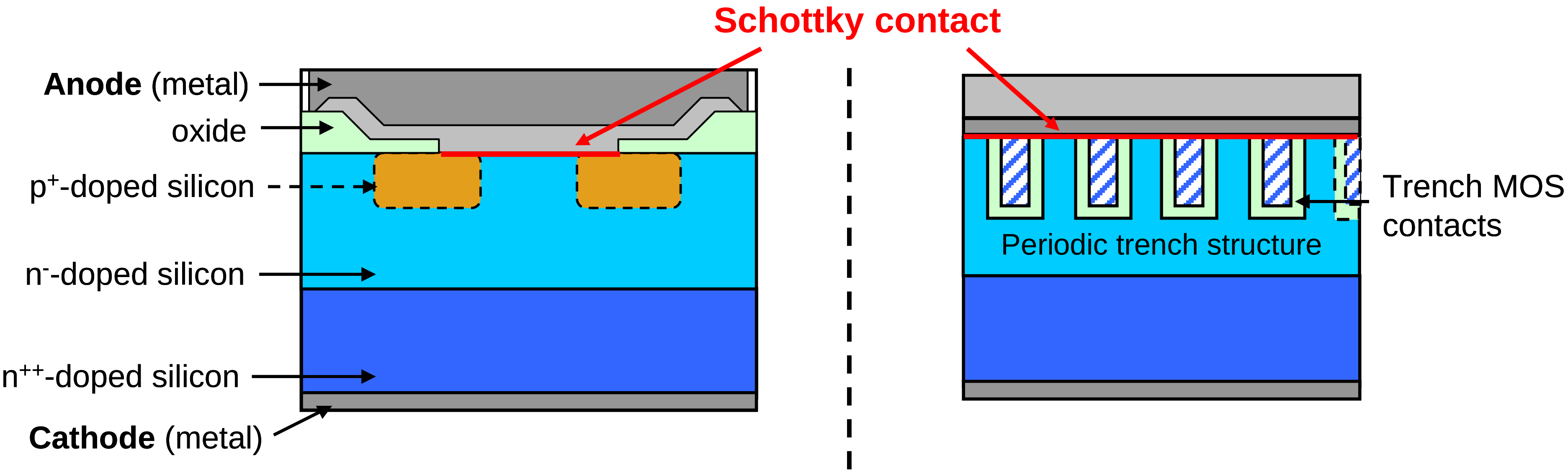
« Classical » diode structure

NTST20120CTG

V_{RRM}=120 V (max reverse voltage)

Trench structure

A new electric field distribution to improve electrical performances



SEB in Schottky diodes

- SEB in <u>reverse polarized planar</u> Schottky diodes (heavy ion tests)

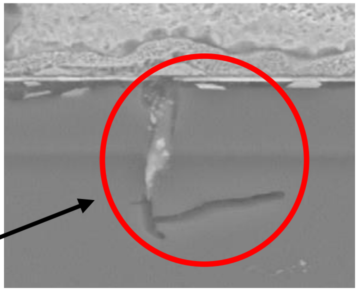
[George,2013] [Theiss,2015] [Casey,2017]

Charge injection

Impact ionization

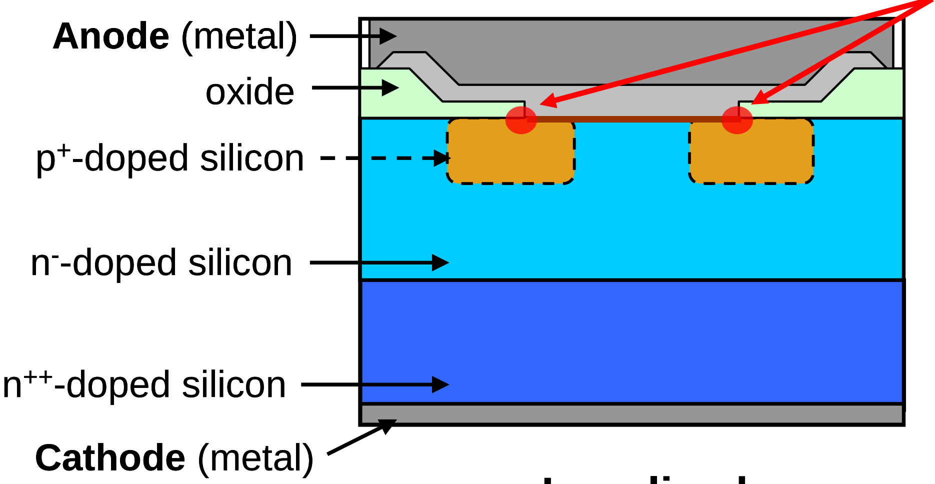
Local temperature increase

Thermal runaway ➔ local fusion

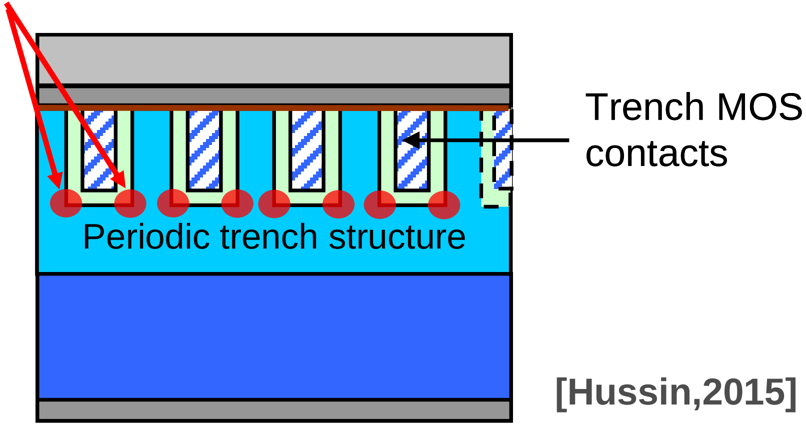


[Casey,2017]

Highest electric field regions → probable sensitive areas



<u>Localized</u>
spatial sensitivity



[Hussin,2015]

<u>Periodic</u>
spatial sensitivity

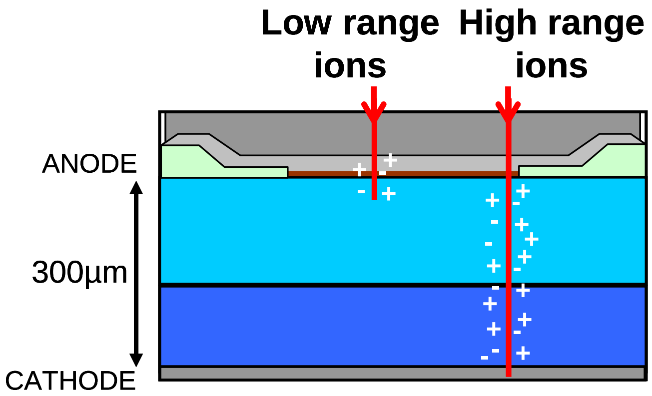
Heavy ion tests

- **Heavy ion testing**
  - **Destructive events at <u>low</u> range (< 300µm)**
    - **Planar diode**

      from LET = 45MeV.cm^2.mg^{-1} @ V_R = 100% V_{RRM}
    - **Trench diode**

      from LET = 20MeV.cm^2.mg^{-1} @ V_R = 90% V_{RRM}

      → Trench = more sensitive



  - **Destructive events at <u>high</u> range (> 300µm)**
    - <u>Increase of the sensitivity</u> → anode/cathode electrical short circuit ?

Xe : LET = 32.4MeV.cm^2.mg^{-1}

Ref.	**LOW RANGE**	**HIGH RANGE**
Planar MBRF10L60CTG	**PASS** @ 100%V_{RRM}	**FAIL** @ 100%V_{RRM}
Trench NTST20120CTG	**PASS** @ 75%V_{RRM}	**FAIL** @ 75%V_{RRM}

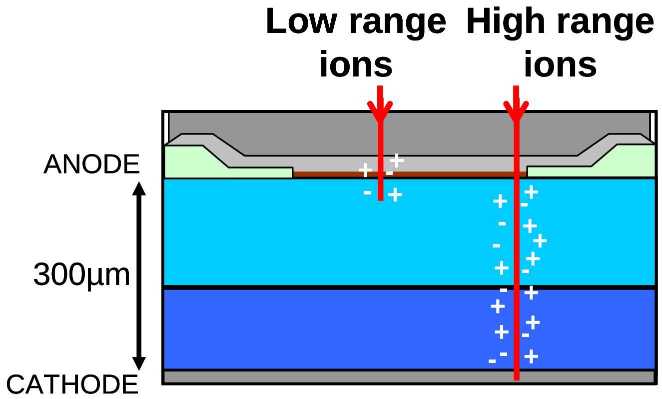
V_{RRM} : max. reverse voltage

→ Interest of laser tests (high range)

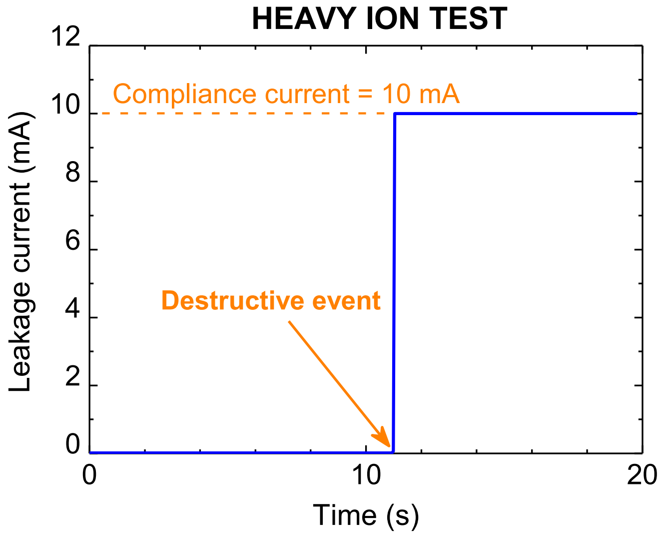
HI vs laser tests

Test conditions

$V_R = 100\%V_{RRM}$



Leakage current behaviour



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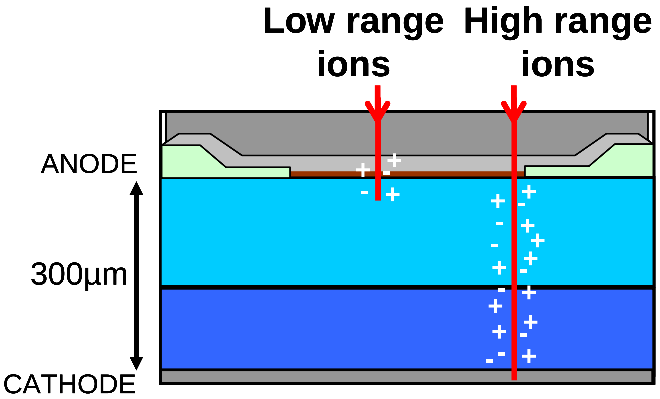

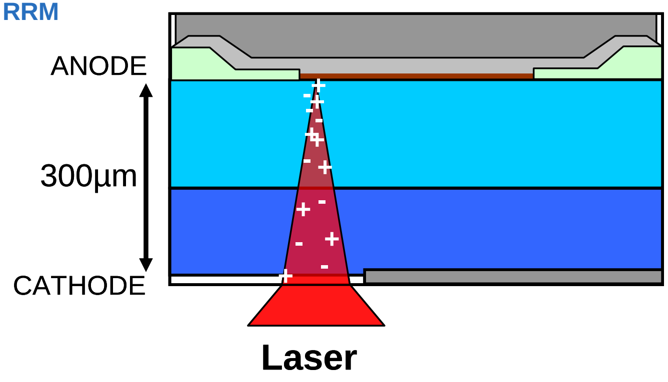

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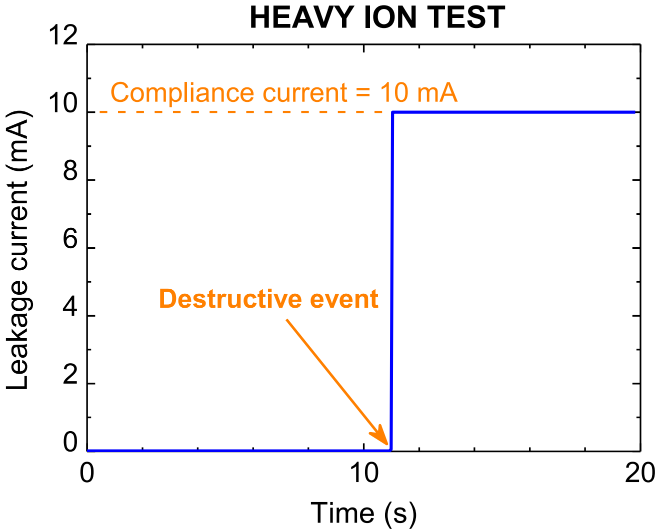
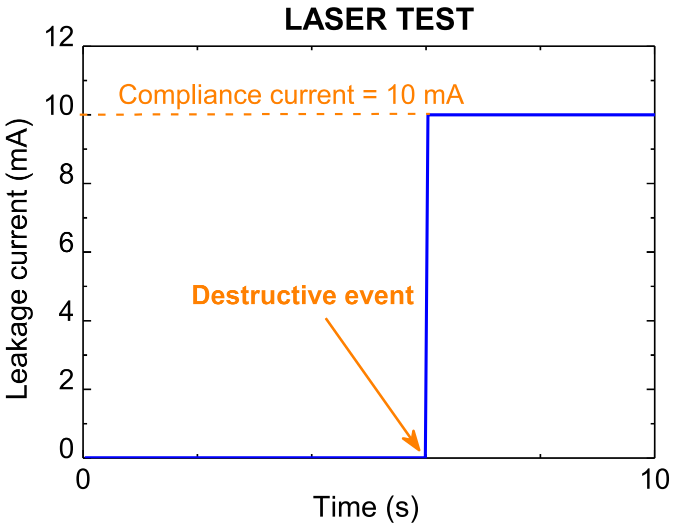


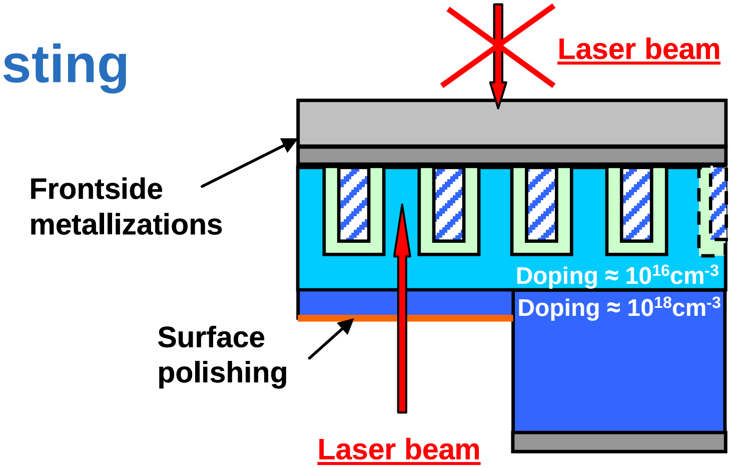


Destructive event triggered by laser pulse

Laser tests

Backside device preparation for laser testing

- Delidding
- **Thinning : ~130µm**
  - Maximization of the sensitive area accessibility
  - Preservation of the electrical performances
- Polishing



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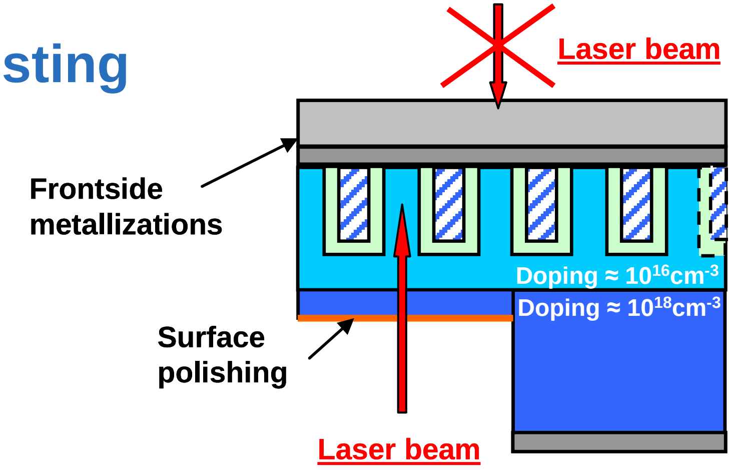
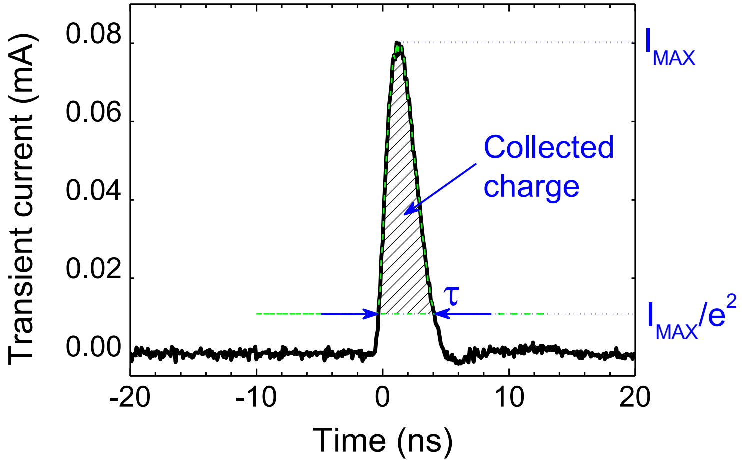


Transient photocurrent measurements below SEB threshold

Decoupled power supply, 4GHz oscilloscope connected with SMA cable

- **Average transient duration** @1/e²
- **Average collected charge** @1/e²
  - Mainly from drift currents
    → linked with destructive events

Dependence on energy, focusing depth, reverse voltage



Laser energy dependence

Collected charge : laser energy dependence

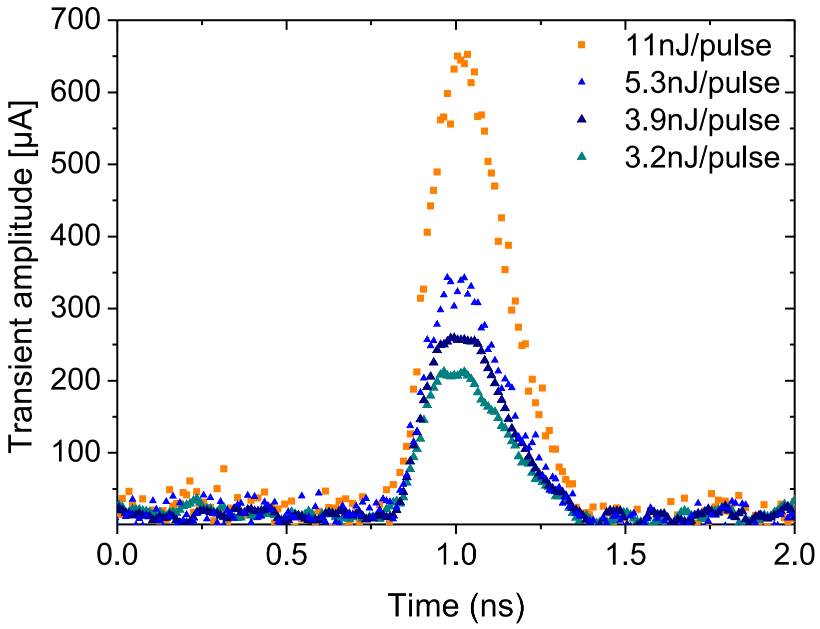
λ = 1.064µm

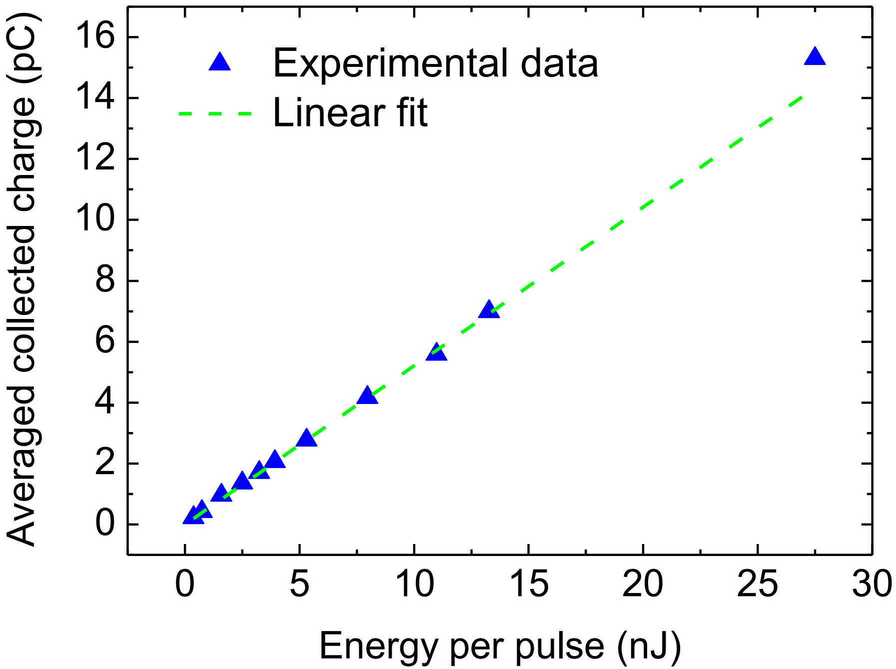
$N_D < 10^{17}$ cm^{-3}

→ two photon absorption **negligible**
(10^{10} times less than single photon abs.)

→ intraband absorption **negligible**

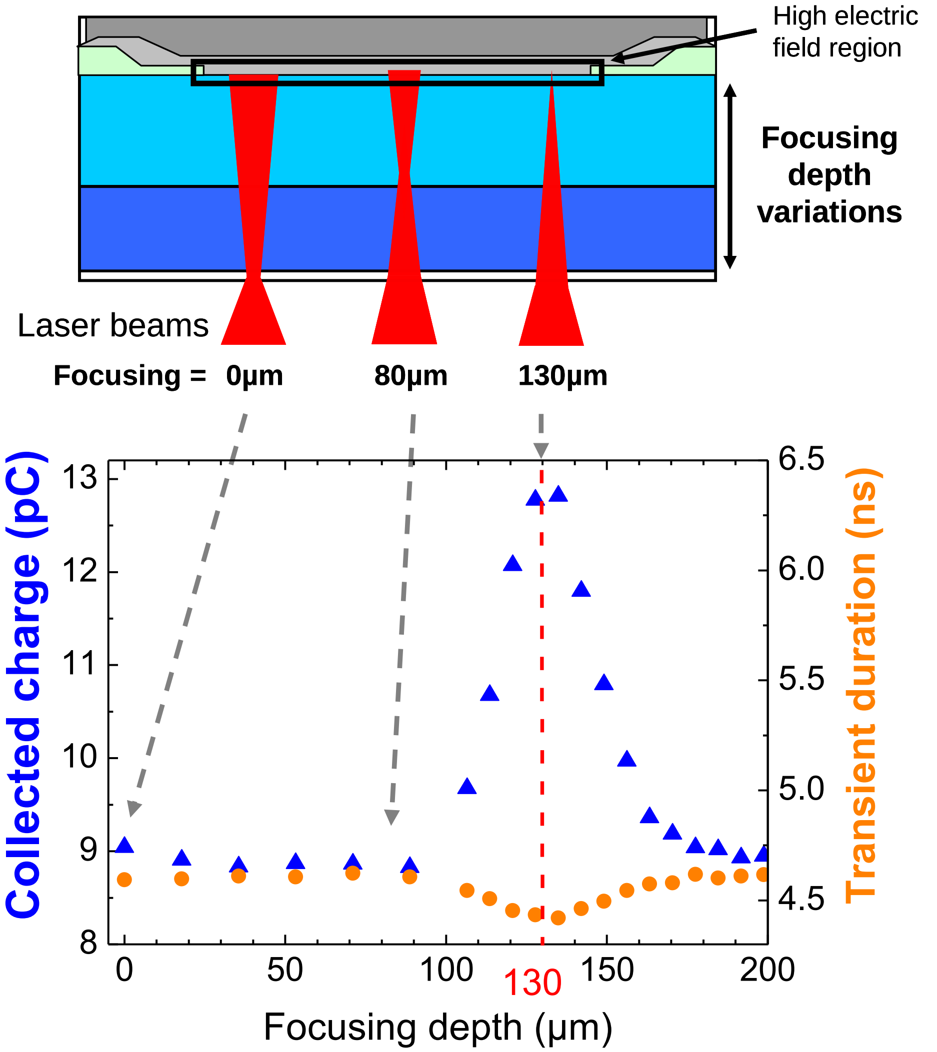
→ main absorption process = **single photon absorption**
linear dependence with energy





Laser focusing depth dependence

- **Laser focusing depth dependence**



- Collected charge mainly due to **drift currents (in the depletion region)**

- **Analysis**

Focusing depth close to the depletion region

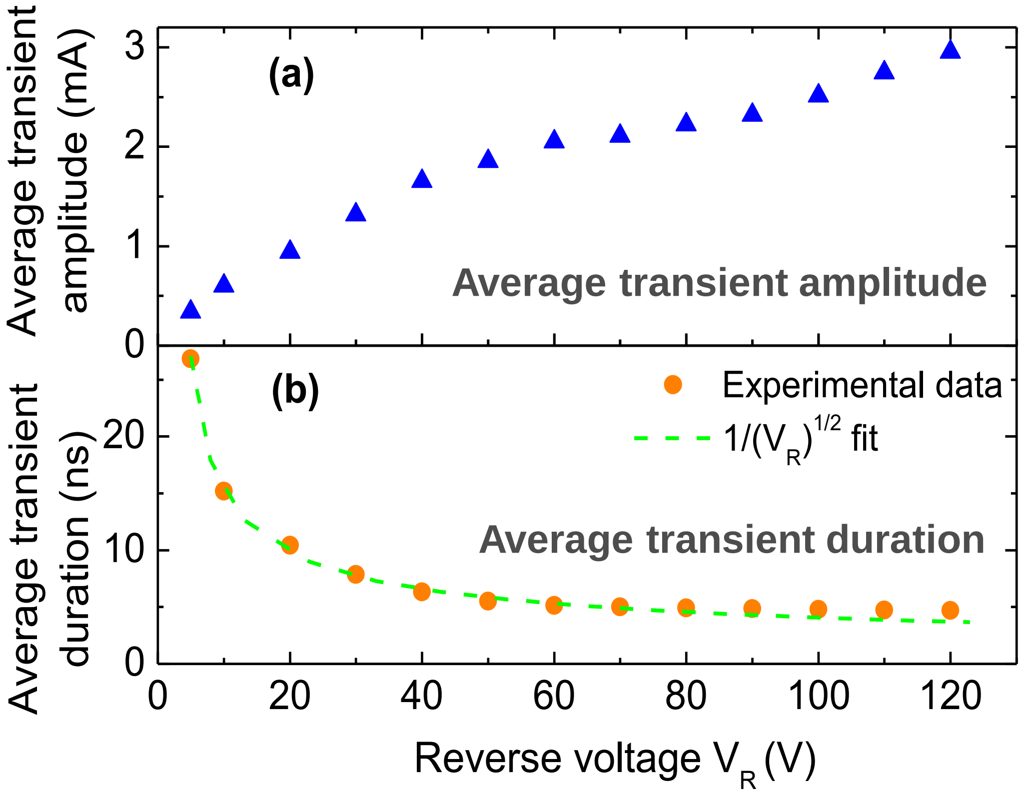
Maximization of drift currents

→ transport efficiency increase
→ charge velocity increase (electric field)
→ potential impact ionization

Increase of collected charge (+50%)
Decrease of transient duration (-5%)

Reverse voltage dependence

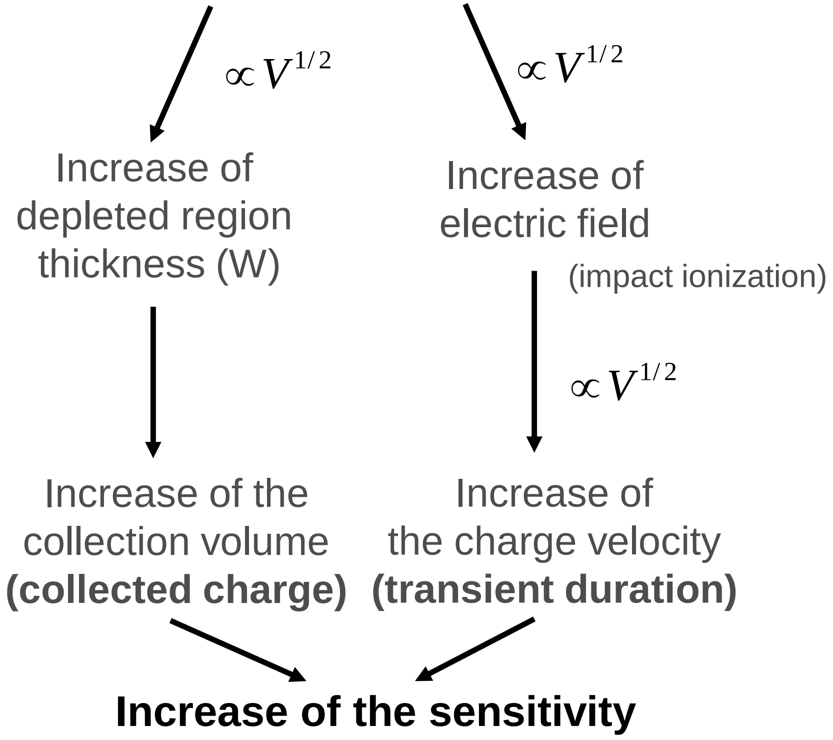
- **Laser test : reverse voltage dependence (focusing depth = depletion region)**



- Collected charge mainly due to **drift currents (in the depletion region)**

- **Analysis**

Increase of reverse voltage (V_R)



$\propto V^{1/2}$

Increase of depleted region thickness (W)

Increase of the collection volume **(collected charge)**

$\propto V^{1/2}$

Increase of electric field

(impact ionization)

$\propto V^{1/2}$

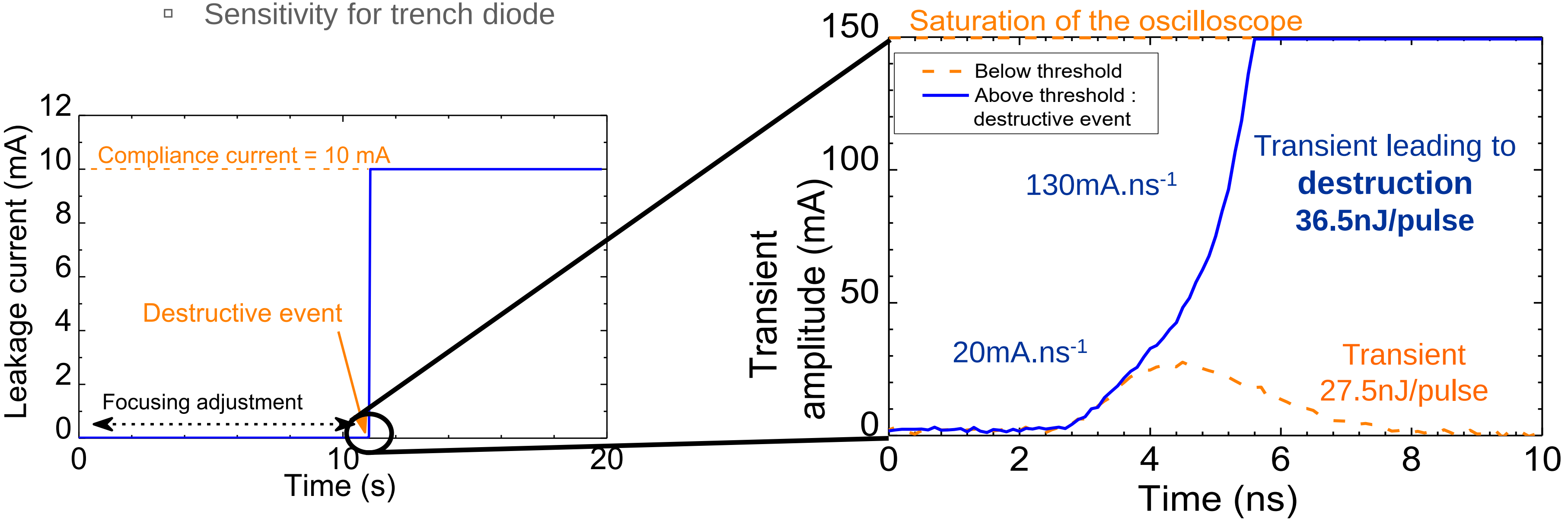
Increase of the charge velocity **(transient duration)**

Increase of the sensitivity

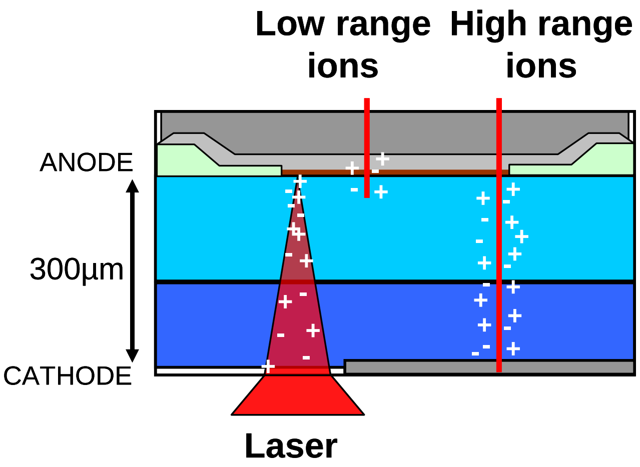
Destructive laser tests

Laser energy above SEB threshold

- **Laser testing in PLANAR diode**
  - **Collected charge < 25 times less than expected (< 0.1pC)**
    → No destructive event
- **Laser testing in TRENCH diode**
  - **Critical parameters to trigger events :**
    - Energy, reverse voltage, ⚠ focusing depth
  - **Reproducible destructive events at 36.5nJ/pulse @100% V_{RRM}**
  - **Comparison with heavy ion tests :**
    - Destructive signature comparable to heavy ions
    - Sensitivity for trench diode

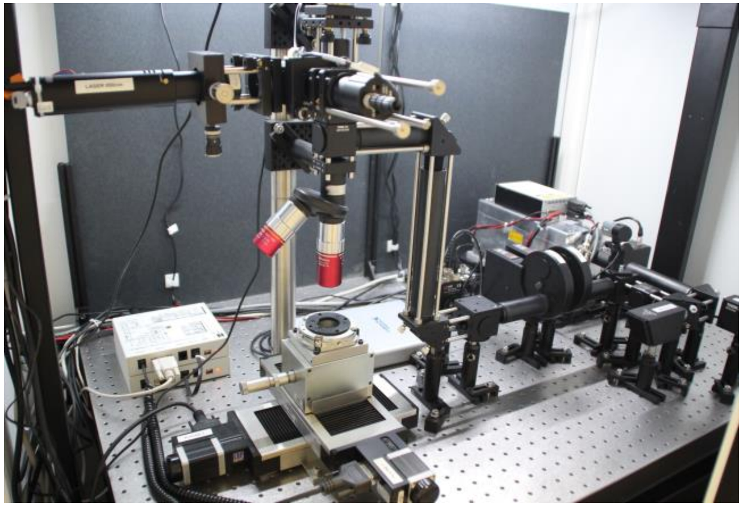


Conclusion



- One-photon laser testing for Si Schottky diodes
  - **Reproducible destructive events**
  - **Comparison with heavy ion test results**
    - Destructive signature
    - Electrical parameters
  - **Important impact of doping levels and structures**

- Further studies for heavy ions / laser correlation
  - **Transient measurements during heavy ion tests**
    - LET / laser energy SEB threshold
  - **TCAD with photogeneration and transport model**
    - To further understand laser test results
  - **Laser tests**
    - Spatial sensitivity study
    - Other planar and trench references

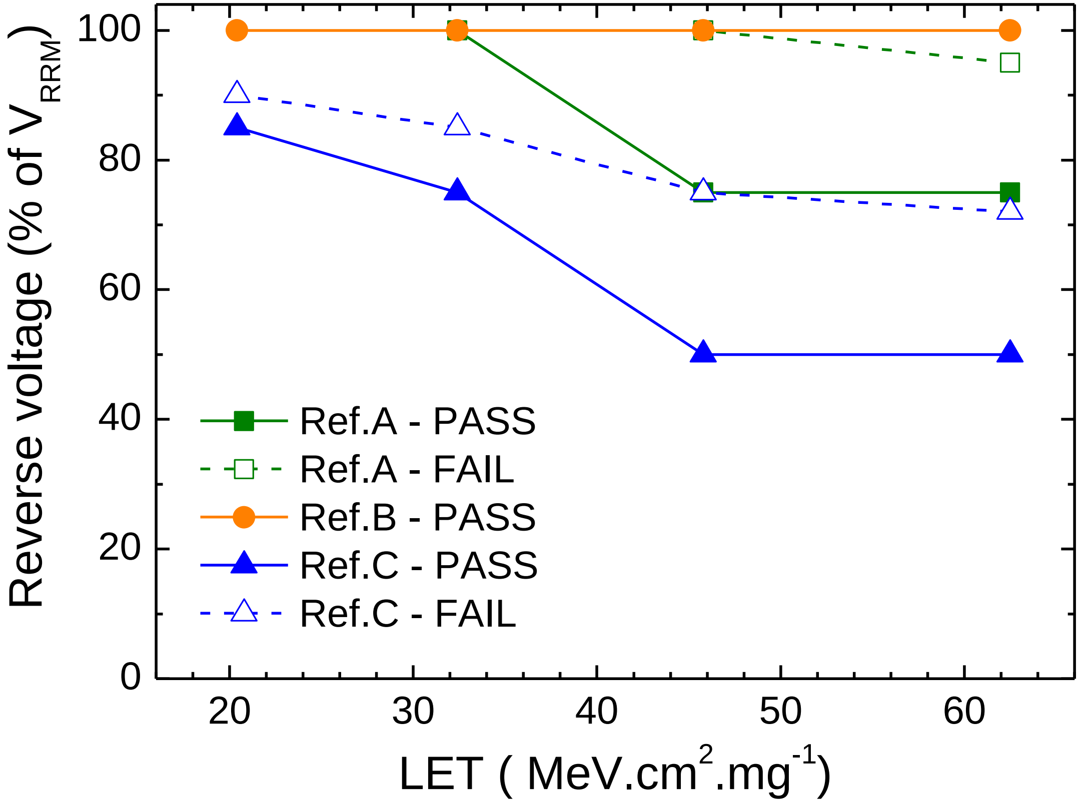


Thank you

Questions ?

Additional material

- **Heavy ion test results**
  - Performed at UCL (Université Catholique de Louvain, Belgium)



Simulation

- **Photogenerated collected charge**
  - **Based on an SPA analytical model from [Buchner,2013]**
  - **Funneling extension and collection efficiency neglected**
  - **Collected charge : a few pC**