Using TPA laser testing for characterizing the depth of SEE sensitive volumes

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Outline

- Two Photon Absorption (TPA) technique
  - **Principle**
  - Experimental implementation
  - Characterization
- Application to SEE sensitivity testing
  - State of the art
  - Methodology
  - SET experiment
  - SEL experiment
  - SEB experiment
- Summary and main recommendations
- Work in progress at IMS

SPA vs TPA

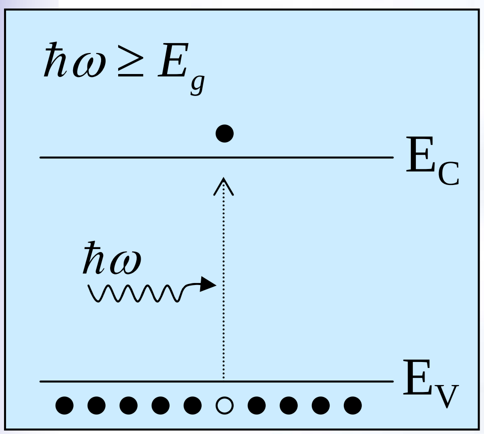
Linear (Single Photon) Absorption

$$\alpha = \underbrace{\alpha_{IB} + \alpha_{FC}}$$

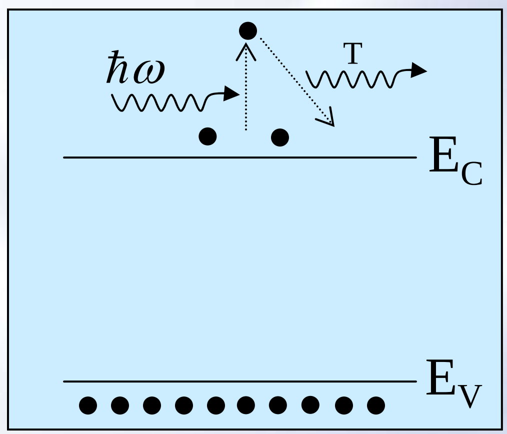
Two-Photon Absorption

$$\beta$$

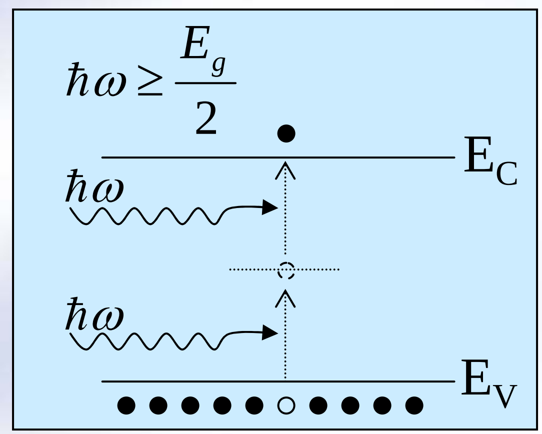
Interband absorption



Free carriers absorption



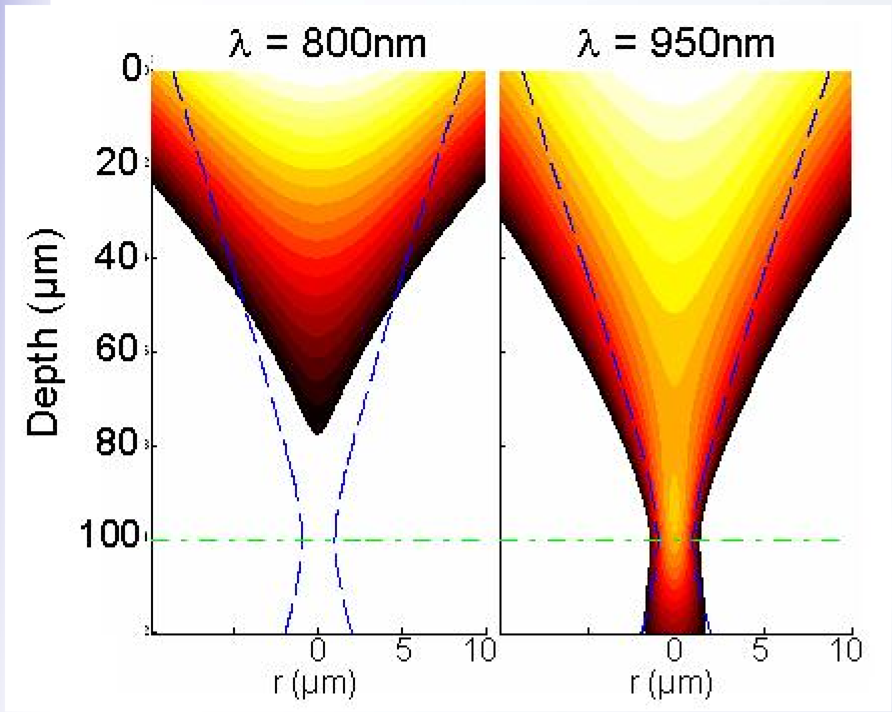
Non-linear absorption



Generated carriers distribution

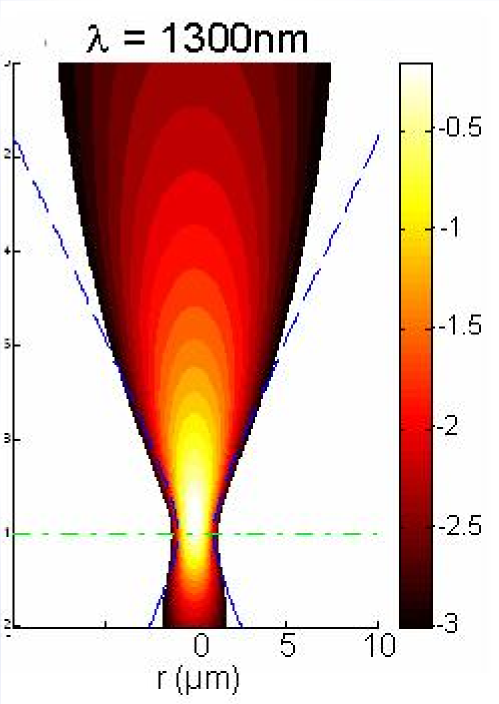
Linear (Single Photon) Absorption

α



Two-Photon Absorption

β



Generated carriers density (log)

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Experimental implementation

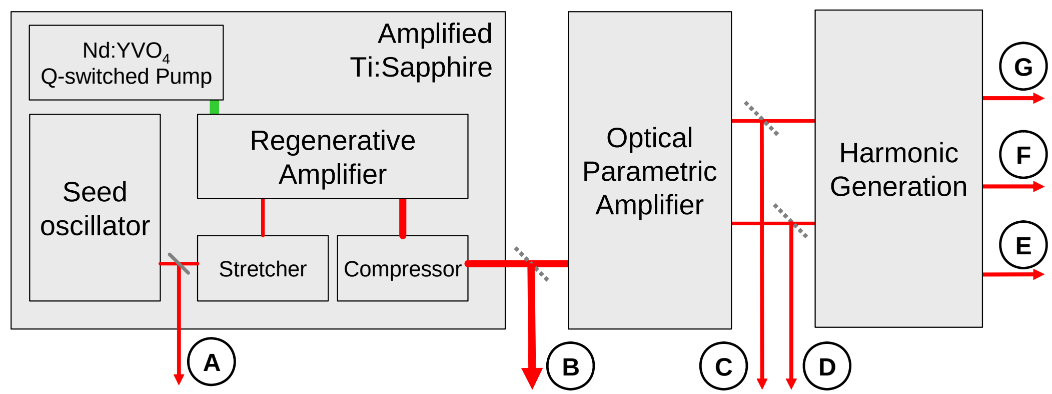
- Laser source
  - High peak intensity required for TPA $\Rightarrow$ 100fs pulses
  - Not many solutions for nanojoule femtosecond pulses above 1100nm
  - OPA or OPO pumped by Ti:Sa oscillator or amplifier (>1150nm)
  - Er fiber-based oscillator (1550nm)

- Adapt pulse selection method to intensity and repetition rate

- NIR optimized objective lenses
  - Laser pulse spectral width >10nm
  - Limit chromatic abberations

Experimental implementation

- ATLAS
  - OPA pumped by regenerative Ti:Sapphire amplifier



	Wavelength	Pulse duration	Pulse energy	Repetition rate
A	800nm	100fs	5nJ	80MHz
B			1mJ	
C	1600 - 2630nm	130fs	10µJ	
D	1150 - 1600nm	100fs	50µJ	Single shot - 1kHz
E	800 - 1200nm			
F	600 - 800nm	130fs	1µJ	
G	400 - 600nm			

Si devices ← (row D)

Wide Band gap material devices ← (row G)

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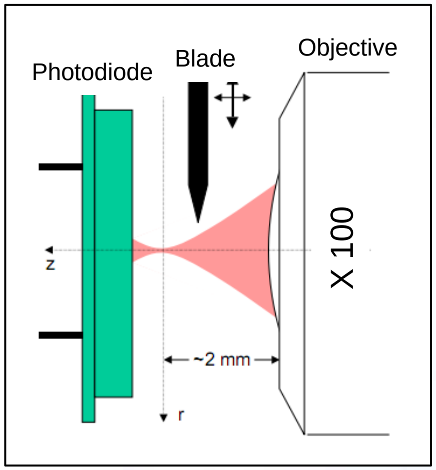
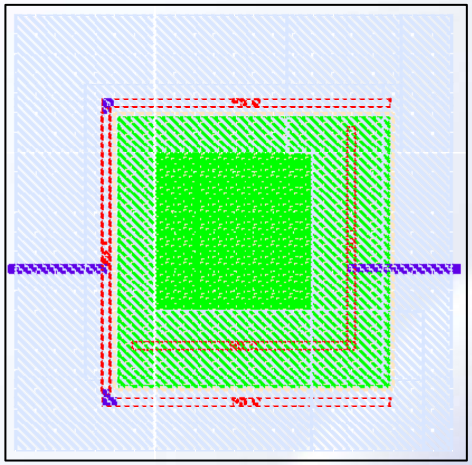
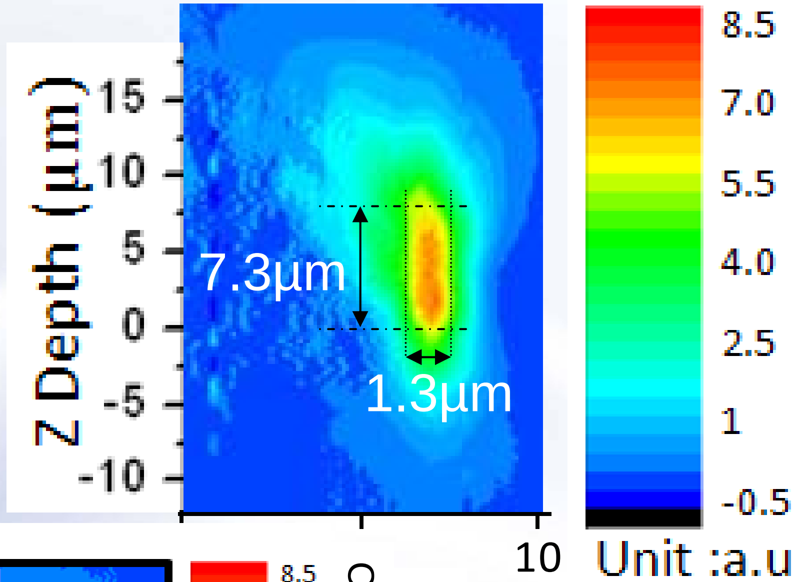
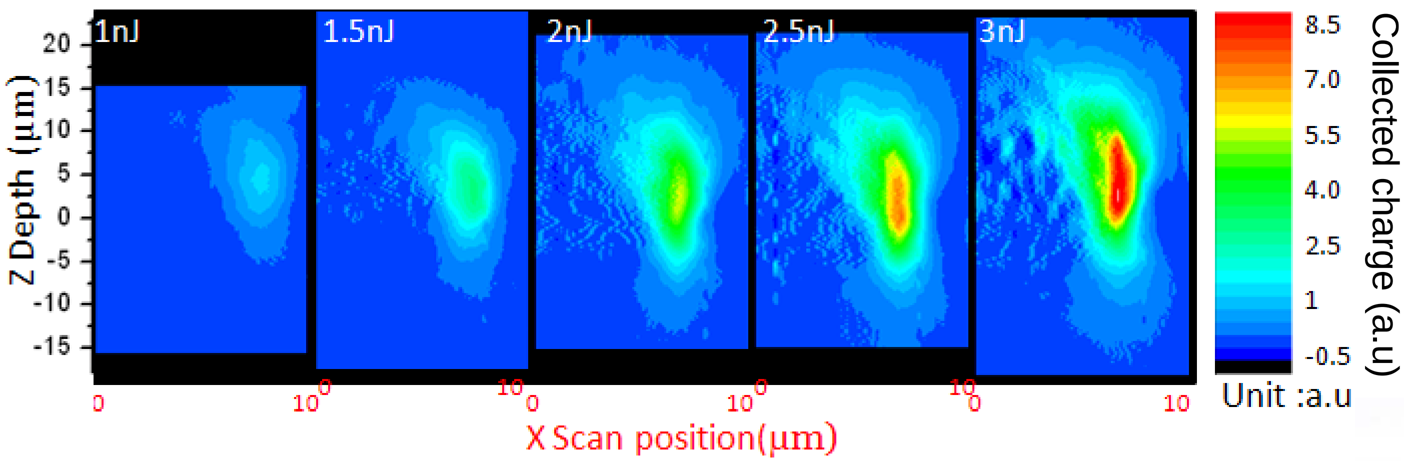
3D Characterization of TPA spot

Knife-edge method using integrated diode









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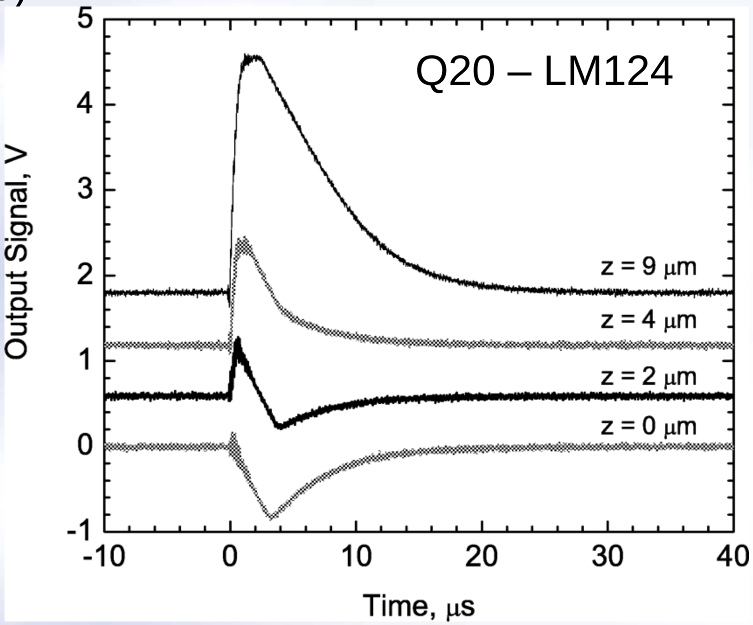
Applications to SEE testing

- State of the art
  - SET, McMorrow (TNS 2002, 2003)
  - SEU, McMorrow (TNS 2004, 2005)
  - SEL, McMorrow (TNS 2006)
  - Empirical calibration, Schwank (RADECS 2010)
- TPA at NRL
  - Used to use 590nm for frontside SPA
  - No wavelength available for backside SPA
  - Switched to TPA at 1260nm for backside
  - « Limit the amount of charge deposited »
- Other TPA facilities
  - ATLAS (2006)
  - University of Sevilla (2009)



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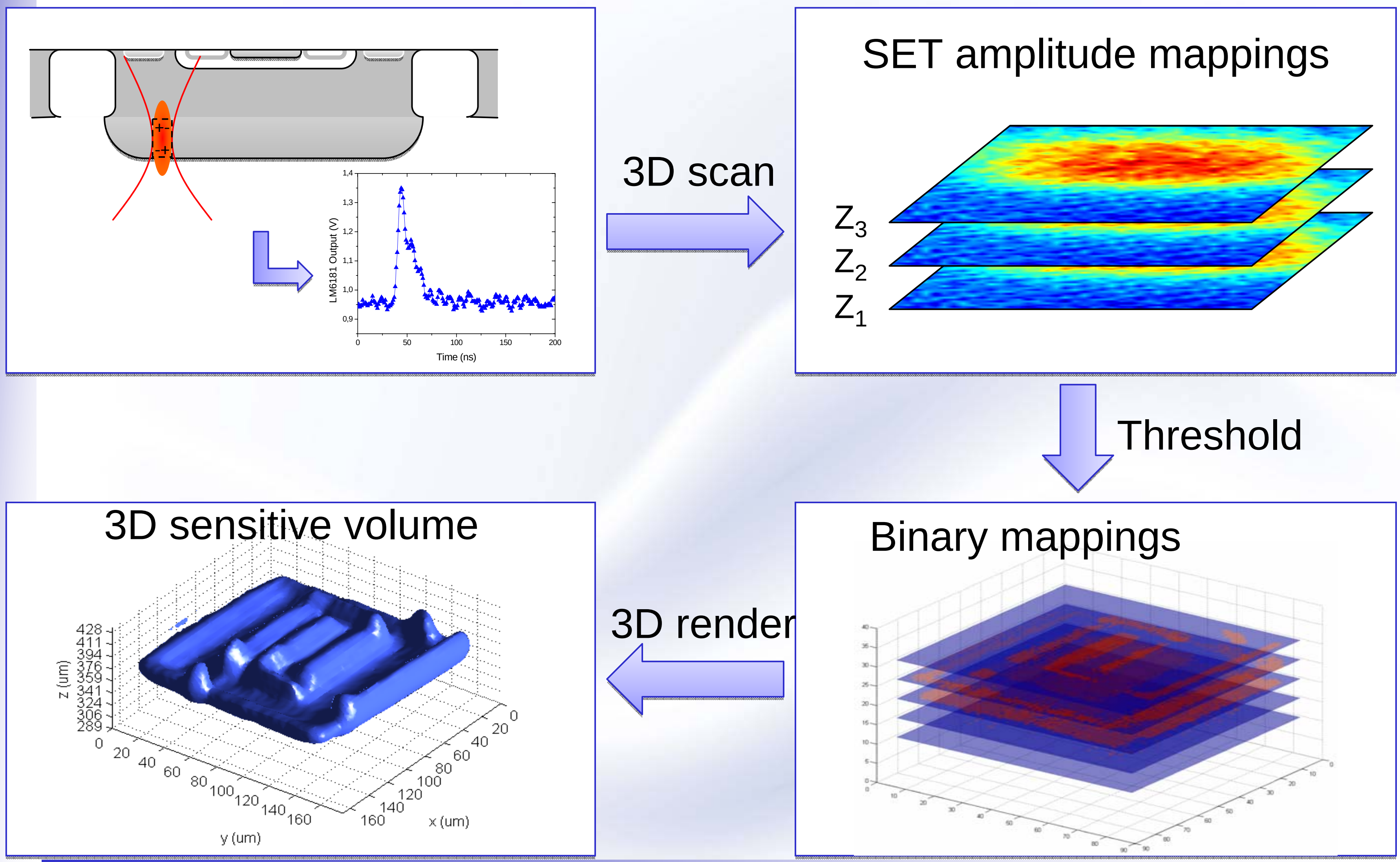
Experimental methodology

- Start with SPA mapping of sensitive areas
  - TPA much more sensitive to focus and thickness variations ⇒ not suited for large area scans
  - SPA scans performed at ATLAS-i (1064nm, 400fs pulses)

- TPA mappings of representative sensitive areas for different Z positions and pulse energies

SET : 3D scanning principles



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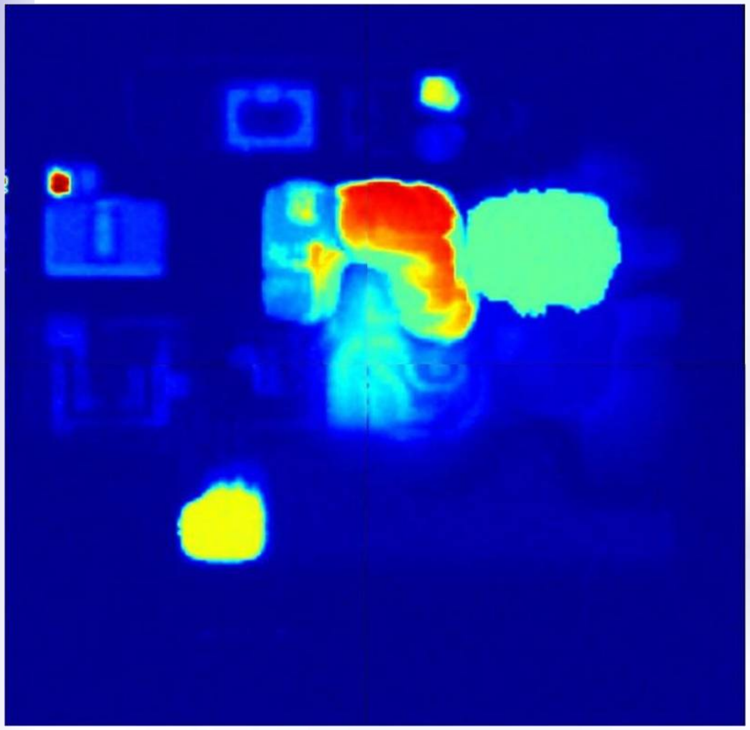
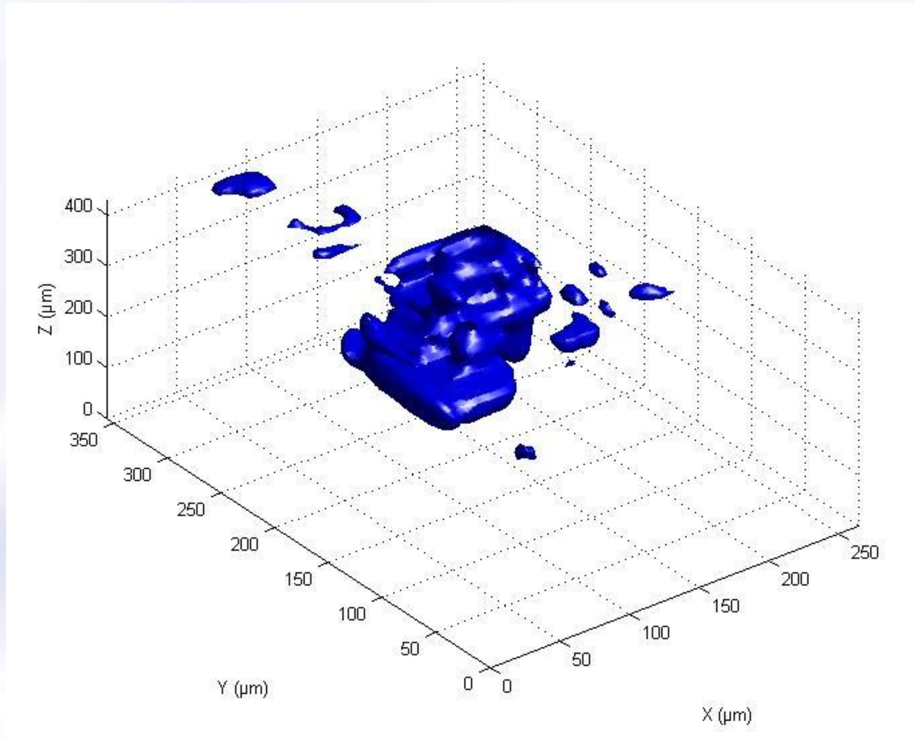
SET

- SET sensity Mapping of an LM324 AN



SPA: SET amplitude mapping

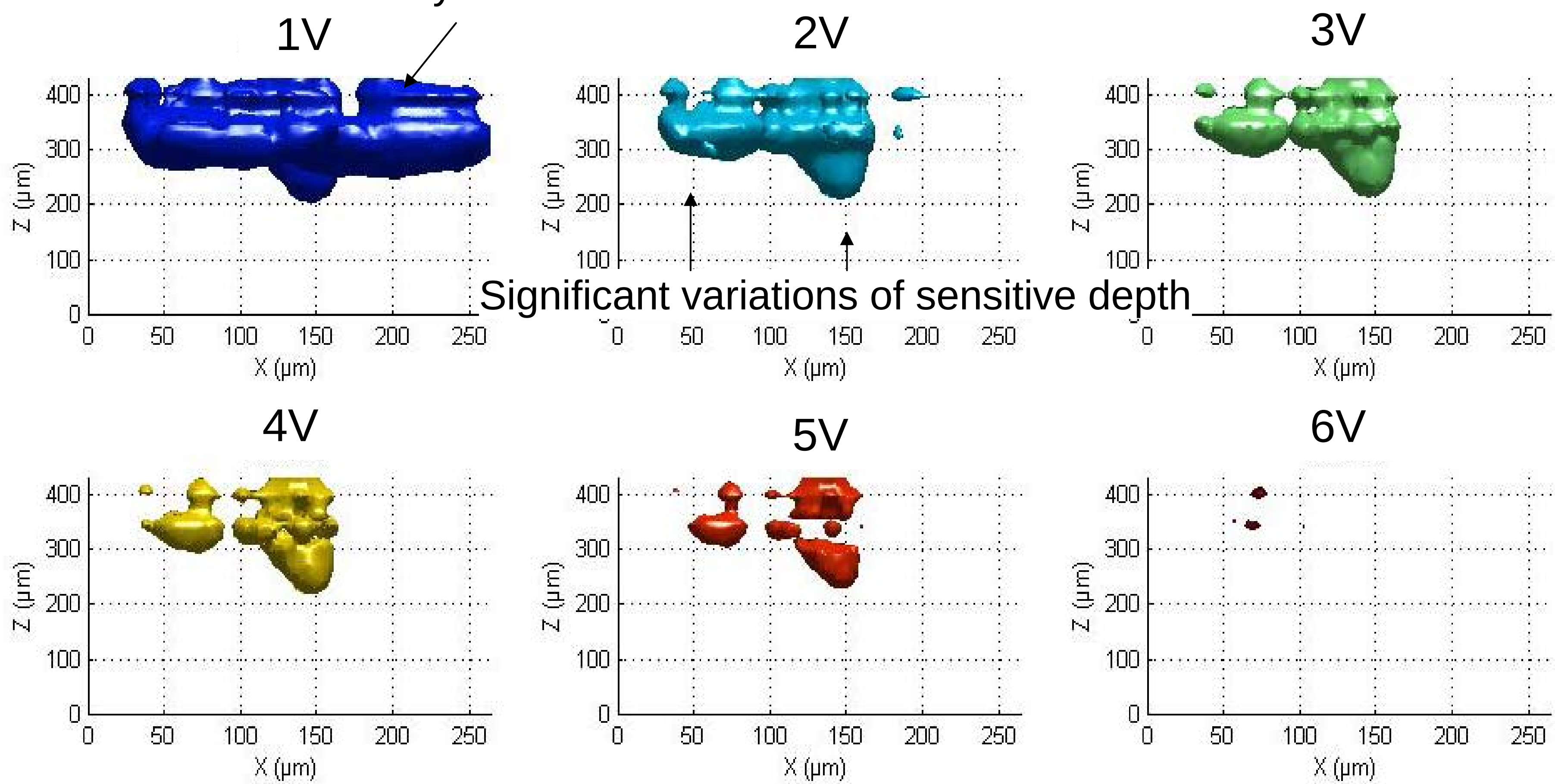


TPA: Peak-to-peak amplitude > 2V, E=1nJ

SET

- SET « sensitive volume » vs amplitude threshold

Artifacts due to metal layer reflections



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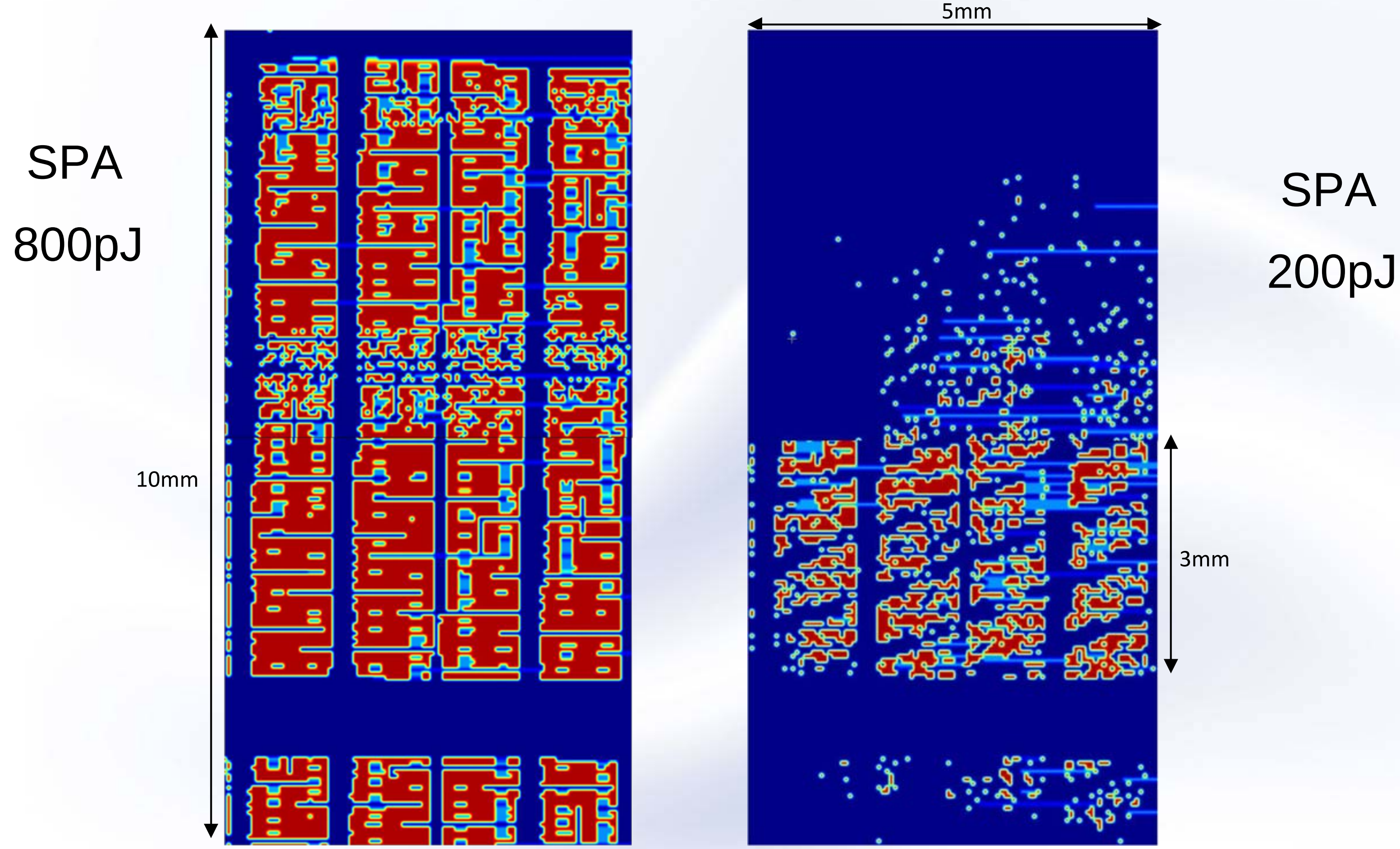
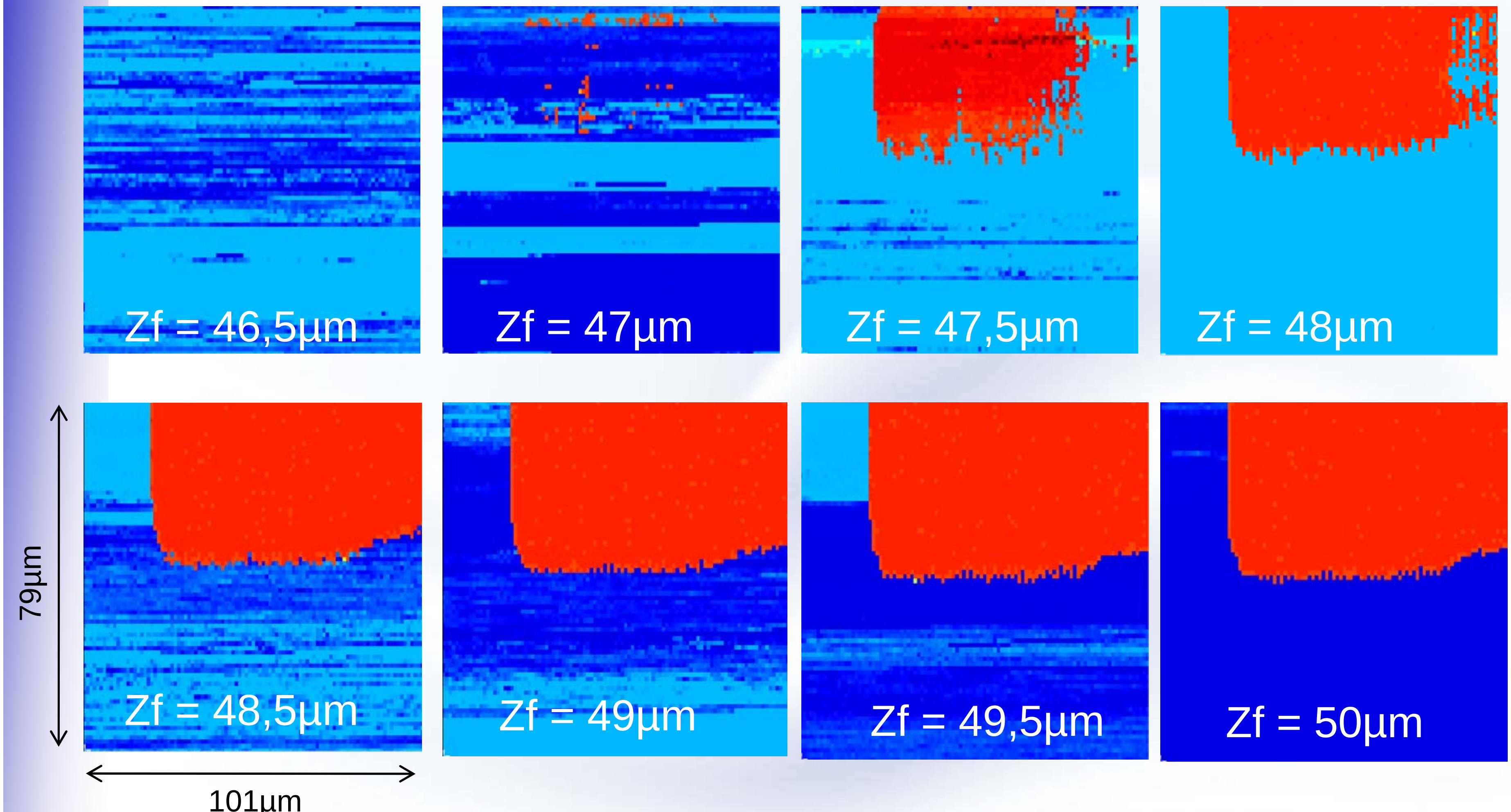
SEL

- SRAM CYPRESS CY7C1069AV33

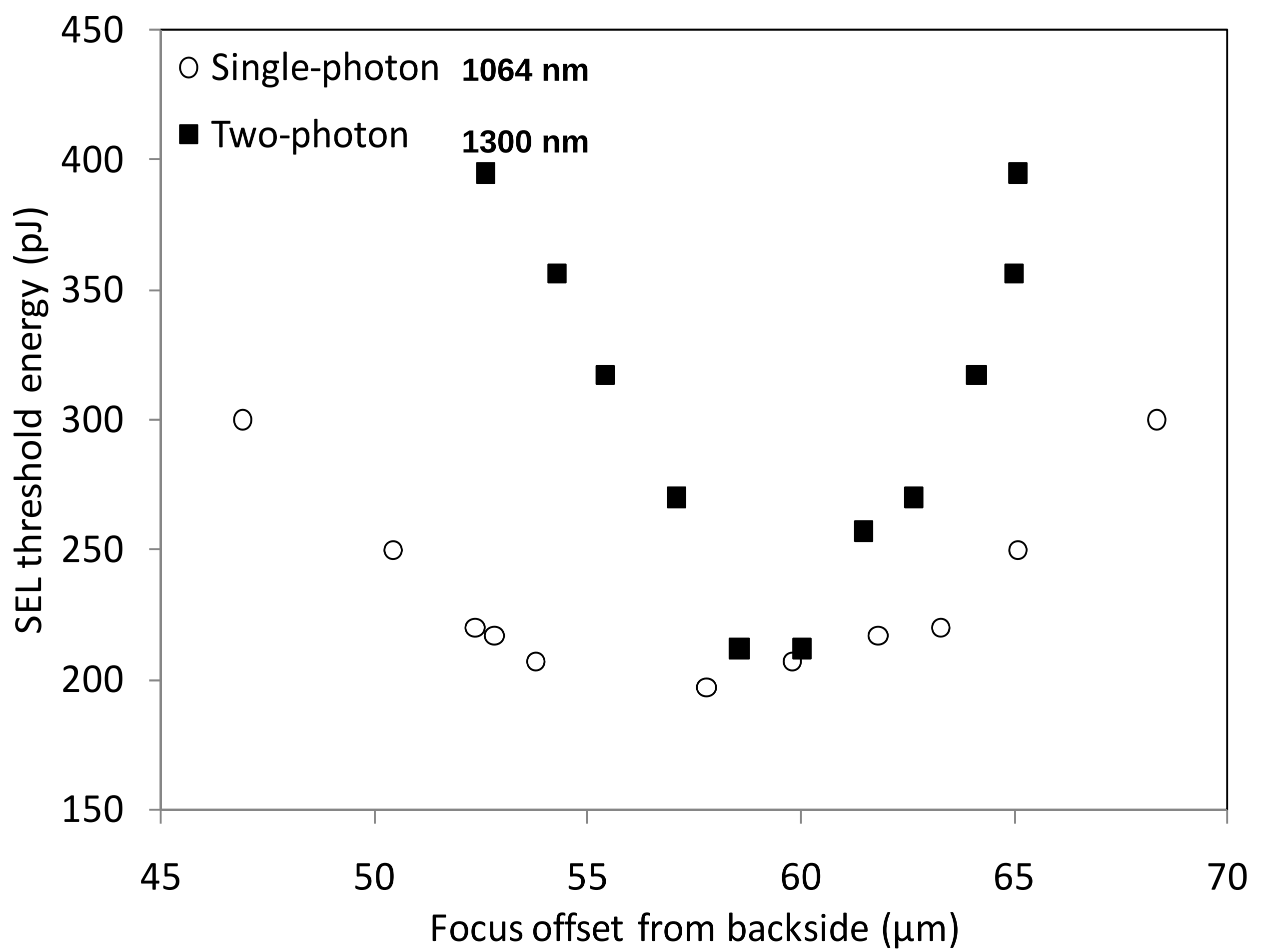


SEL

- TPA


Zf = 46,5µm
Zf = 47µm
Zf = 47,5µm
Zf = 48µm
Zf = 48,5µm
Zf = 49µm
Zf = 49,5µm
Zf = 50µm
79µm
101µm

SEL



To be presented at NSREC 2011 – Las Vegas

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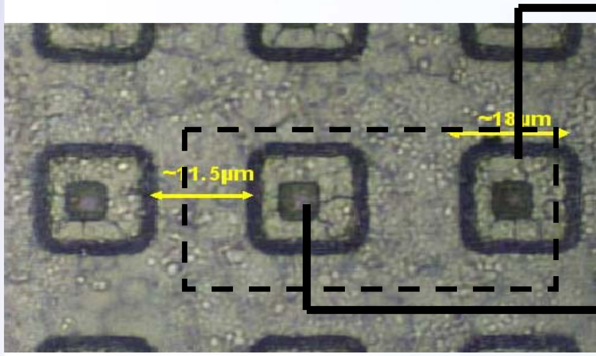
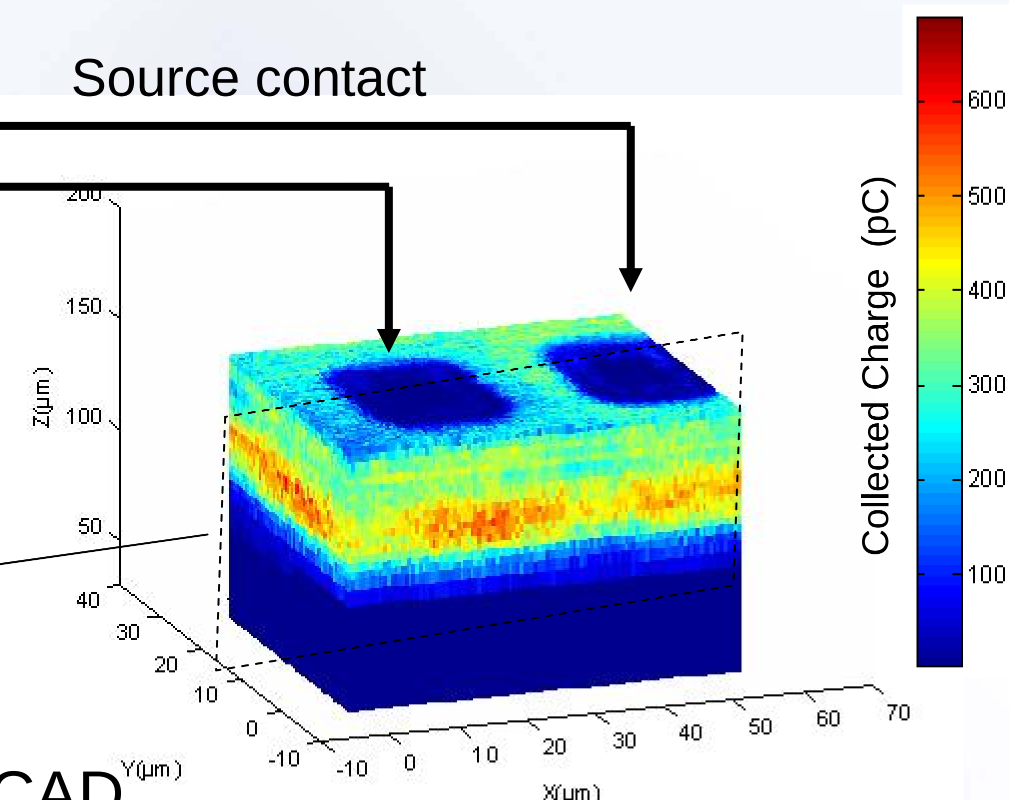
SEB

- Charge collection 3D mapping of BUZ30A 200V SiPMOS VdNMOSFET from Infineon

Scanned Area



Source contact

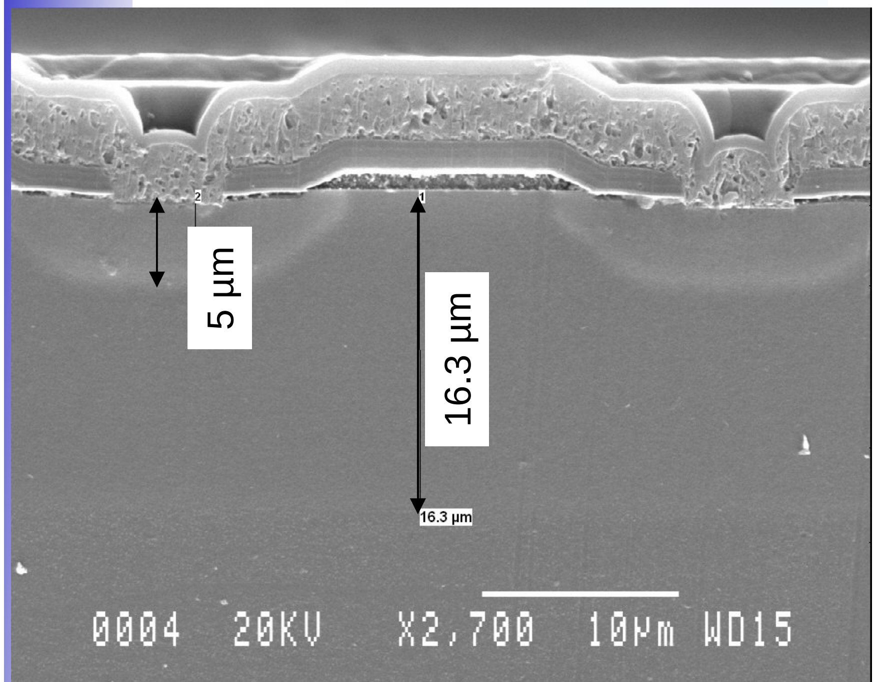


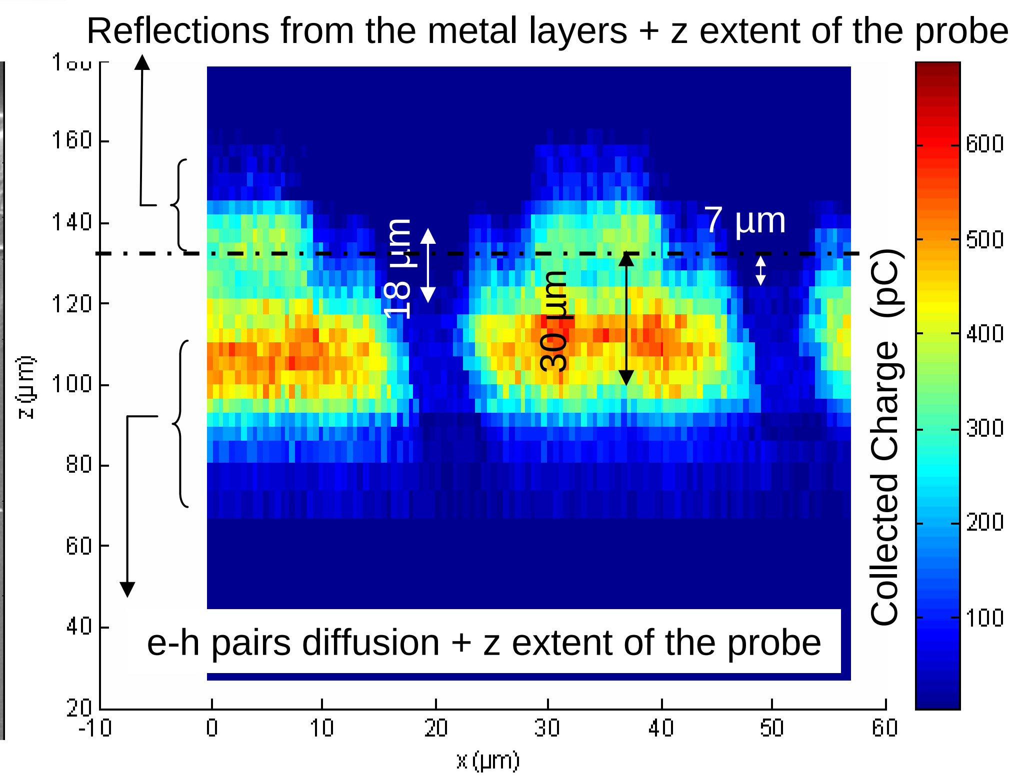
cut

Laser TPA λ=1300 nm
Vds Bias = 25 V
31 x,y Maps

- Correlates well with TCAD simulations

SEB





No SEB sensitive volume yet because of an occurrence of a destructive event during the mapping procedure.

Improvement of the protection of the device under test. SEB sensitive volume under investigation in the following weeks.

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Results summary

- TPA can induce SET, SEL, SEB
- Demonstrated 3D resolution
  - For SEE volumes depth > 5µm
- Probably improves lateral resolution
- Main experimental difficulties
  - Laser pulse-to-pulse energy instability around 10%
    - Intrinsic to OPA technology
  - Reliability of laser source (alignment, motors, crystals)
  - Incident energy measurement calibration and linearity
  - Backside surface quality is critical
  - SEB test setup issues

Main recommandations

- Don't expect quantitative results from TPA
  - To date, TPA can only measure relative variations of sensitive depth with respect to other parameters (position, supply voltage…)
- Start with SPA if sensitive area not previously localized
  - Scanning large areas sensitive to loss of focus
- Backside high quality preparation mandatory
  - Mirror polishing
  - Thickness uniformity
- For synchronous testing, adapt test setup and acquisition method to sync with 1kHz laser clock

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Work in progress at IMS (1/4)

- 3 PhD Thesis related to TPA
  - Kai SHAO
    - Using TPA for improved resolution in failure analysis
    - Modeling, characterization, FA case studies
  - Adele MORISSET
    - Development of new optical components and methods for non-linear imaging of integrated circuits
    - Modeling, experimental development
  - Nogaye MBAYE
    - Application of laser testing to recent power technologies (SiC, GaN)
    - Use two photon for stimulating wide bandgap materials

Work in progress at IMS (2/4)

- Modeling
  - Currently evaluating MEEP
    - MIT open source framework for FDTD simulation
  - Many effects to consider
    - Non-linear absorption
    - Kerr effect (self focusing)
    - Self phase modulation
    - Intrinsic free carriers absorption
    - Generated free carriers induced index variation
    - Generated free carriers induced absorption (self absorption)
    - Intrinsic dispersion
    - Self induced dispersion
    - Chromatic abberations

    …
  - Some physical parameters not found yet in litterature
    - To be measured

Work in progress at IMS (3/4)

- Experimental developments
  - 65nm test vehicle including many different structures
    - TPA spot size characterization
    - Impact of ageing on SEE sensitivity
  - Acquisition of a new laser source for TPA
    - Fiber technology : much more stable output energy (1%)
      - Real single-shot capability
    - Oscillator, min 1MHz repetition rate
      - Easier acquisition synchronisation and averaging
  - Development of a new electrical test bench for SEB
  - New energy calibration setup to improve linearity and reproducibility

Work in progress at IMS (4/4)

- Development of fiber compoents to transport femtosecond pulses
  - In replacement of free space propagation
    - Much more stable beam pointing and spot size
    - More secure
  - Final objective: integration into PULSCAN systems

- TPA using visible (green and blue) beams
  - SEE in wide band-gap devices