

4th DRD3 Week, CERN, 10-15 November 2025

First 3PA on irradiated 3D RD50 CNM + 2PA, 1PA

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Content

TCT

➤ 3PA

➤ 2PA

➤ 1PA

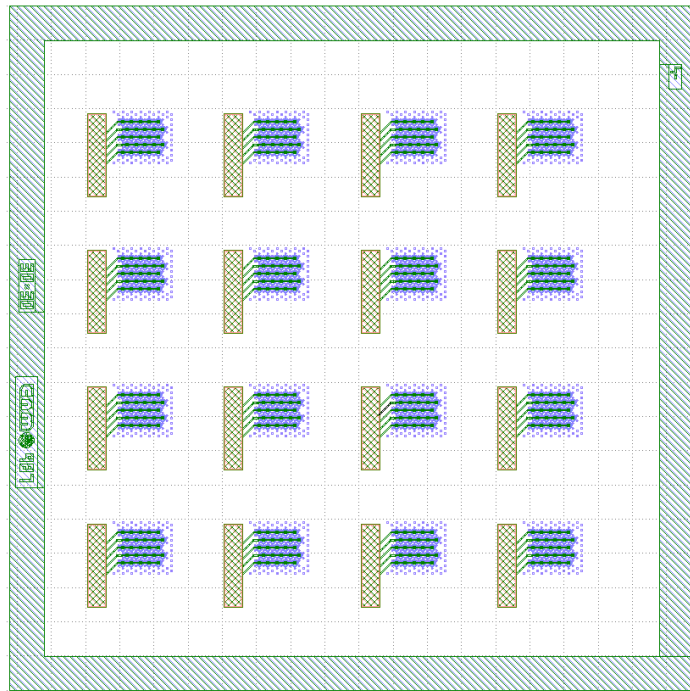
Samples

3D CNM Hex

Devices and Characterization technique

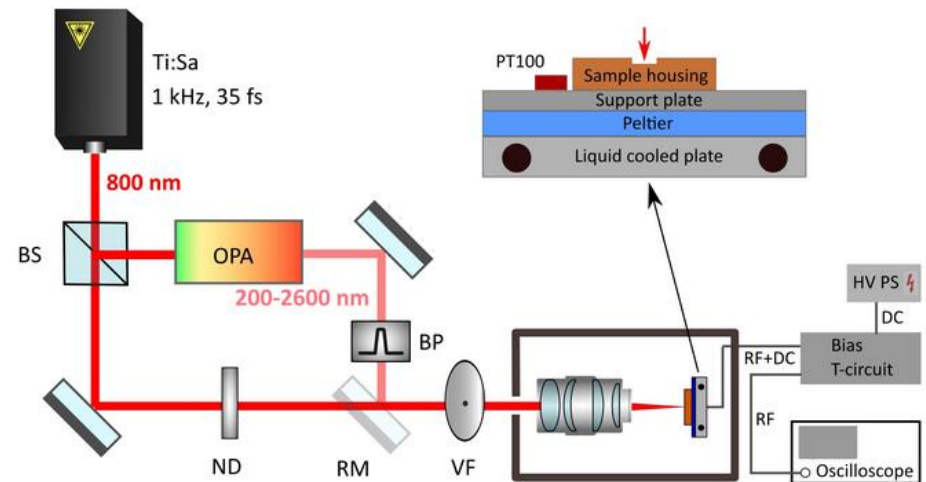
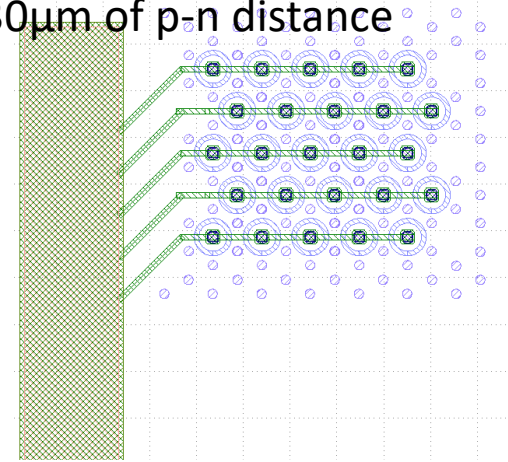
4-X is only one type of 3D sensors that we have in non-irradiated and irradiated version (two fluences $5e15$ and $1e16$ n_{eq}/cm^2)

HEX 4-X



4000 μ m

Arrays of 5x5 pixels in hexagonal geometry with 30 μ m of p-n distance

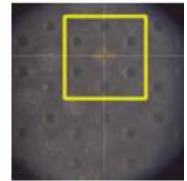
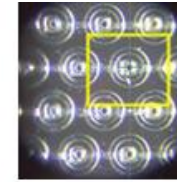


Charge vs. Depth

scanning area 100 x 100 μm
(backside)

Charge vs depth (front face = 0)

650 pJ / 40 V



Fixed scale for every map

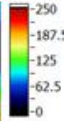
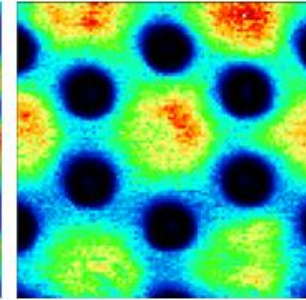
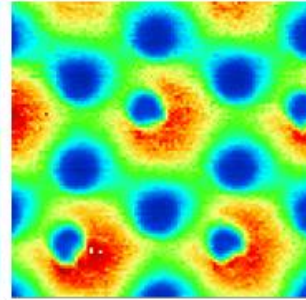
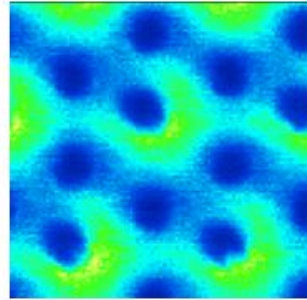
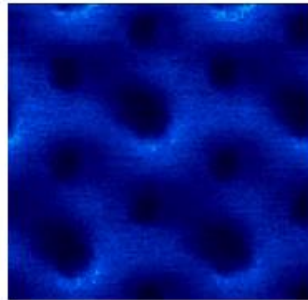
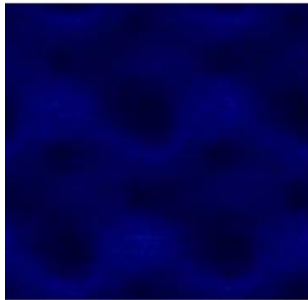
35 μm

100 μm

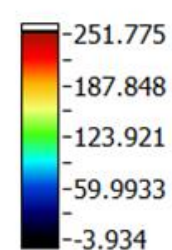
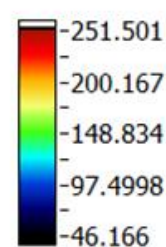
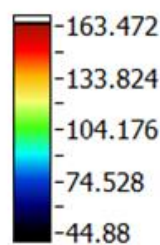
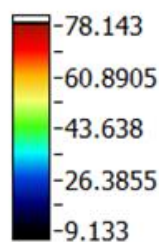
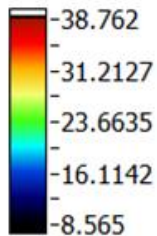
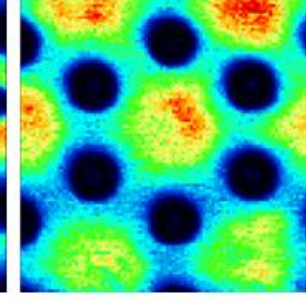
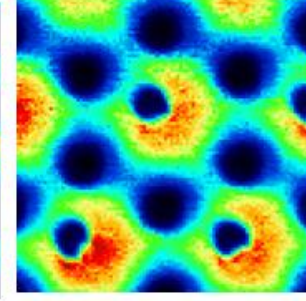
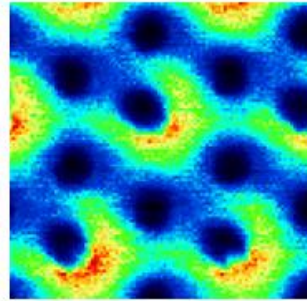
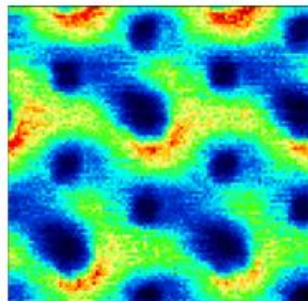
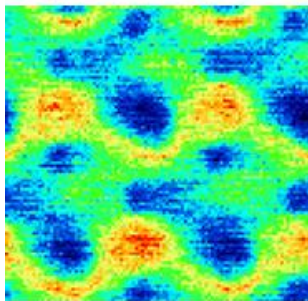
140 μm

185 μm

250 μm



Optimized scale for every map (for comparison)



area 100 x 100 μm

Rise Time (RS vs depth (front illumination))

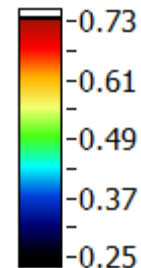
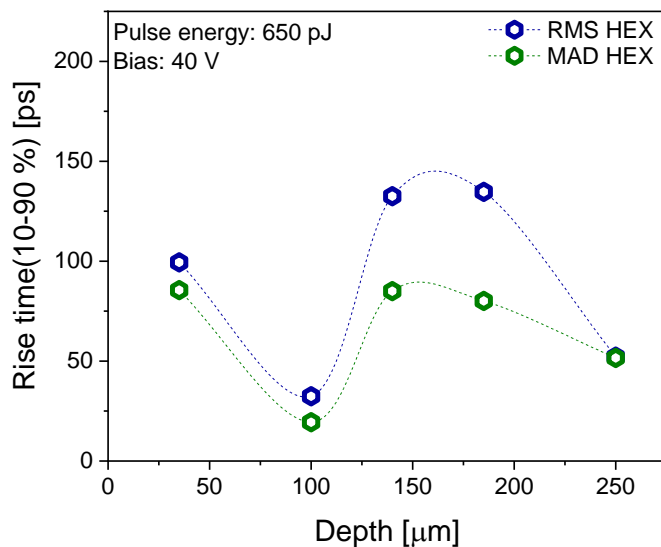
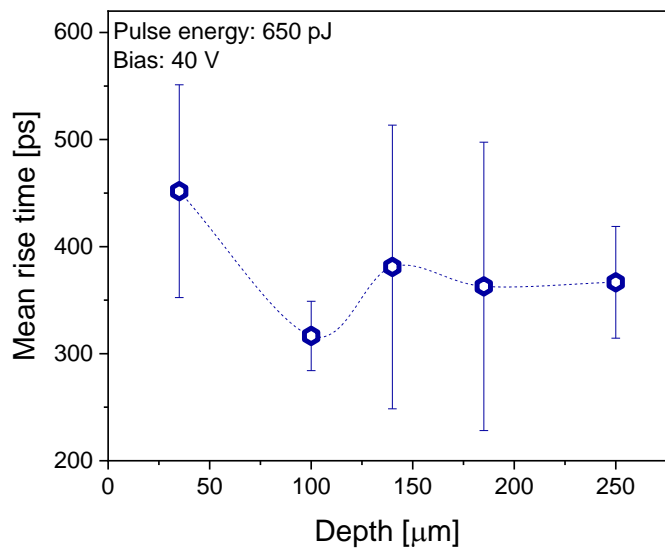
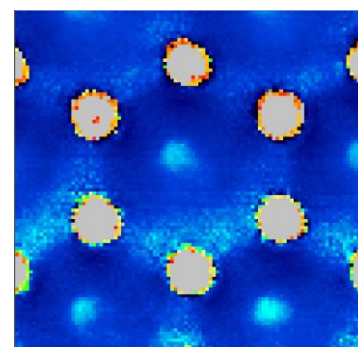
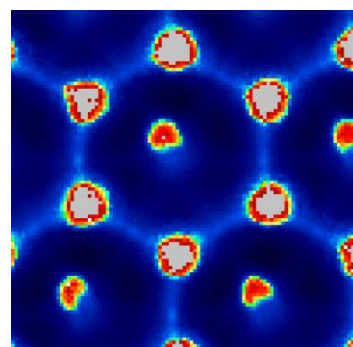
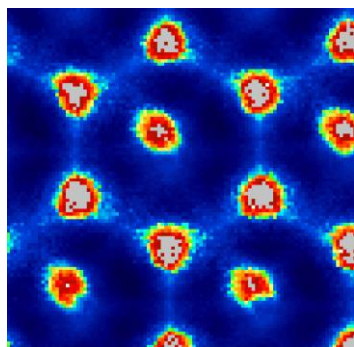
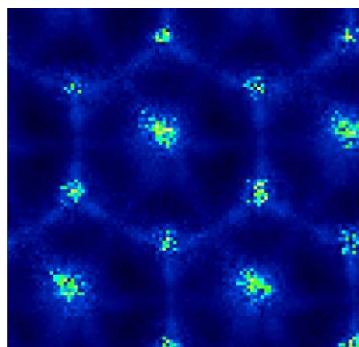
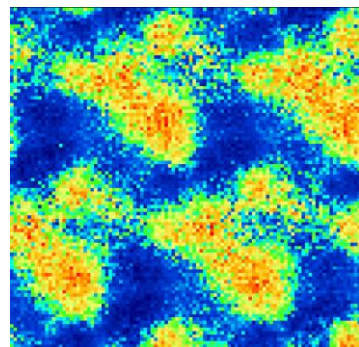
35 μm

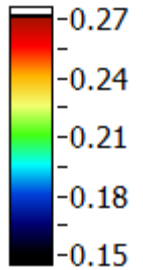
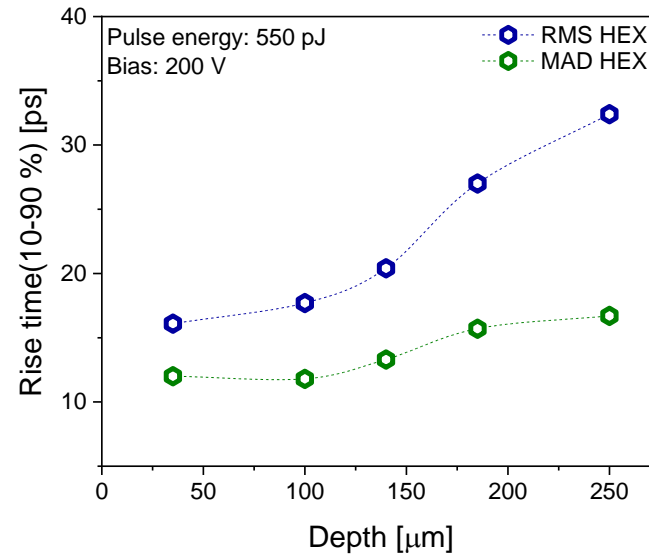
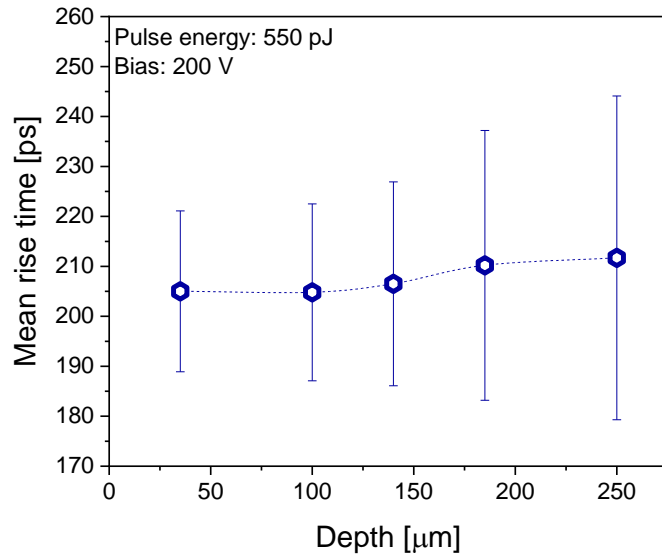
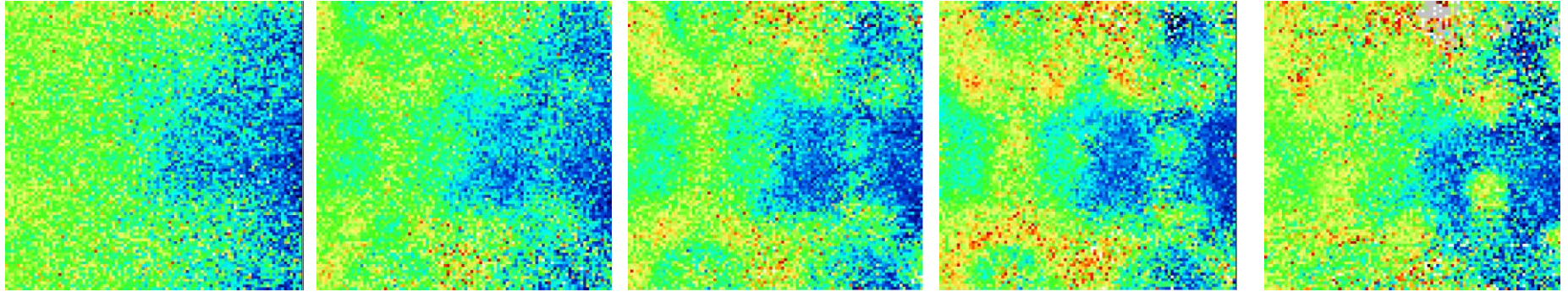
100 μm

140 μm

185 μm

250 μm



area 100 x 100 μm 35 μm 100 μm 140 μm 185 μm 250 μm 

ToA (25%) vs depth (front face)

area 100 x 100 μm

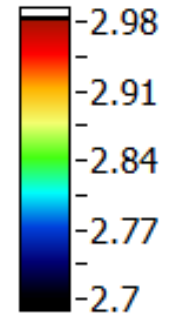
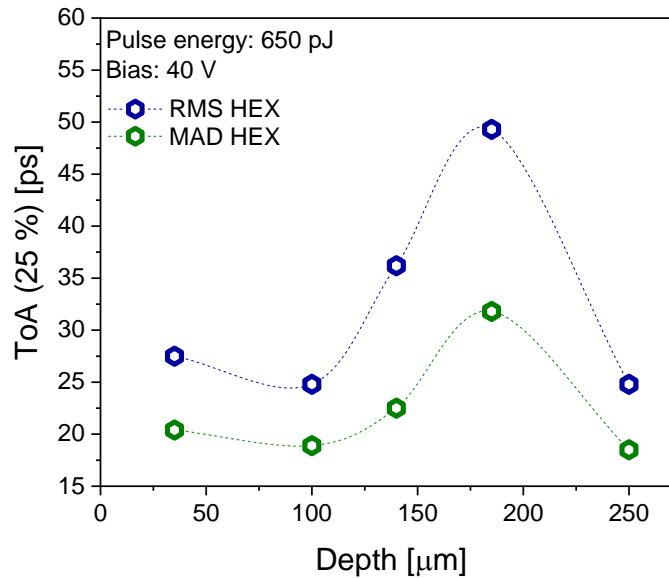
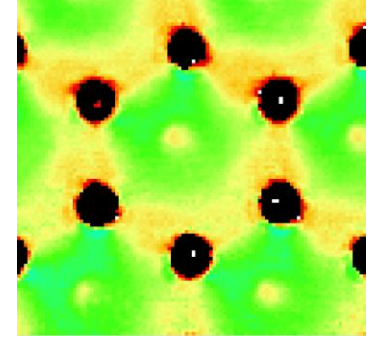
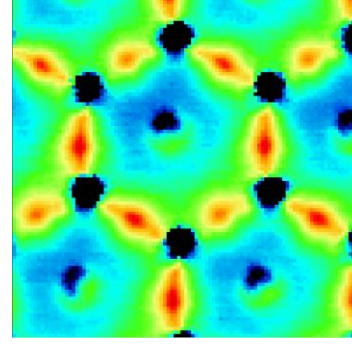
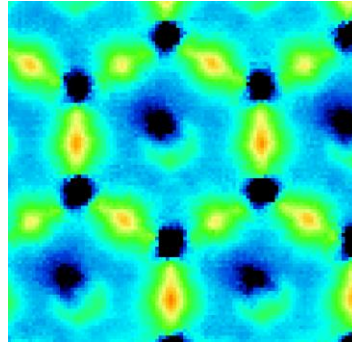
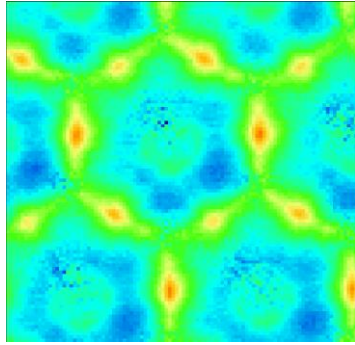
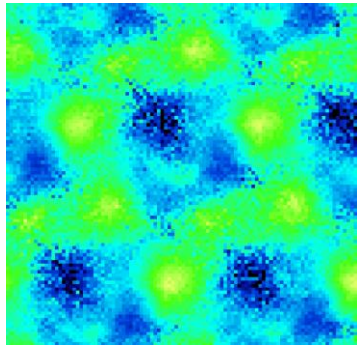
35 μm

100 μm

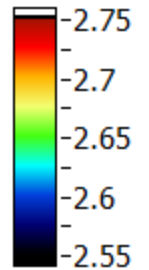
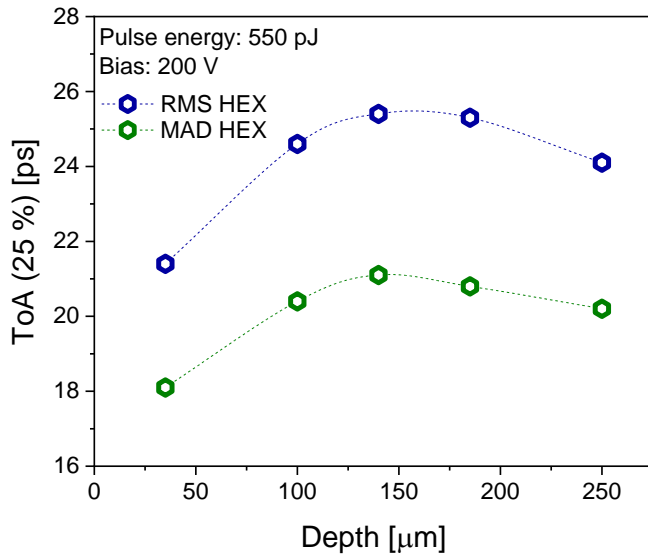
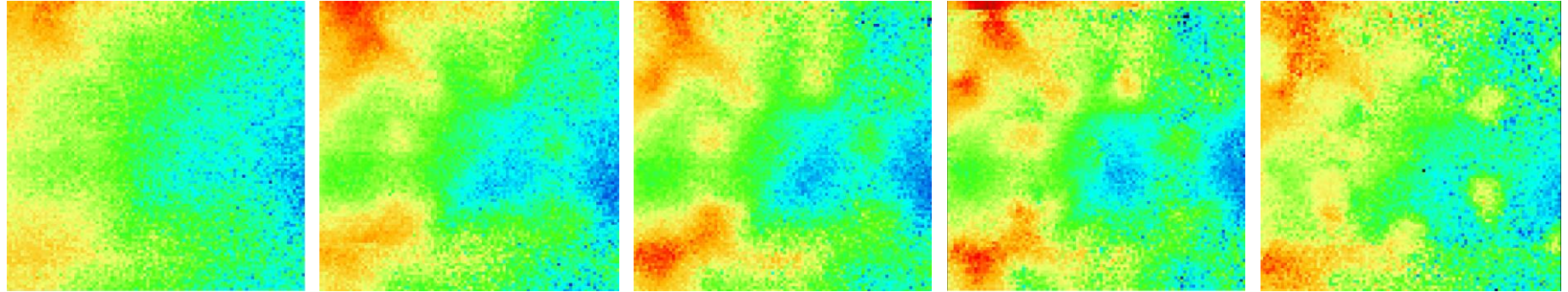
140 μm

185 μm

250 μm



ToA (25%) vs depth (front face = 0)

area 100 x 100 μm 35 μm 100 μm 140 μm 185 μm 250 μm 

ToA (50%) vs depth (front face = 0)

area 100 x 100 μm

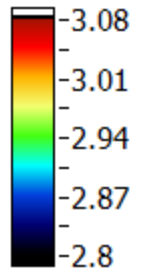
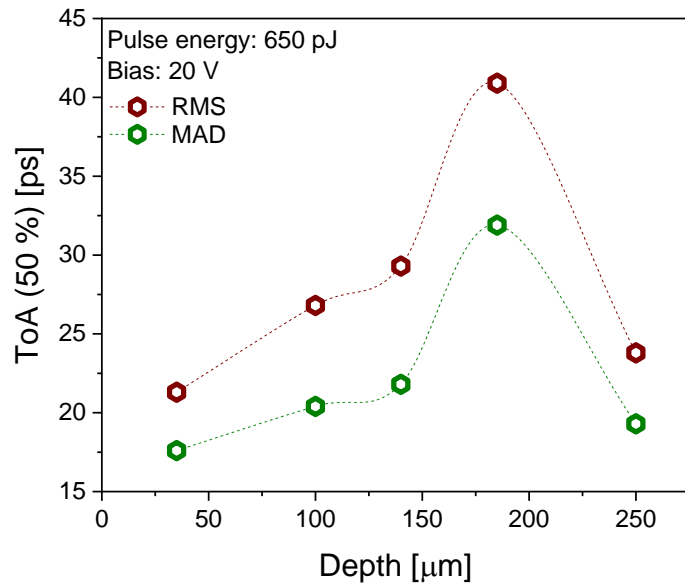
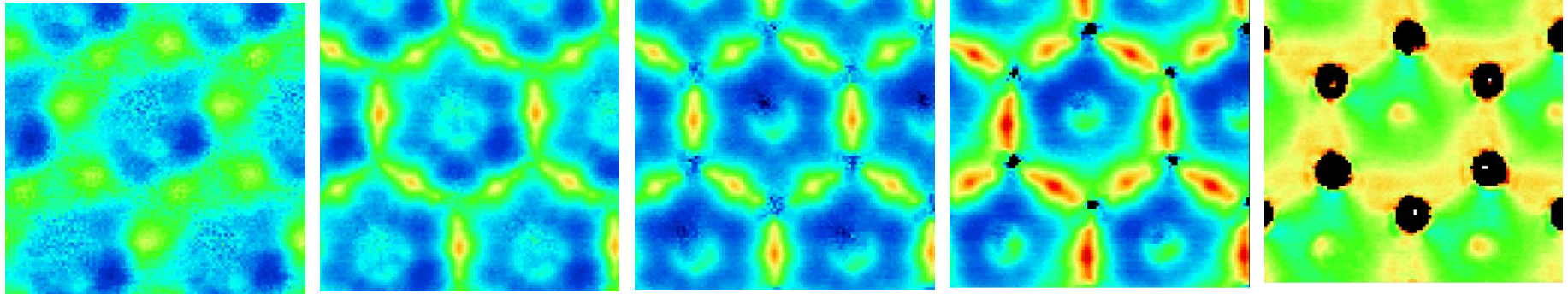
35 μm

100 μm

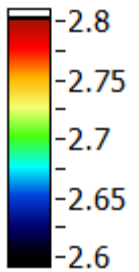
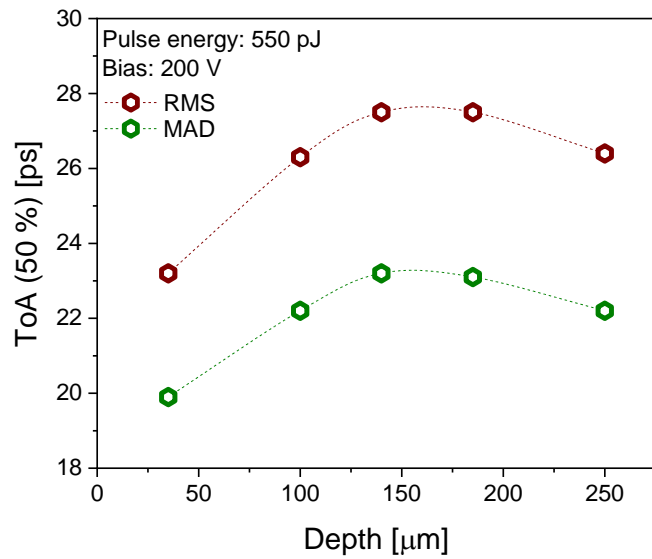
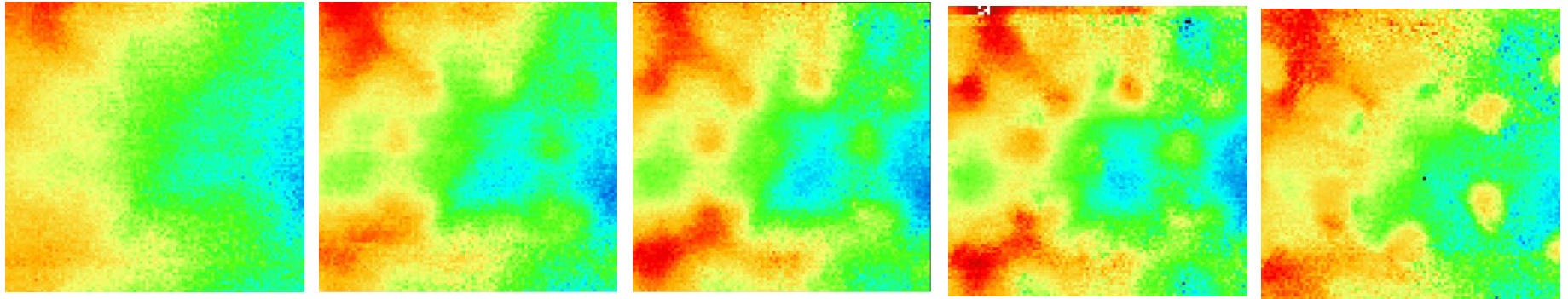
140 μm

185 μm

250 μm



TA-50 vs depth (front face = 0)

area 100 x 100 μm 35 μm 100 μm 140 μm 185 μm 250 μm 

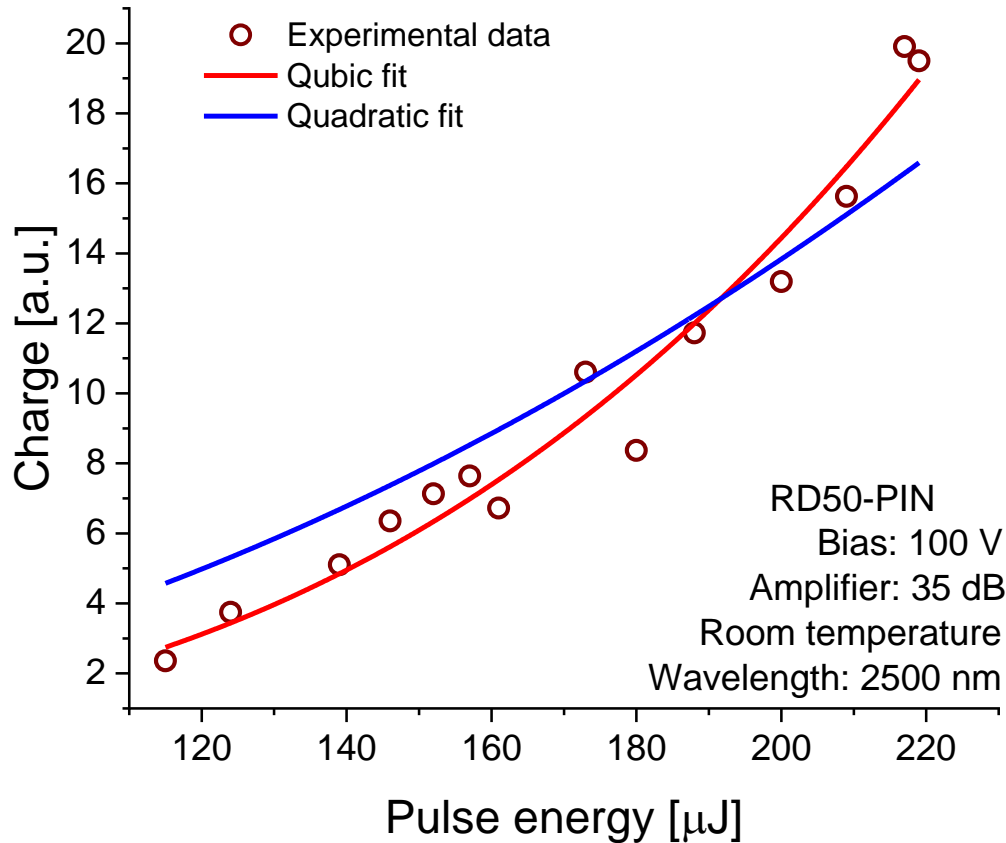
3PA in Si sensor

Applied wavelength: 2500 nm = 0.496 eV

TPA not possible $2 \times 0.496 = 0.992 \text{ eV} < 1.12 \text{ eV}$ (Si bandgap)

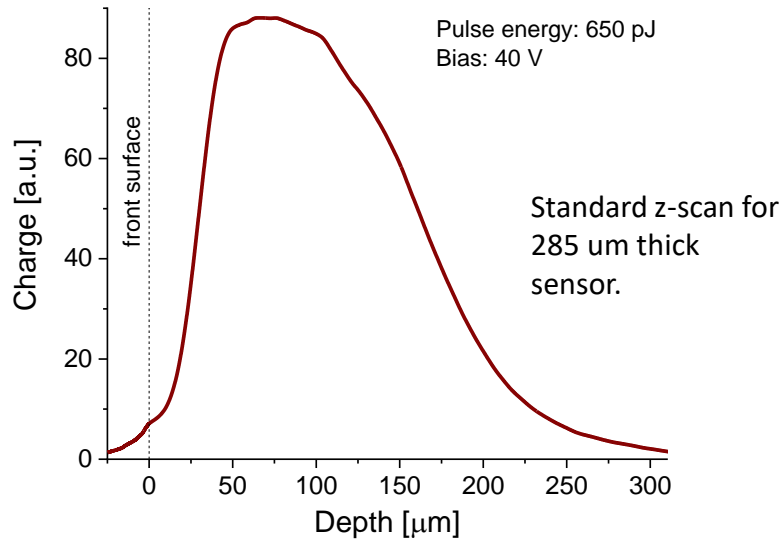
3PA should exhibit cubic dependence vs power

Test performed on standard Si PIN (RD50 production): 3PA confirmed

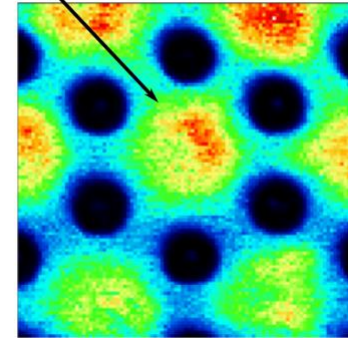


3PA vs TPA: Z-scans comparison for non-irradiated and irradiated ($5e15$) 3D sensor

TPA - nonirr (1550 nm, 650 pJ, 40 V)



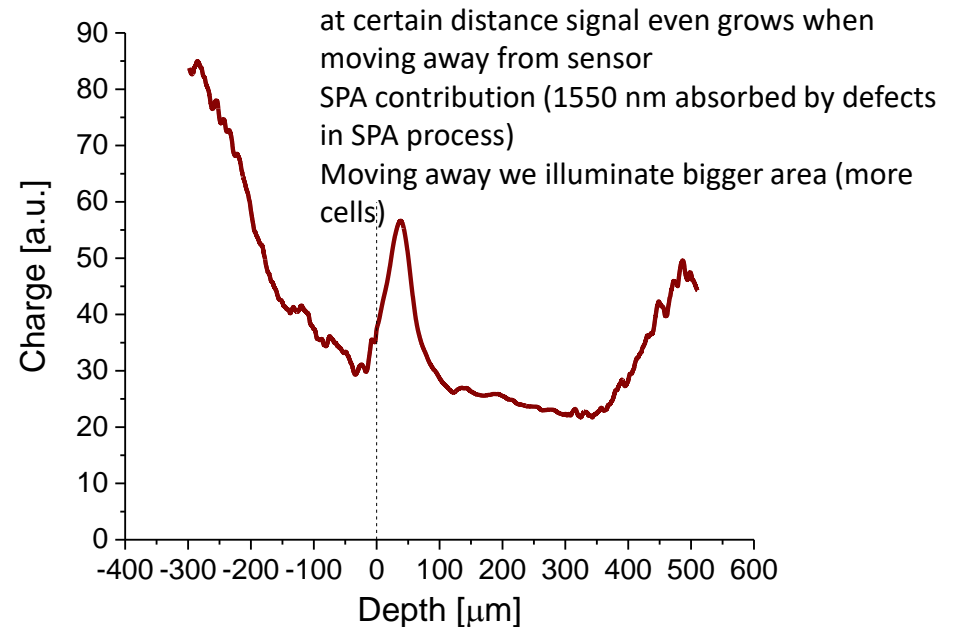
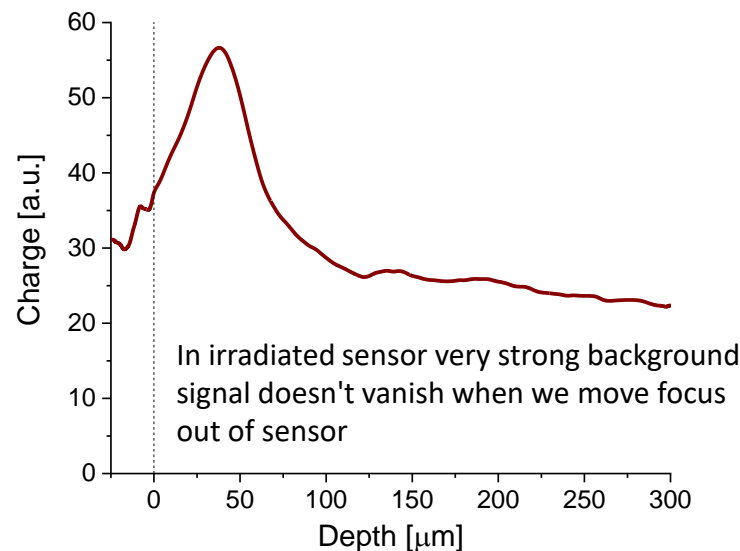
testing point



TPA charge map at 185 μm depth (100 μm from backside)

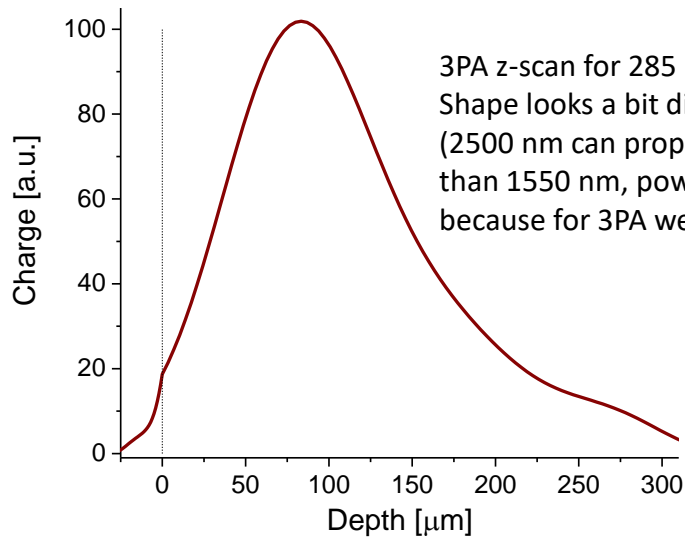
For z-scan the testing point lying between electrodes was chosen to minimize beam clipping. Scan was taken by illumination from backside

TPA - irr $1.5e15$ (1550 nm, 550 pJ, 40 V)

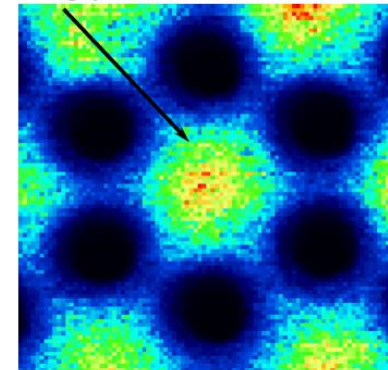


3PA vs TPA: Z-scans comparison for non-irradiated and irradiated ($5e15$) 3D sensor

3PA - nonirr (2500 nm, 235 nJ, 40 V)

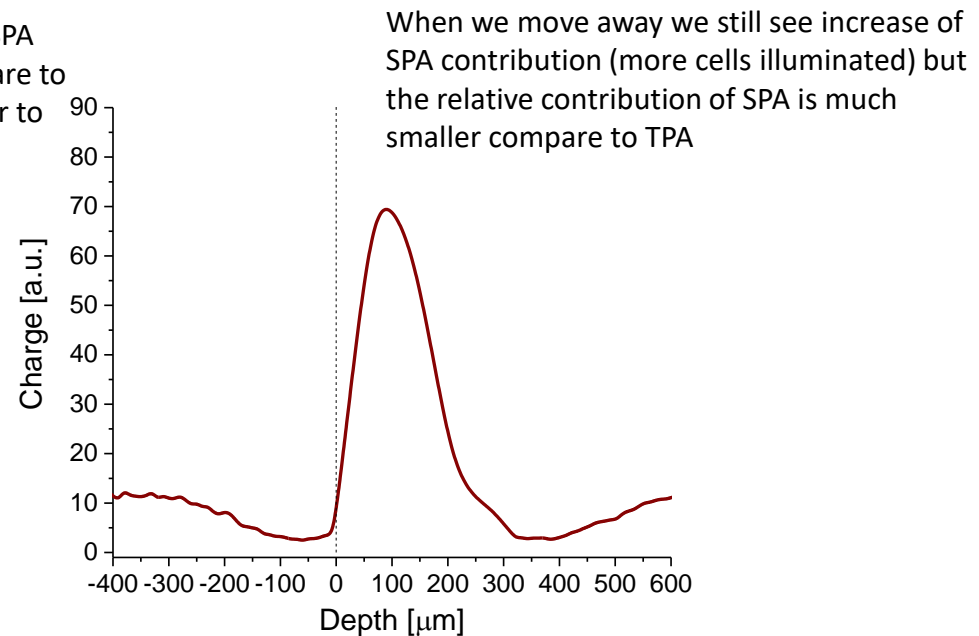
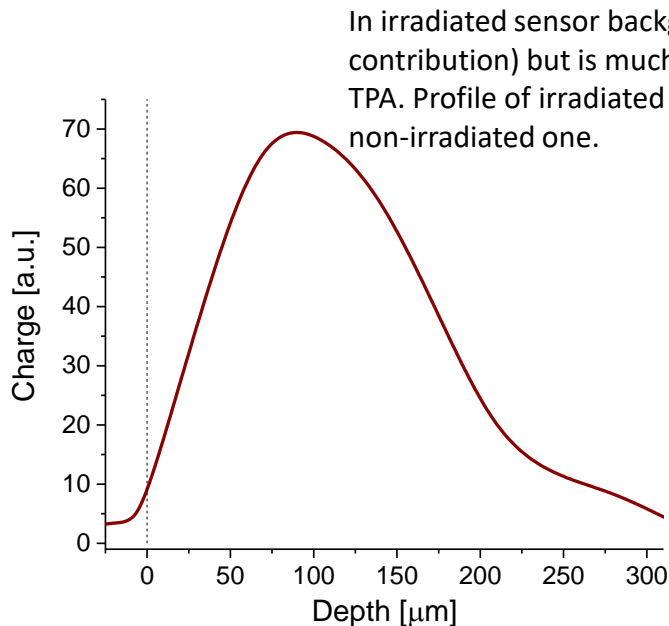


testing point

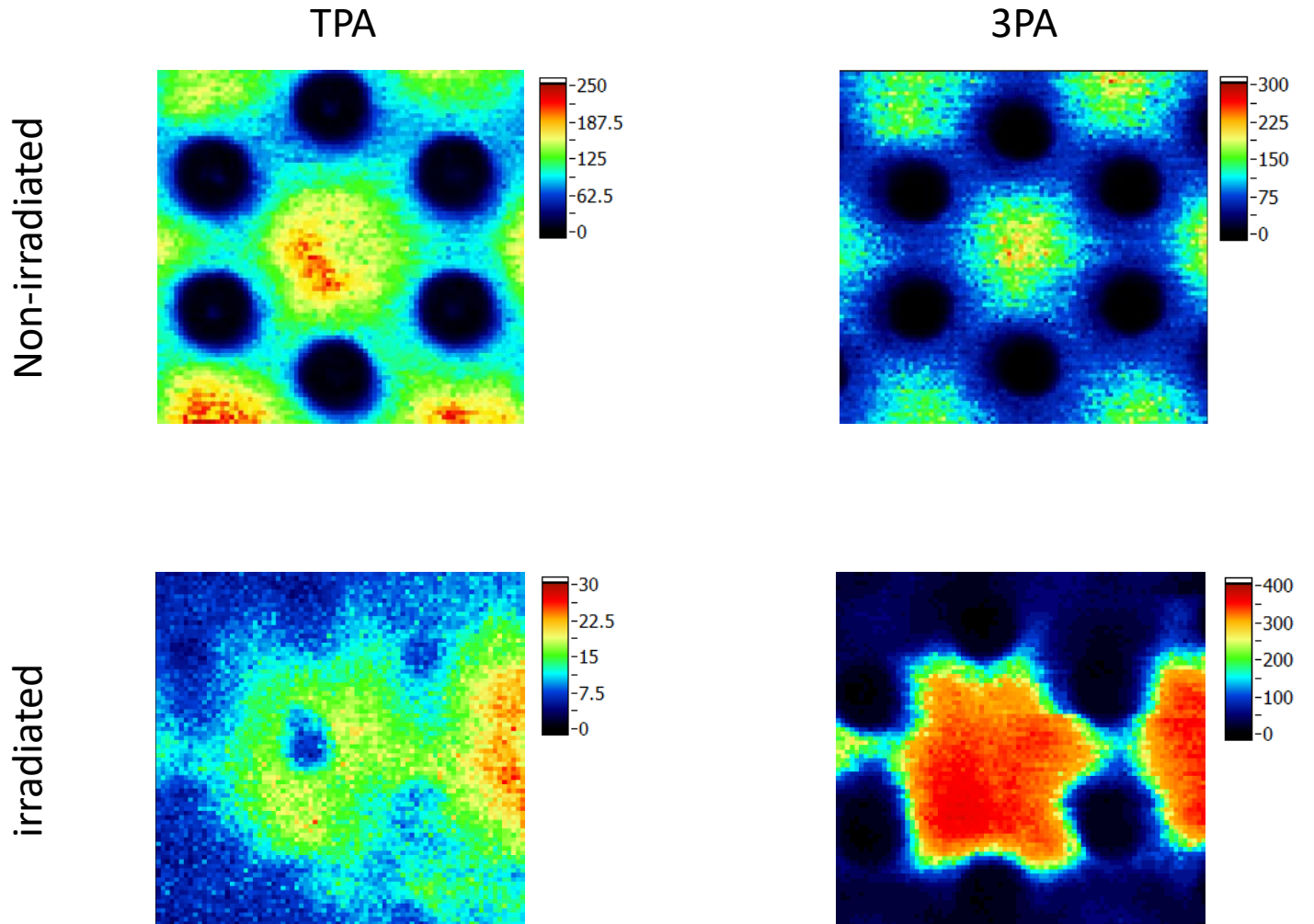


For z-scan testing point lying between electrodes was chosen to minimize beam clipping. Scan was taken by illumination from backside

3PA - irr $1.5e15$ (2500 nm, 235 nJ, 200 V)



3PA vs TPA: charge maps comparison (depth 185 um)

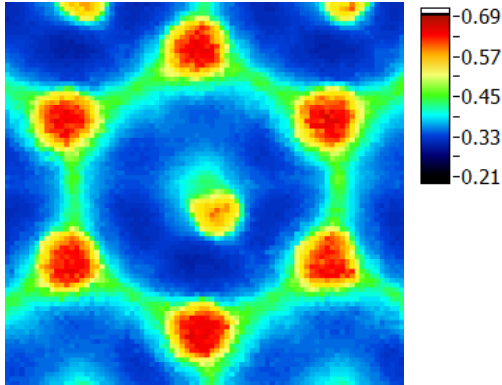


Better contrast in 3PA case for irradiated sensor

3PA vs TPA: rise time maps comparison (depth 185 um)

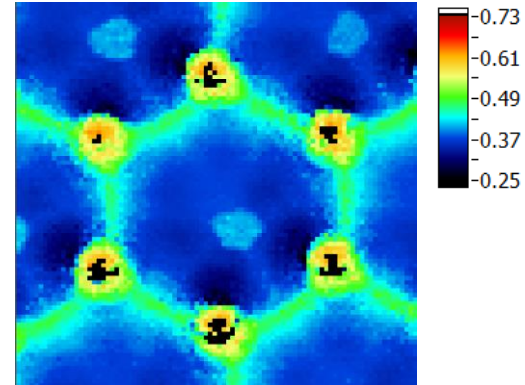
Non-irradiated

TPA



Mean: 363 ps / RMS: 52.9 ps

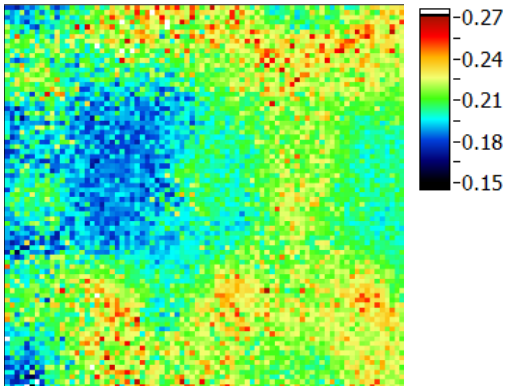
3PA



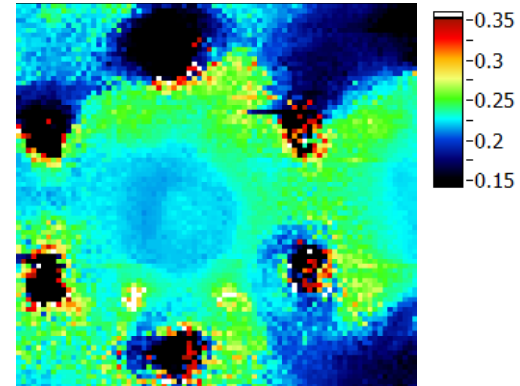
Mean: 398 ps / RMS: 49.9 ps

For non-irradiated sensor both method give similar maps and timing parameters.

irradiated



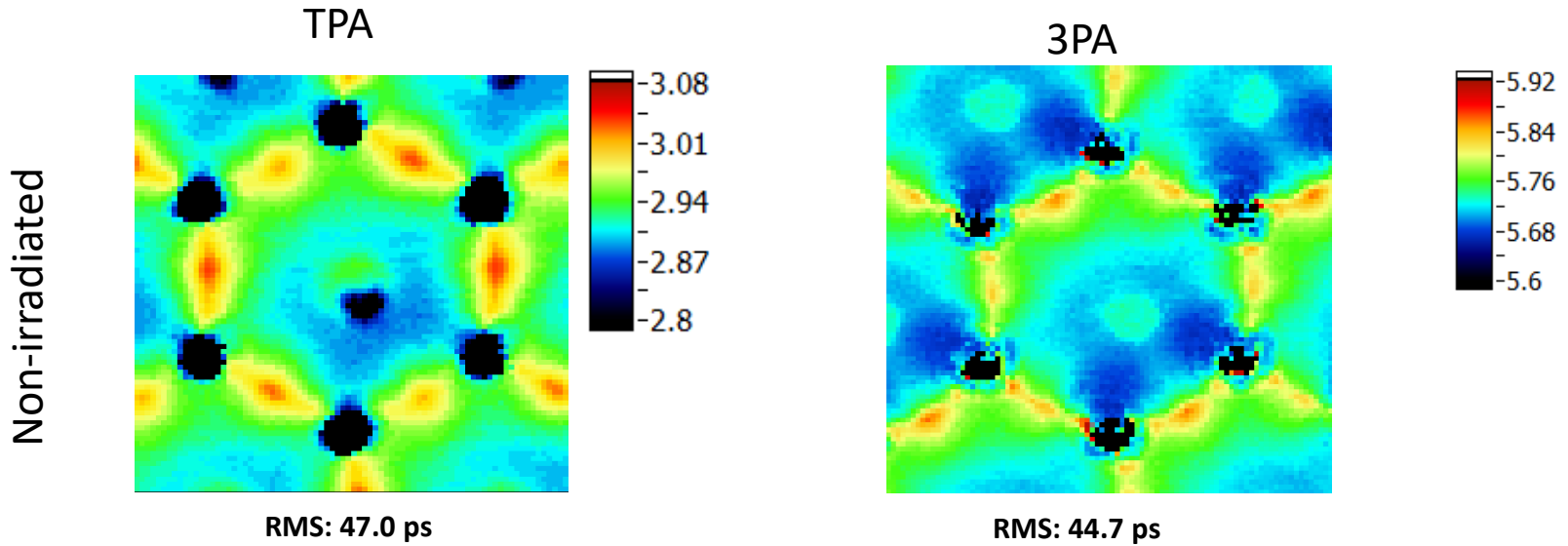
Mean: 225 ps / RMS: 25.1 ps



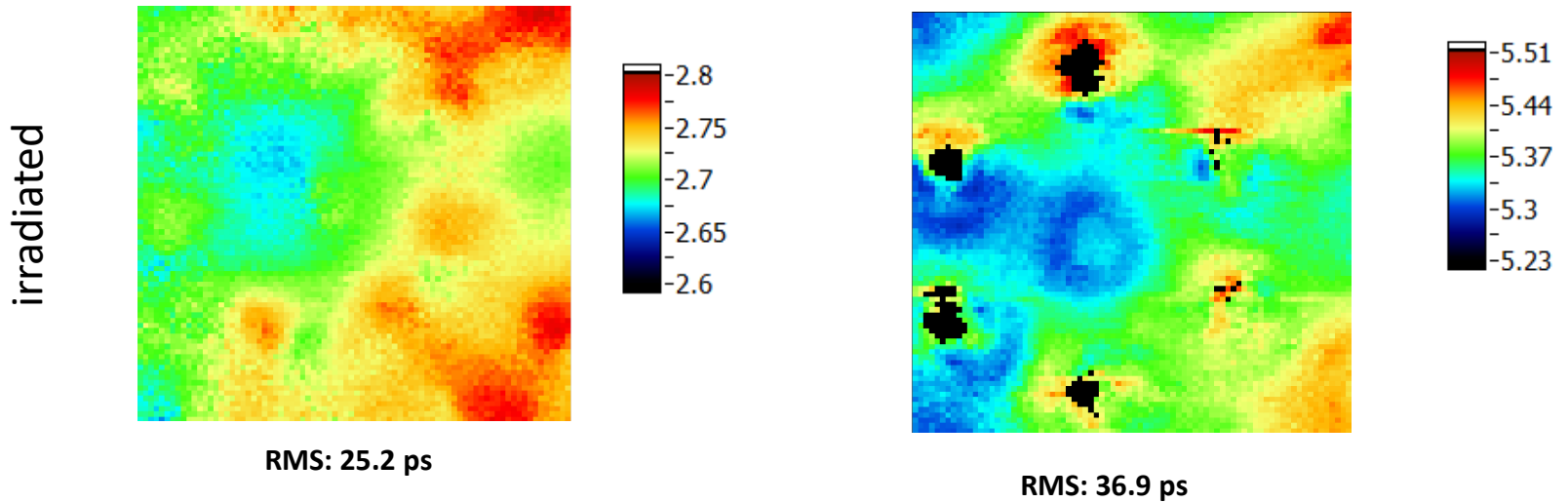
Mean: 210 ps / RMS: 17.8 ps

Better contrast in 3PA case for irradiated sensor

3PA vs TPA: ToA (50 %) maps comparison (depth 185 um)

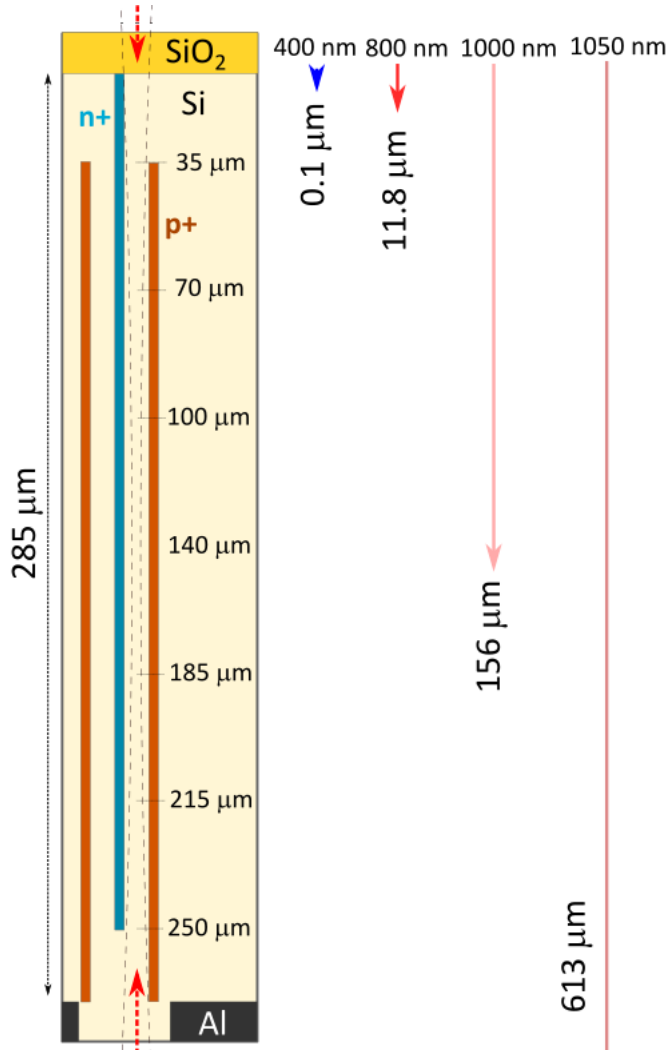


For non-irradiated sensor both method give similar maps and timing parameters.



Better contrast in 3PA case for irradiated sensor

SPA at different wavelengths



Penetration depths in Si from:

<https://www.pveducation.org/pvcdrom/materials/optical-properties-of-silicon>

Selected wavelengths:

400 nm – to test surface

800 nm – to test region with one type of electrode only

1000 nm – to test region with both electrodes

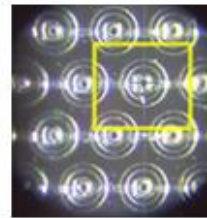
1050 nm – to go through entire sensor

- All measurements at room temperature and with 35 dB amplifier
Laser power was adjusted in every case to give similar level of signal (clearly measurable but low enough to avoid plasma)
Color scales for all maps were optimized individually to obtain best details.

Non-irradiated sensor: bias 40 V

Irradiated (5e15) sensor: bias 200 V

Maps were measured by scanning 80x80 μm around the central cell



Illumination from front is not a big problem for this sensor.

Illumination from backside requires much more power. It seems that back surface is not pure silicon but it's something else. Even on microscopic images both surfaces (front and back) look very different.

Charge

area 80 x 80 μm

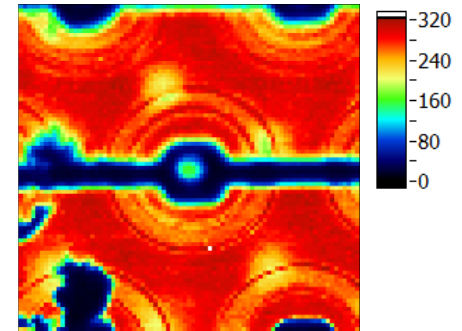
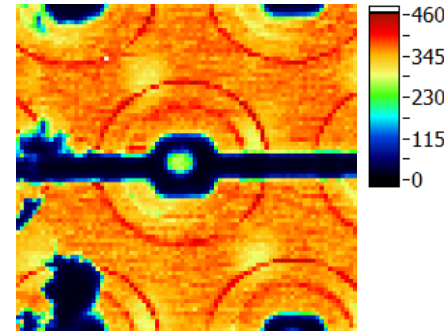
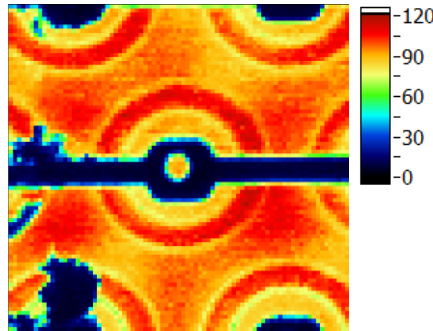
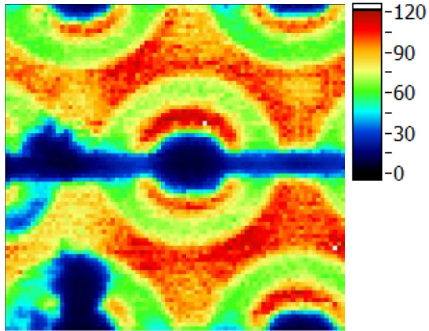
400 nm

800 nm

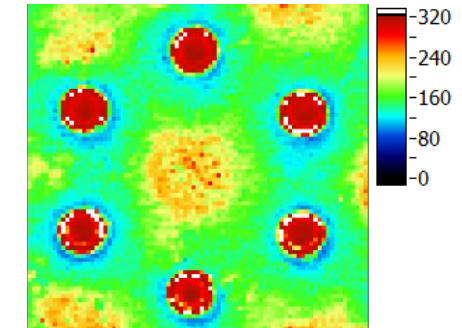
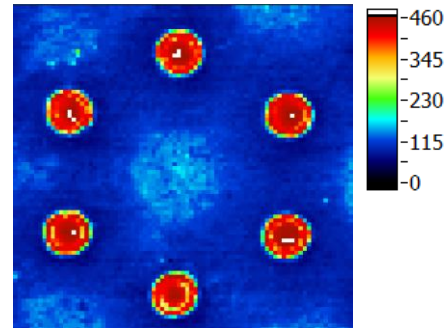
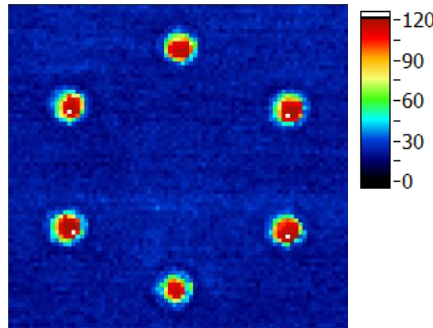
1000 nm

1050 nm

front



back



For back illumination, laser pulse of 400 nm does not give any signal (even for high power). 800 nm gives signal only in areas of p+ column. It looks that for these wavelengths the back surface is not transparent at all. For 1000 and especially for 1050 nm we have some everywhere so probably/ signal/structures are visible for this wavelengths the surface is partially transparent and for power high enough we can see some structural details.

Pulse energies front:

400 nm – 1 pJ

800 nm – 0.5 pJ

1000 nm – 0.5 pJ

1050 nm – 0.5 pJ

Pulse energies back:

400 nm – no signal

800 nm – 25 pJ

1000 nm – 3 pJ

1050 nm – 4 pJ

Non -IRR

ToA (50%) [ns]

area 80 x 80 μm

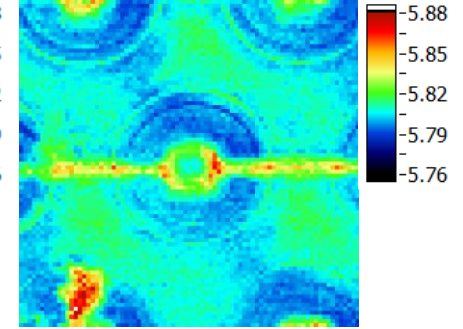
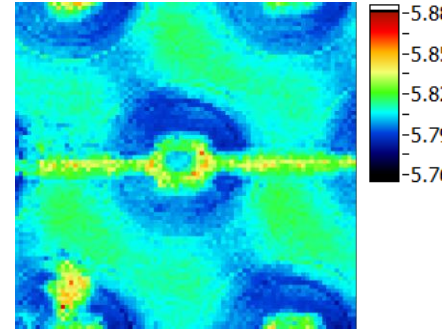
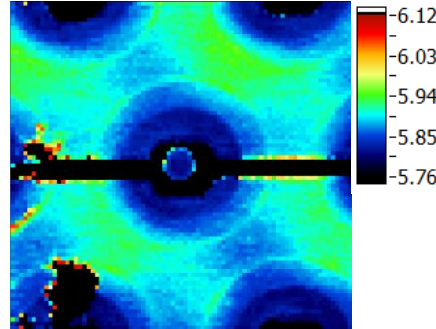
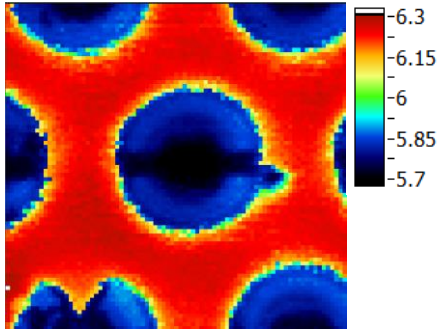
400 nm

800 nm

1000 nm

1050 nm

front



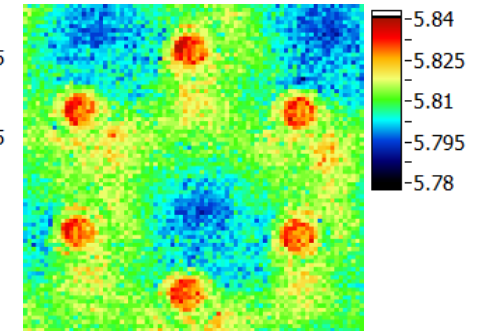
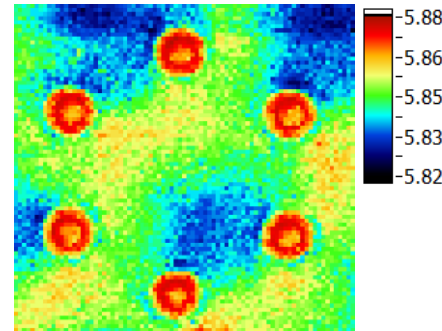
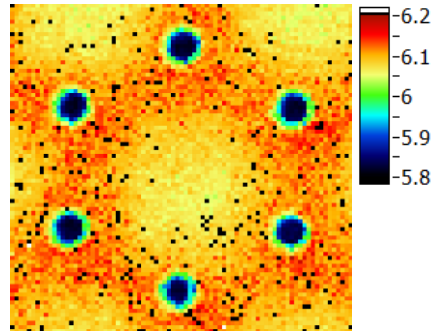
RMS: 232 ps

RMS: 31.3 ps

RMS: 10.8 ps

RMS: 10.2 ps

back



RMS: 53.2 ps

RMS: 9.8 ps

RMS: 7.9 ps

Non -IRR

ToA (50%) [ns]

area 80 x 80 μm

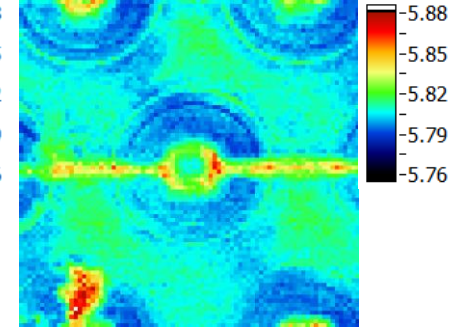
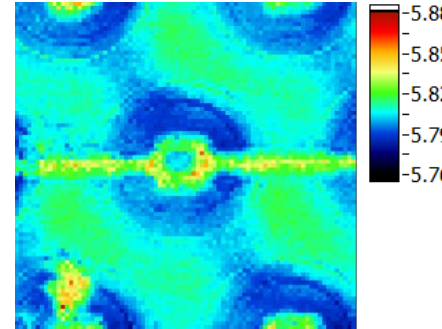
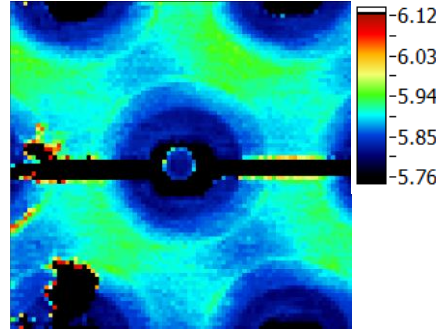
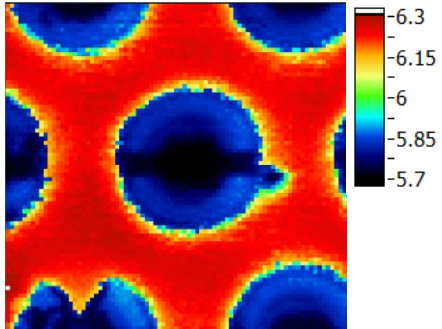
400 nm

800 nm

1000 nm

1050 nm

front



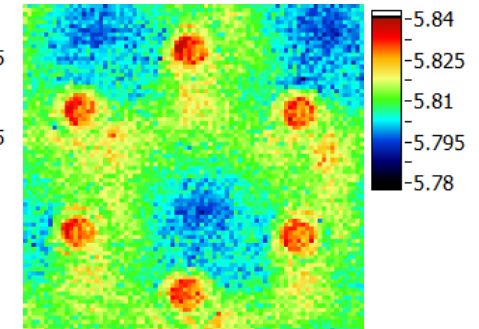
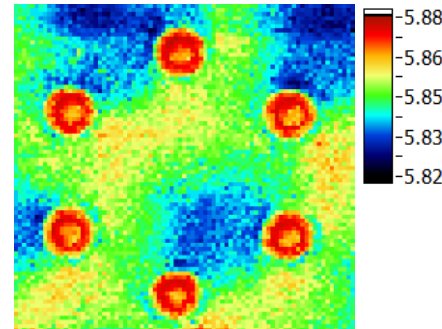
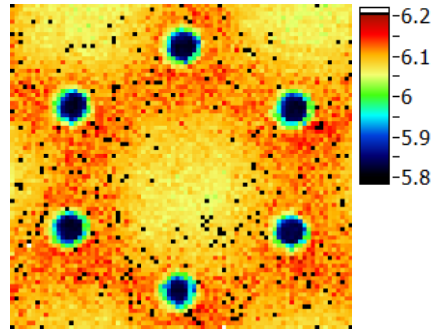
RMS: 232 ps

RMS: 31.3 ps

RMS: 10.8 ps

RMS: 10.2 ps

back



RMS: 53.2 ps

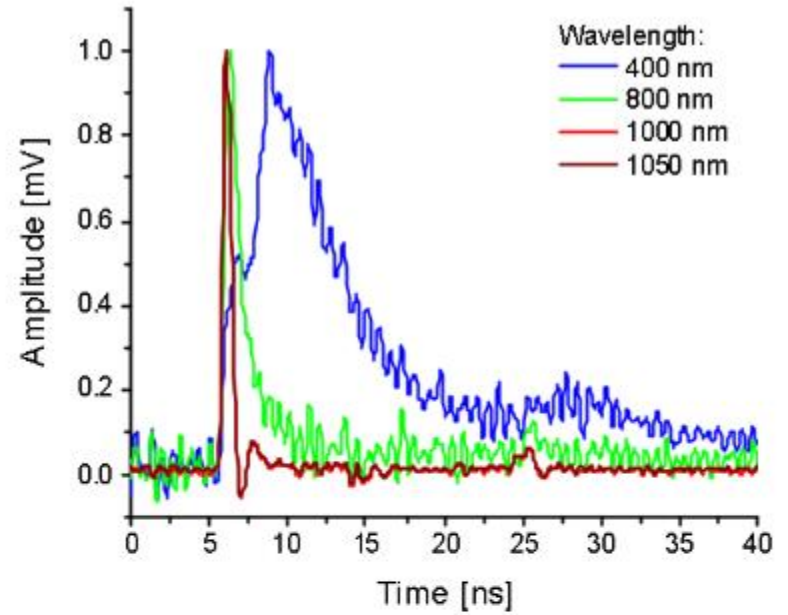
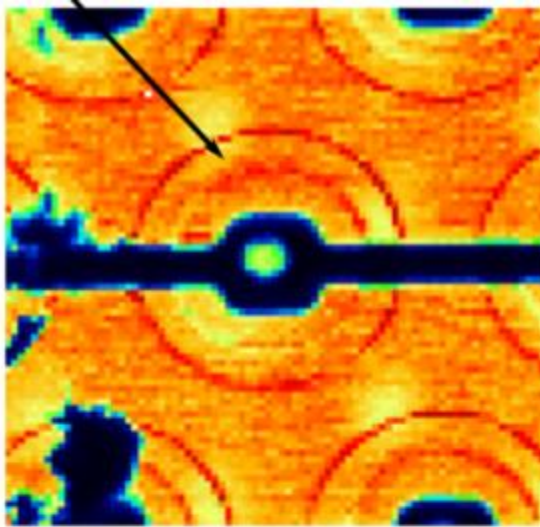
RMS: 9.8 ps

RMS: 7.9 ps

Non -IRR

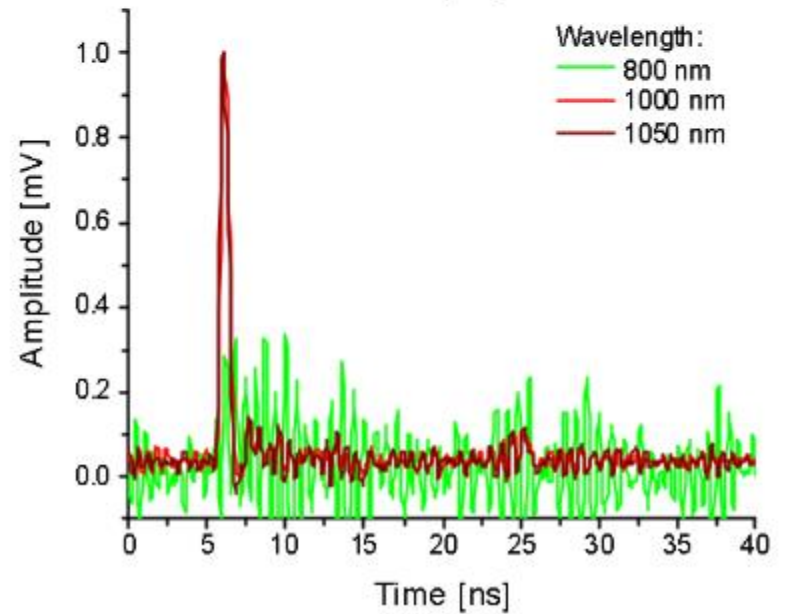
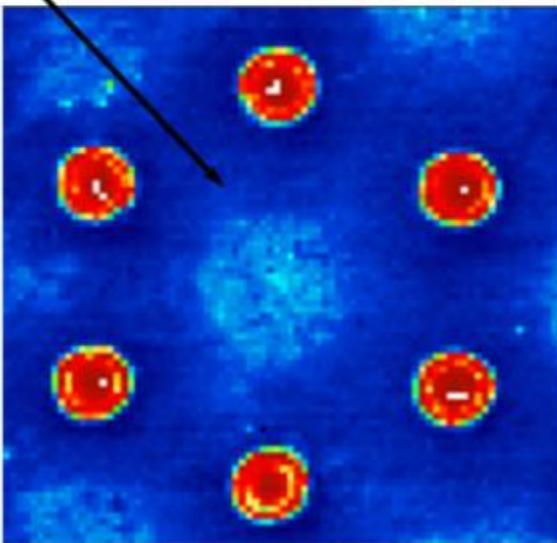
Example Waveforms

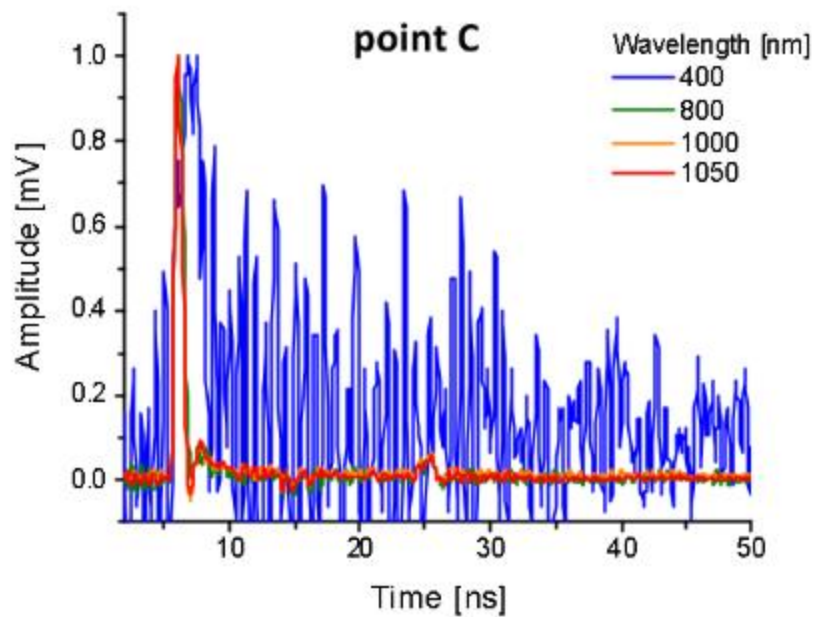
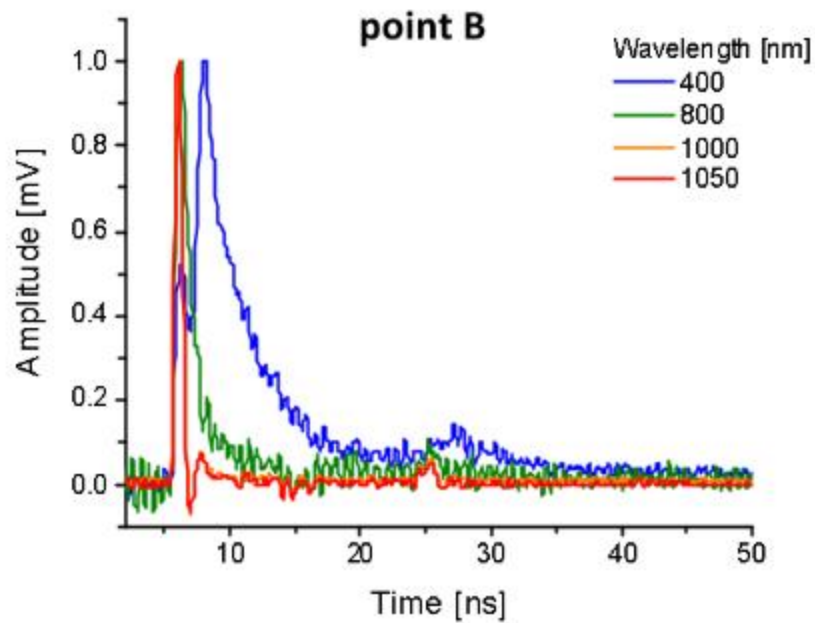
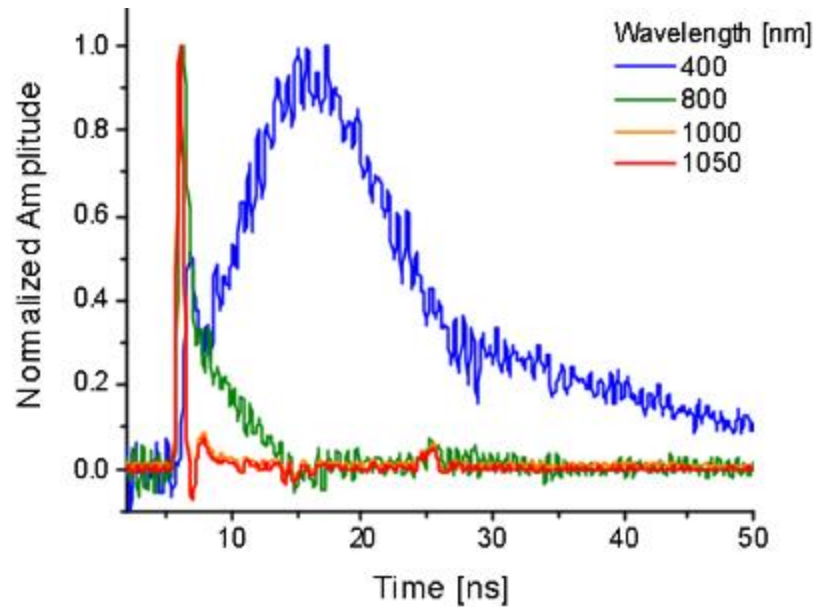
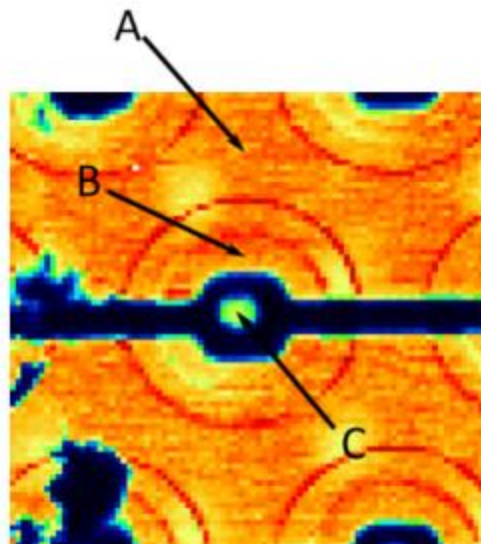
front



back

testing point





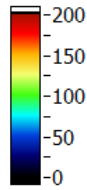
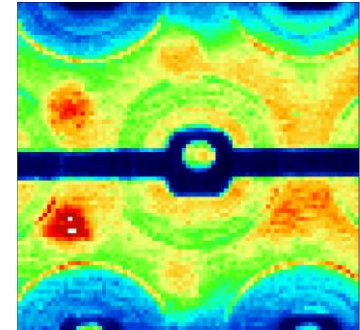
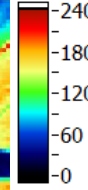
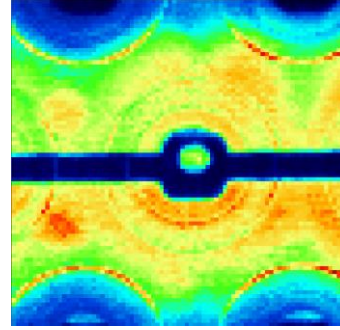
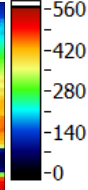
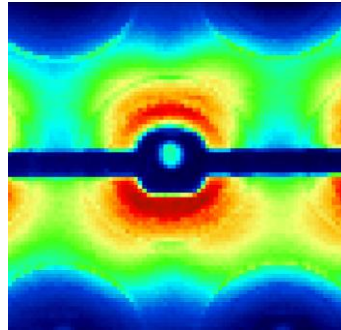
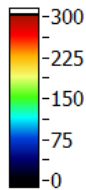
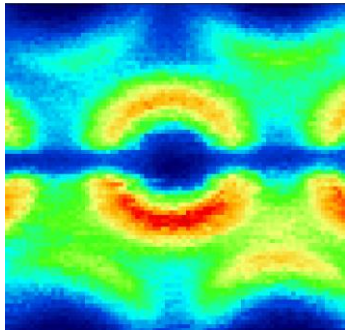
400 nm

800 nm

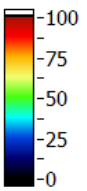
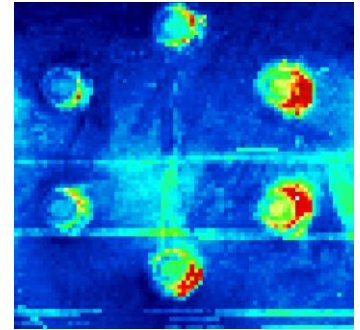
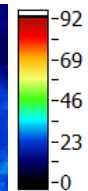
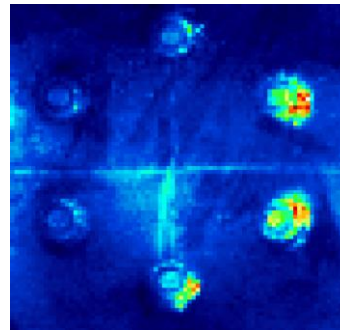
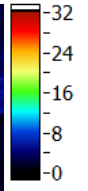
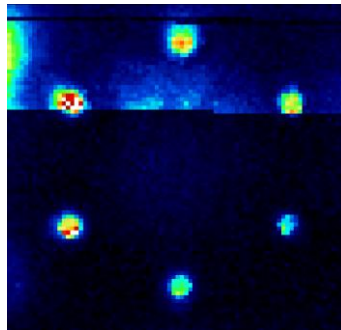
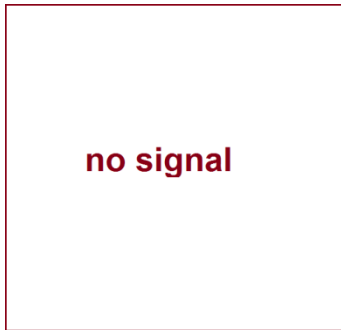
1000 nm

1050 nm

front



back



For back illumination in irradiated sample it's clearly visible that surface is not homogenous what is also visible in microscopic images. Removal of metallic part does not leave nice smooth surface on the back side. In TPA (or 3PA) is not so important because for used wavelengths it's highly transparent (even if not fully) but SPA is strongly affected by surface quality.

Pulse energies front:

400 nm – 35 pJ

800 nm – 35 pJ

1000 nm – 11 pJ

1050 nm – 17 pJ

Pulse energies back:

400 nm – no signal

800 nm – 310 pJ

1000 nm – 70 pJ

1050 nm – 76 pJ

Rise time [ns]

area 80 x 80 μm

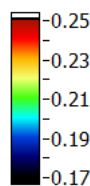
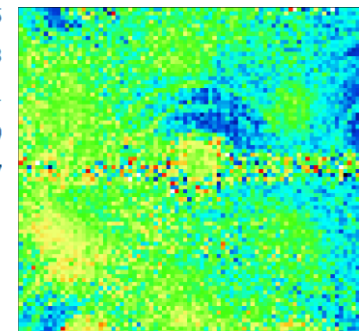
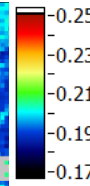
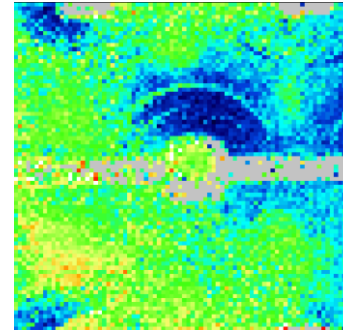
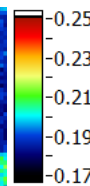
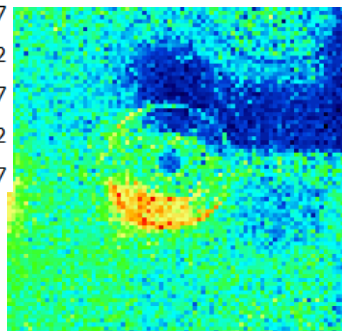
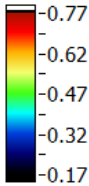
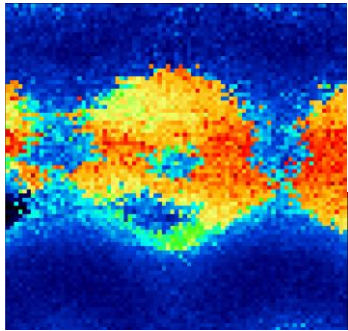
400 nm

800 nm

1000 nm

1050 nm

front



Mean: 369 ps / RMS: 165 ps

Mean: 211 ps / RMS: 9.3 ps

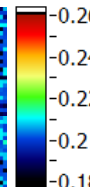
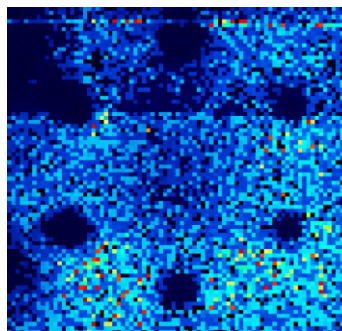
Mean: 222 ps / RMS: 10.8 ps

Mean: 208 ps / RMS: 9.7 ps

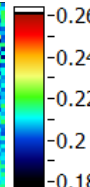
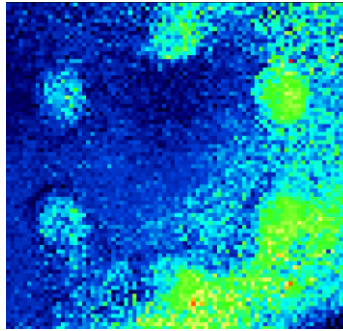
back



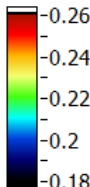
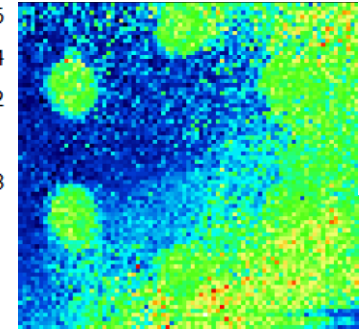
no signal



Mean: 463 ps / RMS: 168 ps



Mean: 203 ps / RMS: 10.8 ps



Mean: 212 ps / RMS: 12.1 ps

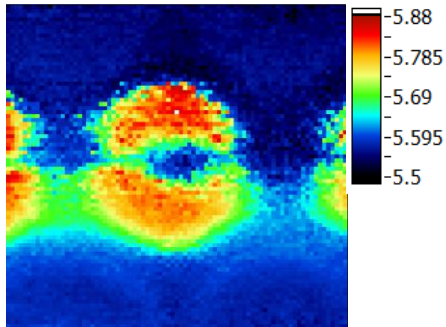
400 nm

800 nm

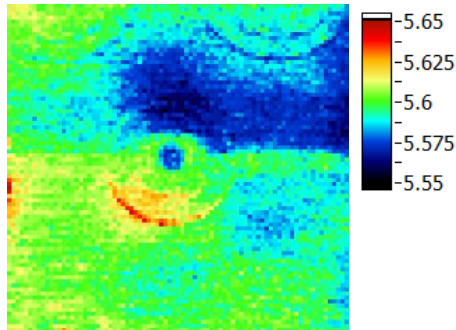
1000 nm

1050 nm

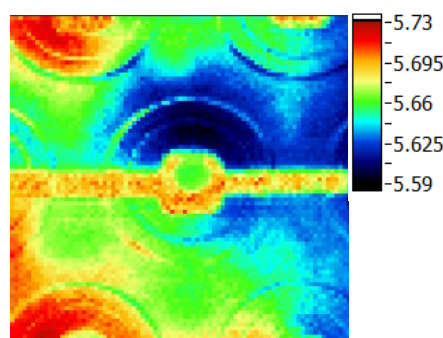
front



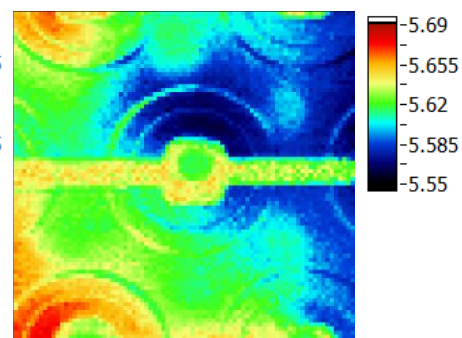
RMS: 88.3 ps



RMS: 13.2 ps

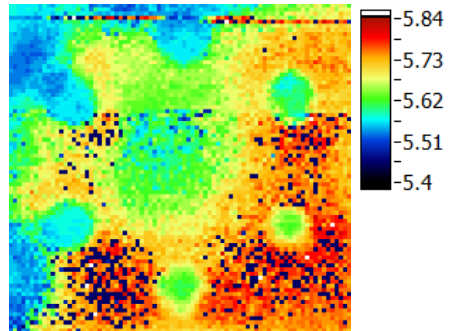


RMS: 23.0 ps

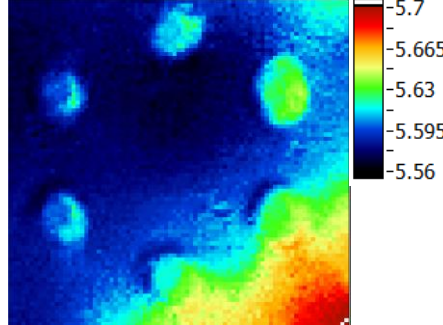


RMS: 21.2 ps

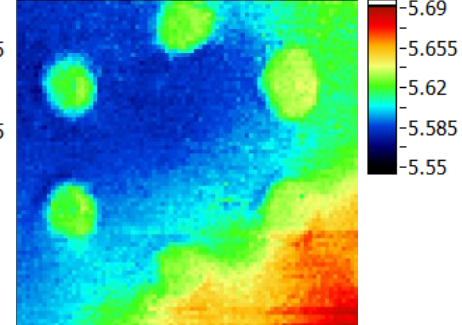
back



RMS: 74.2 ps

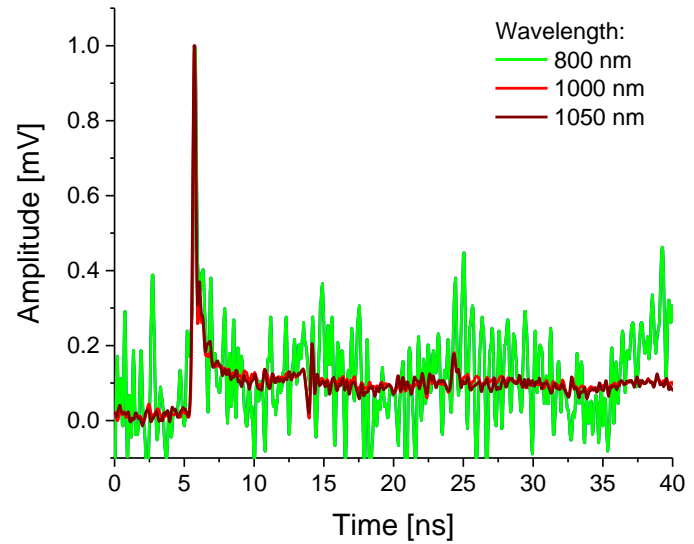
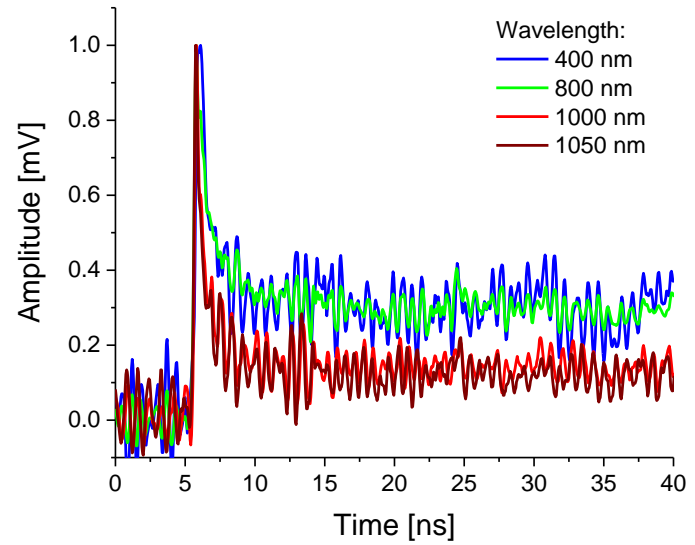
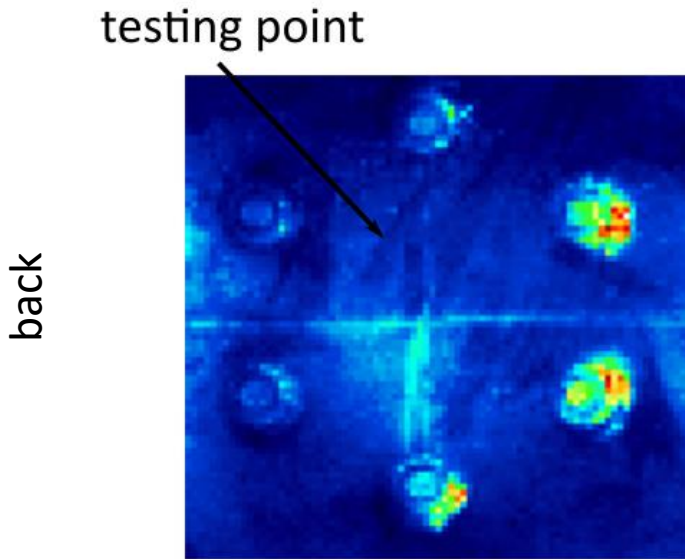
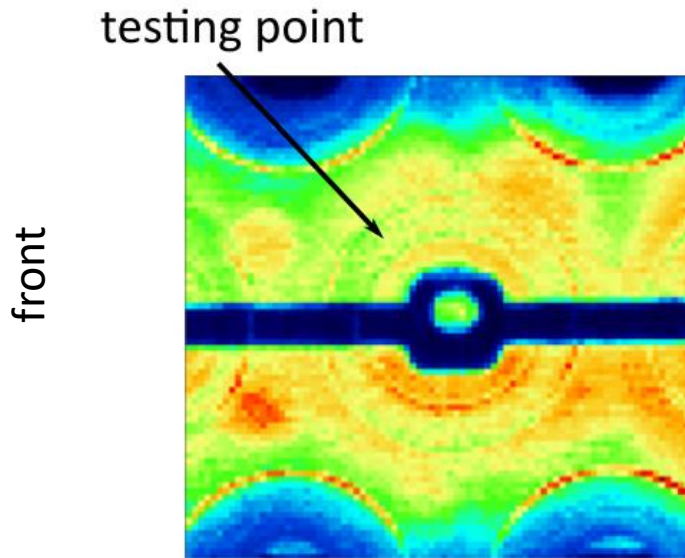


RMS: 30.6 ps



RMS: 28.4 ps

Example Waveforms



Conclusion

- ❑ The first, preliminary, 3PA results on 3D CNM devices are shown
- ❑ 3PA on irradiated samples is compared to no 3PA on non-irradiated
- ❑ SPA and 2PA are compared to 3PA
- ❑ 3PA confirms to be more advanced for irradiated samples