Preliminary results on measurements of surface recombination velocity on slim-edge passivated Si structures

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Outline

- Motivation for measurements
- Samples
- Principles of determination of recombination parameters
- MW-PC transients
- Surface recombination velocity in different samples
- Summary

Motivation

Devices with "slim edges“ have been fabricated to reduce a possible distance between the point of particle interaction and active area of detector.

Devices with "slim edges“ enable better construction and tracker performance. The cutting (especially cleaving) and proper passivation (oxide/nitride for n-type and alumina for p-type) makes it possible to put the edge close to the active area and still have low leakage current and high breakdown voltage.

An investigation of recombination processes at the cleaved edge is important to make a choice of the passivation procedure.

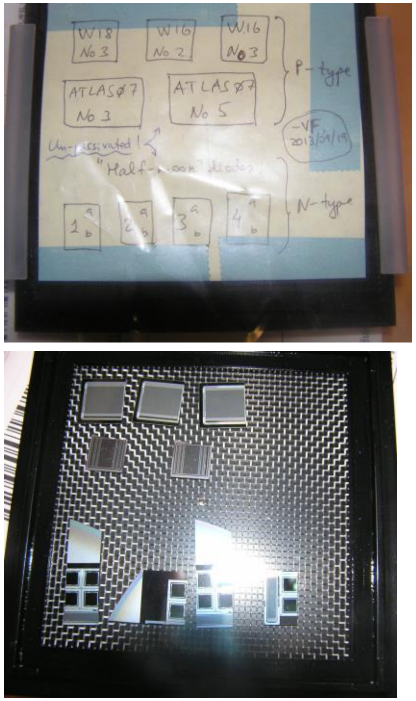
Samples

-- Size: 12x12 mm^2 of 0.3 mm thickness.
-- Material: Bare chips with silicon bulk.

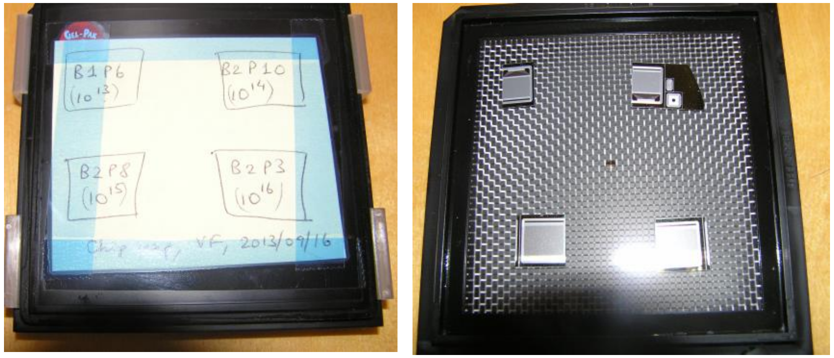
There is aluminum back- and top-side metallization.

The thicknesses are ~0.1 micron and <= 1 micron.

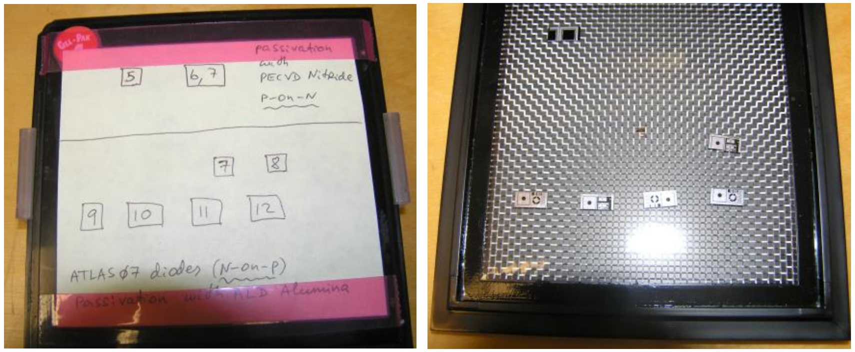
There is silicon oxide on top surface. It's likely about 1 micron thick.
-- Irradiation type: 800 MeV protons.
-- Irradiation fluences (one chip per fluence):
-o- 1.34e13 p/cm^2 (0.95e13 neq/cm^2), +29.0% - 25.8%
-o- 8.14e13 p/cm^2 (5.78e13 neq/cm^2), +15.6% -14.3%
-o- 6.79e14 p/cm^2 (4.82e14 neq/cm^2), +10.9% -10.3%
-o- 5.55e15^ p/cm^2 (3.94e15 neq/cm^2), +9.1% -8.7%



Passivated/ non-irradiated

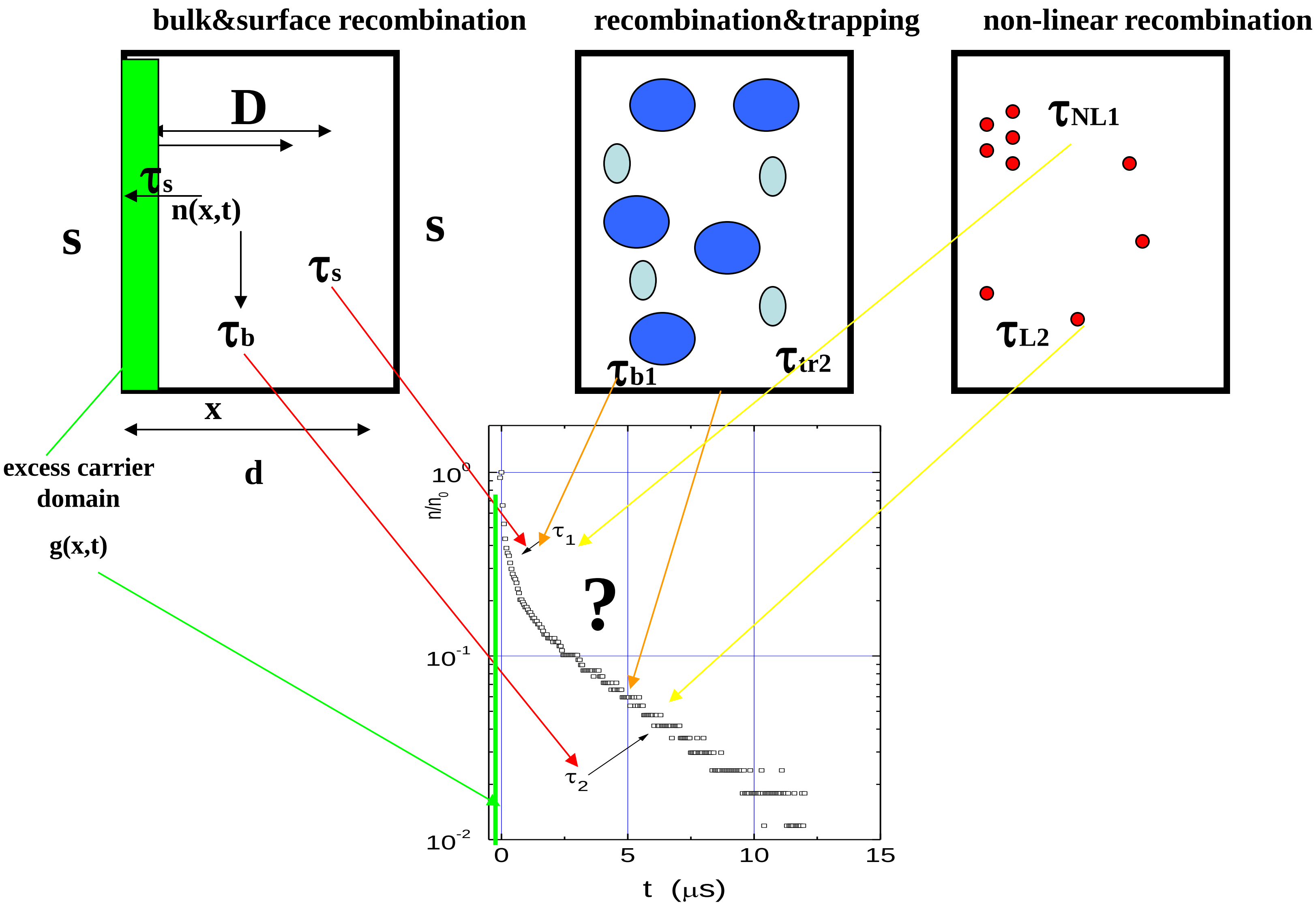


Irradiated



Non-passivated/ non-irradiated

Principles of determination of recombination parameters



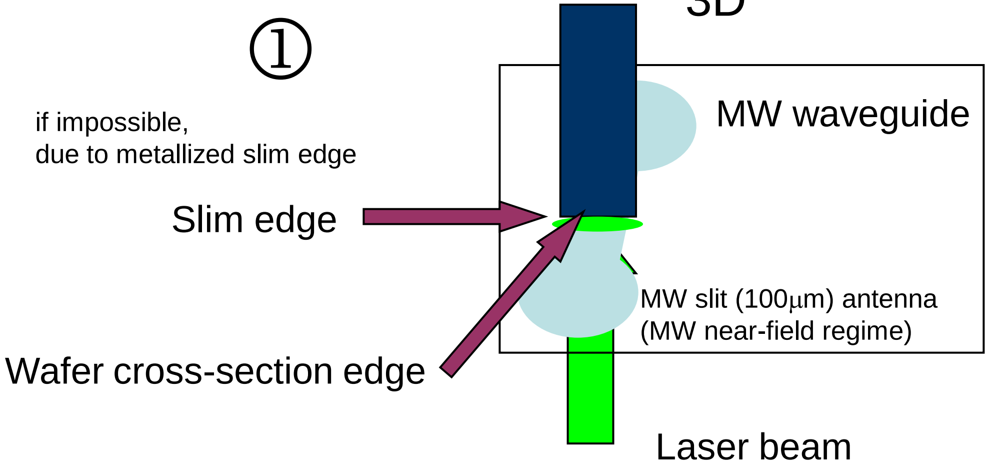
bulk&surface recombination

recombination&trapping

non-linear recombination

Experimental arrangement of MW-PC to implement cross-sectional measurement geometry

①



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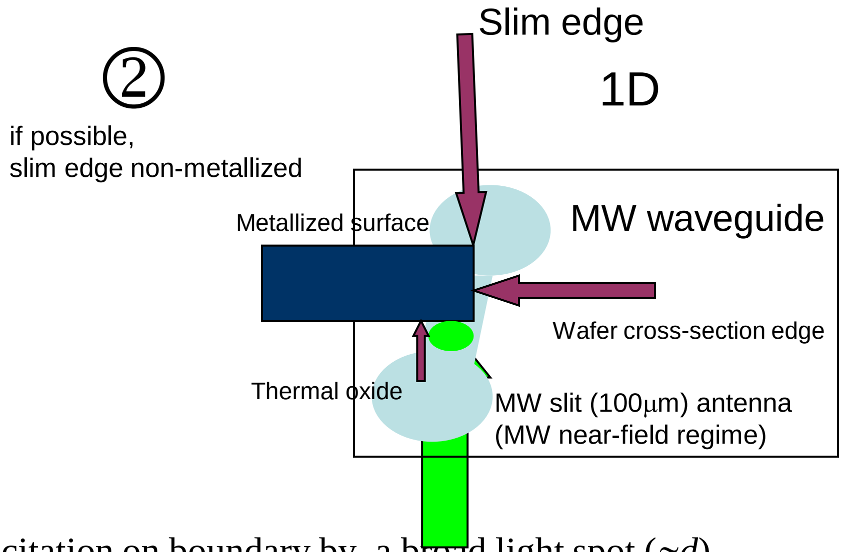


- MW-PC technique modification using a perpendicular excitation on boundary by a broad light spot ($\approx d$) and probe by a near-field slit MW antenna .

- MW-PC response $\langle n(t)\rangle|_d = n(t=0)\Sigma_{m=1}^{\infty} A_m(\eta_m d)\exp[-(\eta_m^2 D+1/\tau_b)t] = n(t=0)\Sigma_{m=1}^{\infty} A_m(\eta_m d)\exp(-t/\tau_{ef})$

  to evaluate *s* it is necessary to extract $A_1(\eta_1(s))$ and $\tau_{ef}(\eta_1(s),\tau_b)$

- *For the reliable and separate evaluation of* $A_1(\eta_1(s))$ and $\tau_{ef}(\eta_1(s),\tau_b)$,*at least, two excitation wavelengths are employed (as* A_1 *is also* $A_1(\alpha,\eta_1(s))$*) for verification whether* A_1 *(the main decay mode) is reached.*

  τ_{ef} *is measured for 1062 nm* while A_1 *is extracted at 531 nm excitation.*

Principles of determination of recombination parameters

$$n(x,t)=\sum_{m=1}^{\infty}A_m e^{-(D\lambda^2+1/\tau)t}\sin(\lambda_m x+arctg\frac{D\lambda}{s_0})$$

normalised response amplitude,- *to determine absolute value of s*

$$\frac{<n(t)>_{\Delta,d}}{<n(0)>_{\Delta,d}}=\sum_{m=1}^{\infty}A_m e^{-(D\lambda^2+1/\tau)t}K_{m;\,\Delta,d}$$

$$<A_m>_d=\frac{8\sin\frac{\lambda_m d}{2}\cos\frac{\lambda_m(2(y_1-x_0)+\Phi)}{2}\sin\frac{\lambda_m\Phi}{2}\cos\frac{\lambda_m(d/2-x_0)}{2}}{(\lambda_m\Phi)(\lambda_m d+\sin\lambda_m d\cos\lambda_m(2x_0-d))}$$

position of maximum amplitude within asymptotic decay,- *to separate asymmetry of surface recombination: s_0, s_d*

$$\lambda x_0=arc\,ctg\frac{D\lambda}{s_0}\cdots\lambda(d-x_0)=arc\,ctg\frac{D\lambda}{s_d}$$

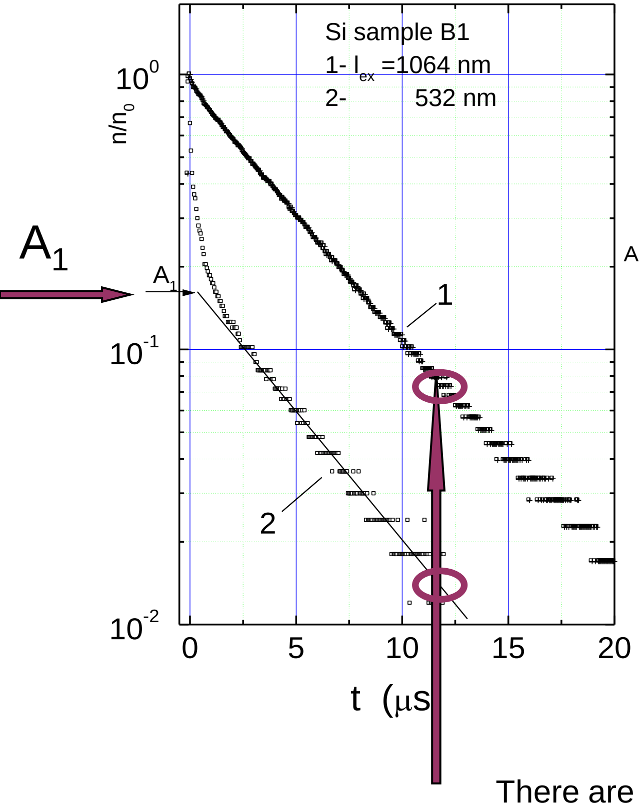
asymptotic decay time, - *to extract bulk recombination lifetime*

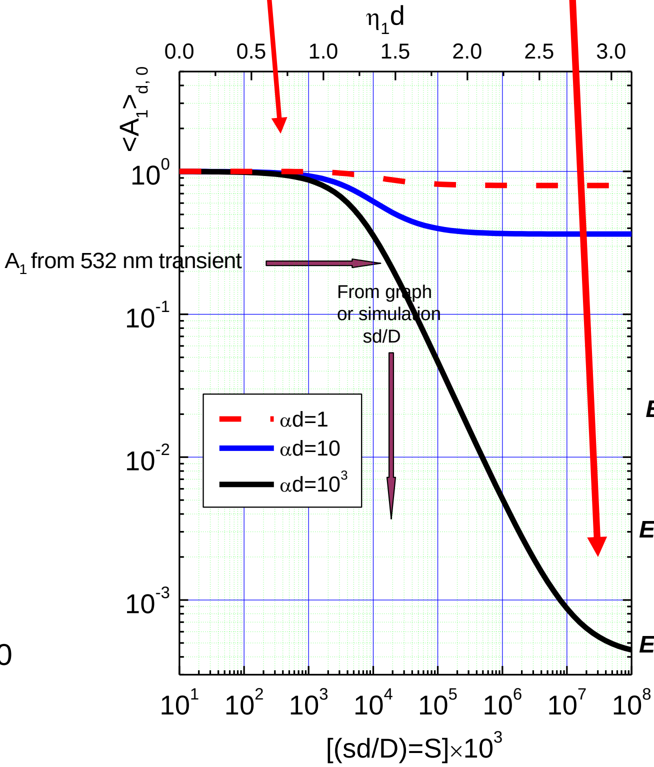
$$\tau_b^{-1}=\tau_{eff}^{-1}-\frac{D(\lambda_1 d)^2}{d^2}$$

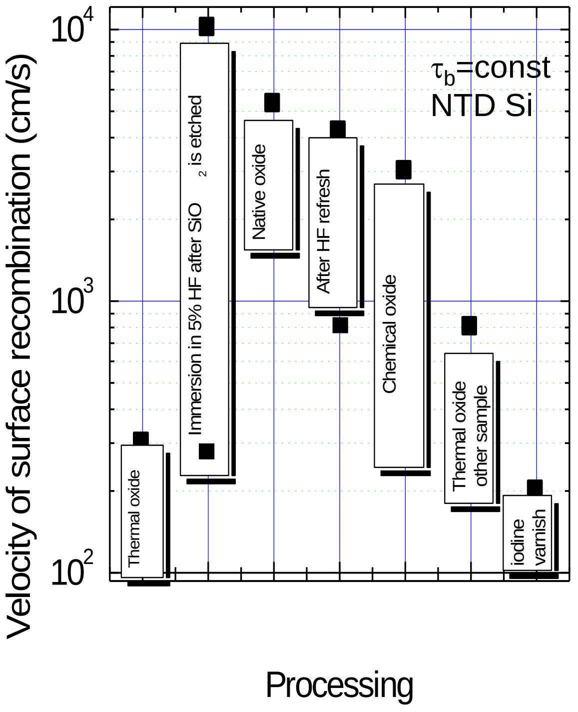
Principles of determination of recombination parameters

To resolve s<30 cm/s
very thick homogeneous samples,
extremely passivated with $\tau_b >> \tau_s \approx d/2s$,
should be used and other effects
(trapping, near surface strain etc)
should be suppressed

Extraction of $s>10^5$ cm/s
is limited by diffusion:
$\tau_D = d^2/\pi^2 D$, very thin
samples are necessary







There are assumed a coefficient of carrier ambipolar diffusion *D*≈14 cm^2/s and 1D approximation.

Actually ① 3D process: 1D ⇗ d=0.03 cm
3D ⇒ L=1.2 -3 cm chip width
⇘ w=0.1 cm waist of gaussian laser beam

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E.Gaubas, K.Grigoras, I.Simkiene. **Velocity of surface recombination in silicon after various surface passivation technological procedures.** ***Lith. Journ. Phys. 37(6), pp. 544-550, 1997.***

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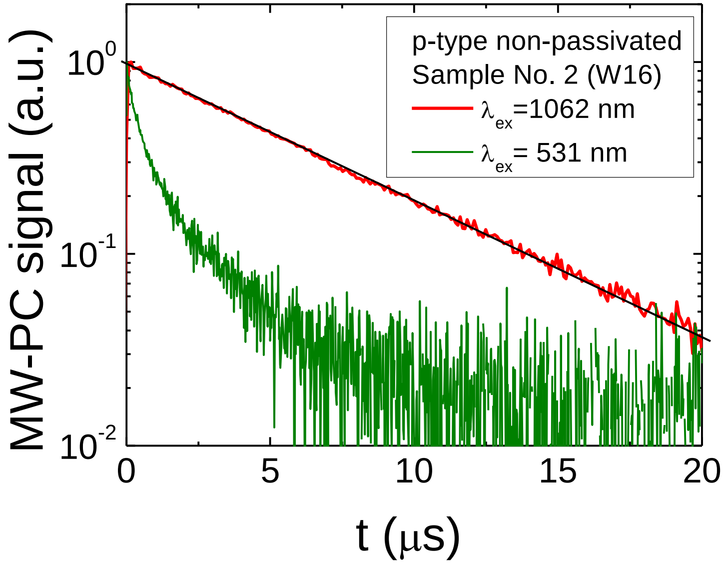
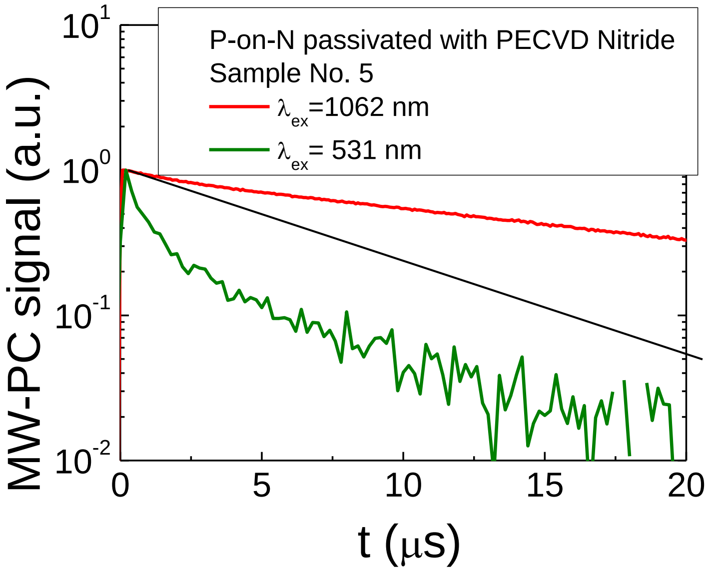
MW-PC transients - s



Non-passivated



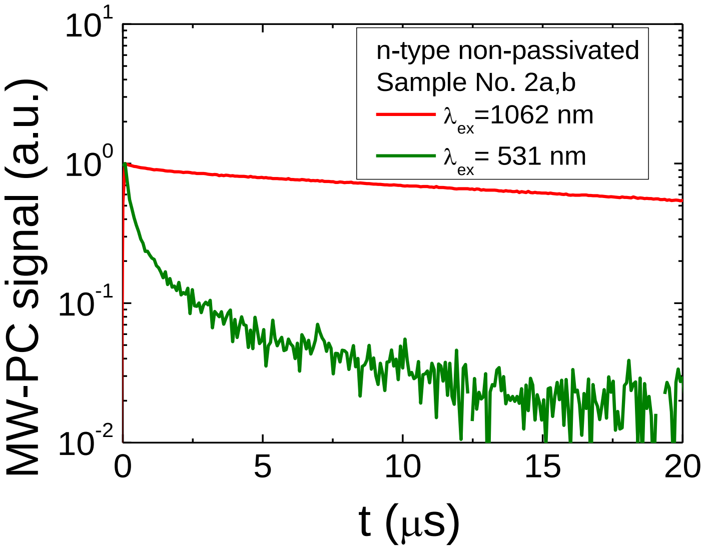
Passivated PECVD nitride

For samples $\alpha=1{,}8\div2{,}2$ **d=300 μm**

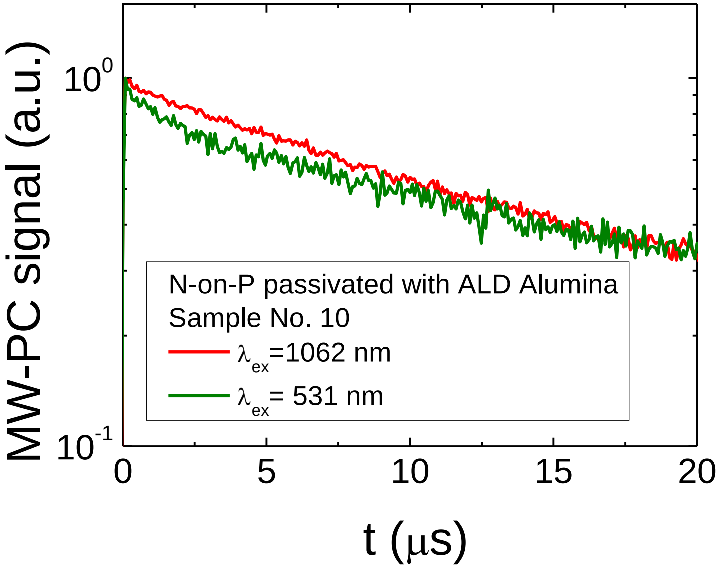
$\tau_{ef}=\tau_D=d^2/\pi^2D\approx6$ μs which is equivalent to $s\to\infty$

MW-PC transients - s

n-Si



Non-passivated



Passivated ALD alumina

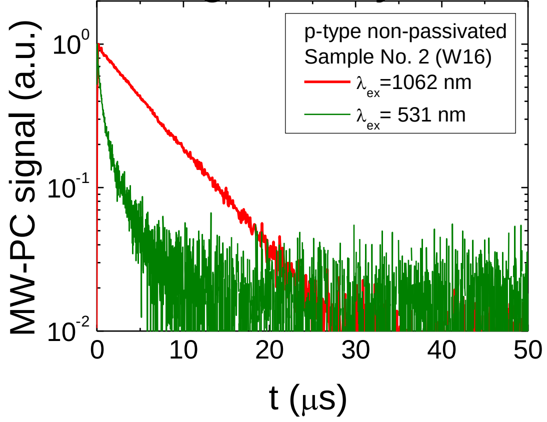
For samples d=300 μm

$\tau_{ef} = \tau_D = d^2/\pi^2 D \approx 6\ \mu s$ which is equivalent to $s \to \infty$

MW-PC transients – trapping effect

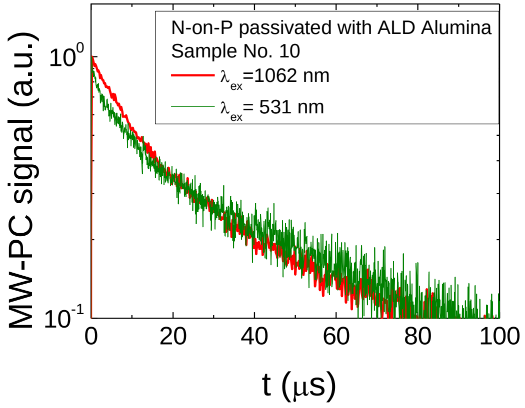
p-Si

3D geometry



Non-passivated

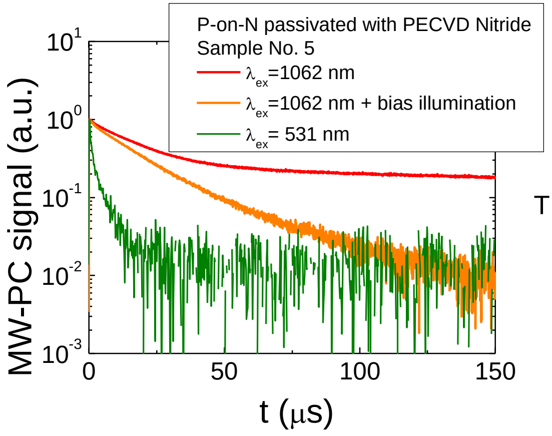
3D geometry



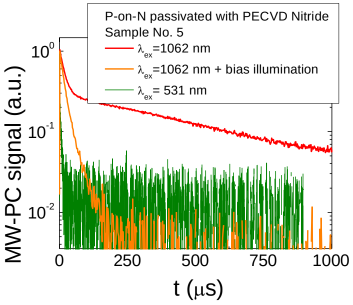
Passivated ALD alumina

n-Si

3D geometry

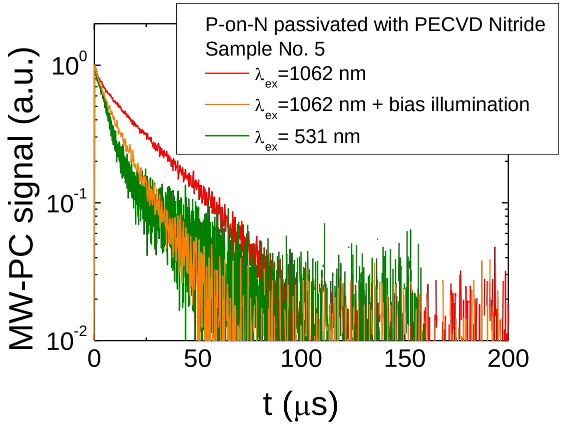


Passivated PECVD nitride



Trapping effect displayed

1D geometry



Passivated PECVD nitride

Surface recombination velocity in different samples

Non-irradiated

p-Si

p-type non-passivated			
Sample	**τ_{eff} (μs)**	**τ_{tr} (μs)**	**s (cm/s)**
W18 No. 3	8	33	9.3×10^{3}
W16 No. 2	6	-	1.9×10^{4}
W16 No. 3	9	62	9.3×10^{3}
ATLAS *Φ*7 No. 3	6		1.9×10^{4}
ATLAS *Φ*7 No. 5	9		1.9×10^{4}

p-type (N-on-P) passivated with ALD Alumina			
Sample	**τ_{eff} (μs)**	**τ_{tr} (μs)**	**s (cm/s)**
8	11	50	560
9	12	64	560
10	15	55	330
11	11	51	370
12	11	62	560

n-Si

n-type non-passivated			
Sample	**τ_{eff} (μs)**	**τ_{tr} (μs)**	**s (cm/s)**
2 a,b	9	610	1.9×10^{4}
3 a,b	17	110	1.4×10^{4}

n-type (P-on-N) passivated with PECVD Nitride			
Sample	**τ_{eff} (μs)**	**τ_{tr} (μs)**	**s (cm/s)**
5	6	480	9.3×10^{3}
6,7	18	270	4.7×10^{3}

Irradiated

Sample	**Fluence (n_{eq}/cm^2)**	**$\tau_{R,b}$ (ns)**
B1P6	0.95×10^{13}	700
B2P10	5.78×10^{13}	130
B2P8	4.82×10^{14}	13
B2P3	3.94×10^{15}	1

Summary

- Passivation of surfaces is rather efficient, - obtained better for n-on-p Si samples (ALD alumina) than for p-on-n Si samples (PECVD- nitride).

- Seem, there are a lot of trapping centers at the interface with passivating (or within) layer, - extremely long instantaneous lifetimes of trapping in 3D measurement geometry relative to 1D (more reliable extraction model) experiment geometry. This trapping effect can efficiently be suppressed by steady-state cw bias illumination.

  It would be necessary to proceed 3D experiments and simulation procedures for separation of the parameters of trapping and of surface recombination velocity, attributed to different passivation technology and material conductivity type.

- Passivation is rather reproducible, - values of *s* in different samples vary not more than 2 times.

- The impact of surface recombination in the irradiated samples is negligible. While, for samples irradiated with fluence $<10^{14}$ neq/cm^2, a weak change of τ_{ef} in 3D geometry relative to that of 1D can be suspected. ***It is promising to use the pre-irradiated detectors to avoid the surface recombination***

- For more reliable evaluation of *s* ascribed to different technologies, wafer fragment samples of larger area (without any additional layers, junctions etc) and various thicknesses should be employed.

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THANK YOU FOR YOUR ATTENTION!

Measured recombination parameters in various materials

Recombination and trapping parameters observed in various materials and several structures by IR and MW absorption transient techniques.

Material/ structure	Effective lifetime (μs)	Bulk recombination lifetime (μs)	Surface recombination velocity (cm/s)	Trapping instantaneous lifetimes (μs)
Si	0.0001-5000	0.0002-1000	30- 10^5	2.0-10^5
GaAs	0.0001-50. 0	0.0001-0.1	10^4 -10^6	-1.0-50.0
CdTe	0.0001-1.0	0.08	10^4	1.4 - 6.0
CdS	0.01-10.0	0.1	10^4	0.5-5.0
SiC	0.3-10.0	0.4		0.5-5
GaN	0.0004-5×10^5	0.0004-0.5	10^3 -10^4	1.0- 5×10^5
diamond	0.0005-1×10^2	0.0005-10		

Dynamic range of the methods

Method	Excess carrier concentration (cm^{-3})	Resistivity (Ω cm) {Si}	Lifetime (μs)
IRA	> 10^{16}	>0.0005	0.0001-10^2
MWR (22 GHz)	> 10^{10}	>0.5	0.0001 –10^4
MWA (10 GHz)	>10^9	>0.5	0.0001 - 10^5

Impact of surface recombination velocity and bulk lifetime in different samples