MODELING OF HgCdTe SWIR DETECTOR INTEGRATION RAMP FOR CONSTANT FLUX AND PERSISTENCE CURRENT

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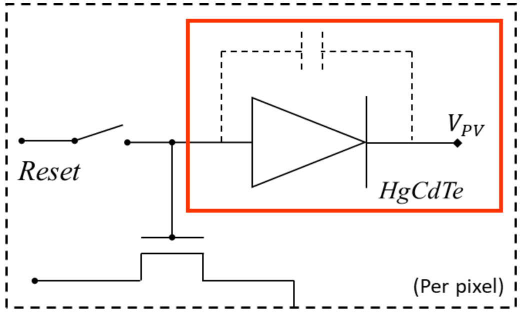
Test Detectors

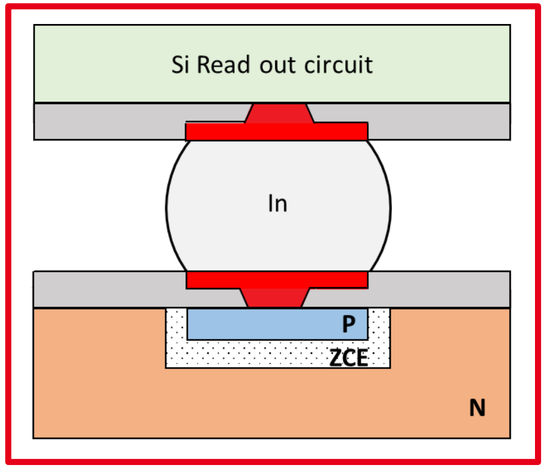
HgCdTe SWIR (2.1µm)

15µm pitch, P/N diodes

SFD ROIC architecture

No nodal capacitance



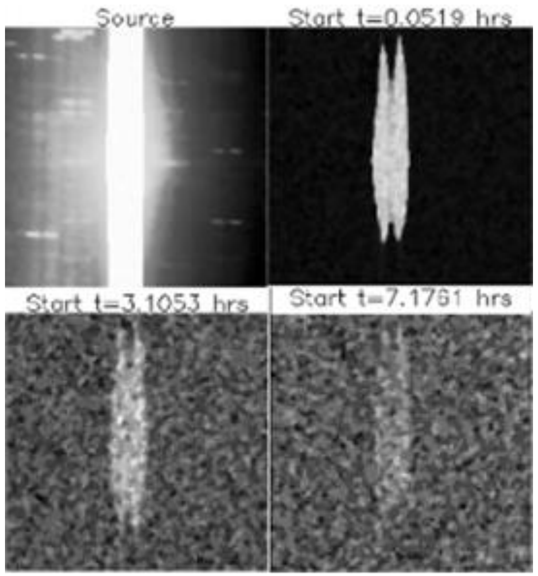


Persistence :

= Influence from previous illumination

Fit : **sum of exponentials**

Signification of this fit ?

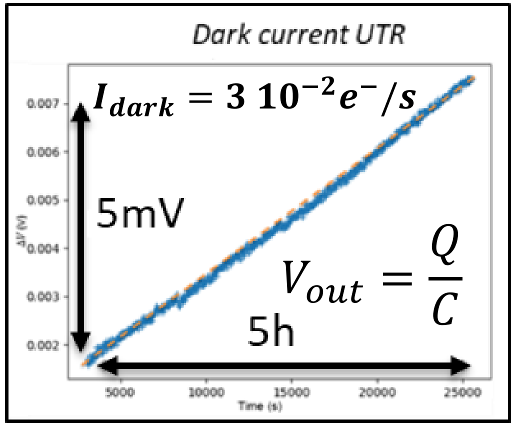


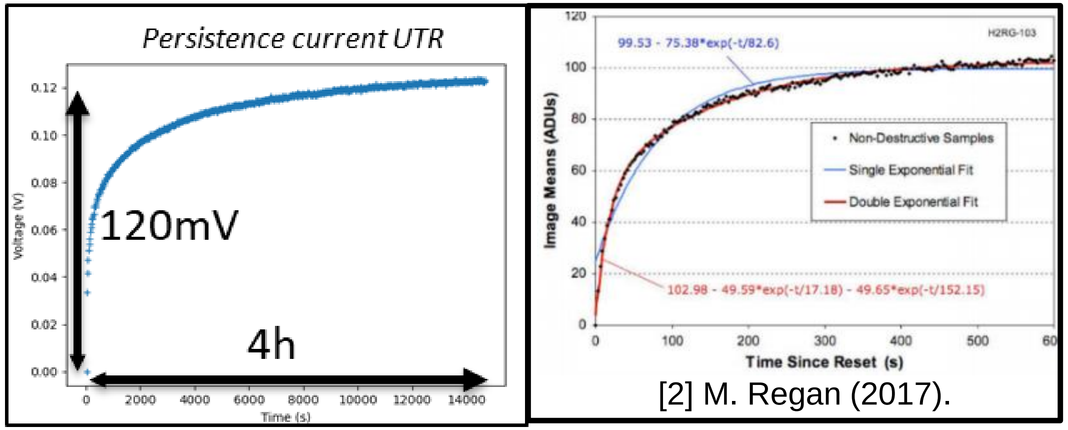
[1] G. Barrick (2012)

Objectives :

SFD integration ramp

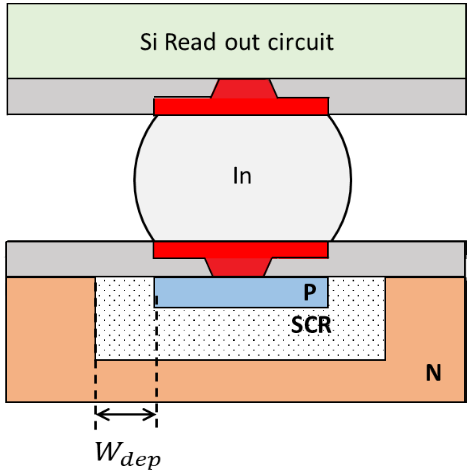
Analytical model for persistence signal





[2] M. Regan (2017).

Modeling of SFD pixel integration ramp



SCR size variation :

$$W_{dep}(t) = \sqrt{\frac{2\epsilon_{MCT}}{qN_D}[V_{bi} - (V_{app} + V_{out}(t))]}$$

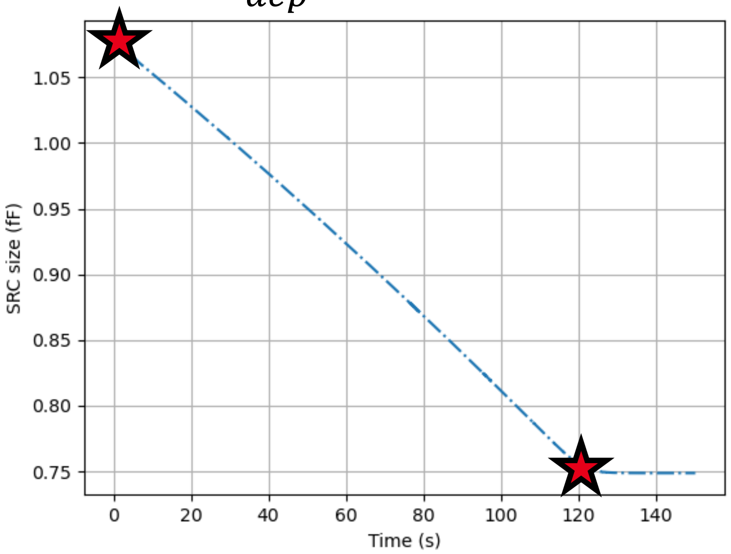
Implies capa variation : $C = C_{int} + \frac{A\epsilon}{W_{dep}}$

Then [3] : $V_{out} = \frac{Q}{C}$ variation

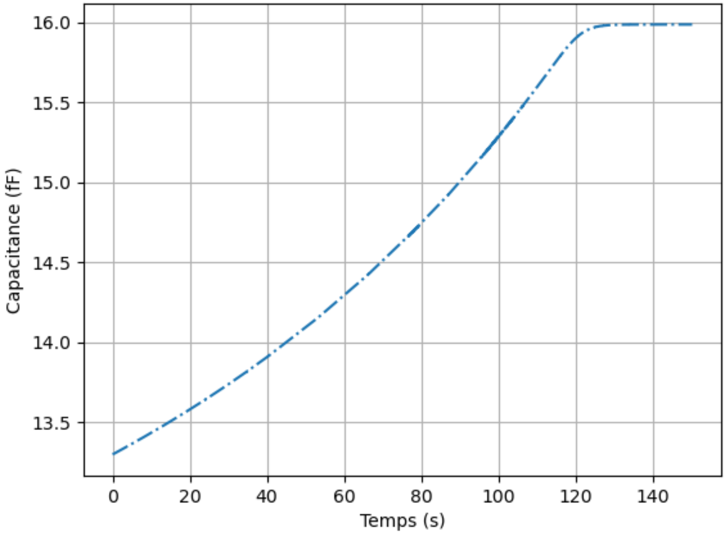
With $I(t) = -I_{sat}\left(e^{\frac{q(V_{app}+V_{float})}{nkT}} - 1\right) + I_{\phi}$

Open circuit equation [4] : $\frac{dV}{dt} = \frac{I(t)}{C}$

W_{dep} size variation



Pixel capacitance variation



[3] : Bezawada N.,Ives D.,Atkinson D., SPIE, 2007
[4] : Weckler G.P, IEEE Journal of Solid-State Circuits,1967

Modeling of SFD pixel integration ramp – application for fitting

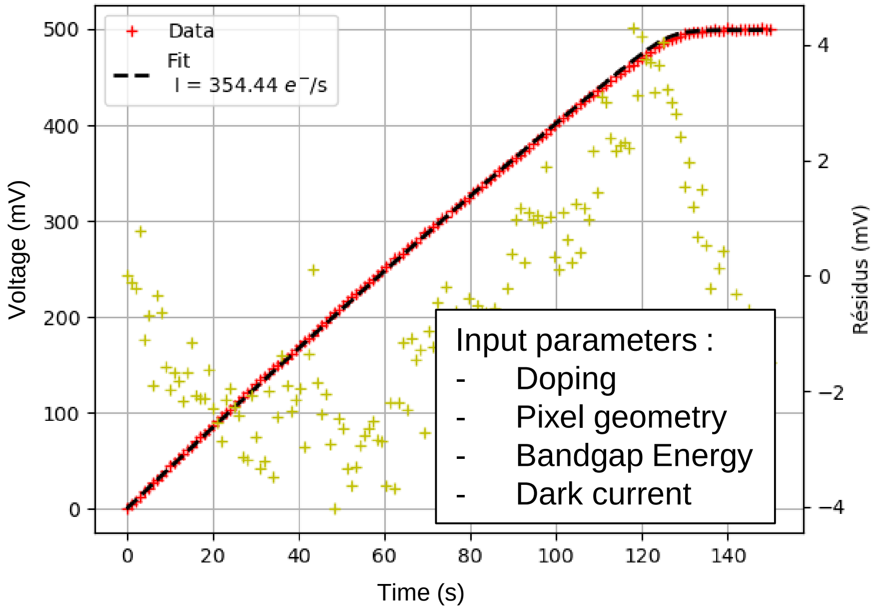
Measured current estimation

Low residuals (~1%)
Consistant with linear fit (1,5% difference)

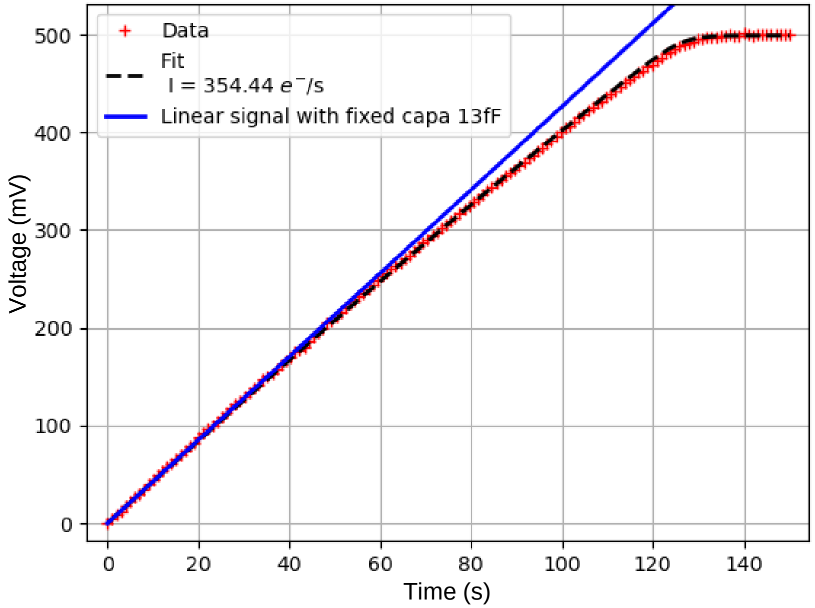
Limits for direct application

Time consuming (VS linear fit)
Accurate values of pixel parameters

Simu VS data and residuals



Model VS constant gain fitting



➔ Next step for persistance : non linear current

Usual explanation :

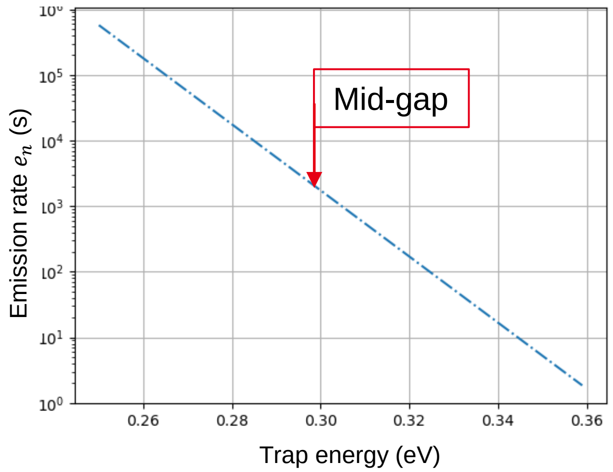
Defects trapping/emission processes from diode SCR with moving edges

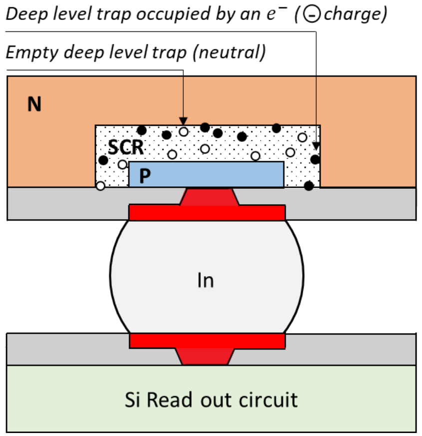
Trap emission dynamics:

$$e_n(E_T) = \sigma_n v_{th} N_c \exp[-\frac{E_c - E_T}{kT}]$$

And $\frac{dn}{dt} = e_n n_T(t)$ et $\frac{dn_T}{dt} = -e_n n_T(t)$

Emission rate function of trap energy for $E_g = 0,6eV$



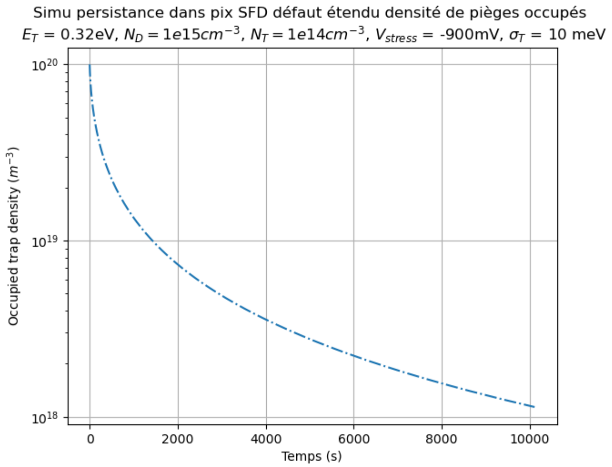


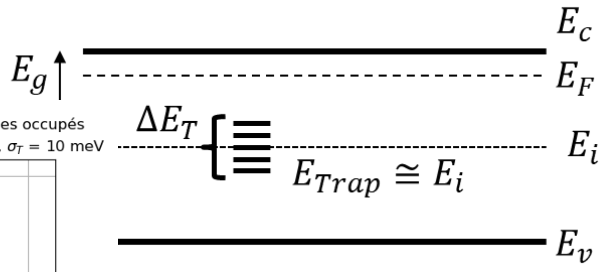
New hypothesis :

Defects with extended energy level distribution

[5] $n_T(t) = n_T(0) \int_0^\infty g(E_{Ti}) \exp[-e_n(E_{Ti})t] \, dE_{Ti}$

$$g(E_{Ti}) = \frac{1}{\sigma_T\sqrt{2\pi}} \exp\left[-\frac{(E_{T0}-E_{Ti})^2}{2\sigma_T^2}\right]$$





[5] P. Omling, L. Samuelson, and H. G. Grimmeiss, Journal of Applied Physics 54, 5117 (1983)

Current from this trap emission [6]:

$I_e(t)$: Carrier emission from traps

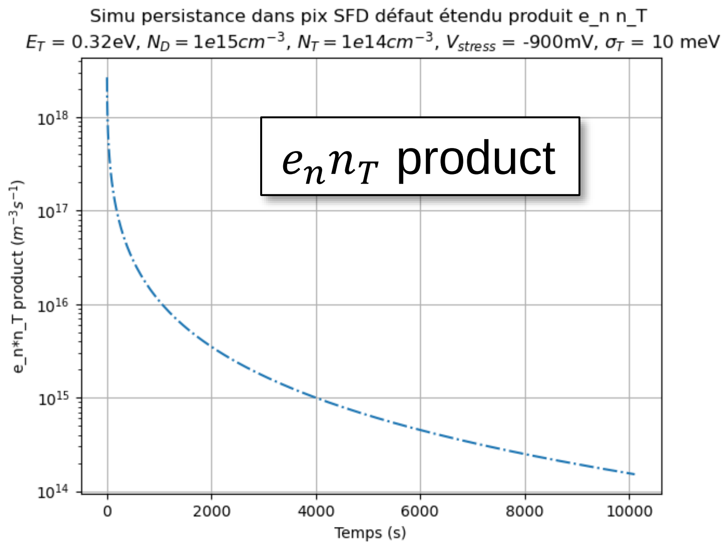
$$I_e(t) = qA \int_{W_0}^{W(t)} \frac{dn}{dt}\, dx = qAe_n n_T(t)[W(t) - W_0]$$

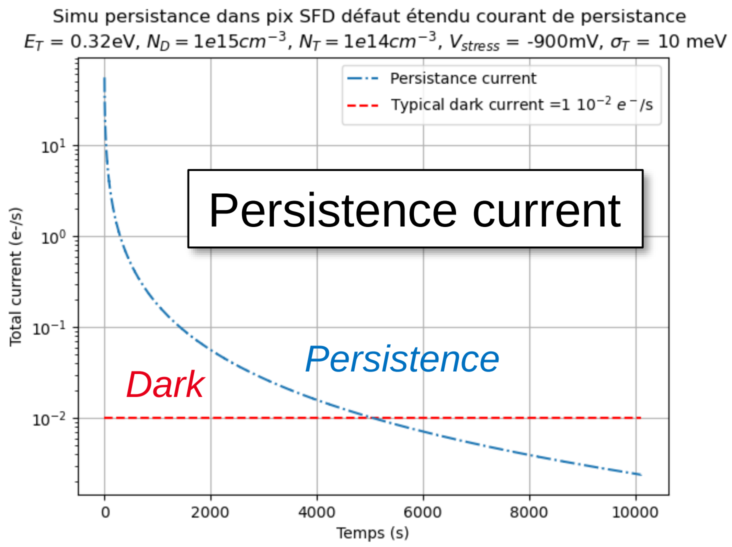
$I_d(t)$: Electric field variation in the SCR due to charge concentration variation

$$I_d = qA \int_{W_0}^{W\,(t)} \frac{dn_T}{dt}\frac{x}{W(t)}\, dx = -qAe_n n_T(t)[\frac{W(t)^2 - W_0^2}{2W(t)}]$$

$$I_{tot} = I_e + I_d + I_l = qA\left[W(t) - W_0 - \frac{W(t)^2 - W_0^2}{2W(t)}\right] e_n n_T(t)$$

$$I_{tot} = qA\left[W(t) - W_0 - \frac{W(t)^2 - W_0^2}{2W(t)}\right] \int_0^{\infty} g(E_{Ti}) \underbrace{e_n(E_{Ti})}_{e_n} \underbrace{n_T(0)\exp[-e_n(E_{Ti})t]}_{n_T(t)}\, dE_{Ti}$$





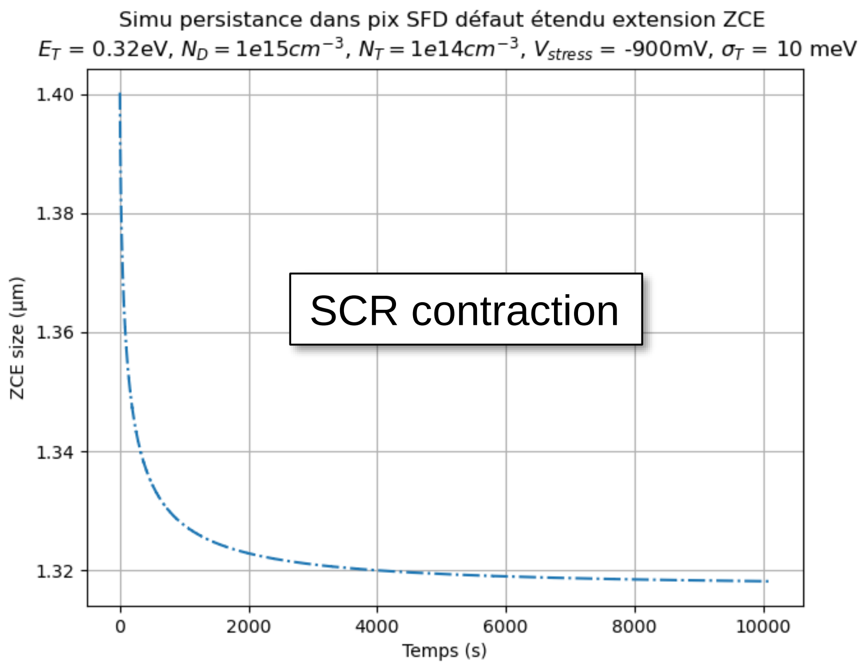
[6] D.K. SCHRODER (2005), 'Semiconductor Material and Device Characterization: Third Edition'

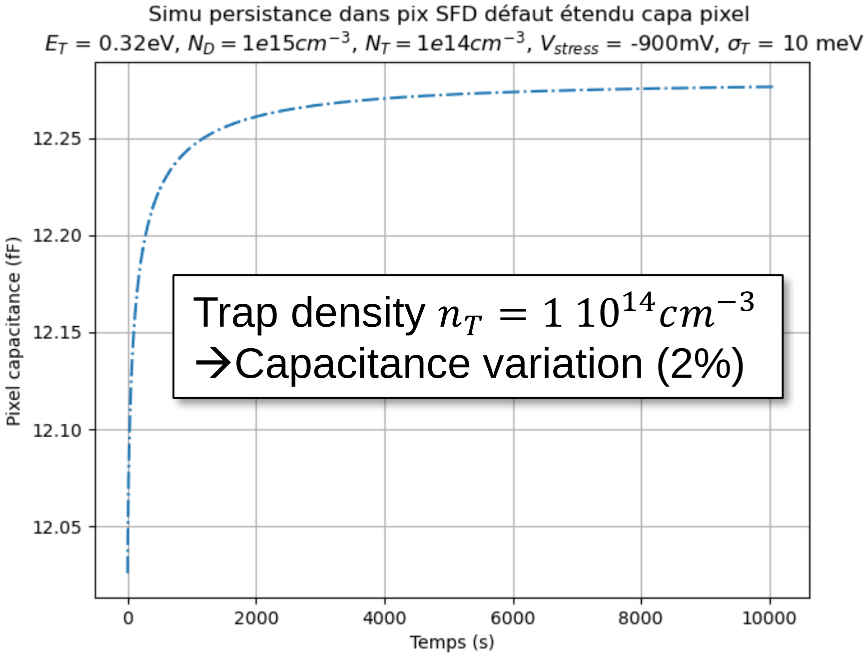
But also capacitance variation :

SFD equations: $C = C_{int} + \frac{A\epsilon}{W_{dep}}$; $\frac{dV}{dt} = \frac{I(t)}{C}$

Persistence in an SFD pixel
- Current transient
- And changing V/e^- conversion gain (if $\frac{n_T}{N_D} \gg 0$)

Persistence: $W(t) = \sqrt{\frac{2\epsilon_{MCT}}{q[\boldsymbol{N_D - n_T(t)}]}\left[V_{bi} - \left(V_{stress} + V_{float}(t)\right)\right]}$; $I_{tot} = qA\left[W(t) - W_0 - \frac{W(t)^2 - W_0^2}{2W(t)}\right]e_n n_T(t)$





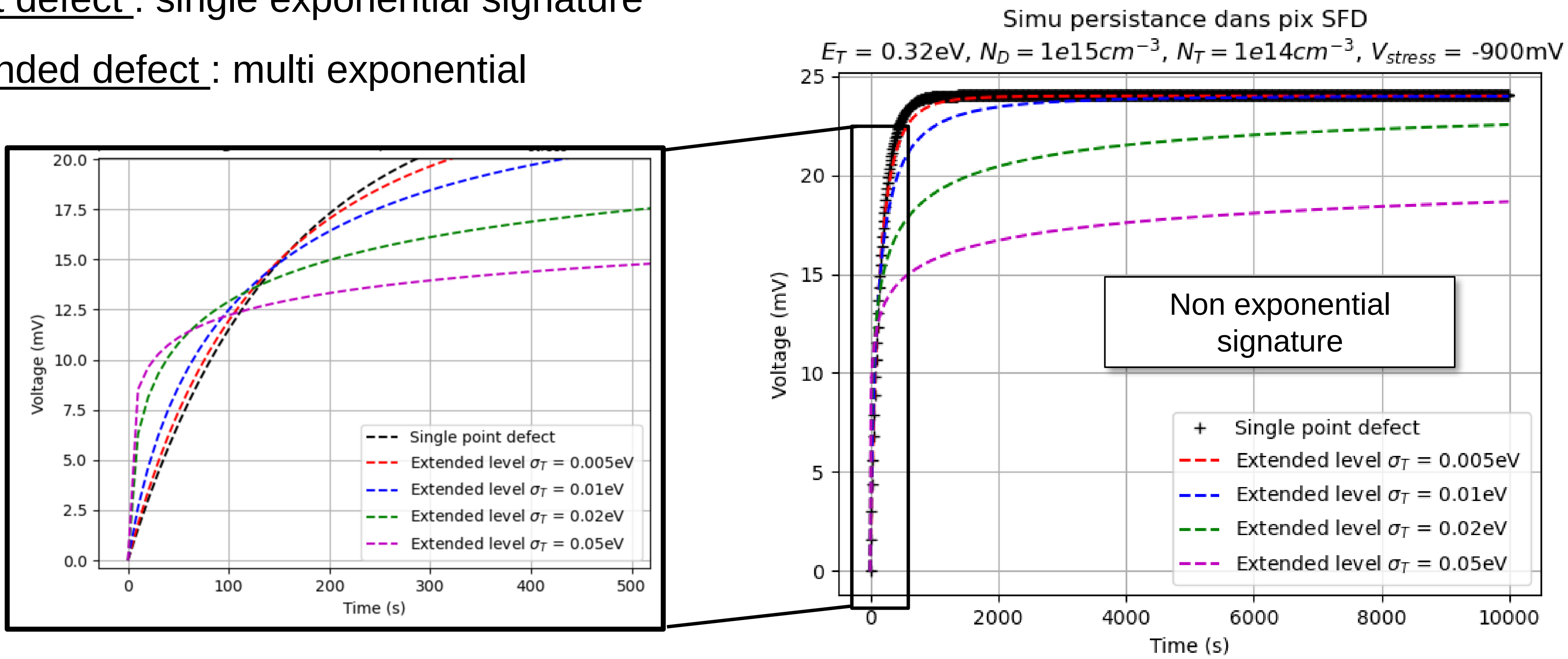
Persistence dynamics : extended defect

Reproduce a muli-exponential shape

No impact on persistance amplitude

Point defect : single exponential signature

Extended defect : multi exponential

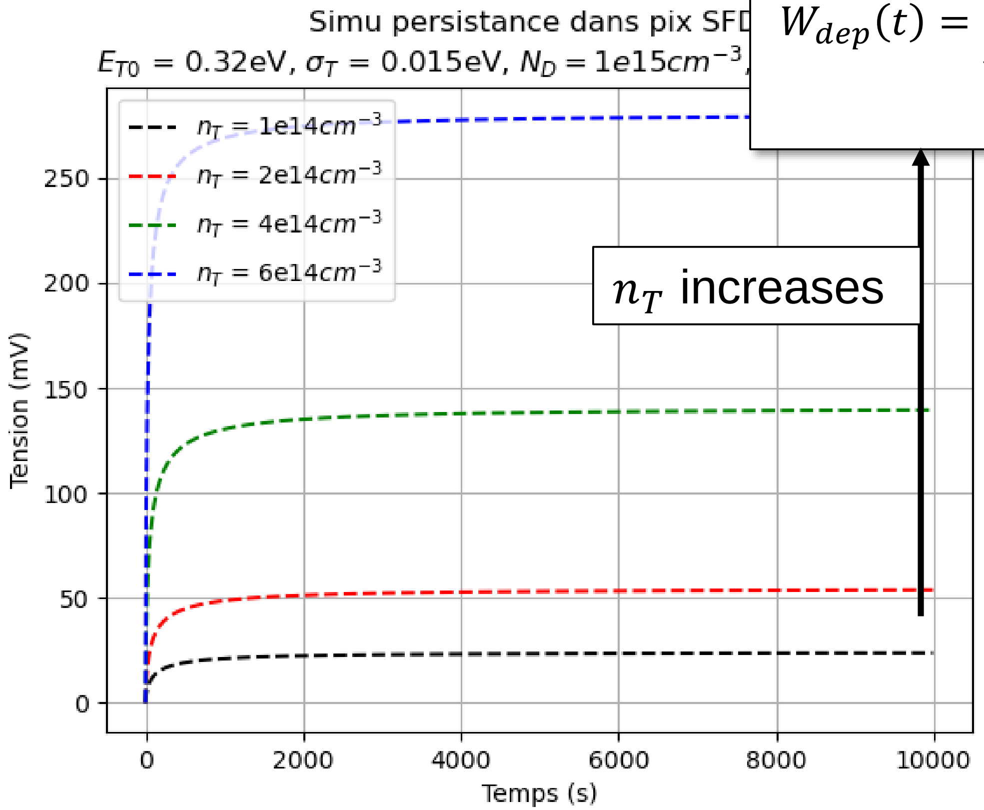


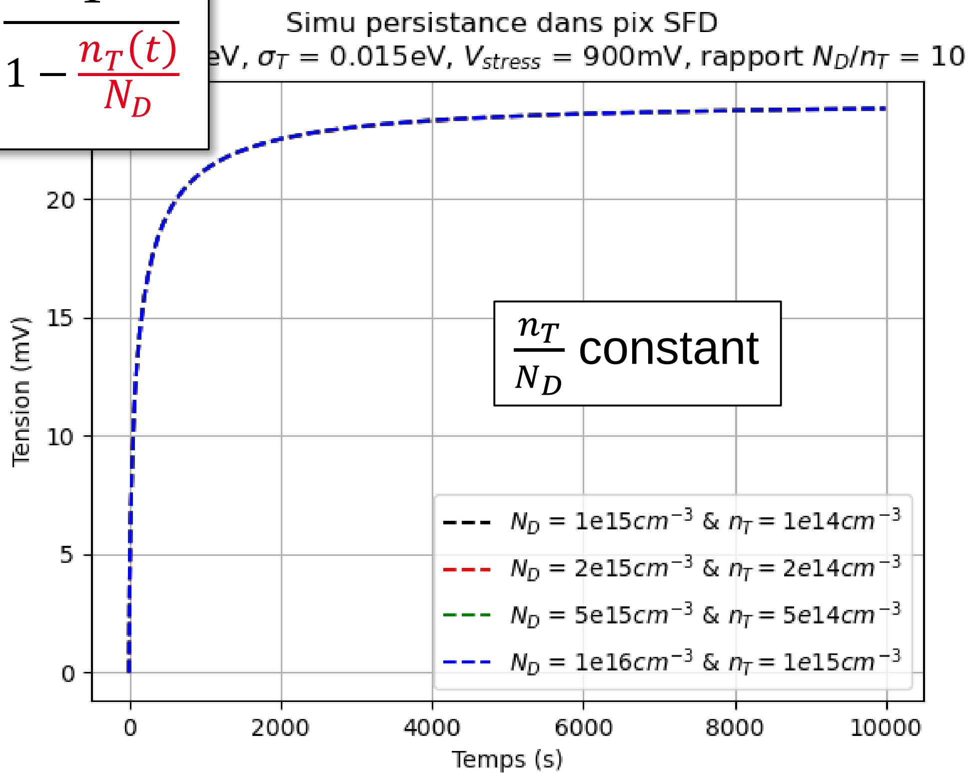
Persistence amplitude : trap density

Increases persistence amplitude

Ratio $\frac{n_T}{N_D}$ prevails

$$W_{dep}(t) = \sqrt{\frac{2\epsilon\left[V_{bi} - \left(V_{app} - V\right)\right]}{qN_D}} \sqrt{\frac{1}{1 - \frac{n_T(t)}{N_D}}}$$





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Measurement protocole

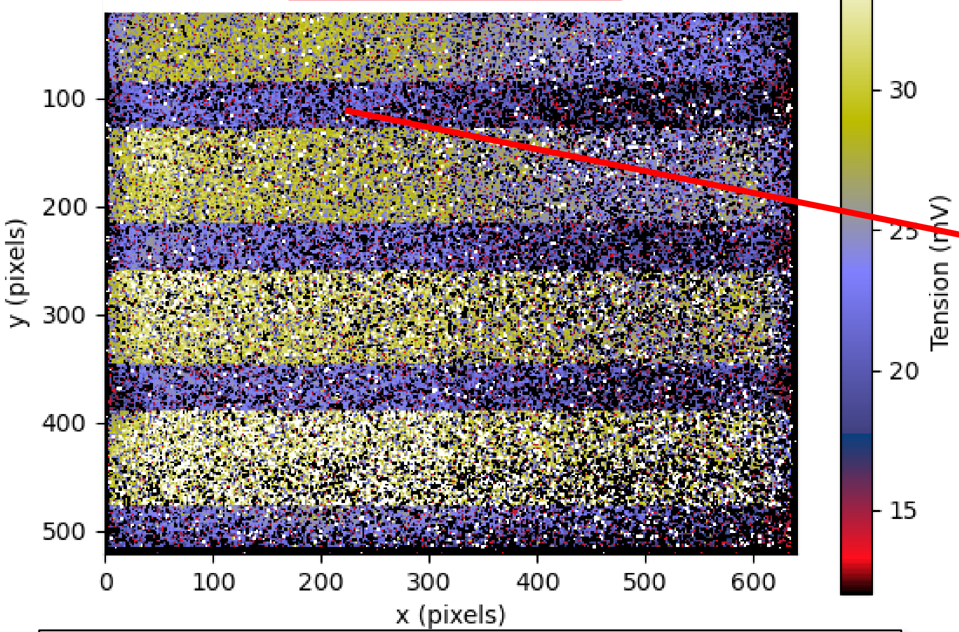
Electrical stress (0V → V_{stress})

All traps are filled

Maximizes persistence signal

Persistence amplitude mapping

Techno 2^{nd} ***GEN***



2-3% persistence, eq to 3 ke^- emitted

Data fitting (1 pixel)

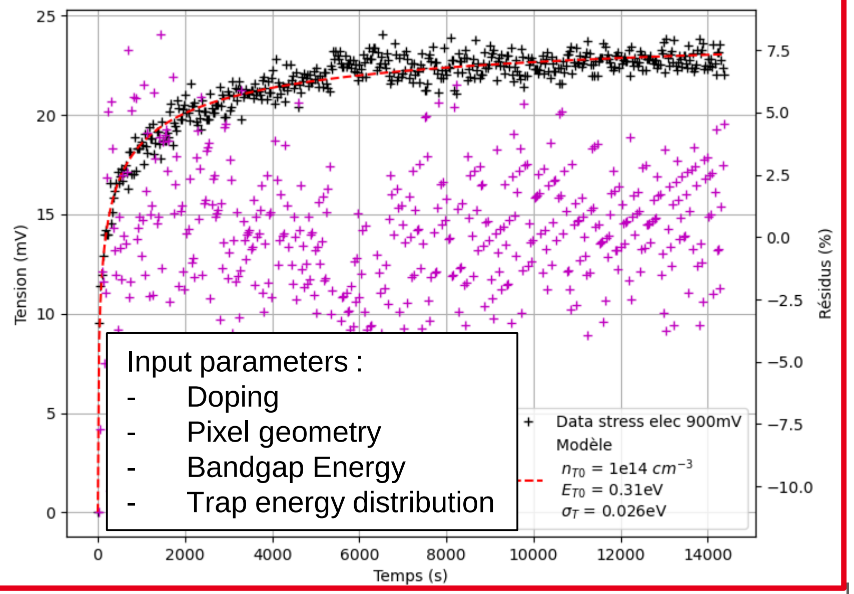
White residuals

Trap density $n_T = 1\ 10^{14}\ cm^{-3}$ $= 10\%\ N_D$

Trap level $E_T = 0{,}31eV$ $\cong \frac{1}{2} E_g$

Trap band extension $\sigma_T = 26meV = 9\%\ E_T$

Persistence ramp of one pixel
Fit with exented defect model



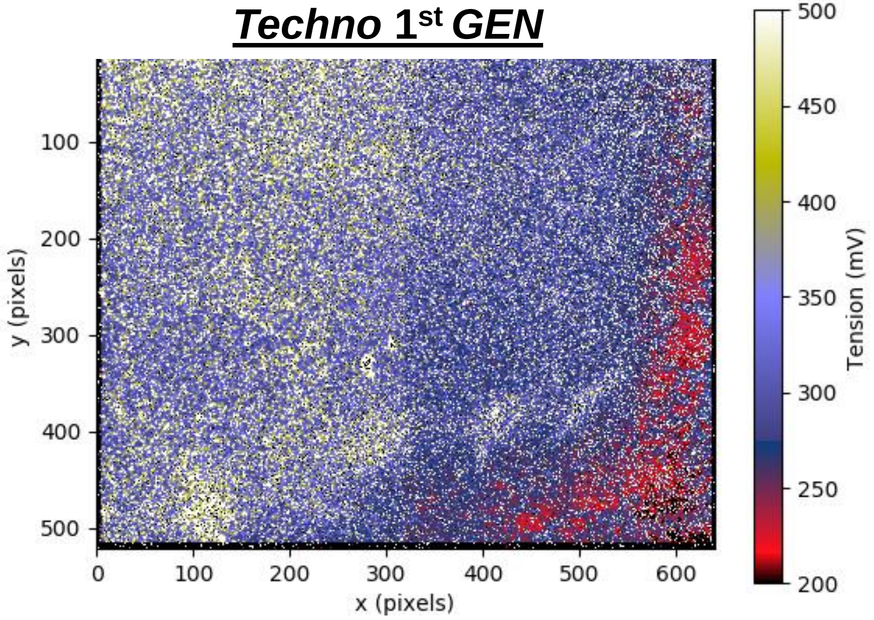
Model limits

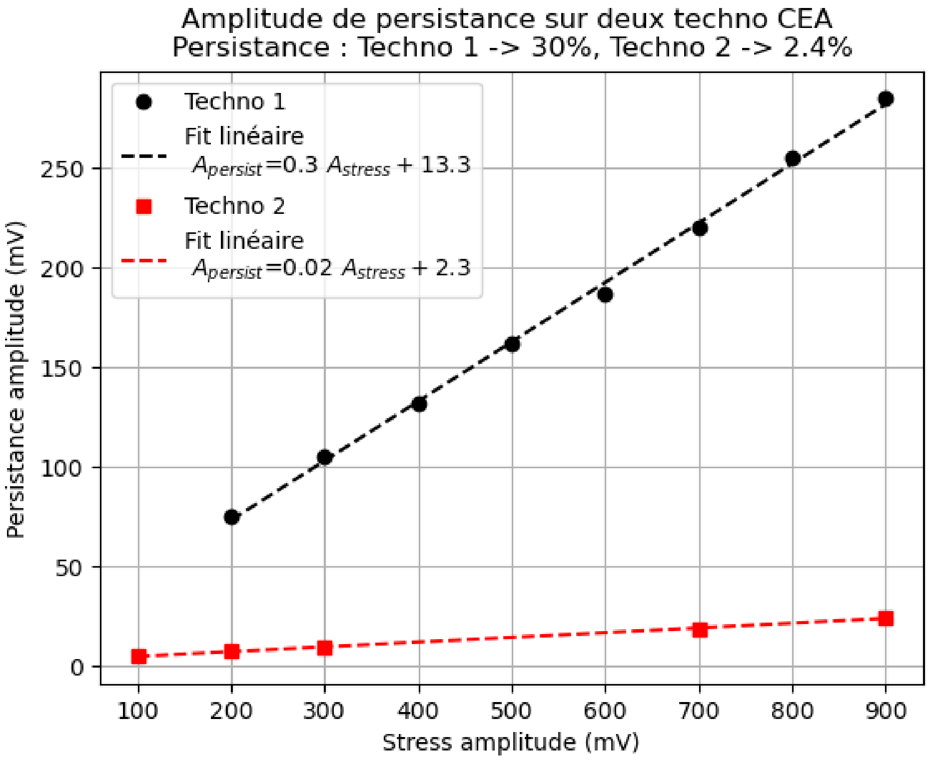
High persistence amplitude

Techno 1st gen : 20-30% persistence → $n_T = 80\%\ N_D$

Techno 2nd gen : 2-3% persistence→ $n_T = 10\%\ N_D$

Persistence amplitude mapping
Techno 1st GEN





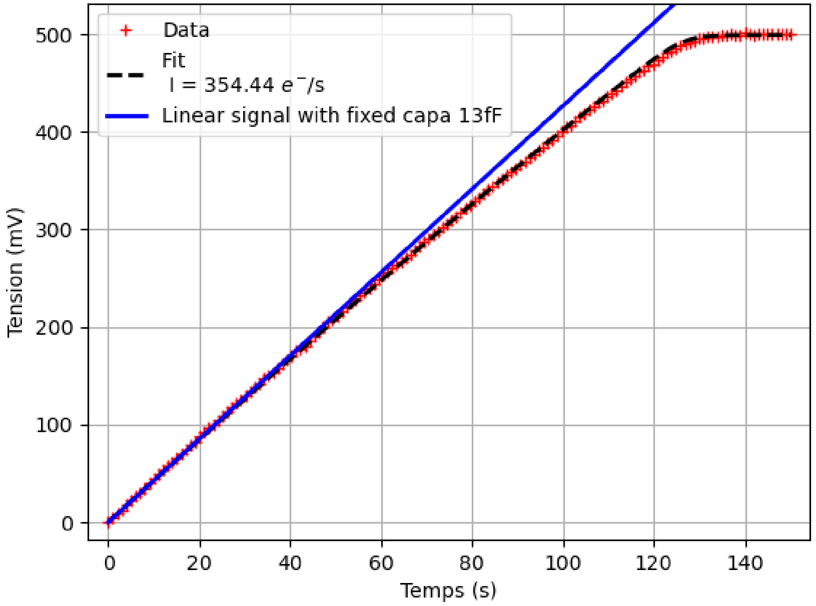
Analytical model for persistence

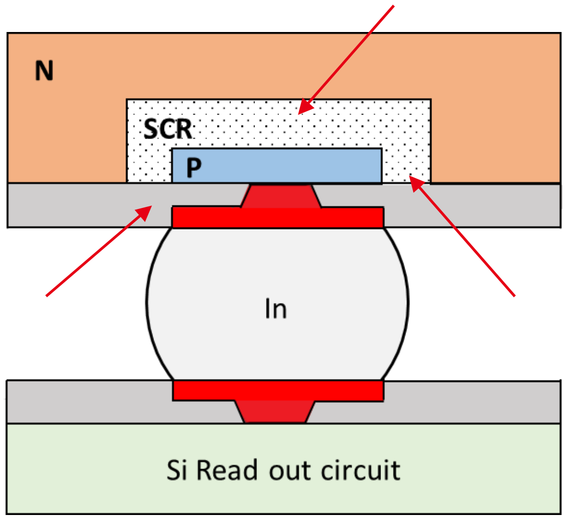
SFD integration ramp

Persistence current : trap emission process
Trap properties : **extended defects**

Multi exponential signature

Consistent with measurement on Techno 2nd gen
Needs improvements and high persistence amplitude





Persistence ramp of one pixel
Fit with exented defect model