Electrical properties of the backside illuminated etched surface of HgCdTe MWIR detectors

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Program

1. Context

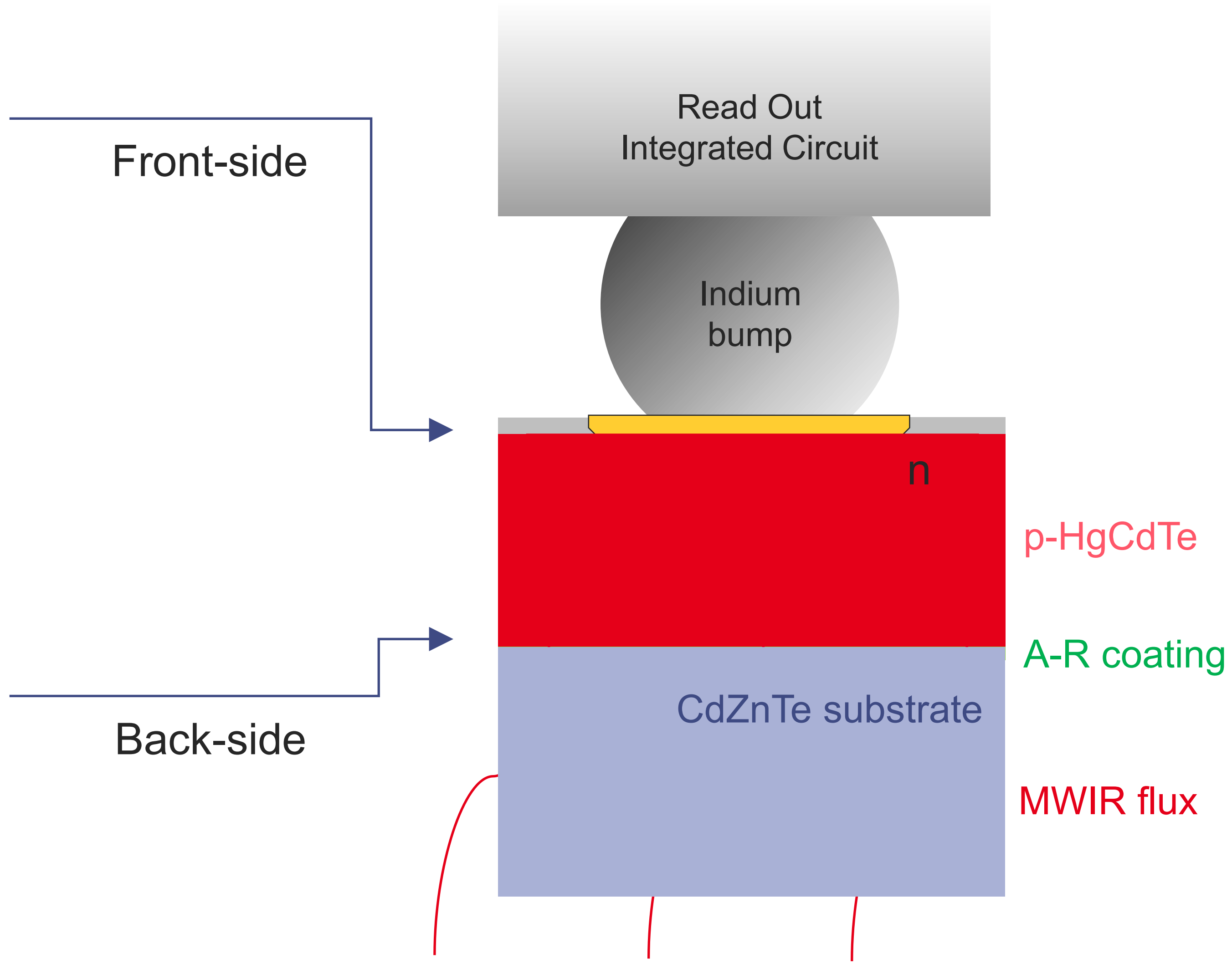
Context

Highly documented

- Side of pn-junctions : electric field - carrier collection
- First order performance parameters
  - QE, noise, short circuit pixels, etc.

Poorly documented even though…

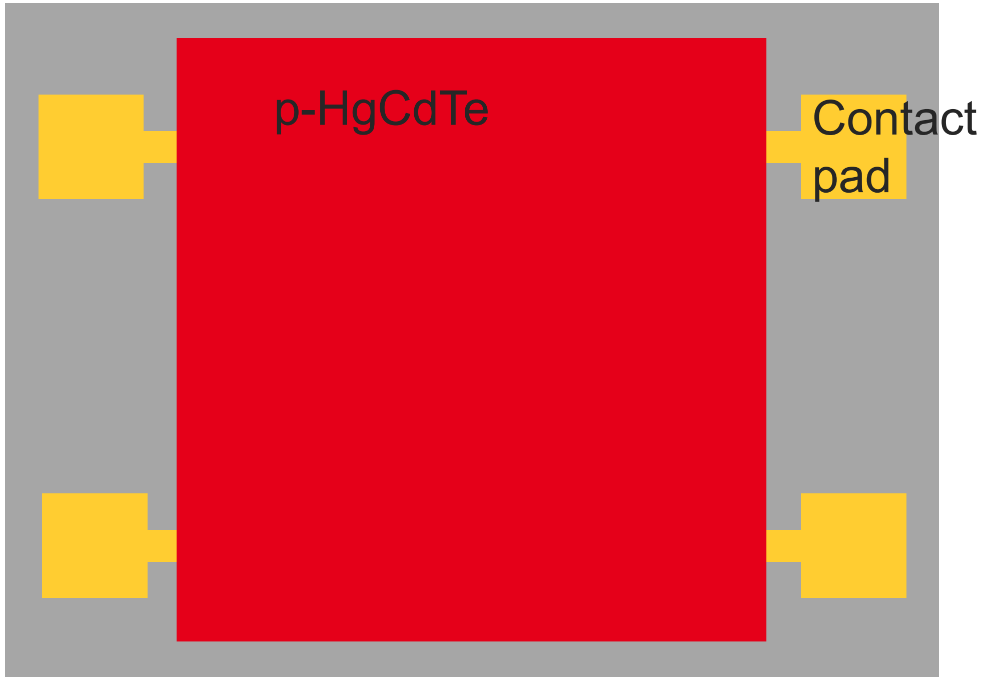
- Incident light : photo generation maximum
  - Beer-Lambert law
- Post-techno process (no high T° annealing)
- LPE growth start

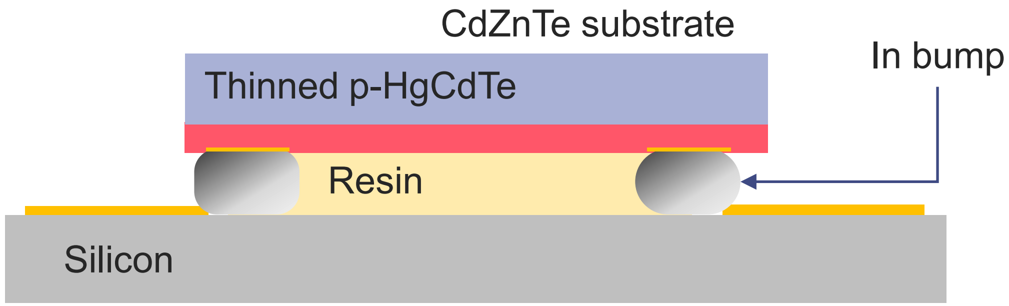


2. Experimental setup & samples

Samples

- 2 LYNRED samples 1cm x 1cm
  - Previous Hall measurements done : bulk doping
- MWIR $x_{Cd} = 0.29 : \ 4.5\mu m \ @ \ 300K$
- Thinned substrate
  - HgCdTe thickness = few μm / tens of μm
- 2 samples :
  - **Two passivations tested** : PASSIV1, PASSIV2

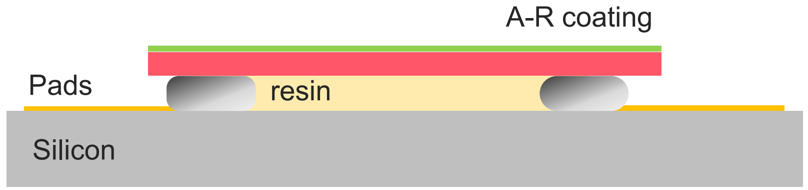




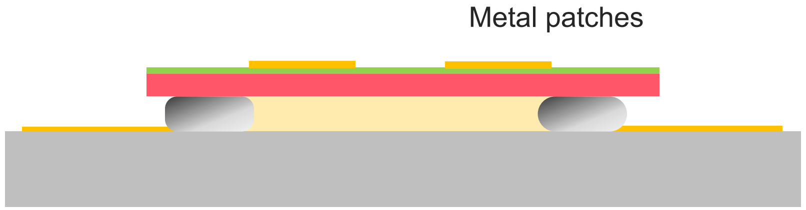
Experimental setup

Reproduction of a detector back-side

- We deposit A-R coating



Electrical properties of an interface ⇨ Metal Insulator Semiconductor structure !



Creation of M-I-S structures

- A-R coating as insulator
- Metallizations on A-R coating
- Tips can lay on metal and MCT contacts

Now we can :

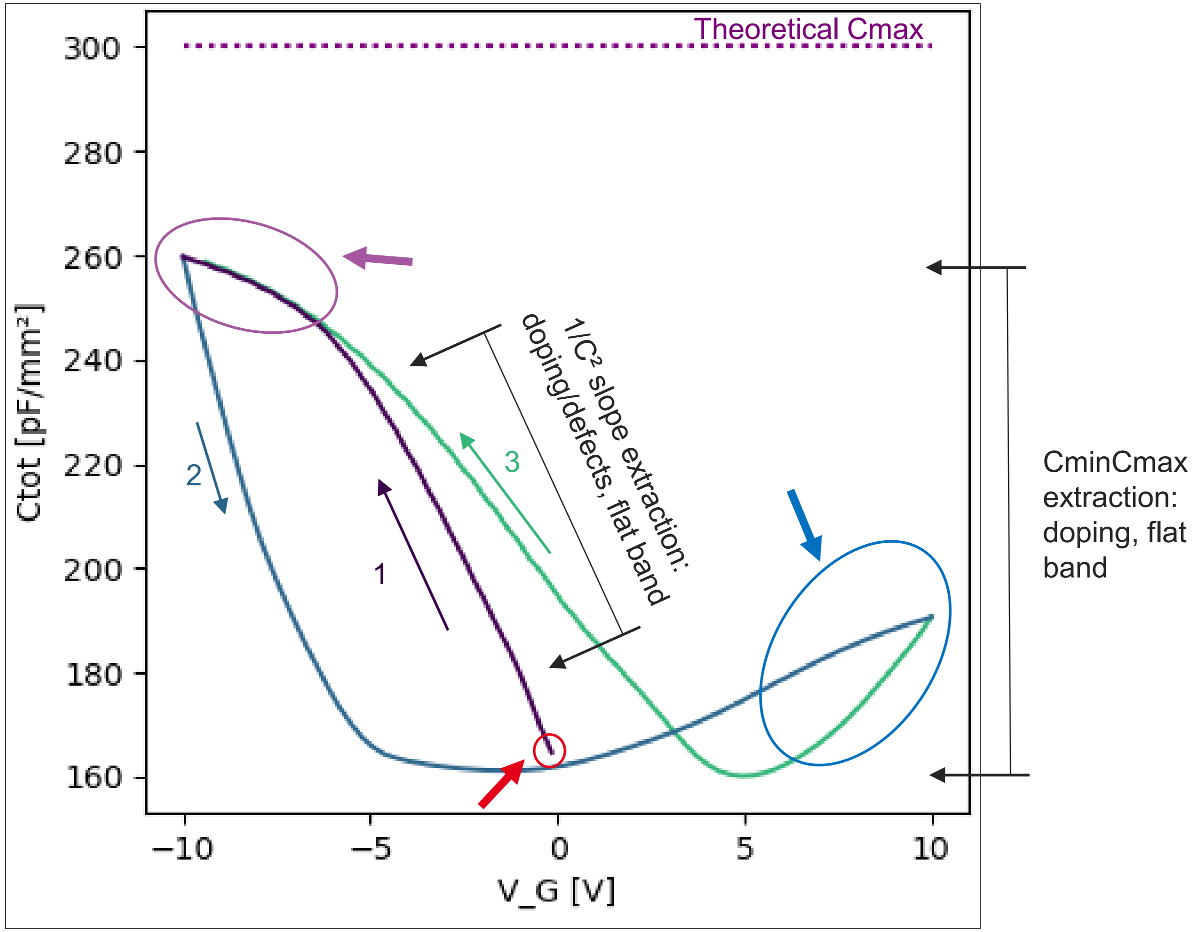
- Probe C-V measurements (100K, flux BB@300K)
- Characterize electrical properties of the backside of CH
  - General health of the interface
  - Interface Charge State (flat band state)
  - Interface defects

3. Results

C-V Results : Passivation #1 sample

- Interface Charge State - **C_0V** :
  - Quasi inverted initial state – positive charges @ interface
  - Minority carriers see the interface
  - Recombination / trapping
- Minority carriers activity at interface :
  - C-V rise in inversion at high freq. (400kHz)
  - Interface active defects - sign of unhealthy interface
- In gap interface defects :
  - Cmax unreached down to -20V
  - Dit strong concentration
  - Cannot be explained by Rserie effects
- **Non ideal backside for a N/P device**

Same trends on all MIS tested

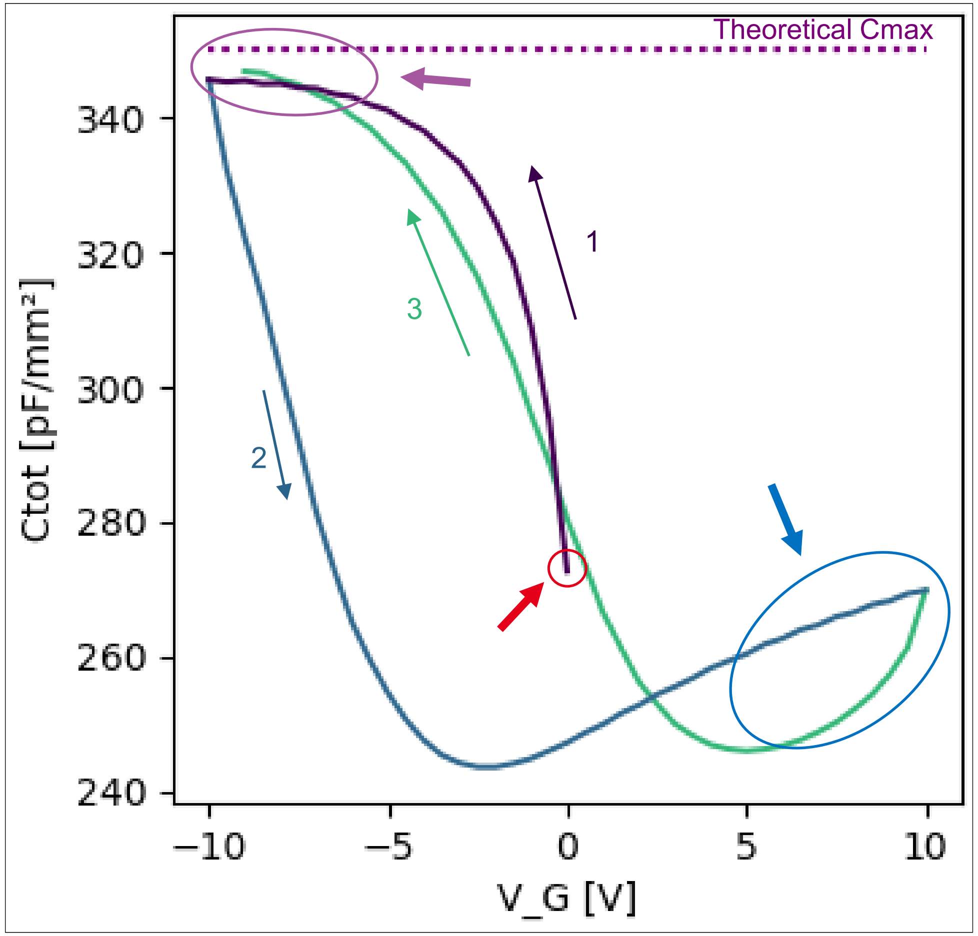


PASSIV1-3B @400kHz 100K
cycle : 0V/-13V/+13V/-13V

Cmax_theo [300, 330] pF/mm²

C-V Results : Passivation #2 sample

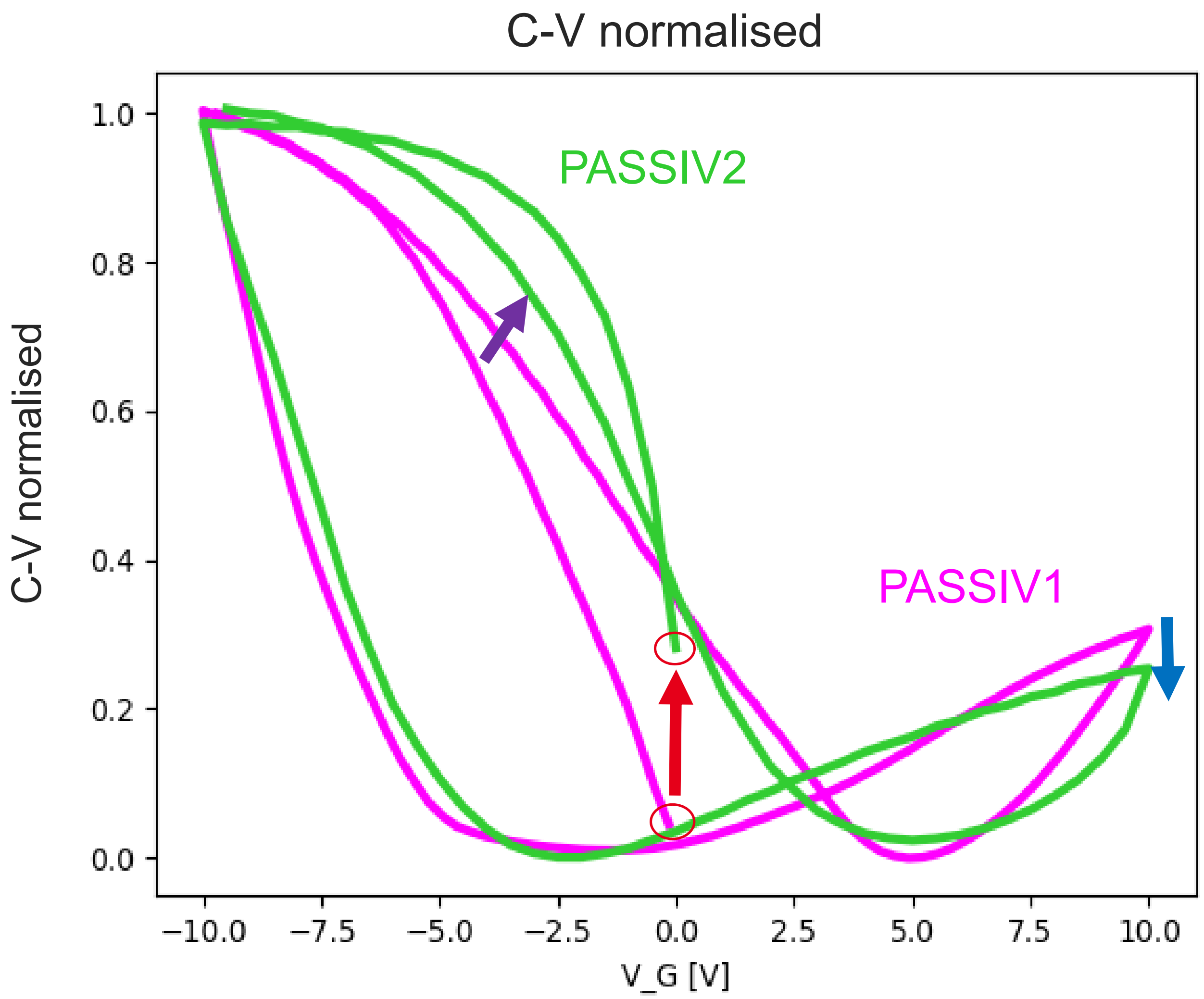
- Interface Charge State - **C_0V** :
  - Inital state improved – more away from inversion
  - Global interface charge decreased
  - Decreased recombination / trapping
- Minority carriers activity at interface :
  - Smaller C-V rise in inversion at high freq. (400kHz)
  - Improvement for low frequencies too (while PASSIV1 degrades strongly)
- In gap interface defects :
  - Cmax quickly reached around -10V
  - Less traps, to be quantified with specific meas.
- Hysteresis unchanged : mobile charges and traps in passivation unchanged
- **PASSIV2 improved the backside for a N/P device**
- Same trends on all MIS tested



PASSIV2-4B @400kHz 100K
cycle : 0V/-10V/+10V/-10V

Cmax_theo 350 pF/mm² [A-R thickness @ ellipso]

Qualitative C-V comparison



PASSIV2-4B /// PASSIV1-3B @400kHz 100K

PASSIV2 improves :

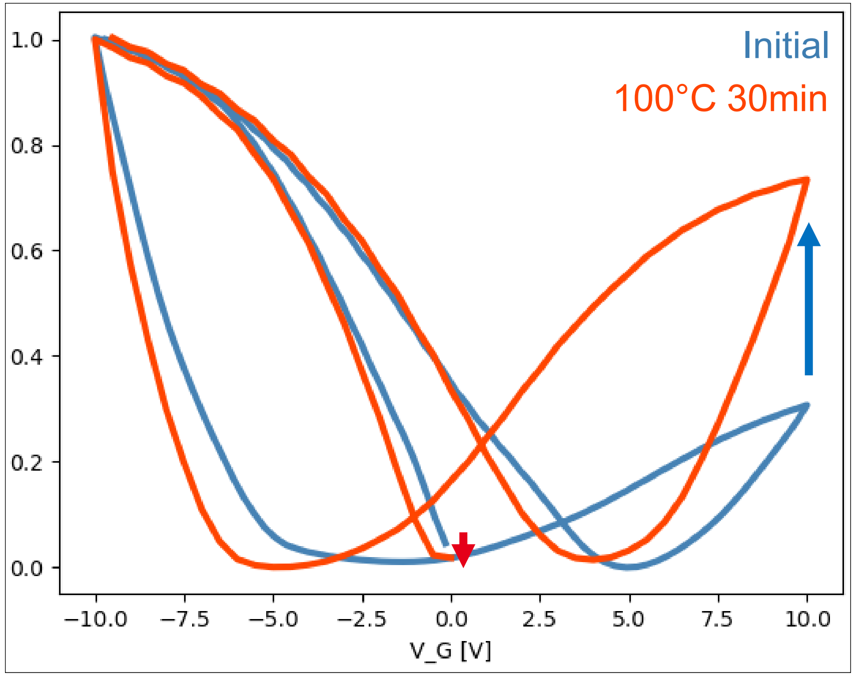
Interface Charge State

In gap interface defects

Minority carriers activity at interface

After 30min @ 100°C annealing

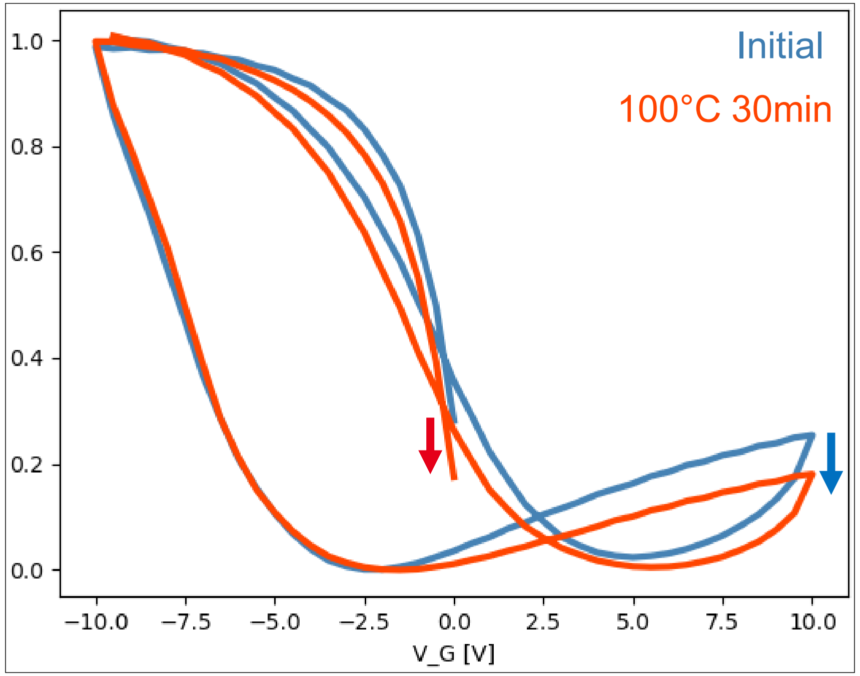
PASSIV1



Interface Charge State : slight degradation

Minority carriers activity at interface : very strong degradation (on all MIS tested)

PASSIV2



Interface Charge State : slight degradation

Minority carriers activity at interface : slight improvement (on all MIS tested)

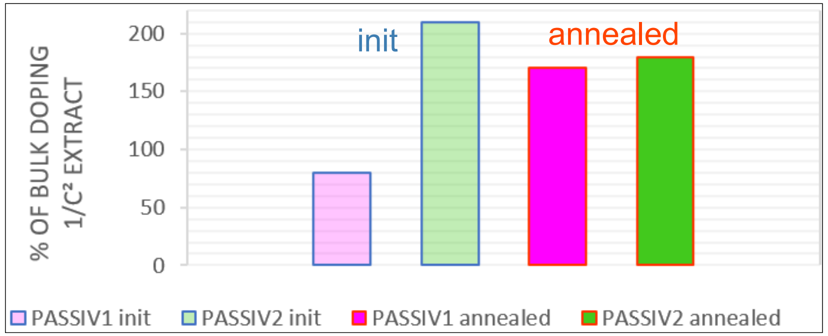
PASSIV1 interface degrades easily, and will not age well

PASSIV2 interface is more stable and ages better (more annealing coming)

Parameters extraction

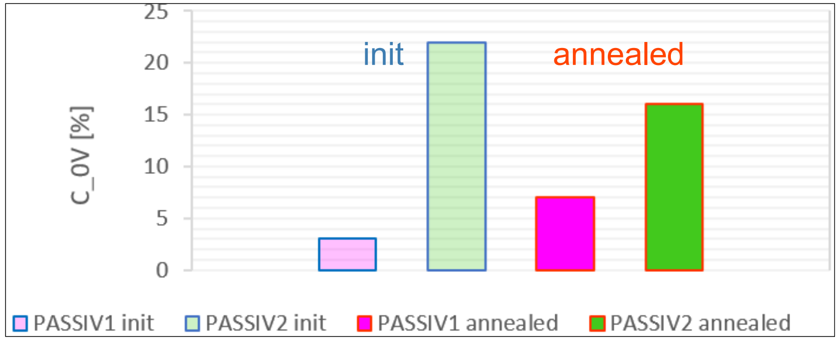
Doping estimation with $1/C^2$ slope

- Extracted doping consistant with Hall measurements
  - $1/C^2$ extraction : 170% bulk doping after annealing
  - CminCmax extraction : 60% - 80% bulk doping (depend on accumulation reach)



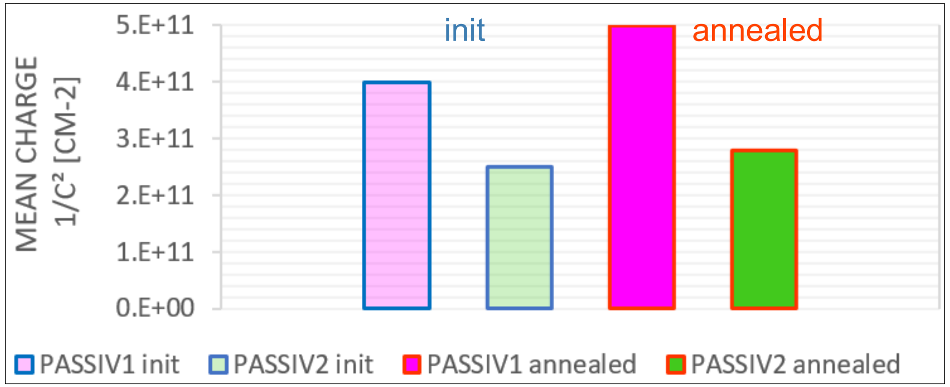
C_0V = initial state

- **0%** = strong inversion - **100%** = fully accumulated
- PASSIV1 C_0V quite low
- PASSIV2 Interface Charge State improves greatly
- Slight degradation after annealing to follow later



Interface charge

- Interface charge = fixe, mobile charges, interface trap
- Positive charge bends bands down (minority c. see interface)
- Typical of MCT native oxide $(+5e11\ cm^{-2}$, Romashko 1998)
- **PASSIV2 divides by 2 the positive interface charge**
- PASSIV2 reaches interface closer to accumulation



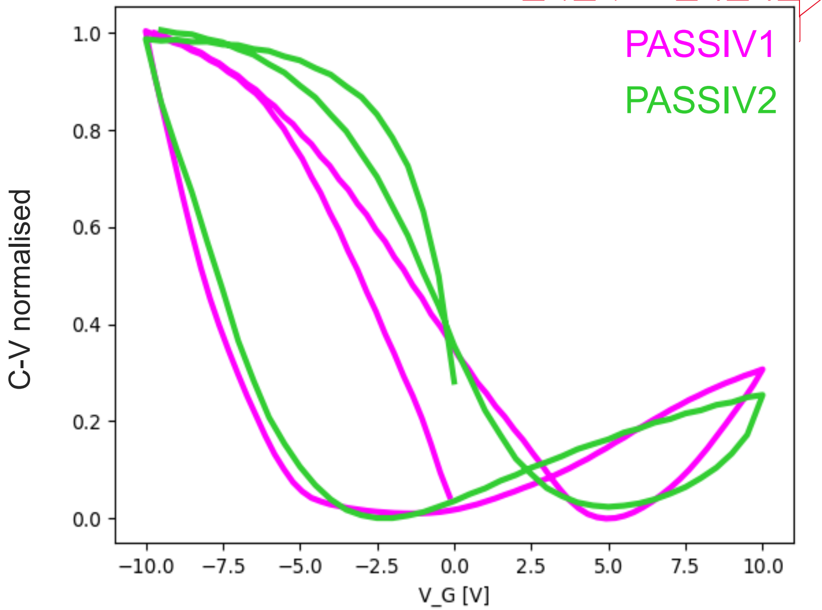
4. Conclusion

Conclusion

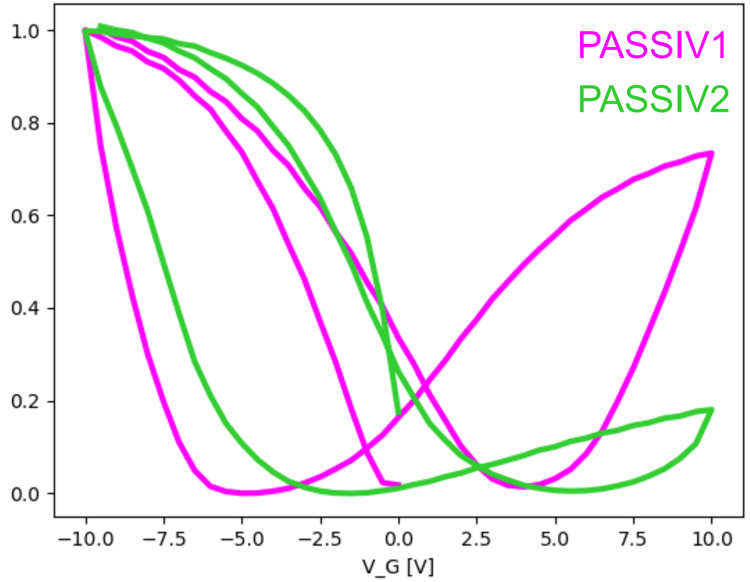
- **Proof of Concept** of device back-side health-check !
  - Open a new interface to improve final performances
  - More samples will be studied to improve statistics

- PASSIV2 has proved useful :
  - **Interface total charge** improvement
  - **In gap defects reduced**
  - **Aging stability**
  - Successfull PASSIV2 on frontside works also on FAR

- Next steps :
  - Understand and quantify interface active defects (C-V specific meas. – dark cond., freq. meas., Dit extract.)
  - Simulation of the backside to quantify its role in final performances
  - Test photodiodes and illumination flux to approach final device



Aging / annealing



PASSIV2-4B /// PASSIV1-3B @400kHz 100K

Thank you for your attention
Do you have questions?

X. Annexes

Parameters extraction

Doping estimation with $1/C^2$ slope

- Extracted doping consistant with Hall measurements
  - $1/C^2$ extraction : 100% - 200% bulk doping
  - CminCmax extraction : 60% - 80% bulk doping (depend on accumulation reach)

INIT	Mean Ndop $1/C^2$ [% of Hall meas.]
PASSIV1	80% (sig 10%)
PASSIV2	210% (sig 67%)

ANNEALED	Mean Ndop $1/C^2$ [% of Hall meas.]
PASSIV1	170% (sig 60%)
PASSIV2	180% (sig 50%)

C_0V = initial state

- **0%** = strong inversion - **100%** = fully accumulated
- PASSIV2 Interface Charge State improves greatly
- Slight degradation after annealing to follow later

INIT	Mean C_0V [%]
PASSIV1	3% (sig 1.5%)
PASSIV2	**22%** (sig 6%)

ANNEALED	Mean C_0V [%]
PASSIV1	7% (sig 2%)
PASSIV2	**16%** (sig 1.6%)

Interface charge

- Interface charge = fixe, mobile charges, interface trap
- Positive charge bends bands down (minority c. see interface)
- Typical of MCT native oxyde $(+5e11\ cm^{-2}$, Romashko 1998)
- PASSIV2 **divides by 2 the positive interface charge**
- PASSIV2 reaches interface closer to accumulation

INIT	Mean Nk $1/C^2$ [cm-2]
PASSIV1	+4e11 (sig 1e11)
PASSIV2	+2.5e11 (sig 3e10)

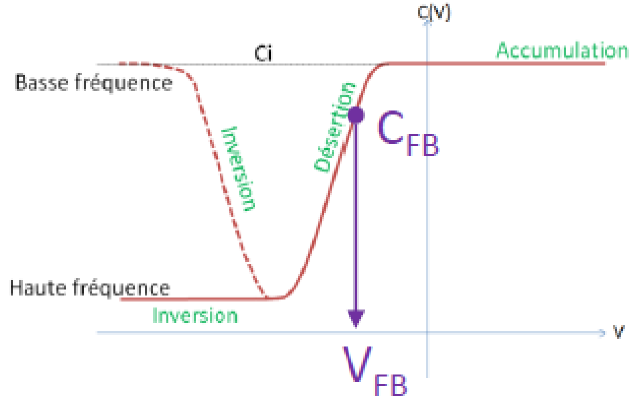
ANNEALED	Mean Nk $1/C^2$ [cm-2]
PASSIV1	+5e11 (sig 2e11)
PASSIV2	**+2.8e11** (sig 3.2e9)

Annexes

CminCmax extraction

$$C_{s\,min} = \sqrt{\frac{\varepsilon_s \, e \, Na}{4\,\Phi f\,(Na)}} \qquad \Phi f(Na) = \frac{kT}{e}\ln\left(\frac{Na}{n_i}\right)$$

$$C_{s\,FB} = \frac{\varepsilon_s}{L_D} \qquad L_D = \sqrt{\frac{kT\varepsilon_s}{q^2 N_{Dop}}} \qquad \frac{1}{C_{FB}} = \frac{1}{C_{ox}} + \frac{1}{C_{s\,FB}}$$



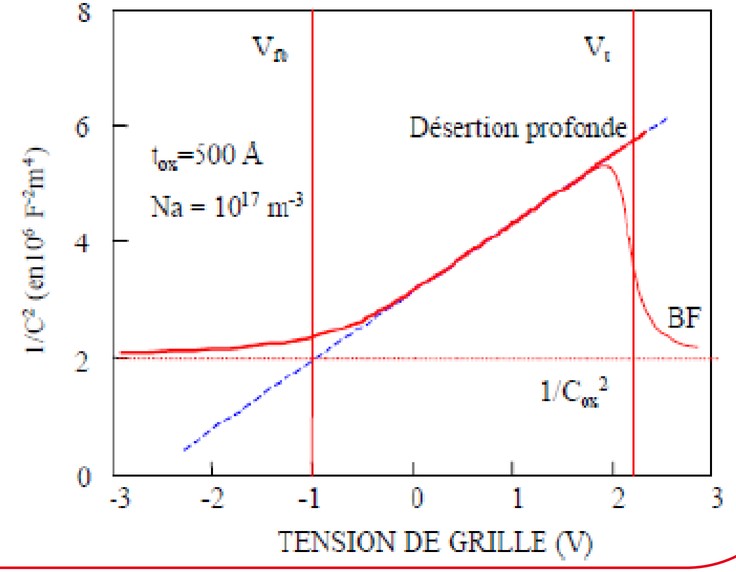
Cours C-V Florent Rochette

$C\_0V = (C - C_{min}) / (C_{max} - C_{min})$

1/C² extraction

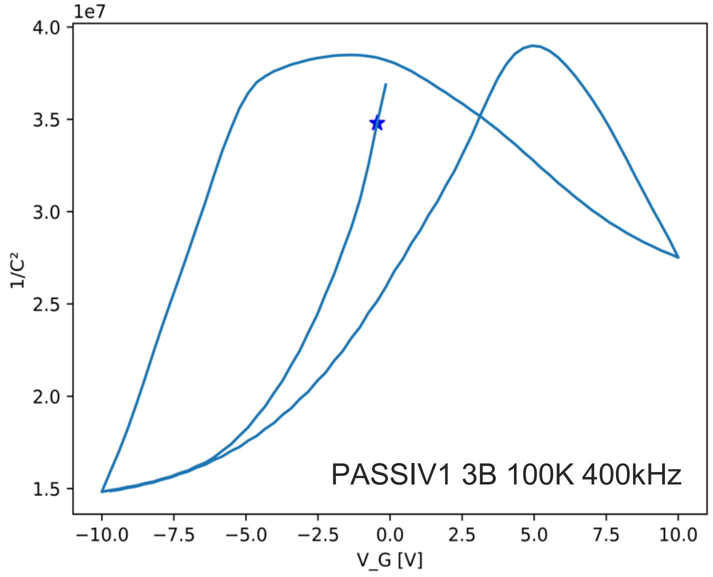
$$\frac{1}{C^2(V_g)} = \frac{1}{C_{ox}^{\;2}} + \frac{2}{Na\, e\, \varepsilon_s}(V_g - V_{FB})$$

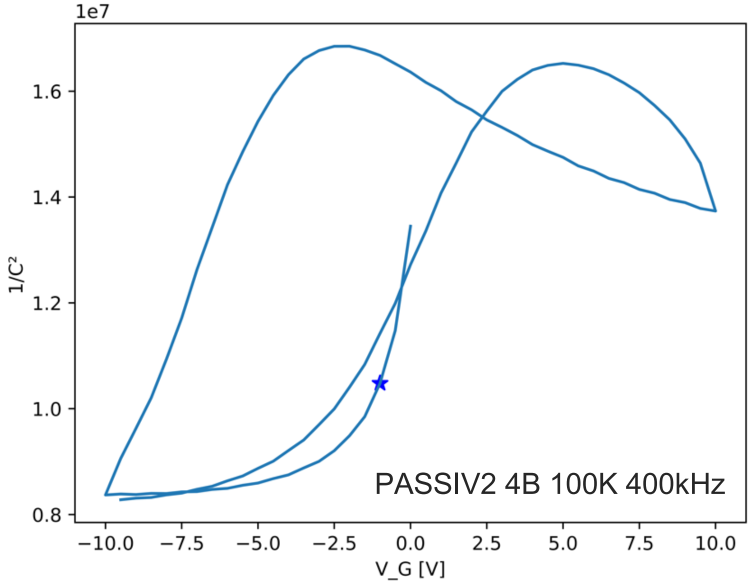
$$V_{FB} = \phi_{MS} - \frac{\sum_i Q_i}{C_{is}}$$

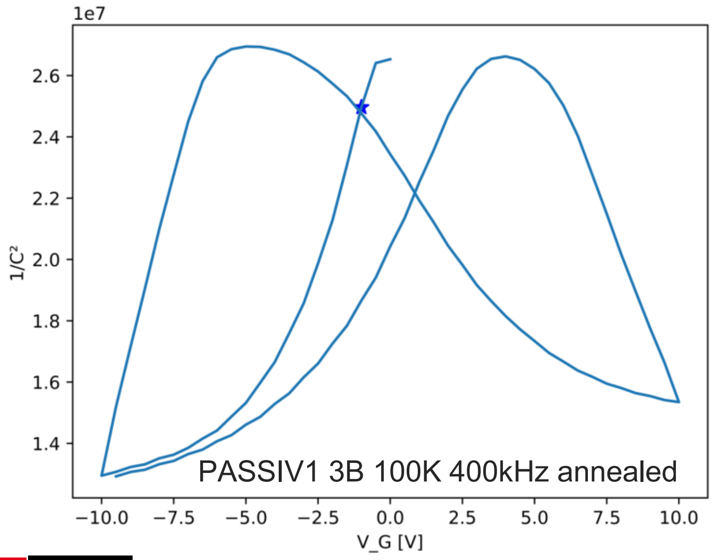


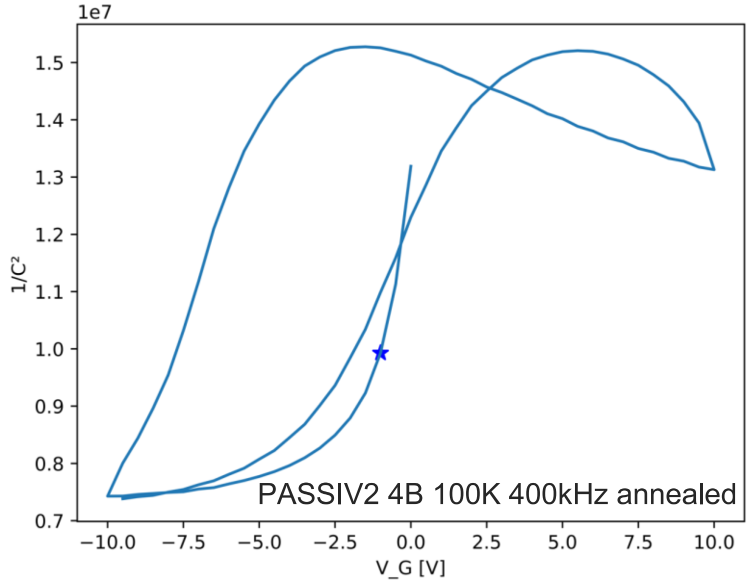
Annexes

1/C² curves + blue star is the polarisation of extraction

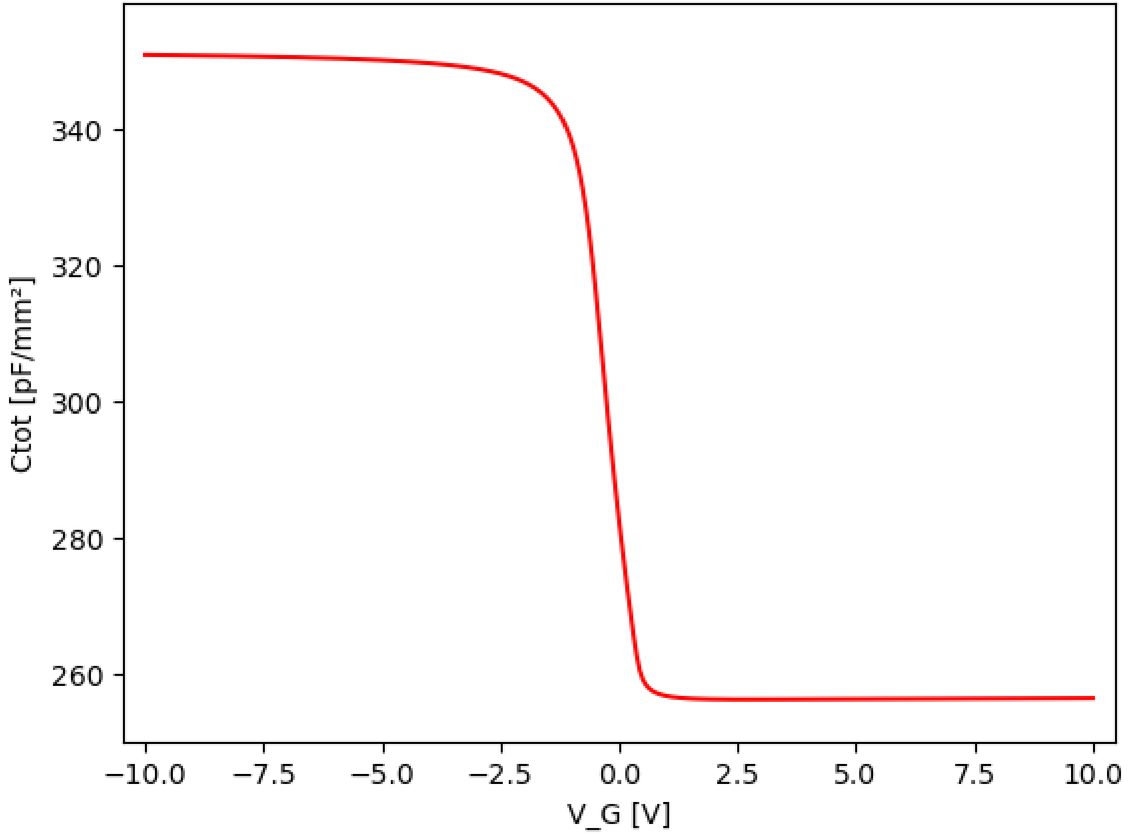








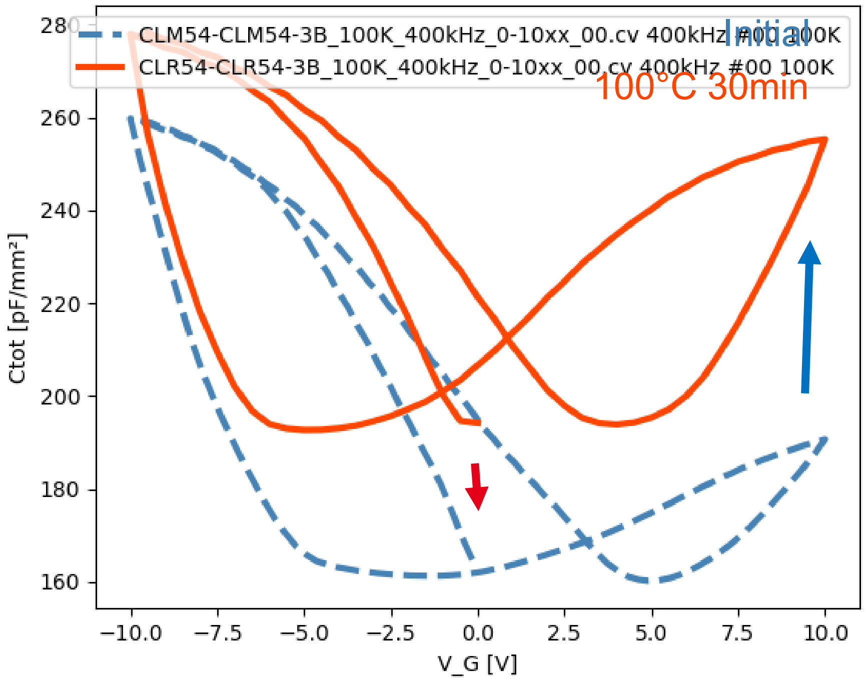
Annexes



Ideal C-V @ high frequency from Schröder model

Annexes : Not normalized - After 30min @ 100°C annealing

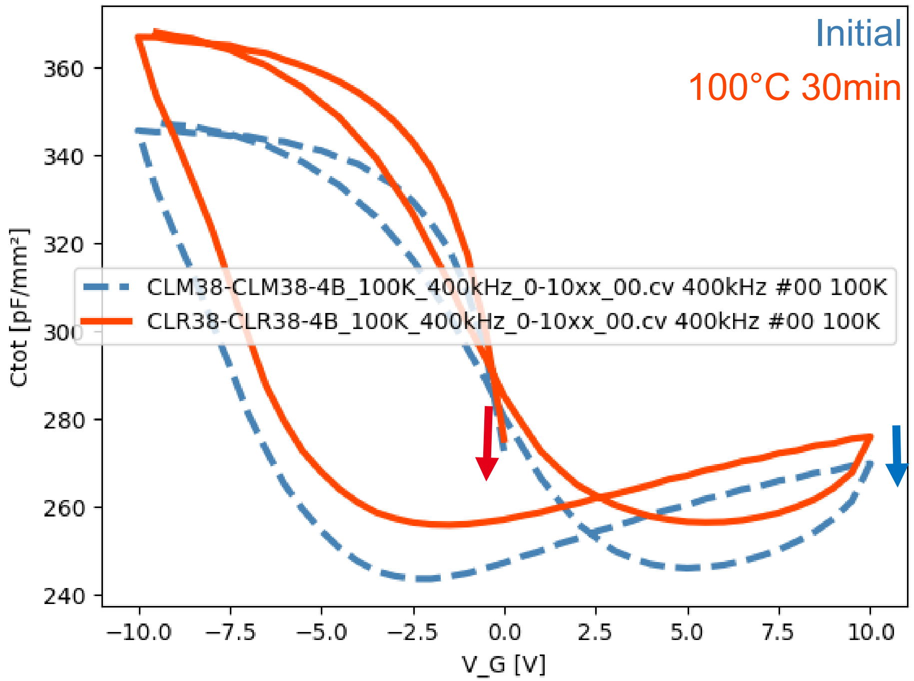
PASSIV1



Interface Charge State : slight degradation

Minority carriers activity at interface : very strong degradation (on all 5 MIS tested)

PASSIV2

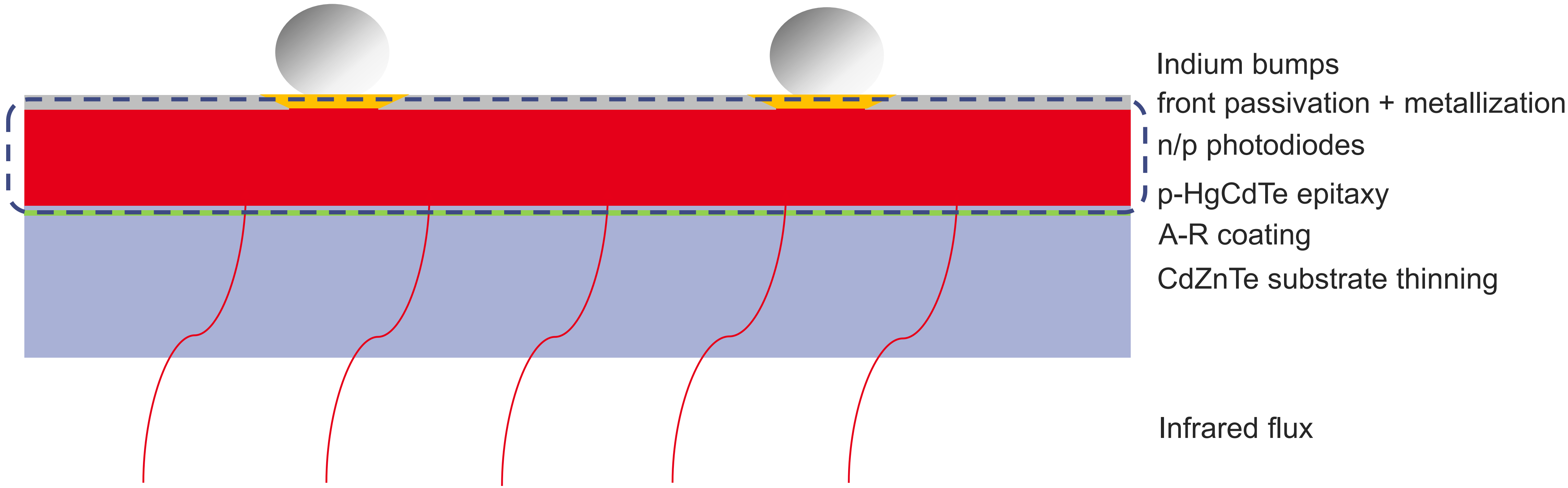


Interface Charge State : slight degradation

Minority carriers activity at interface : slight improvement (on all 3 MIS tested)

The PASSIV1 interface degrades easily, and will not age well

The PASSIV2 interface is more stable and age better (more annealing coming)


Indium bumps
front passivation + metallization
n/p photodiodes
p-HgCdTe epitaxy
A-R coating
CdZnTe substrate thinning
Infrared flux