

## HgCdTe FPA developments for space and science imaging at DEFIR (LETI-Sofradir joint lab)

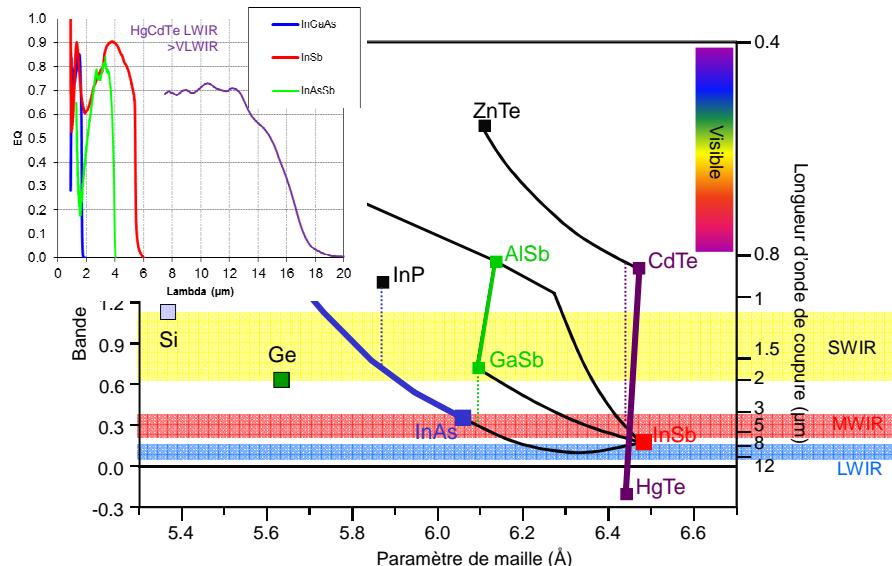
O.Gravrand (LETI)

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- General intro about MCT FPAs
  - MCT alloys
  - A bit of history about LETI and Sofradir
  - Dark current of the photodiode
  - Spectral shape of the photodiode response
  - Avalanche photodiodes (APD)
- Focuses on latest achievements for science imaging
  - Low flux dedicated arrays
    - Ultra low dark current arrays in NIR for Astro needs
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  - APD rapid array for Adapative optics and photon counting

## cea tech Material systems for IR imaging

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## cea tech Brief history of IR detection at LETI

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Creation of LIR (laboratoire IR)  
 • 100 people  
 • Establishment the IR detectors 2<sup>nd</sup> gen in France  
 • HgCdTe choice

CEA – DGA (french MoD) convention

1978 1986 1998 2002 2003 2008 2013

III-V lab  
 LETI è III-Vlab  
 • QWIP  
 • InGaAs

SAFRAN

LETI-Sagem common lab

• InSb dev't

SALIN

DEFIR: LETI-Sofradir Common lab

Creation of Sofradir  
 (SOciété FRAnçaise de DéTECTeurs IR)  
 • Cooled MCT detectors



Creation of Ulis



Gathering of all french IR  
 detection activities  
 in Sofradir group  
 • HgCdTe  
 • InSb / InGaAs / QWIPs

FOCUS

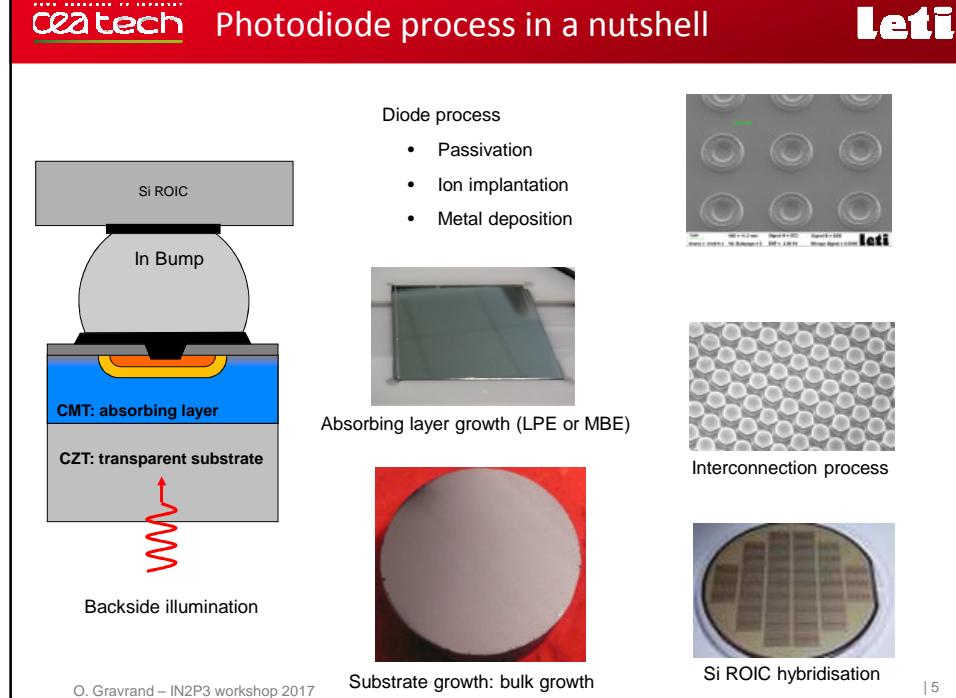
Focus labex

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## cea tech Photodiode process in a nutshell

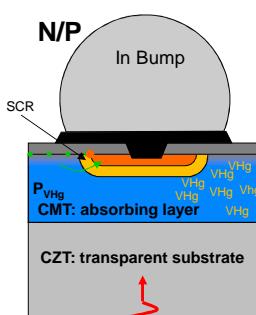
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## cea tech HgCdTe dark current issue

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**Intrinsic:**  
Low lifetime  $\tau$   
High doping  $N_{dop}$



Diffusion current from absorbing layer

$$J_{diff} = q \frac{n_i^2}{N_{Dop}} \frac{t_{diff}}{\tau}$$

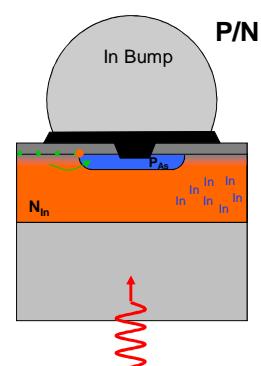
$S$ : recombination velocity  
via recombining interface trap(s)

$$J_s = q \frac{n_i}{2} S$$

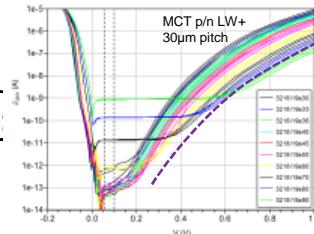
GR current in SCR and at interfaces

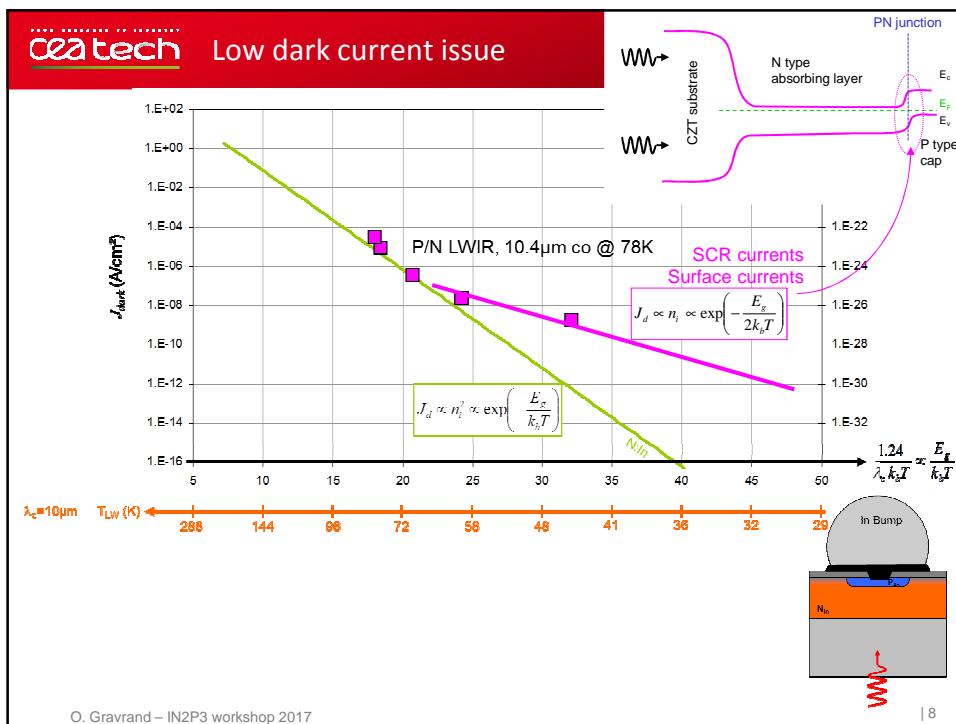
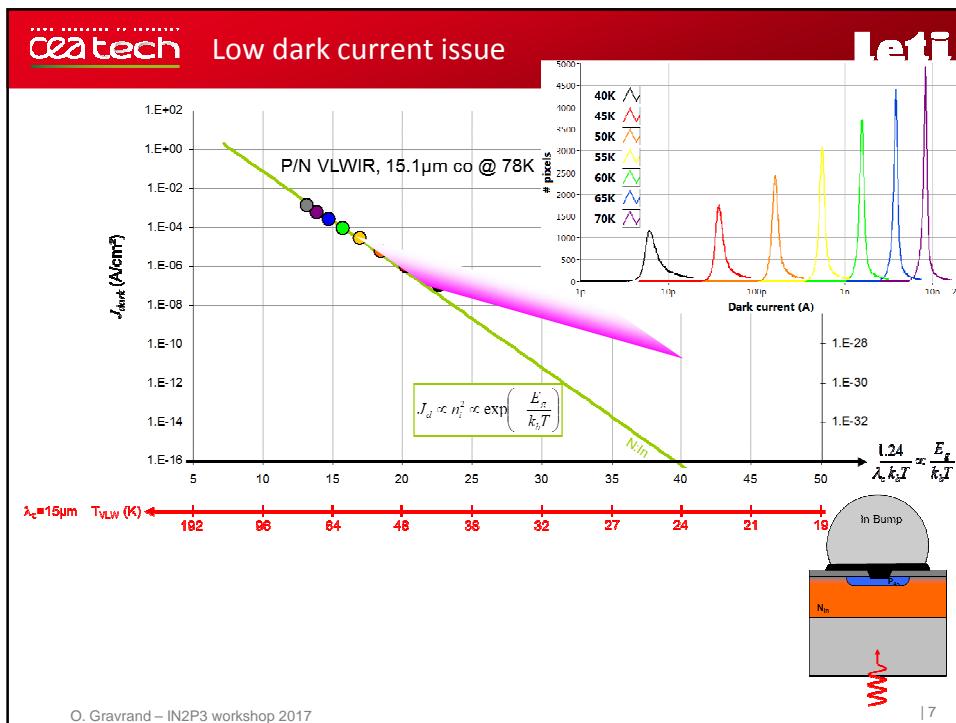
$$J_{GR} = q \frac{W}{\tau_{GR}} n_i$$

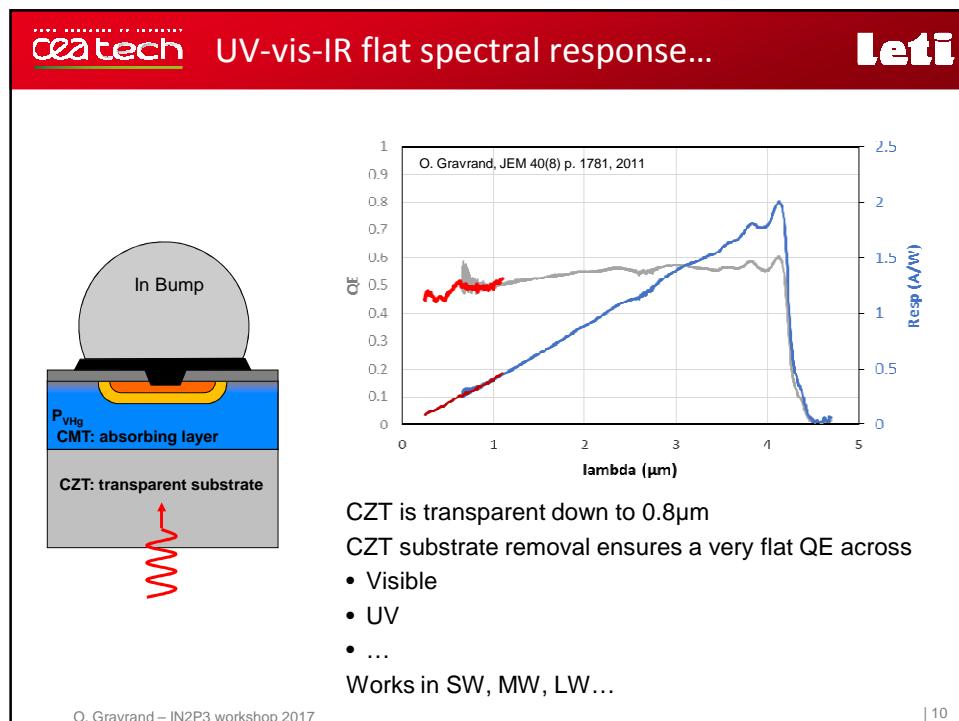
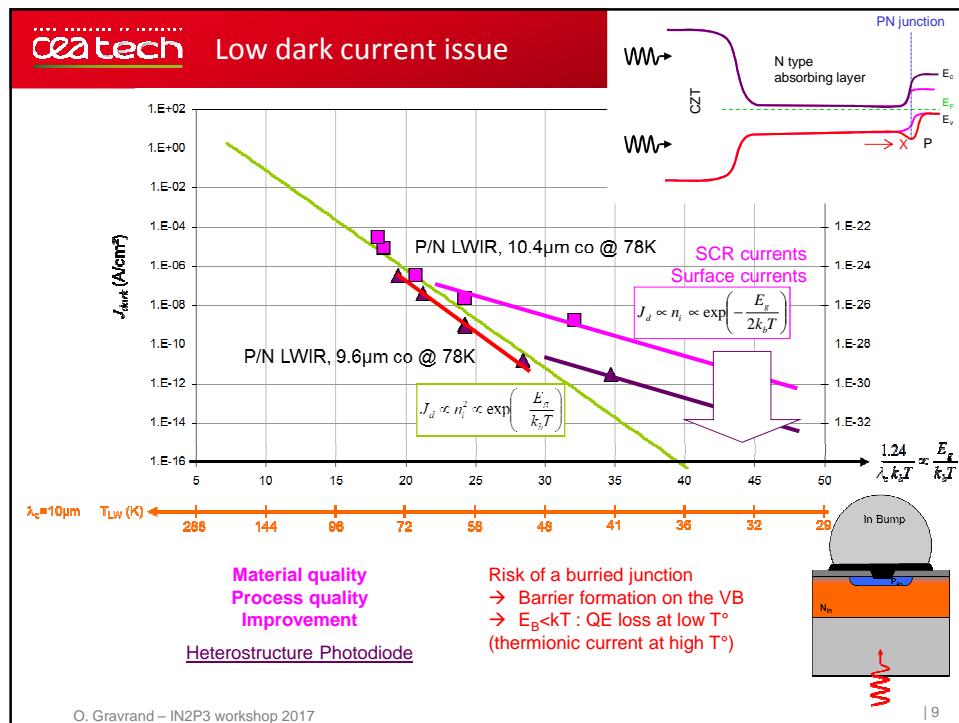
**Extrinsic:**  
Higher lifetime  $\tau$   
Lower doping  $N_{dop}$

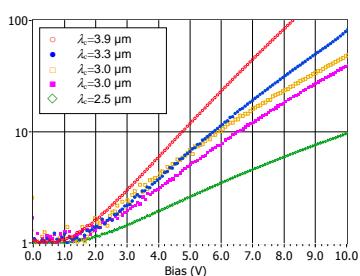
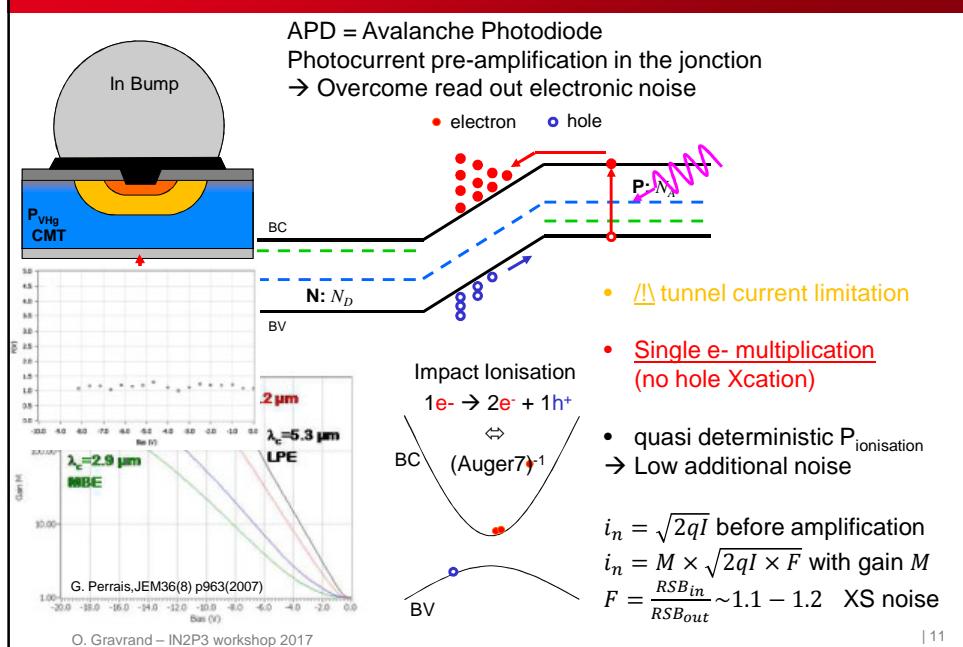


Tunnel Currents  
-specific to LW-VLW









$$SNR = \frac{\phi QE t_{int}}{\sqrt{F \phi QE t_{int} + \left(\frac{n_{noise}}{M}\right)^2 + \left(\frac{n_{dark} t_{int}}{M}\right)^2}}$$

$$\approx \sqrt{\frac{QE}{F}} \phi t_{int} = \sqrt{QEFR} \phi t_{int}$$

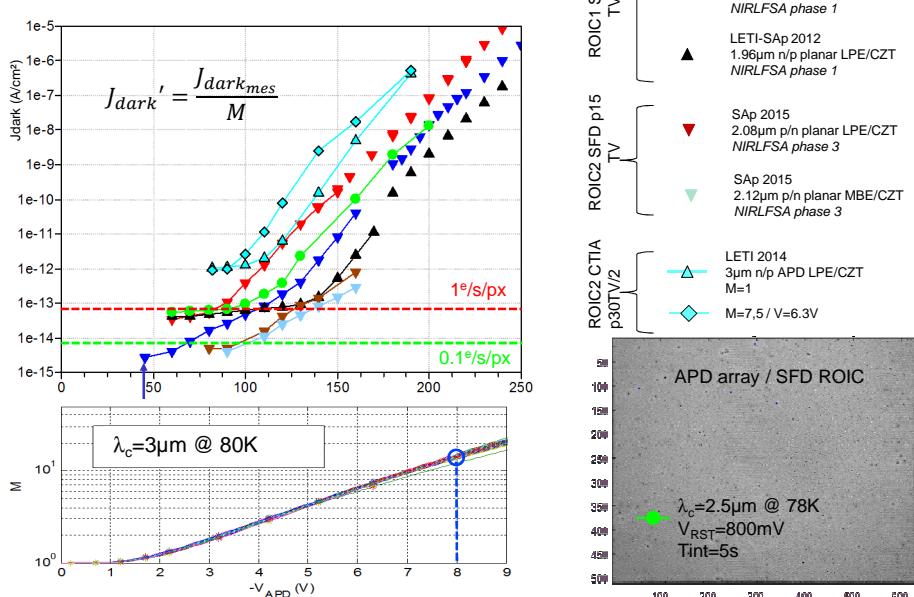
- **MCT APDs amplify the photo-current without loosing information**
  - Large gain values  $M > 10 - 100$  and low excess noise  $F = 1.1 - 1.3$
- **The APD gain allows to obtain photon shotnoise limited SNR for shorter integration times**
  - **SNR Degradation measured with  $\frac{QE}{F} = QEFR > 50 \%$**

Short observation times applications : Adaptive optics and interferometry...

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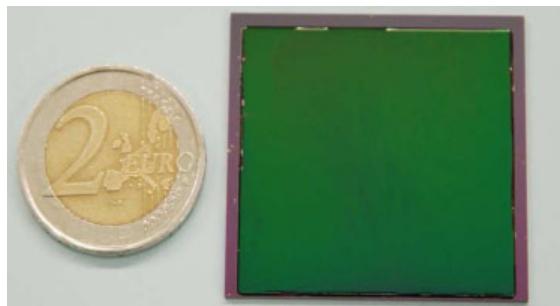


## cea tech Ongoing effort for large formats

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ALFA = Astronomical Large Format Array

- Funding ESA + FOCUS + H2020
- Consortium LETI + IRFU + Sofradir
- Goal :
  - Availability of 2kx2k NIR arrays in Europe (ITAR less detectors) for astronomy and science
  - Rendez vous in 2020!



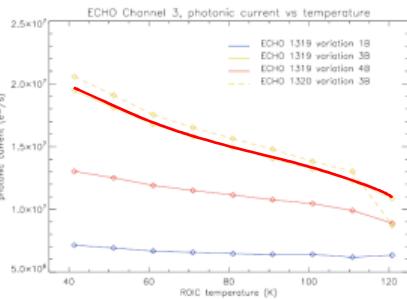
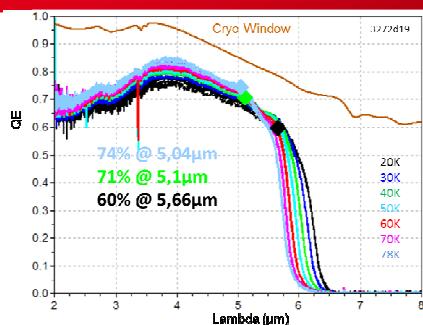
First mockup 2kx2k 15µm pitch HgCdTe/Si

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## cea tech MWIR n/p VHg

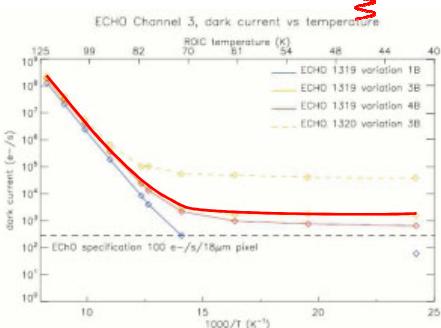
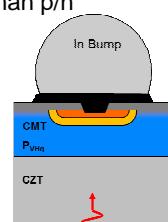
leti

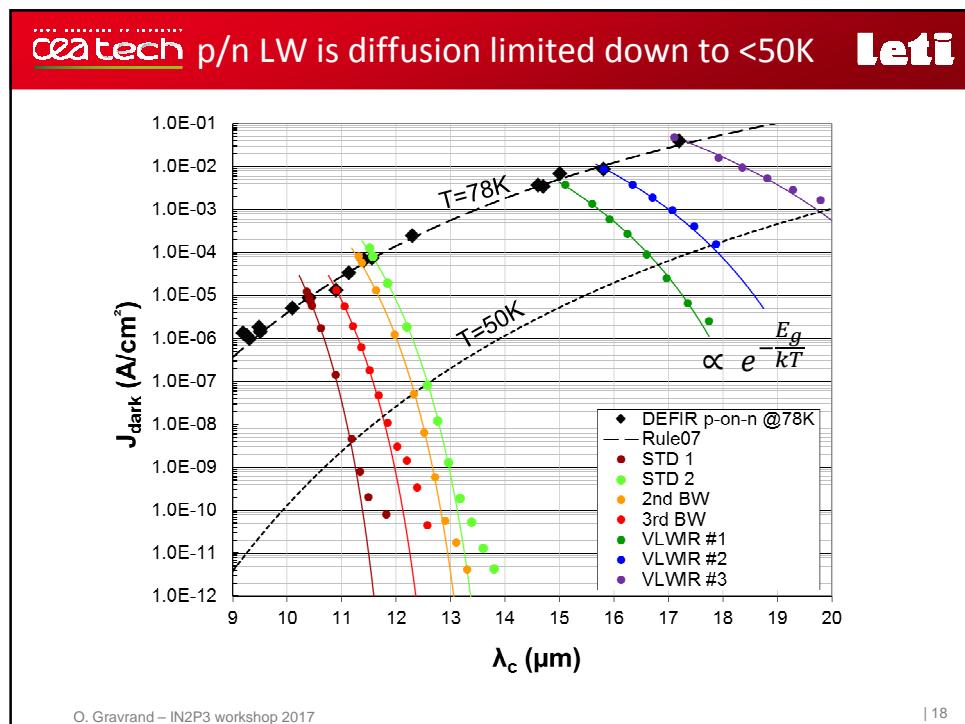
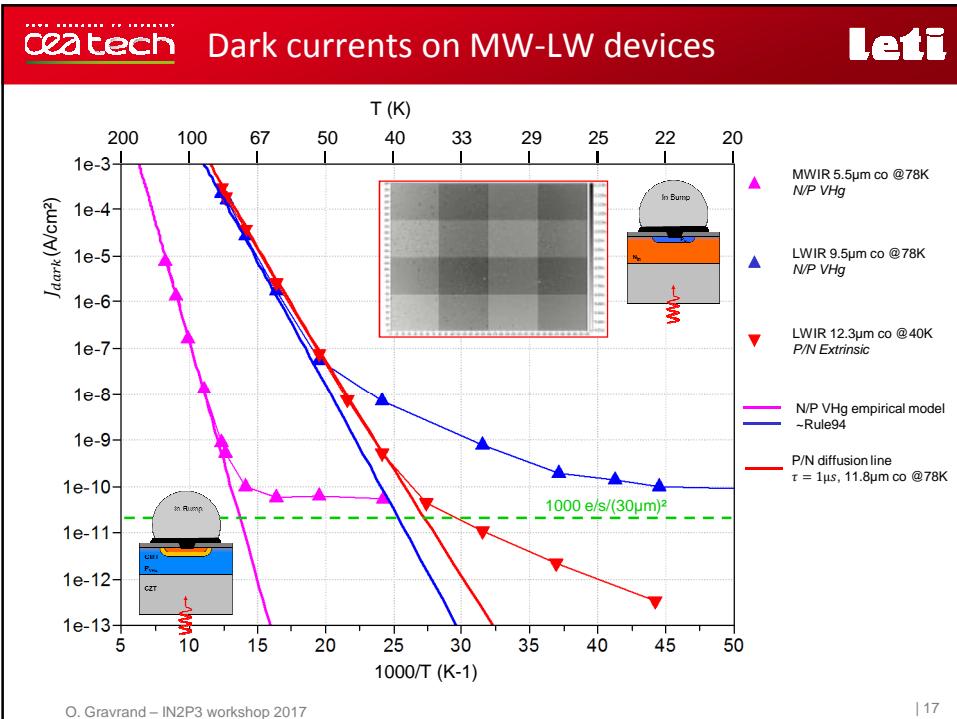


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n/p VHg:

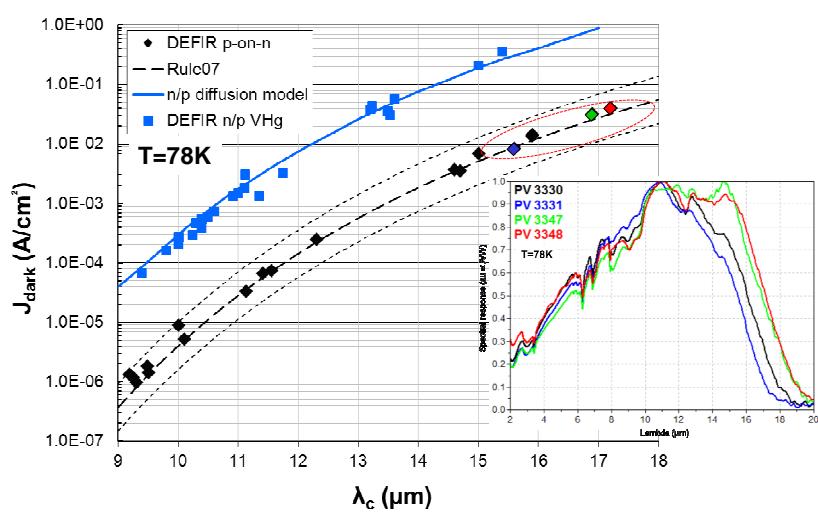
- larger diffusion current than p/n
  - More mature (and thus cheaper)
- Down to which T° do we stay in diffusion regime?



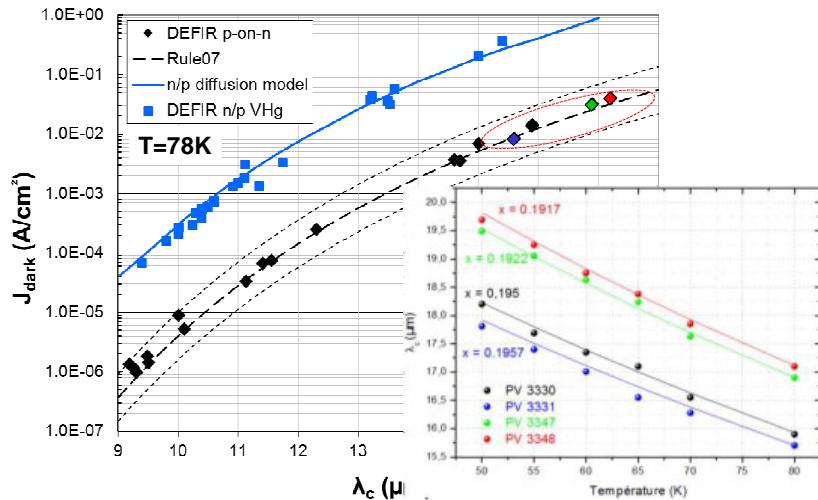


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- 4 layers investigated
- Cutoffs from  $15.6$  up to  $17.1\mu\text{m}$  @ 78K,  $\langle\text{QE}\rangle\sim80\%$



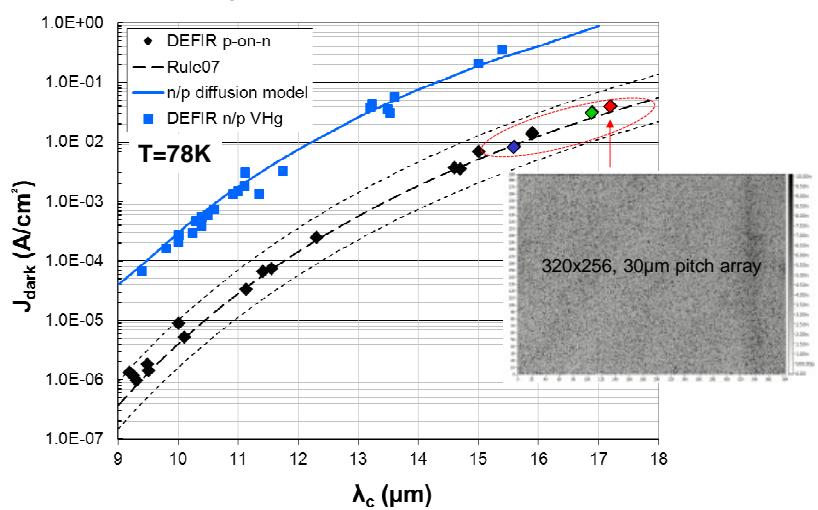
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- → 20μm co @ 50K, longest ever processed at LETI  $\langle QE \rangle \sim 50\%$



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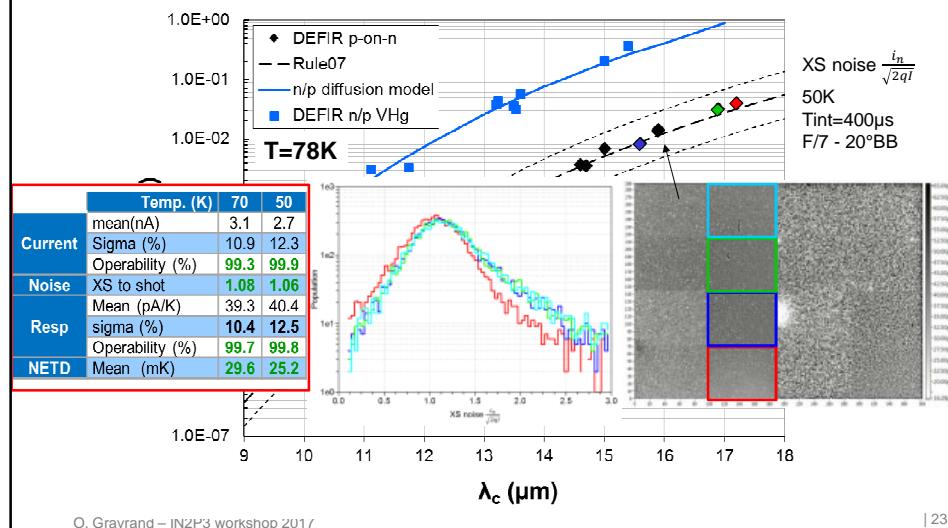
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- Study array to identify best variation
- Optimum configuration gives very low noise defectivity at 50K

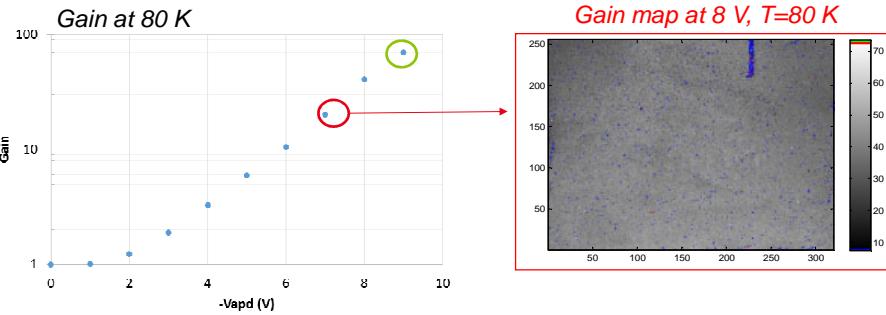


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## NEW RAPID FPAS

- New APD arrays with increased gain and QE

- Lower  $x_{Cd}$ :  $\lambda_c = 3.6 \mu m$
- Larger APDs in the pixels → improved QE due to fill factor

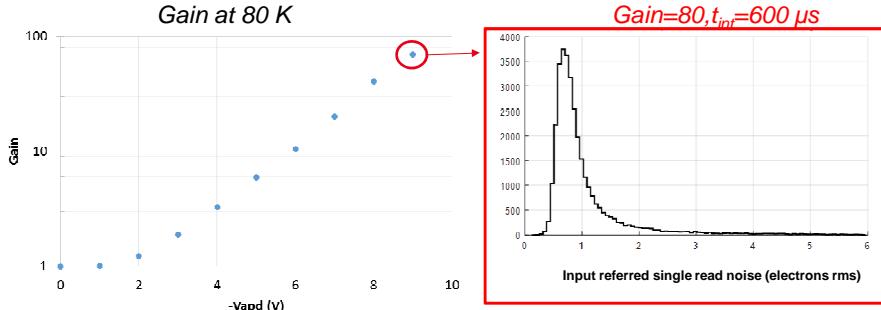


- $< M > = 41$  with pixel operability  $> 99\%$  at  $< M > \pm 50\%$  (wo the crack)
- $< M > = 70$  at 9V reverse bias,  $M > 80$  at 60K
- Very high QEFR = 70%

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## NEW RAPID APD FPAS RECORD LOW SINGLE READ NOISE

Dark noise at  $T=60 K$ ,  $V_{pol}=9 V$   
 $Gain=80, t_{int}=600 \mu s$



- 0.8e single read noise achieved with RAPID ROIC at  $t_{int} = 600 \mu s$
- Photon counting imaging is possible with CEA/LETI APDs FPAs with non-destructive read-out (and/or lower ROIC noise)
  - Single photo-detection with SFD multiread circuit demonstrated in 2012 with single elements (G. Vojetta et al., SPIE proc. 8375-35)

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