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QE of front side and back side thinned CMOS Image Sensors between 100 and 400nm

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Presentation Outline

- Types of thinning to increase sensitivity
- Theory behind the need of an AR coating
- Obtained QE of various thinning types
- VUV measurements
- Take Home Message

Device Selection and Definitions

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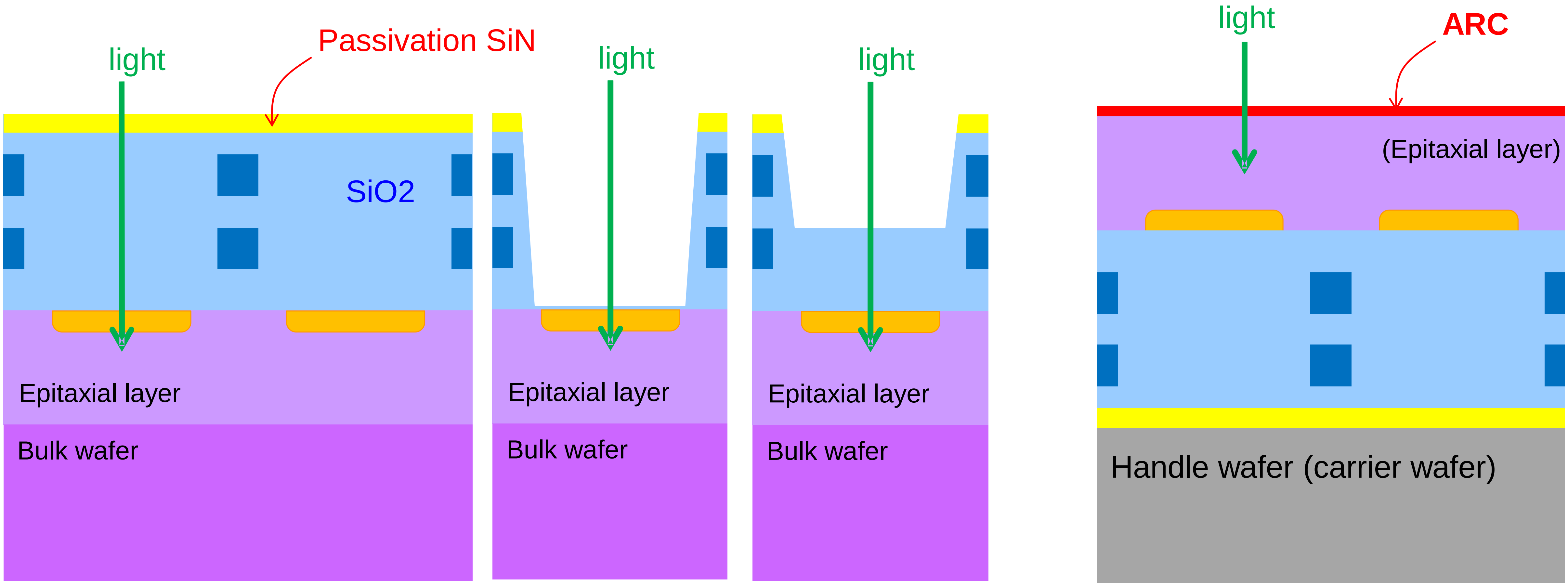
- All devices tested have nearly identical geometrical and operational parameters. Devices are processed at 3 different foundries/processes, in 110 and 180nm CIS nodes with various process options related to BSI, FST, ARC (anti-reflective coating) and wafer starting material

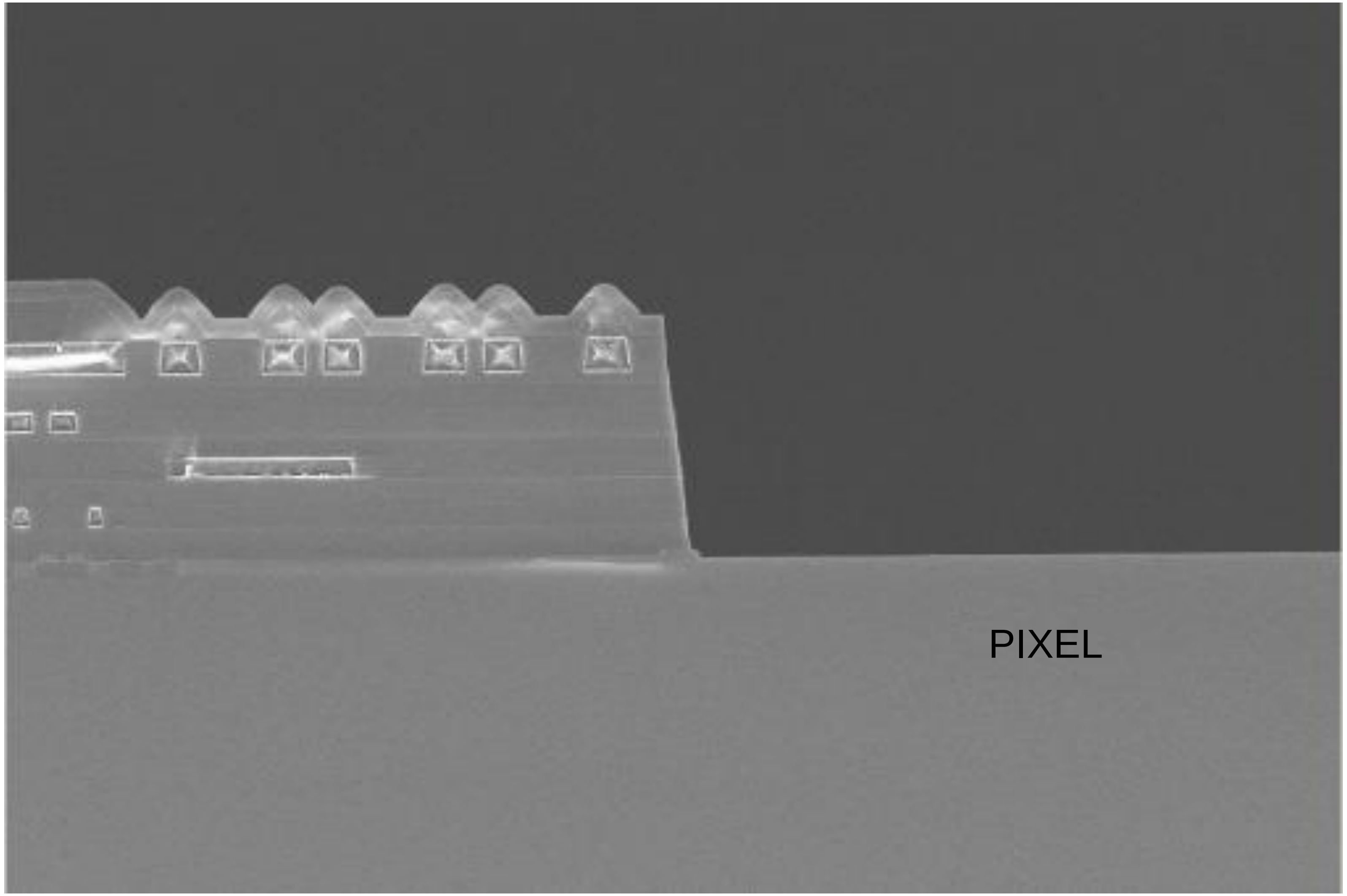
Name	Description
FSI	Classic frontside illuminated
FFST	Fully frontside thinned down to Silicon, apart from thin layer of SiO_2
PFST	Partially frontside thinned: passivation removed, about half the SiO_2 remaining
BSI	Backside illuminated, various ARC options, various epi-thickness and resistivity options

Types of Thinning

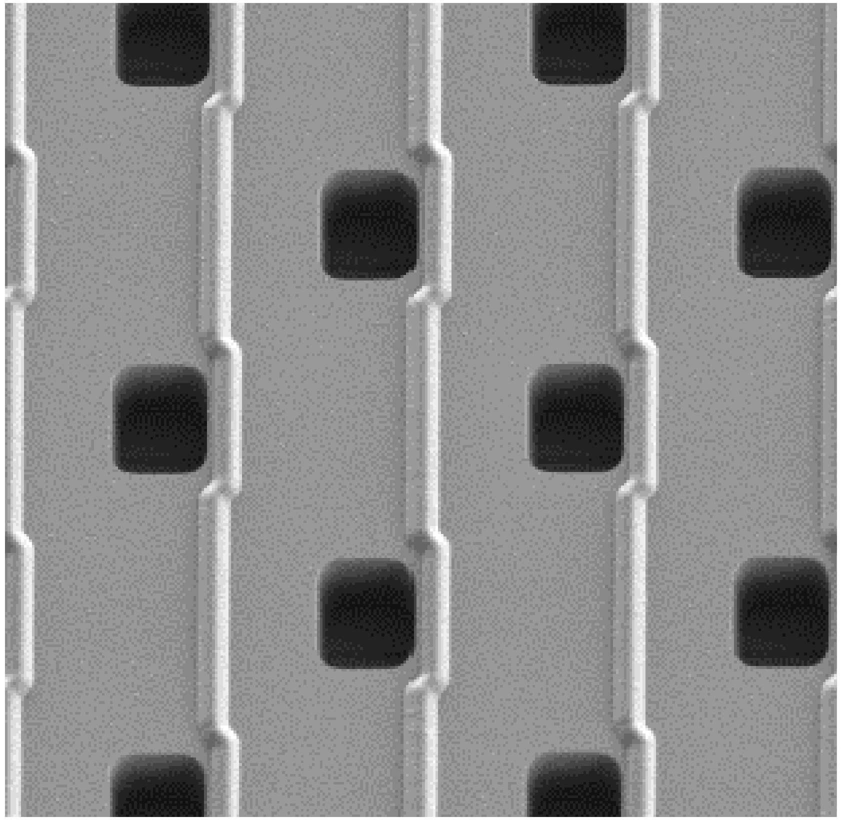


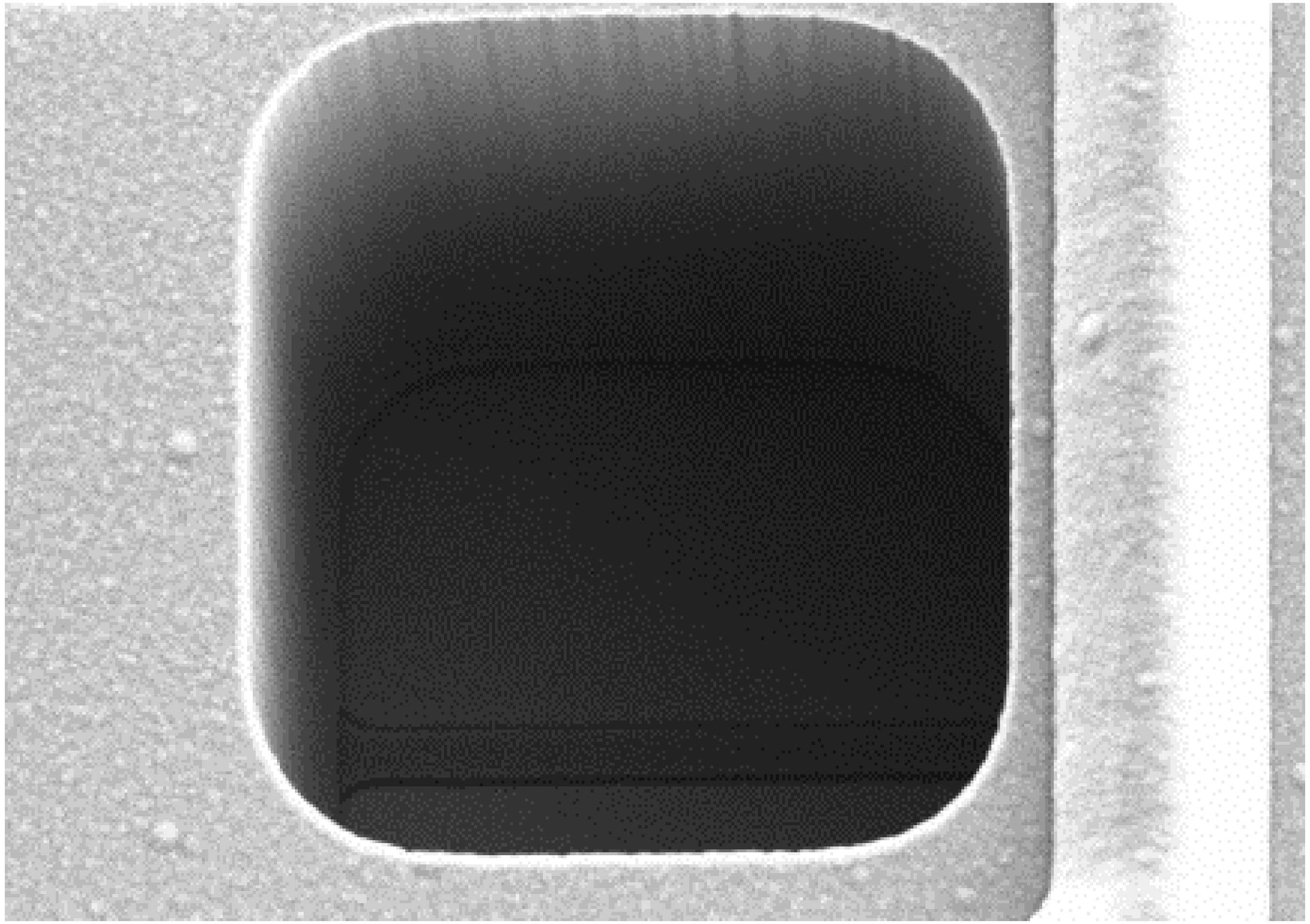
Classic frontside illuminated | **FFST** | **PFST** | **Backside thinned Backside illuminated**

Fully FST SEM cross section (device “d”)



2nd Fully FST example (device “BASTION”)





BSI example SEM cross-section (device “R”)

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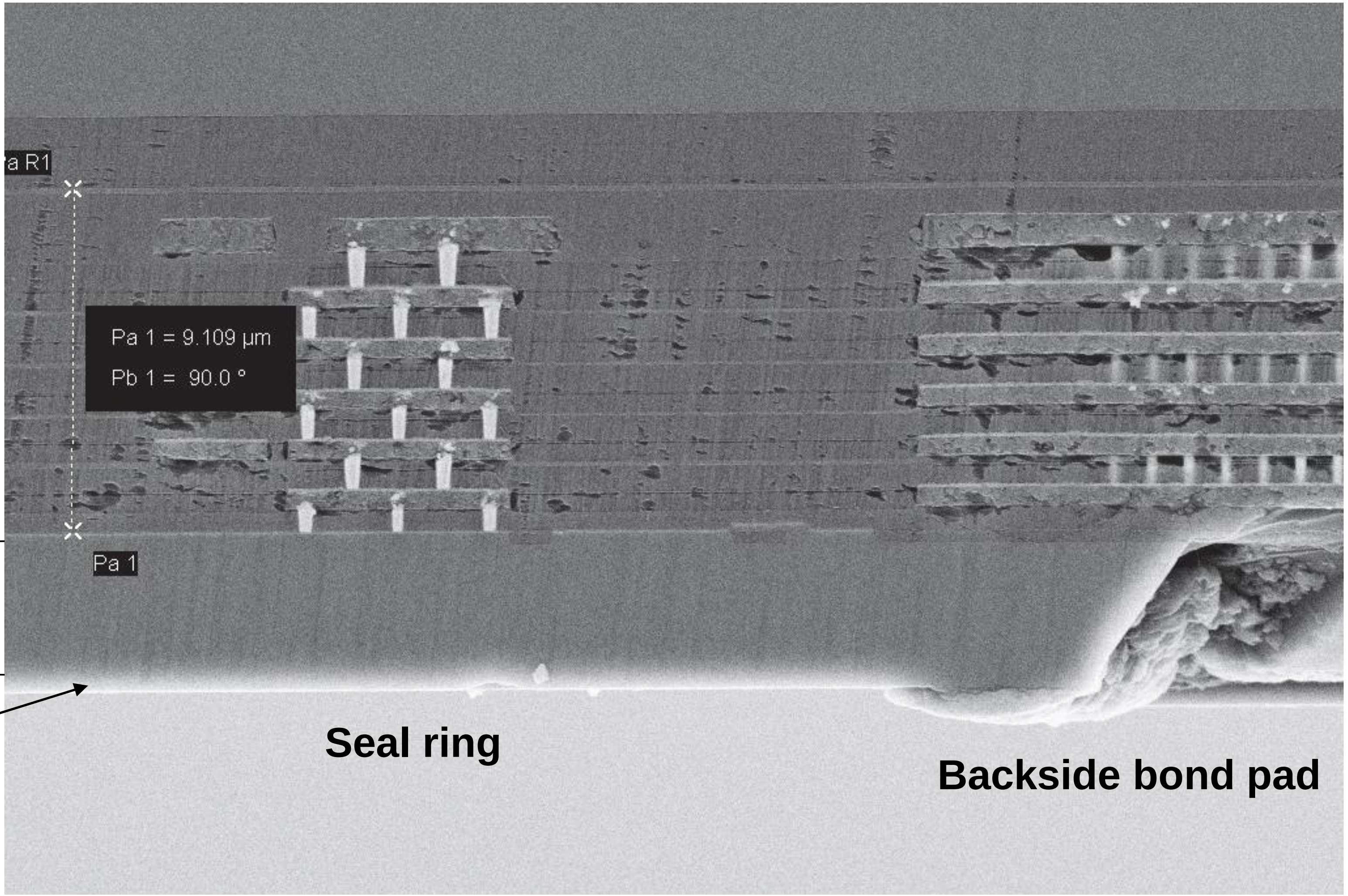
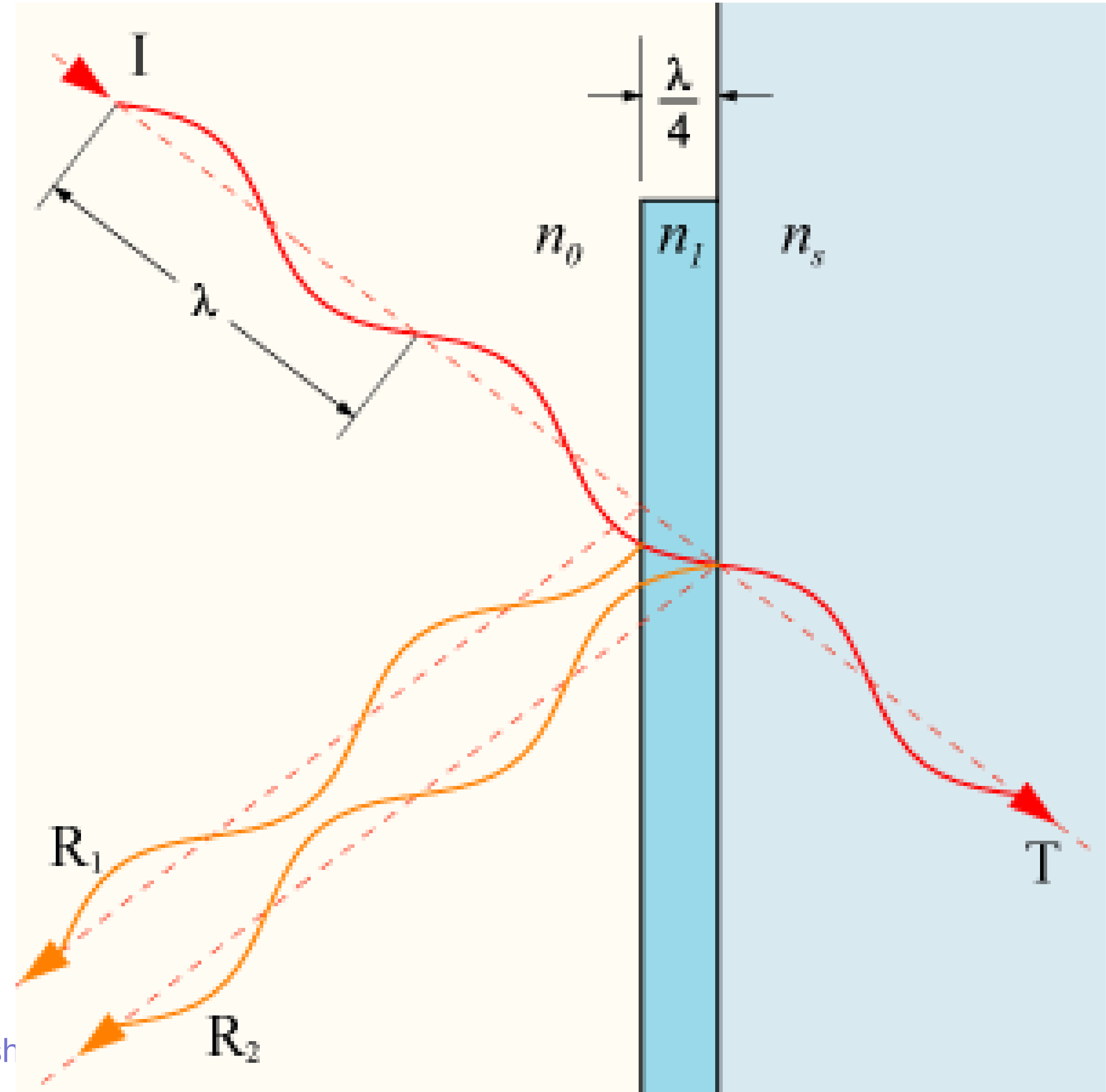


Some Theory

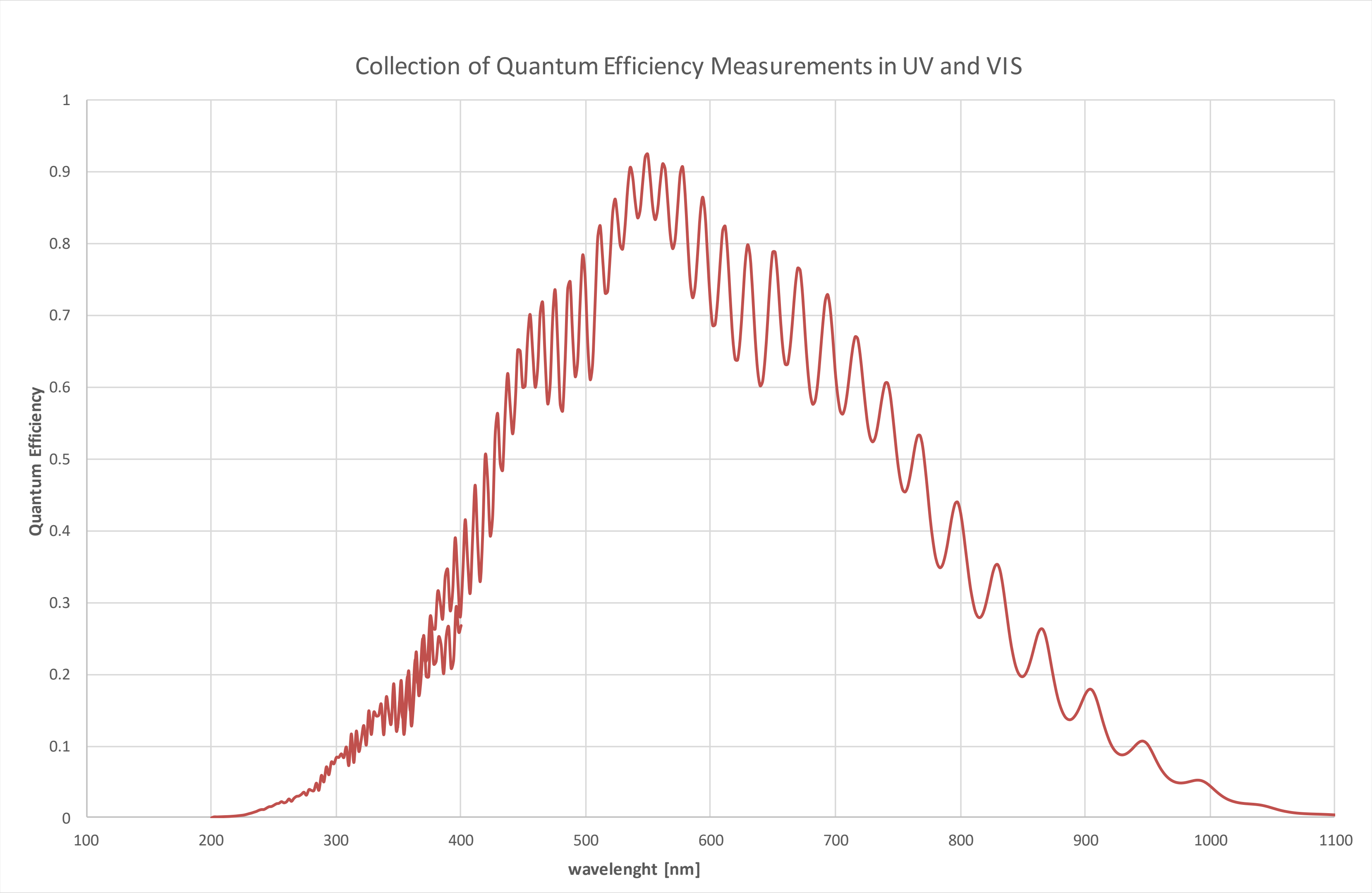
- Silicon has high refractive index.
- Without Ar coating, 30-40% reflection.
- For UV, difficult to find CMOS compatible transparant materials



Anti reflection coating (ARC)

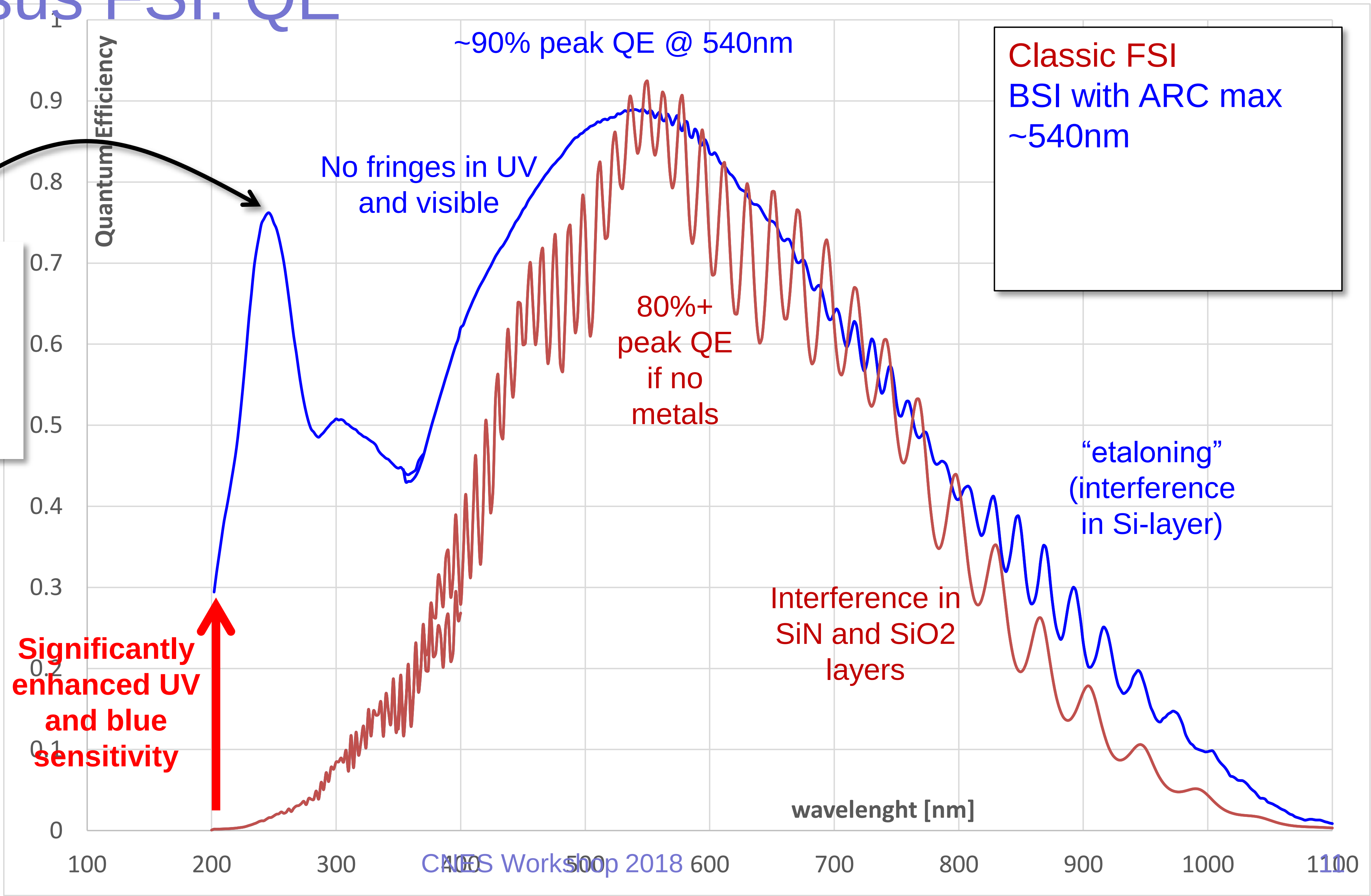
- Maximal QE is determined by reflection at air-Si interface
  - ⇒ $n_{Si} \approx 4$ => huge reflection
- Adding a coating can reduce the reflection
- Single layer
  - ⇒ At a fixed wavelength, perpendicular reflection can be removed by a simple single layer coating
    - $n_{ARC} = \mathrm{sqrt}(n1 * n2)$
    - $d_{ARC} = \lambda/(4 * n_{ARC})$
  - ⇒ Still reflection at other wavelengths, other angles
- Multiple layers
  - ⇒ Reflection can be minimized across a range of wavelengths and angles
  - ⇒ Better performance if layers with different refractive indices ($n1 < n < n2$) are available

QE of standard FSI

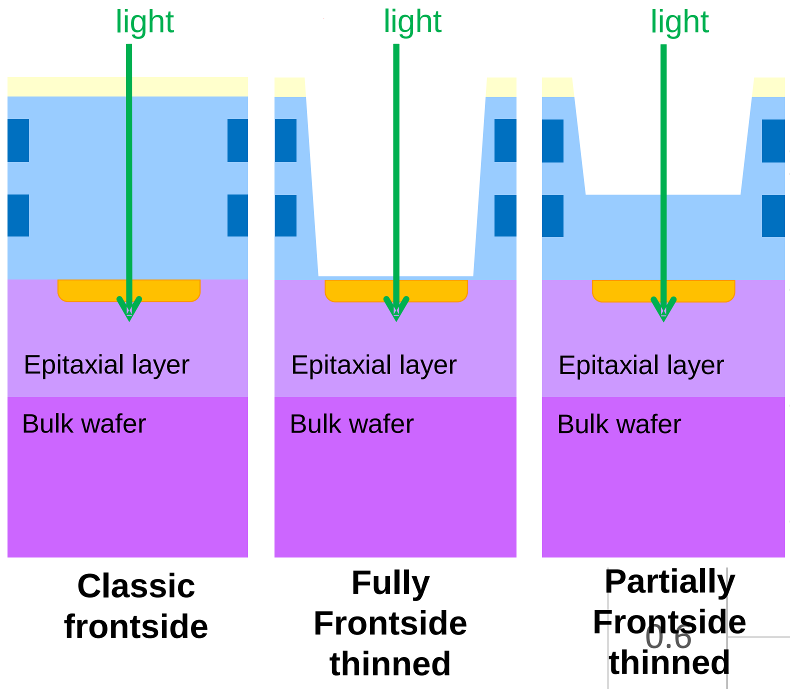


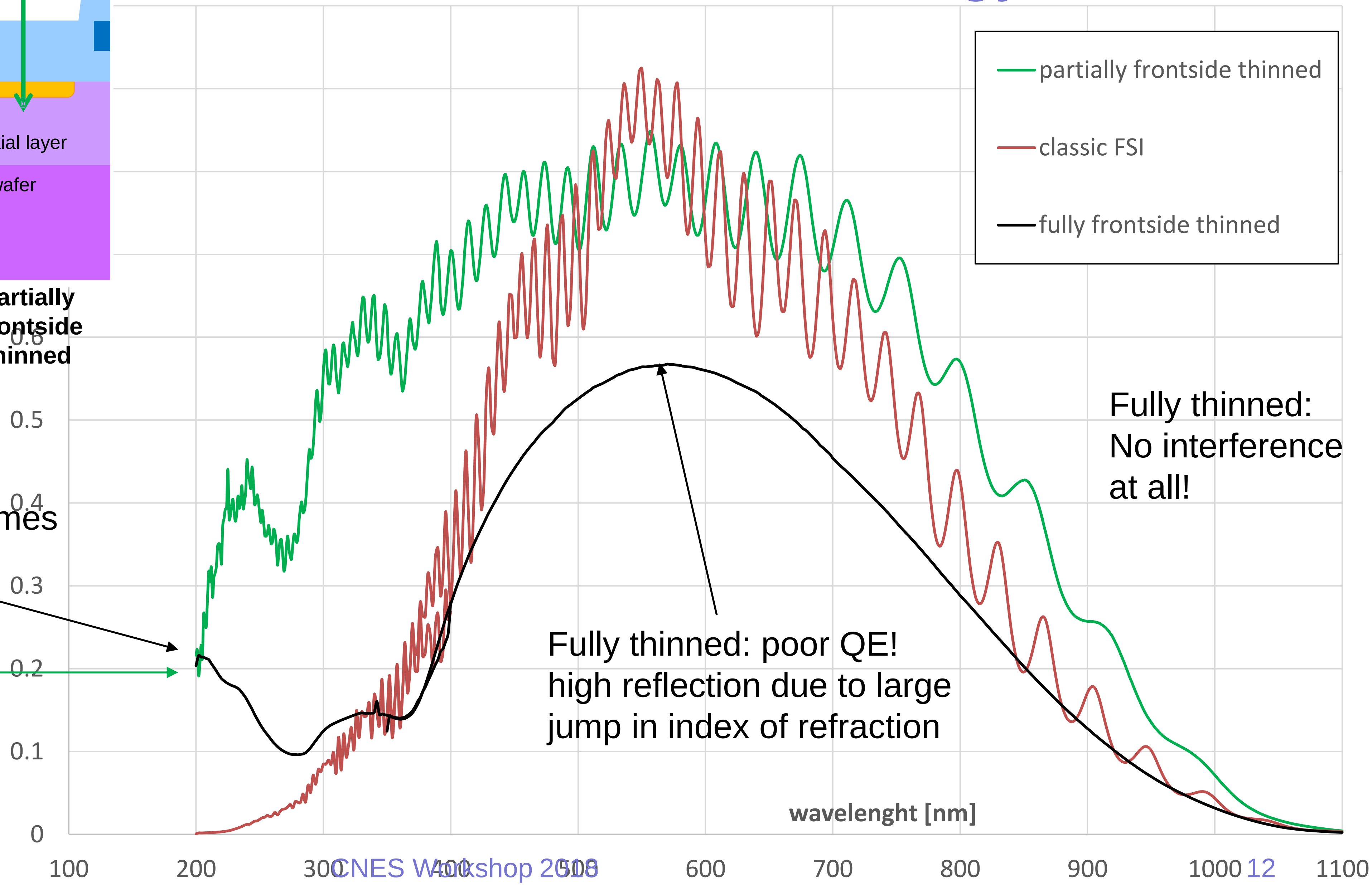
BSI versus FSI: QE

Maximum at 270nm
→ =540nm/2
→ 2 (3, 4…) electrons per photon beyond 3.6eV



FSI/FST same technology





Fully thinned: No interference at all!

Fully thinned: likely becomes best in the VUV (not measured)

Partially thinned: VUV behavior not tested

Fully thinned: poor QE! high reflection due to large jump in index of refraction

VUV measurements

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- 200-1100nm done at Caeleste
- 100-200nm (VUV) at PTB in Berlin
  - Mandatory to do testing in Vacuum.
- UV beam can cause secondary emission which will influence QE results. Shielding required.

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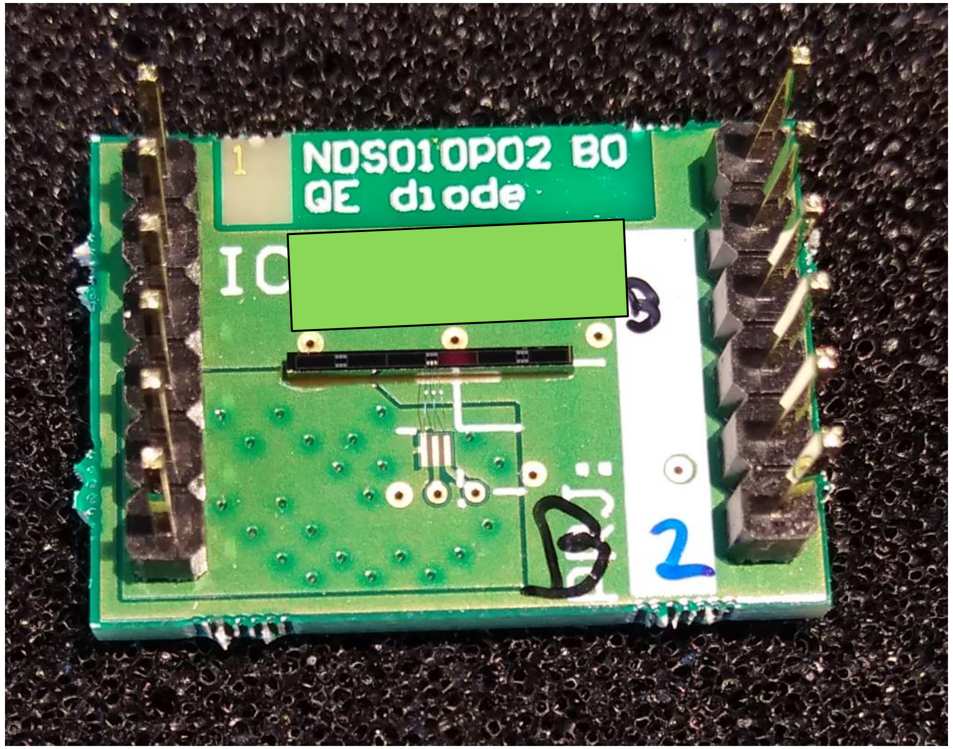
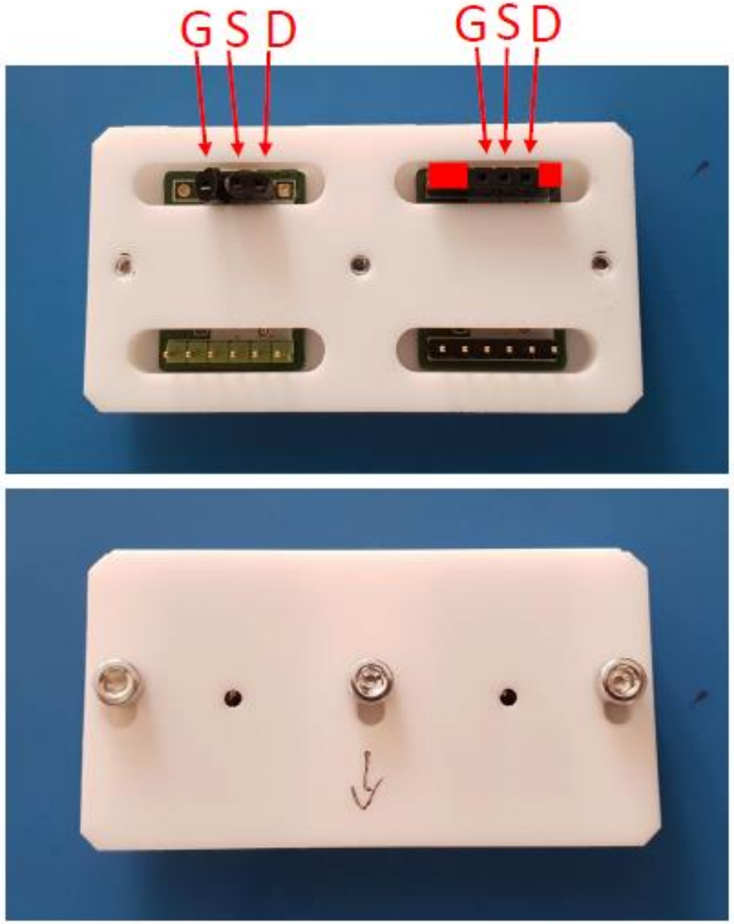
VuV measurements - Setup

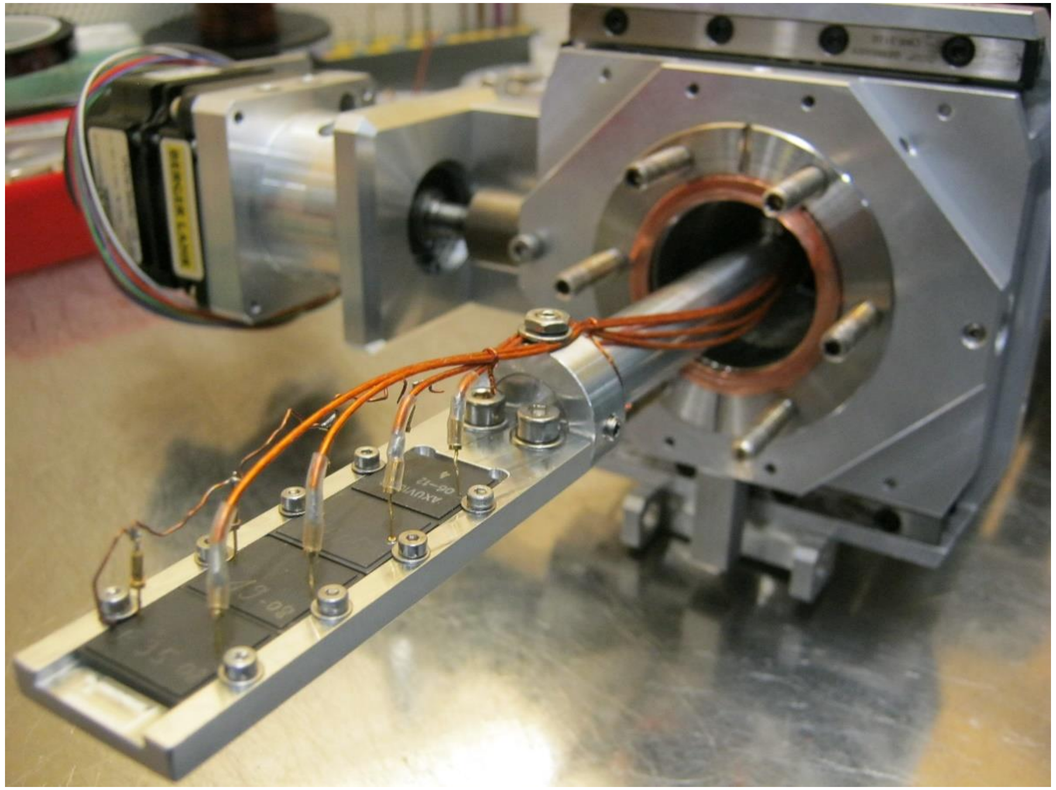


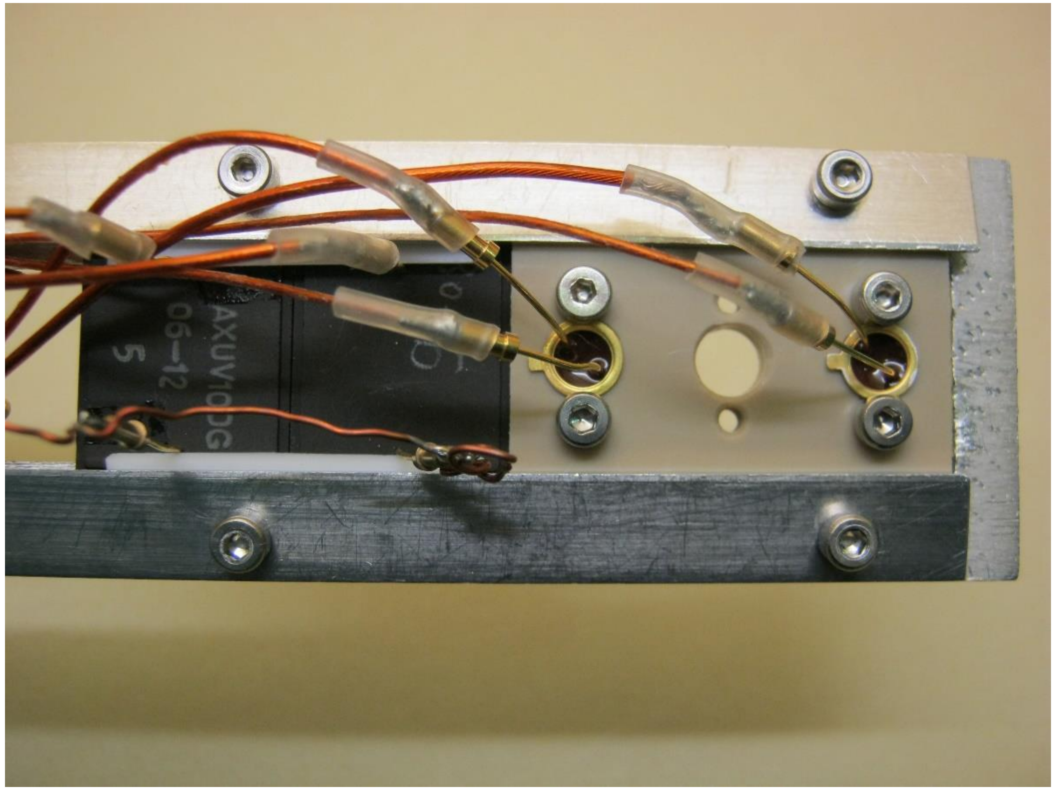
Caeleste QE test Structures
3 bondwires



PEEK holder with pin hole
above the pixel area

Test Setup at PTB





VuV Measurements Results

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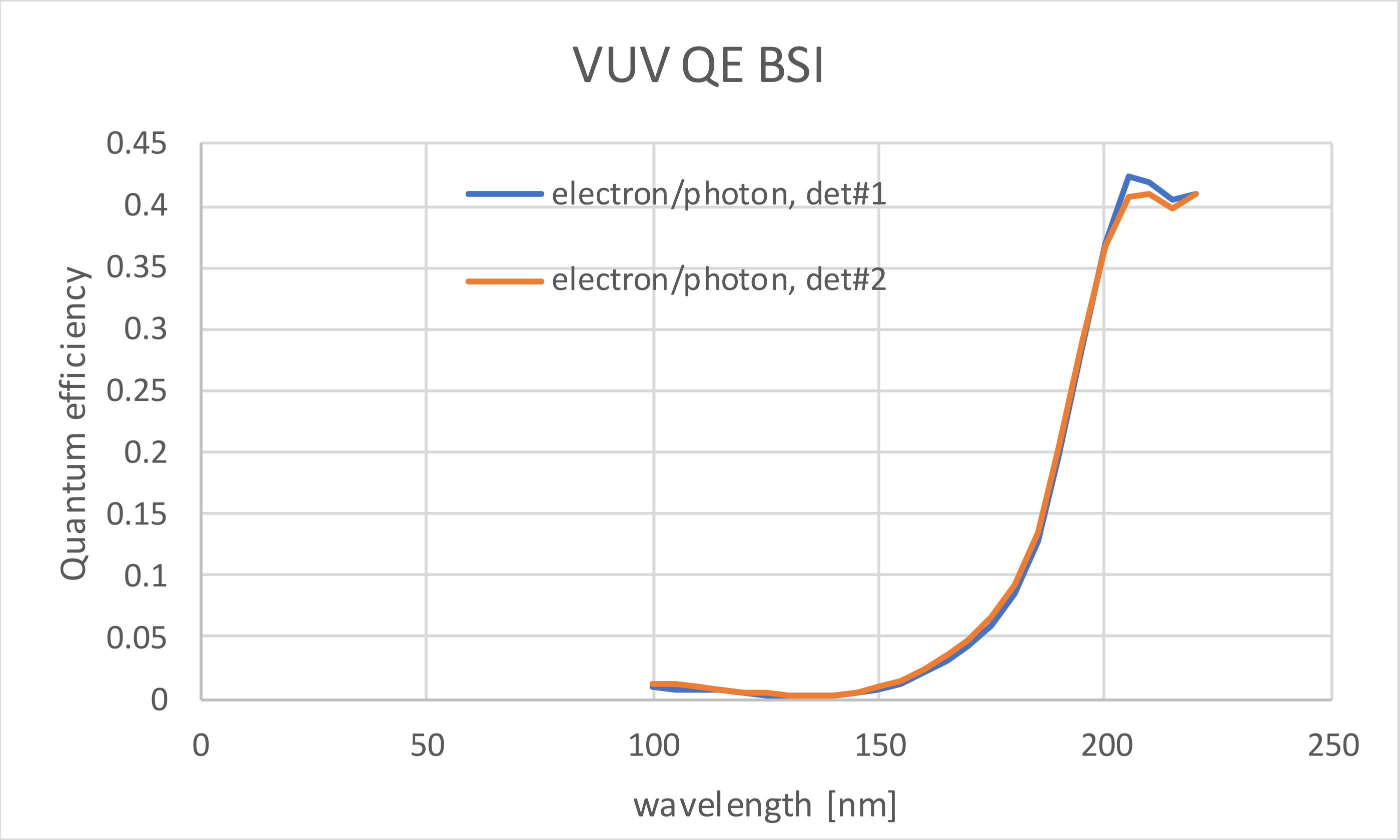
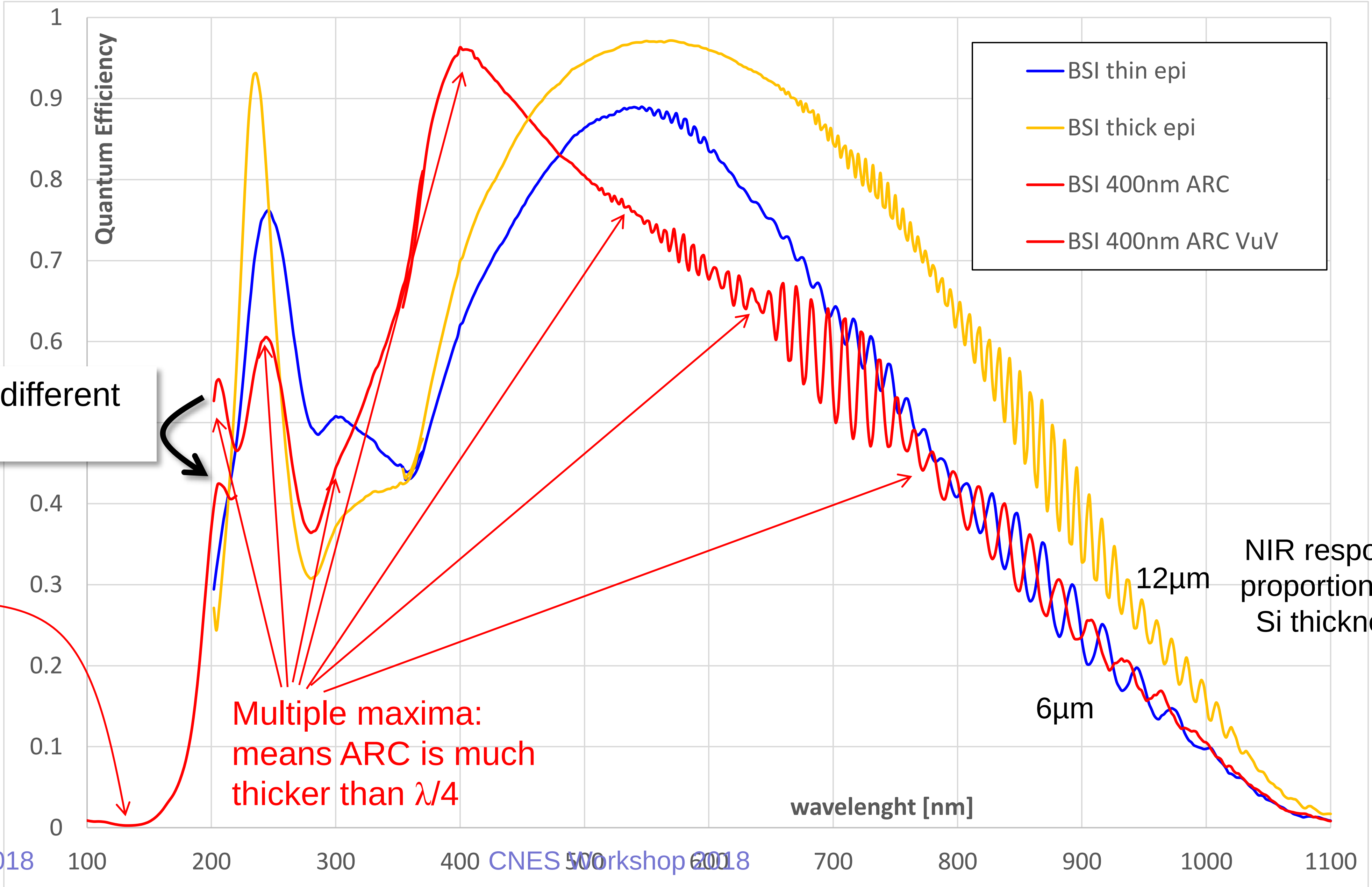


- Thickness of AR coating has a significant impact on the QE performance.
- Thickness of AR coating = 160nm
- Future measurements planned with thinner AR stack and other AR compositions which are more transparant to UV.

BSI cases - combined



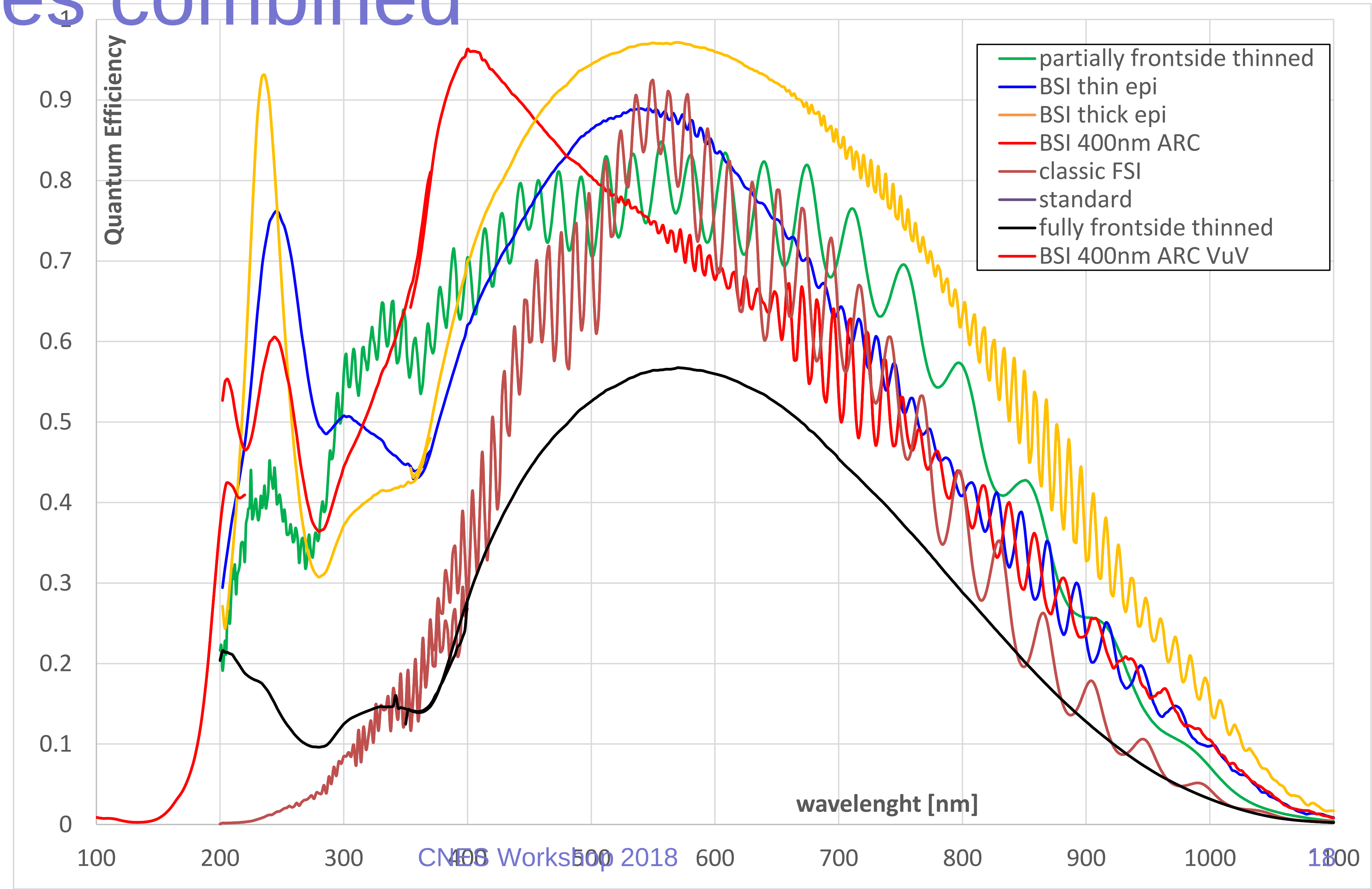
Gap due to different DUT

VUV QE is poor:
Nature and thickness of ARC not suitable

Multiple maxima: means ARC is much thicker than λ/4

NIR response proportional to Si thickness

All cases combined



Take home messages

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- Largest UV sensitivity killer: SiN passivation. BSI or FST are solutions.
- If you want absolutely no interference fringes: fully FST
- If you do not want interference fringes in the UV ➔ green: BSI
- Partial FST yields decent QEs 200-400nm, yet suffers form interference fringes
- Chemical nature and thickness of ARC and Si impacts UV QE
- QE peaks are seen at fractions of ARC wavelength optimum

Questions

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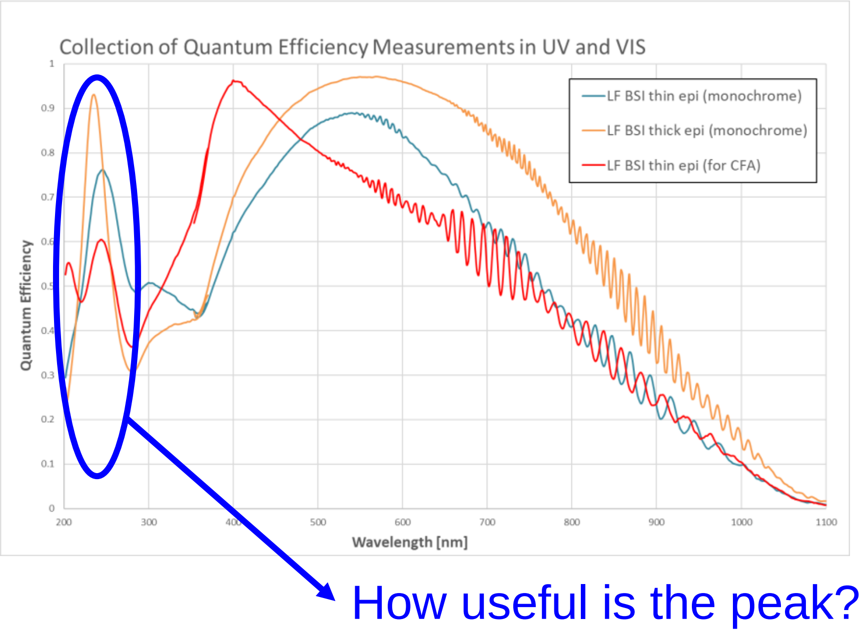
UV peak at 250nm?



- One high energy photon/particle generates a number of e-h pairs
- QE can actually be higher than 100%
- Generation time of e-h pairs no longer random
- Formula of photon shot noise as square root of e-h pairs no longer valid
- Noise will be higher than sqrt(N), excess noise due to non-Poisson distribution
- Peak not very useful