



INTERNATIONAL WORKSHOP ON STRAIN MEASUREMENT IN EXTREME ENVIRONMENTS



Tuesday 28th August, 2012, Glasgow

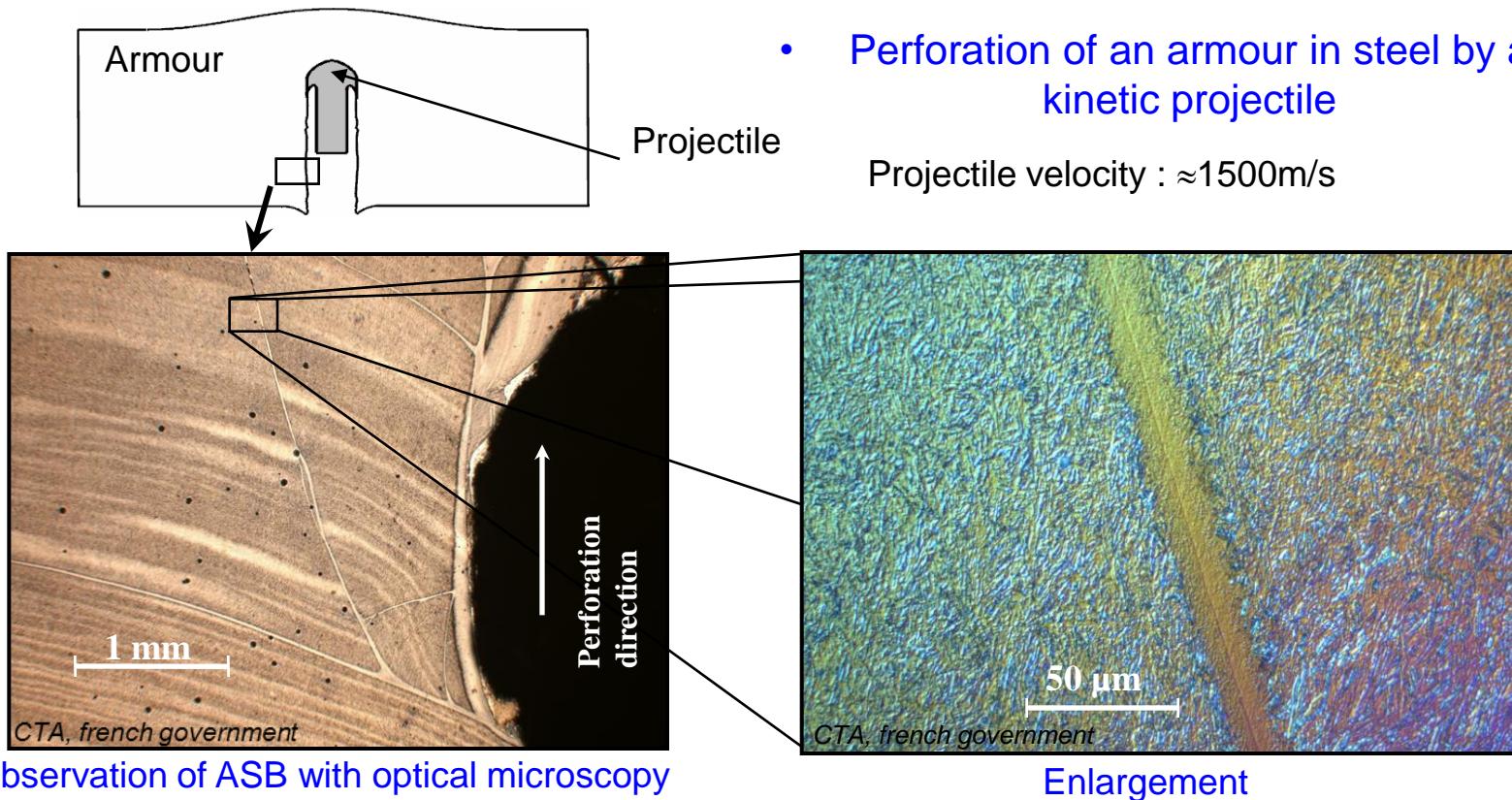


High speed and high spatial resolution pyrometry – application to adiabatic shear band in titanium alloy

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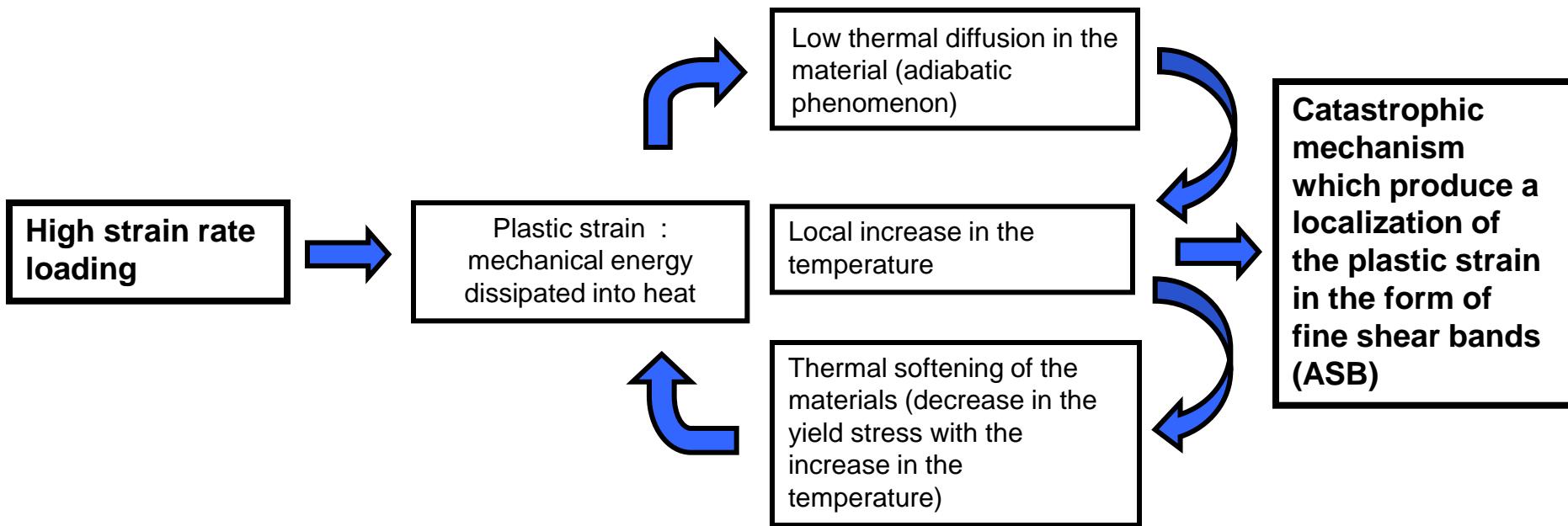
Dynamic loading : application to the armour perforation



To design materials less sensitive to adiabatic shearing
⇒ Improvement of the armour protection

Adiabatic shear band phenomenon

Initiation mechanism proposed by Zener et Hollomon (1944)



Characteristics of these ASB : band width 10µm;
Formation duration of few ten microseconds

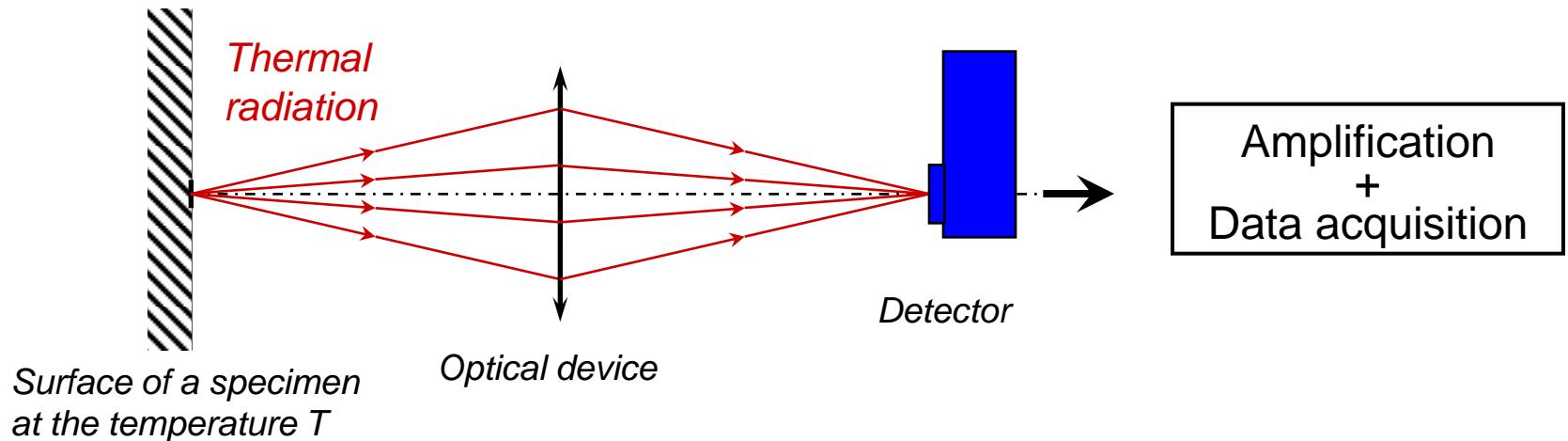
Study of adiabatic shearing

- Objective: understand the initiation and propagation mechanisms of ASB
 - Temperature measurements in the ASB
 - ⇒ Choice of the measurement technique by pyrometry (nonintrusive, fast...)
- Choice of two ranges of temperatures:
 - " Low temperature " 50°C – 300°C; study of band initiation; size of measurement: 50µm, integration time: 1µs, acquisition frequency: 1 MHz and 32 points of measurement
 - " High temperature " 800°C – 1600°C; estimation of the maximum temperature in the band: size of measurement: 2µm, integration time: 10µs; one thermography of 1024x1024 pixels

Plan of the presentation

- Pyrometry : theoretical aspects
- Choice of detectors
 - Maximum of emitted power
 - Maximum of sensibility : low wavelength pyrometry
 - Thermal fluctuation
 - Noise of detectors
- Calibration and emissivity
 - Calibration with a blackbody
 - Effect of emissivity, emissivity measurement
- Measurement device associated with adiabatic shear band study
- Results and conclusion

Pyrometry technique: theoretical aspects



The radiation emitted by the surface of the specimen (spectral intensity I_λ) depend on its temperature and the wavelength:

$$\text{Planck law: } I_\lambda = \varepsilon(\lambda, T) \frac{C_1 \lambda^{-5}}{\exp\left(\frac{C_2}{\lambda T}\right) - 1}$$

$\varepsilon(\lambda, T)$: emissivity $\in [0;1]$ (thermo-optical characteristic of the surface)

$\varepsilon = 1$: blackbody case

Design of a pyrometer :

- design of the optical device
- Choice of a detector

Choice of the detector

Spectral intensity of a blackbody : maximum of energy

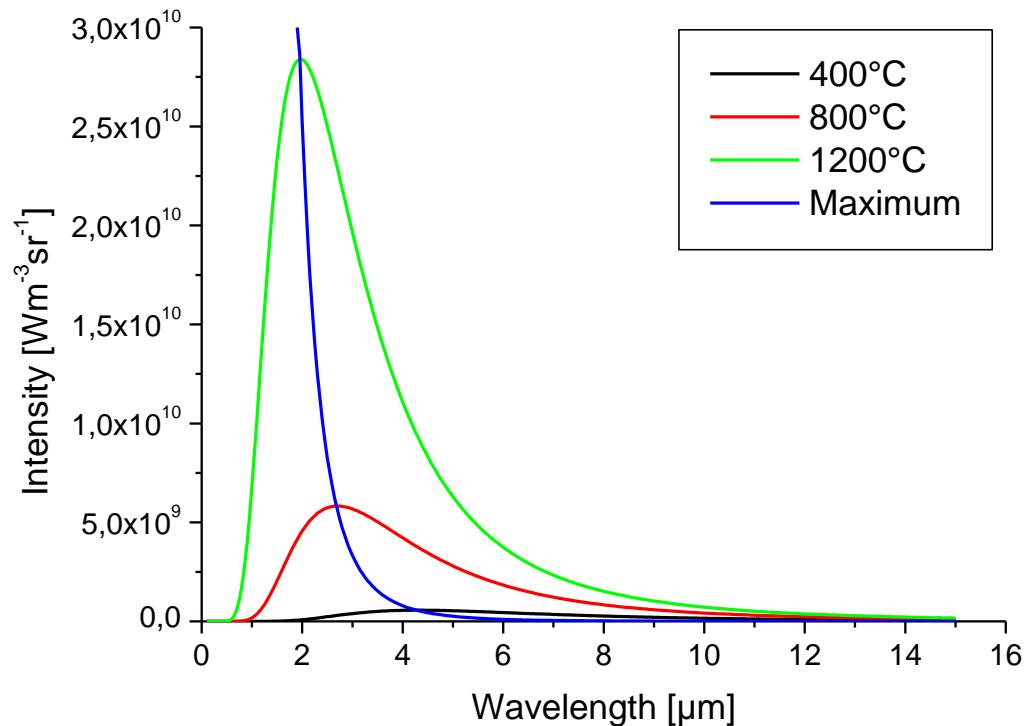
- Blackbody: Spectral intensity given by the Planck's law:

$$I_\lambda = \frac{C_1 \lambda^{-5}}{\exp\left(\frac{C_2}{\lambda T}\right) - 1}$$

- Maximum of emitted energy: Wien's law

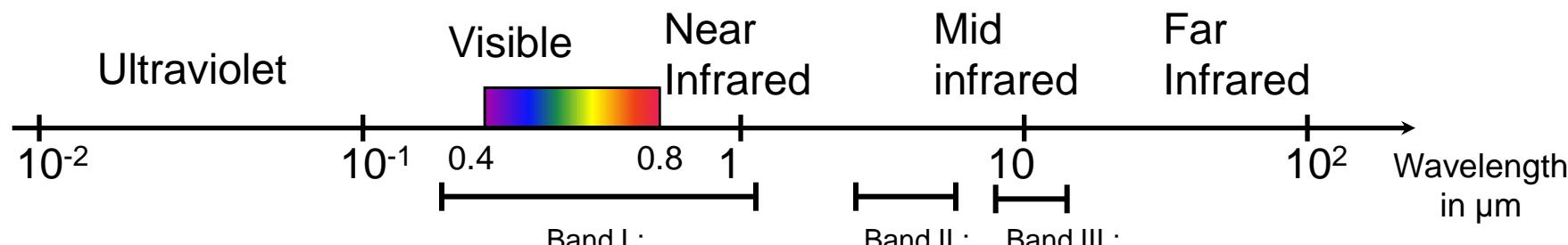
$$\lambda_{\max} = 2900/T$$

- Examples :
 - 77K : $\lambda_{\max} = 38\mu\text{m}$
 - 200°C : $\lambda_{\max} = 6\mu\text{m}$
 - 1000°C : $\lambda_{\max} = 2\mu\text{m}$
 - 1600°C : $\lambda_{\max} = 1\mu\text{m}$



Detectors used in fast pyrometry

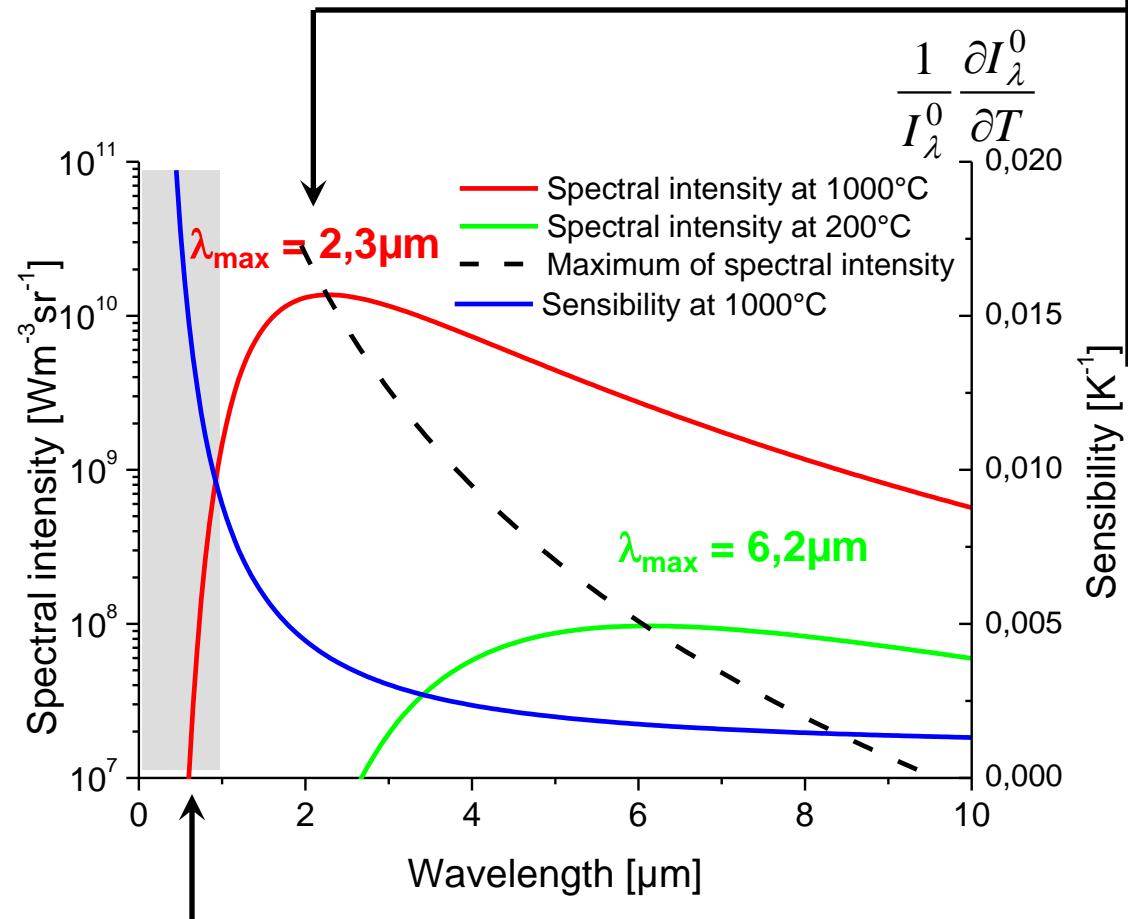
The quantum detectors and their spectral sensitivity :



Photoemissive detectors: (bi-alcali,
multi-alcali, AsGa: $\lambda_c=0.8\mu\text{m}$)
Photomultiplier
Intensified CCD Camera

Photovoltaic or photoconductor
detectors: (InSb $\lambda_c=5.5\mu\text{m}$; HgCdTe
 $\lambda_c=12\mu\text{m}$)
Semiconductors
Infrared CCD Camera

Sensibility of the spectral intensity of the blackbody to a temperature variation



$$\lambda = 2,3\mu\text{m} ; T = 1000^\circ\text{C}$$

(Maximum of spectral intensity)

Sensibility to a variation of 1°C:

$$\frac{\Delta L_\lambda^0}{L_\lambda^0} = 0,4\%$$

$$\lambda = 0,8\mu\text{m} ; T = 1000^\circ\text{C}$$

("short" wavelength)

Sensibility to a variation of 1°C :

$$\frac{\Delta L_\lambda^0}{L_\lambda^0} = 1,0\%$$

⇒ Sensibility almost 3 times higher

Choice of the shortest possible wavelength

Wavelength and detector choices

- Choice of the shortest possible wavelength:
 - ⇒ The detector must be able to detect the emitted signal:
 - the signal to noise ratio must be sufficient
 - for short wavelength, the signal corresponds to a sufficient number of photons?
 - The randomness of the emission does not generate additional noise and errors? (fluctuations)

Fluctuations of the black body intensity for short wavelength

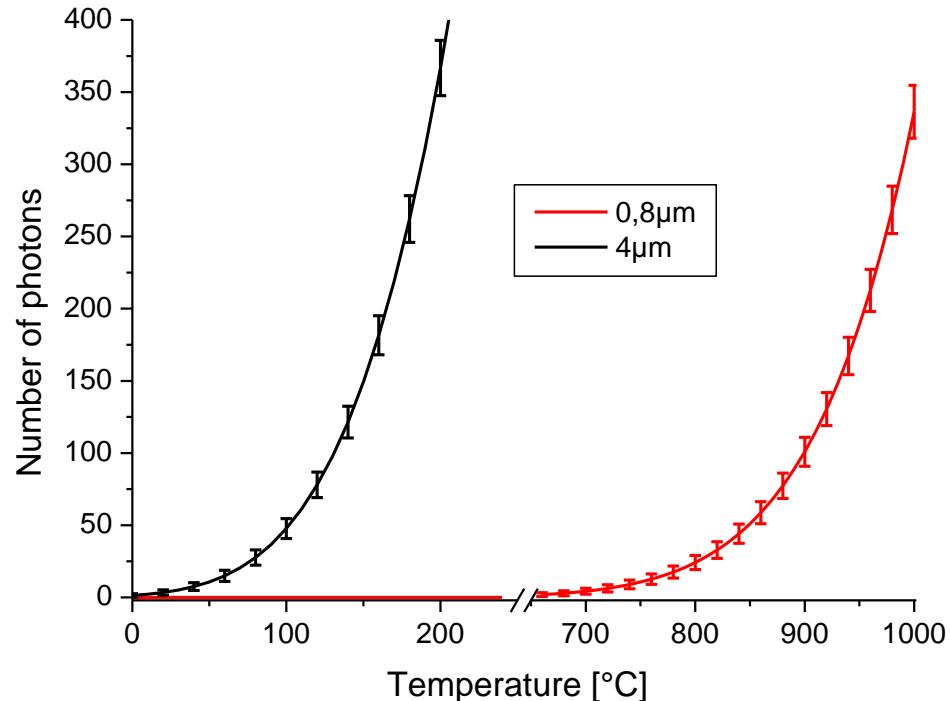
- The photon emission is a random phenomenon**
 (This randomness is all the more significant since the number of emitted photon is small)
- The spectral intensity given by the Planck's law is a mean value:**

$$I_\lambda^0 = \frac{1}{\Delta t} \int_t^{t+\Delta t} i_\lambda^0(t) dt$$

- Root mean square (white noise):**

$$\overline{(\delta i_\lambda^0)^2} = \frac{1}{\Delta t} \int_t^{t+\Delta t} (i_\lambda^0(t) - I_\lambda^0)^2 dt$$

$$\overline{(\delta i_\lambda^0)^2} = kT^2 \frac{\partial I_\lambda^0}{\partial T}$$



Number of emitted photon and fluctuation

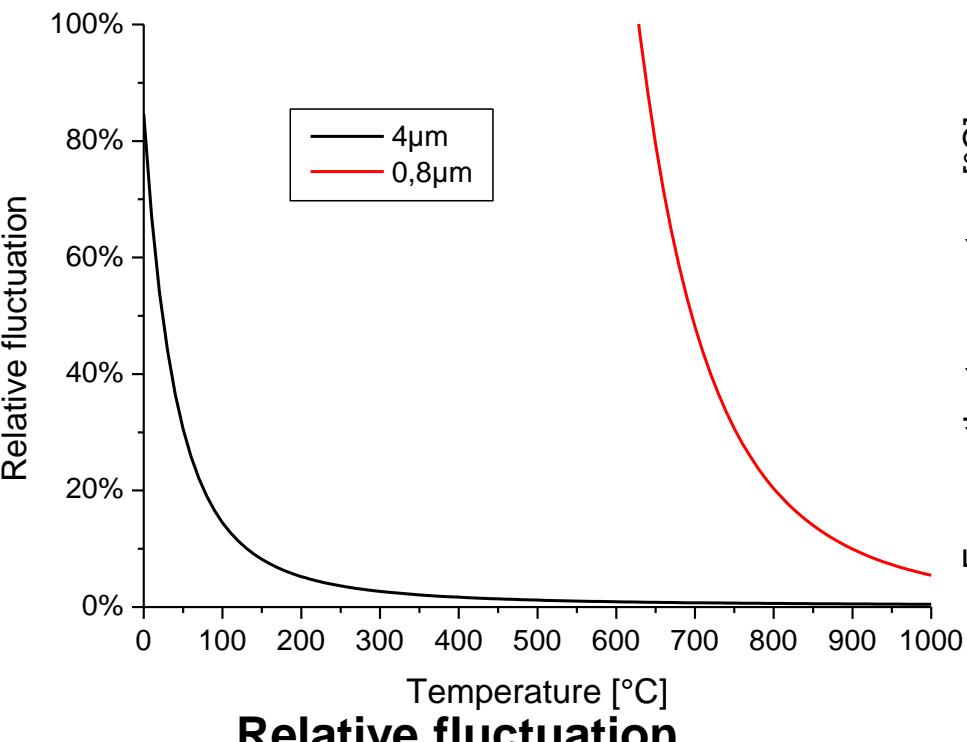
Observed surface: 2μm X 2μm

Duration: 10μs

Spectral width: 10nm

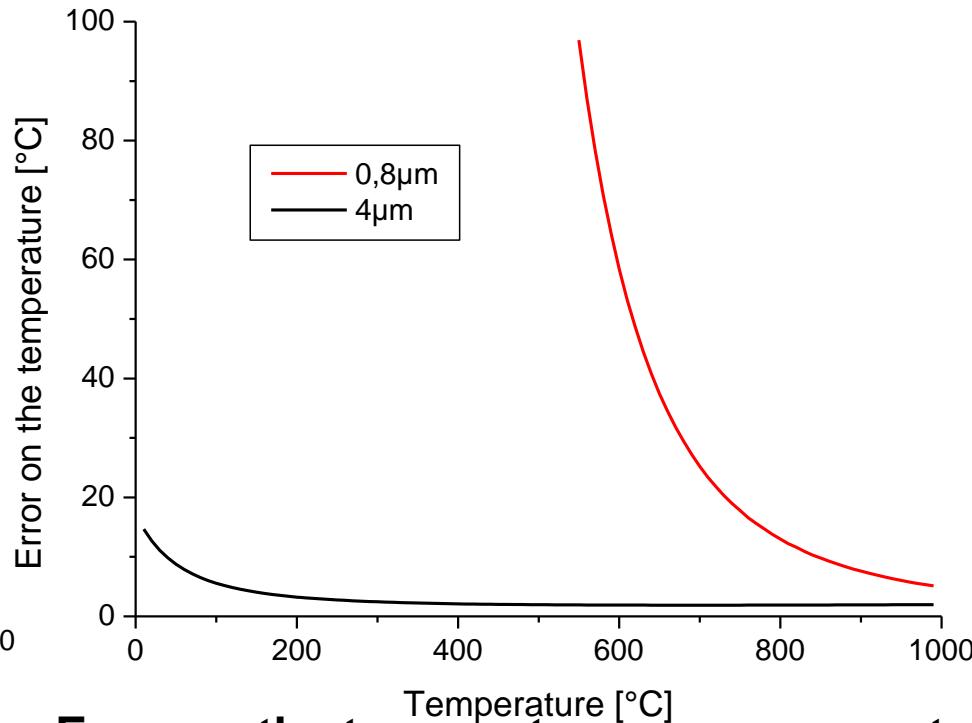
Solid angle: 0,79sr (60°)

Fluctuations: effect on the temperature measurement for the “high temperatures”



Relative fluctuation

Increase in the relative fluctuation when the temperature and the photon number decrease



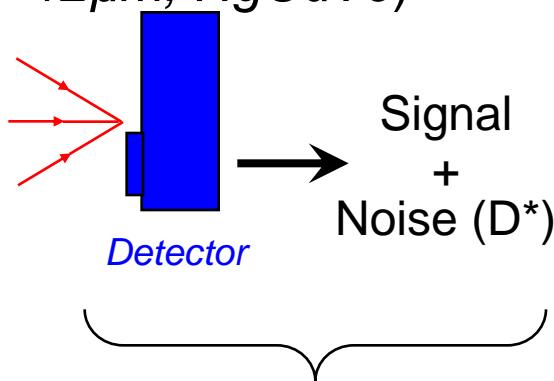
Error on the temperature measurement

For $\lambda = 0.8\text{ }\mu\text{m}$, the fluctuations become negligible for temperatures higher than 900°C

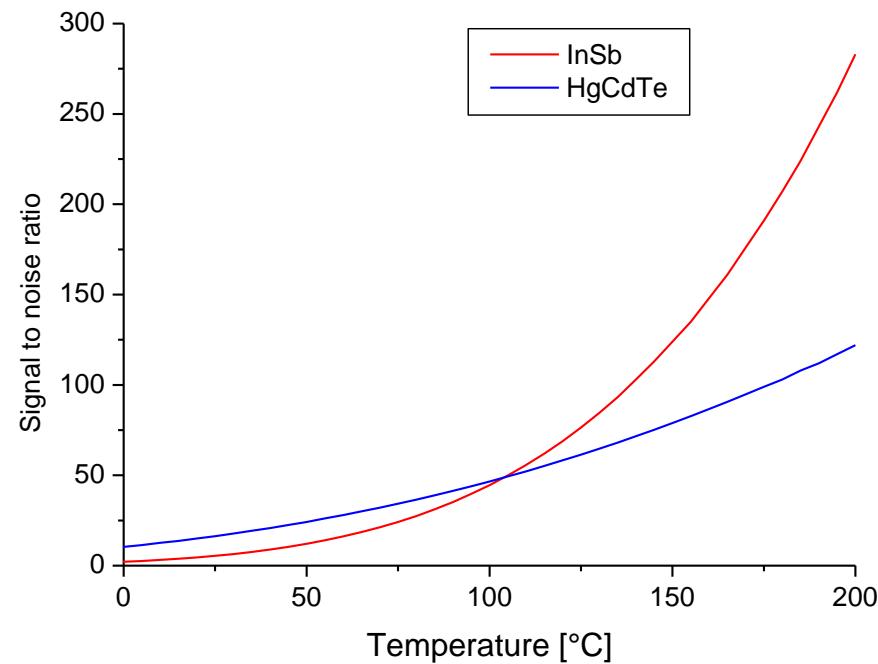
⇒ choice of an intensified camera AsGa for the " high temperatures "

Choice of the detector for the low temperatures ($\approx 200^{\circ}\text{C}$)

- Choice between the band II ($3\mu\text{m} - 5\mu\text{m}, \text{InSb}$) and the band III ($8\mu\text{m} - 12\mu\text{m}, \text{HgCdTe}$)



Better signal to noise ratio



$$\text{InSb : } D^* = 8.97 \times 10^{10} \text{ W}^{-1}\text{cmHz}^{1/2}$$

$$\text{HgCdTe : } D^* = 2.89 \times 10^{10} \text{ W}^{-1}\text{cmHz}^{1/2}$$

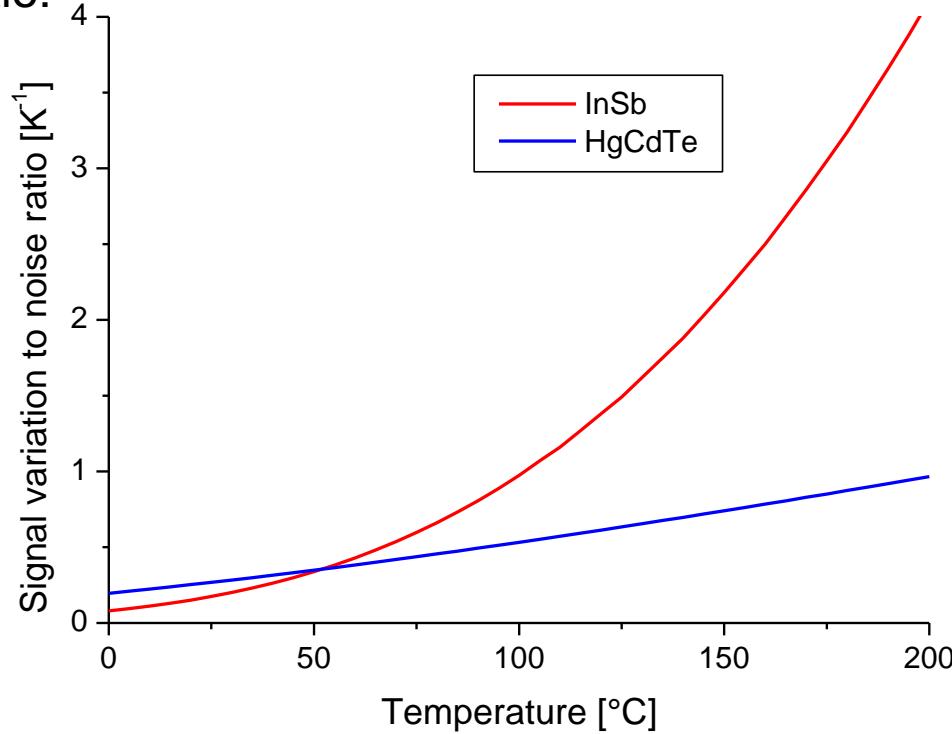
(detector surface: 1cm^2 , aperture: 180° , electronic band width: 1Hz, background temperature: 293K)

Surface Detector surface: $43\mu\text{m} \times 43\mu\text{m}$, magnification: 1, detector aperture: 0.785sr (60°), optical aperture: 0.121sr , electronic band width: 1MHz

⇒ Choice of a InSb detector for the “low temperatures”

Choice of the detector for the low temperatures ($\approx 200^{\circ}\text{C}$)

- variation of signal associated with a temperature increase of 1°C to the noise ratio:

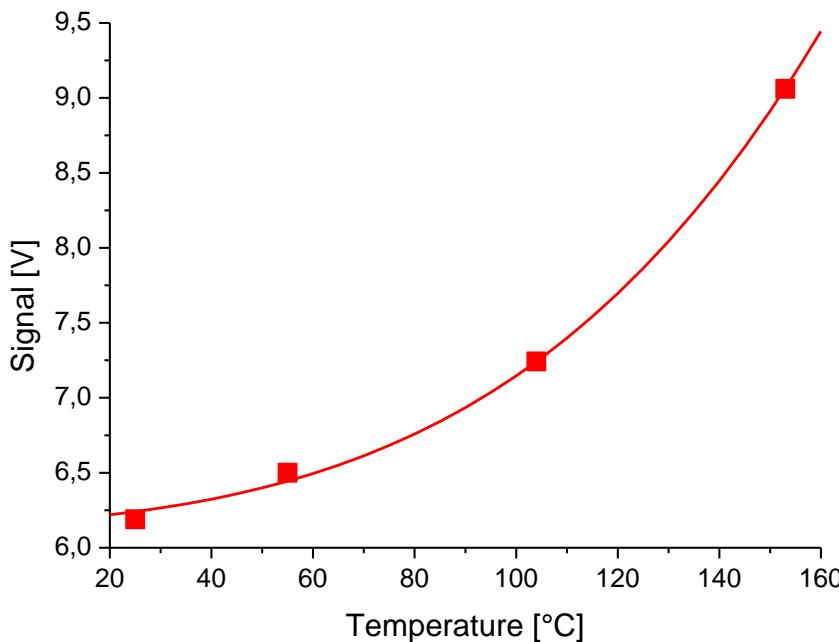


Surface Detector surface: $43\mu\text{m} \times 43\mu\text{m}$, magnification: 1,
detector aperture: $0,785\text{sr}$ (60°), optical aperture: $0,121\text{sr}$,
electronic band width: 1MHz

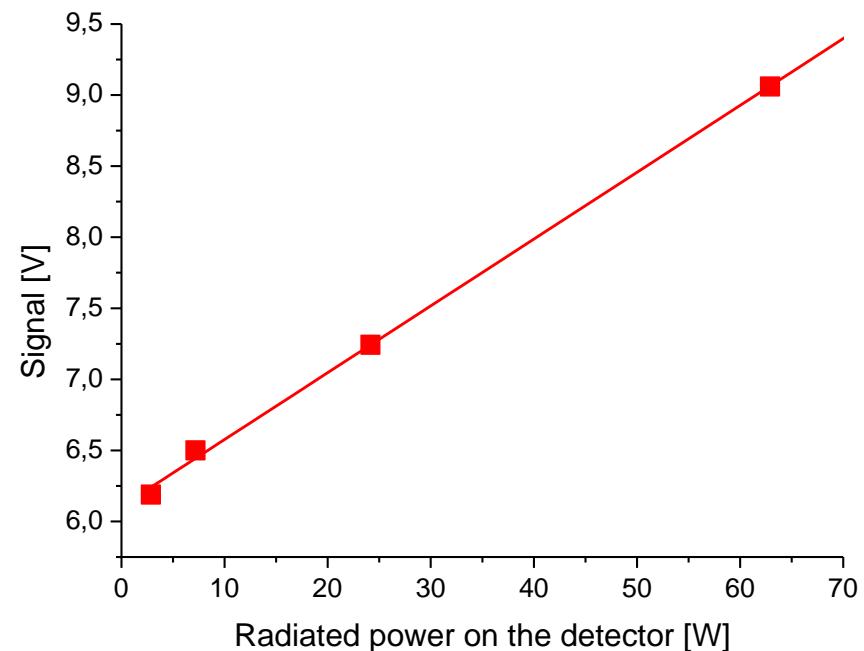
Calibration – Measurement of emissivity

Calibration on a blackbody

Case of the “low temperatures”



Calibration curve of one InSb detector

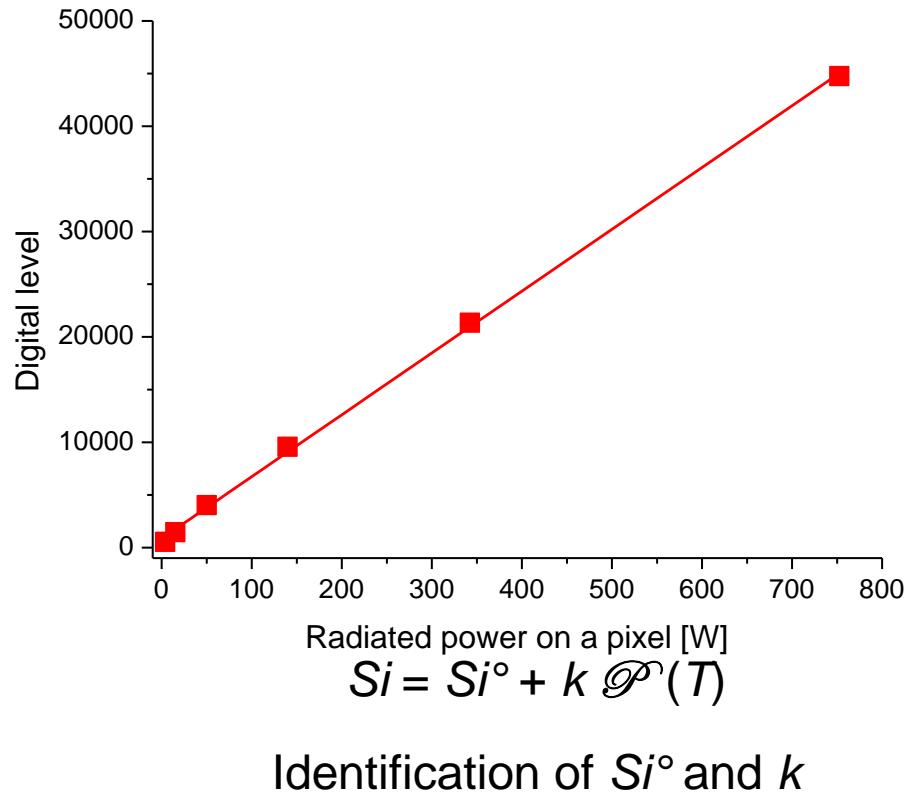
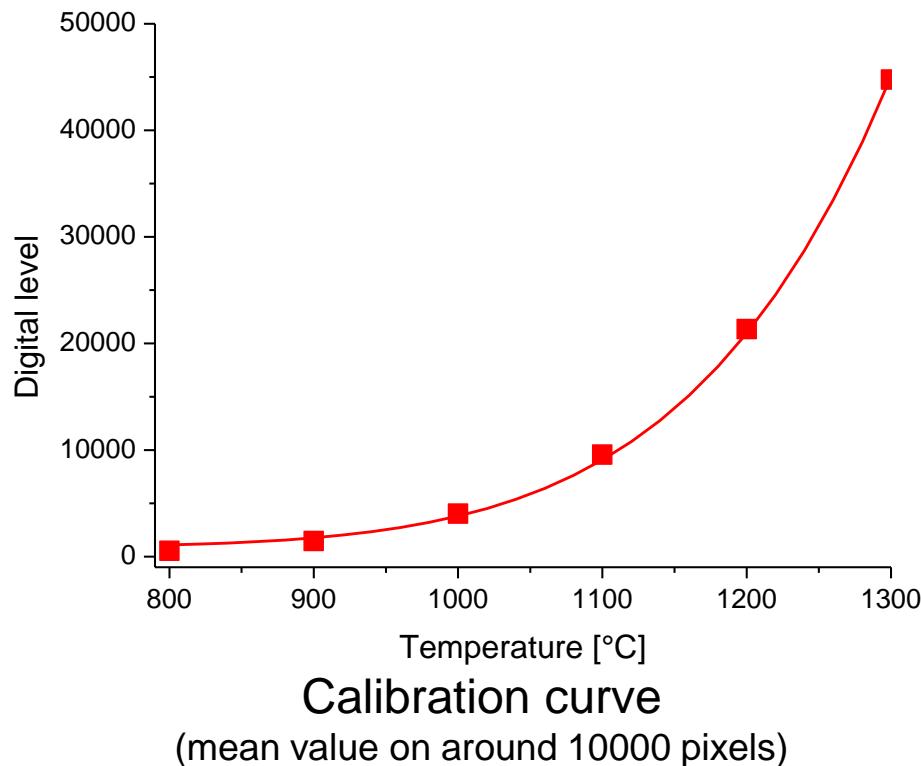


$$Si = Si^\circ + k \mathcal{P}(T)$$

Identification of Si° and k

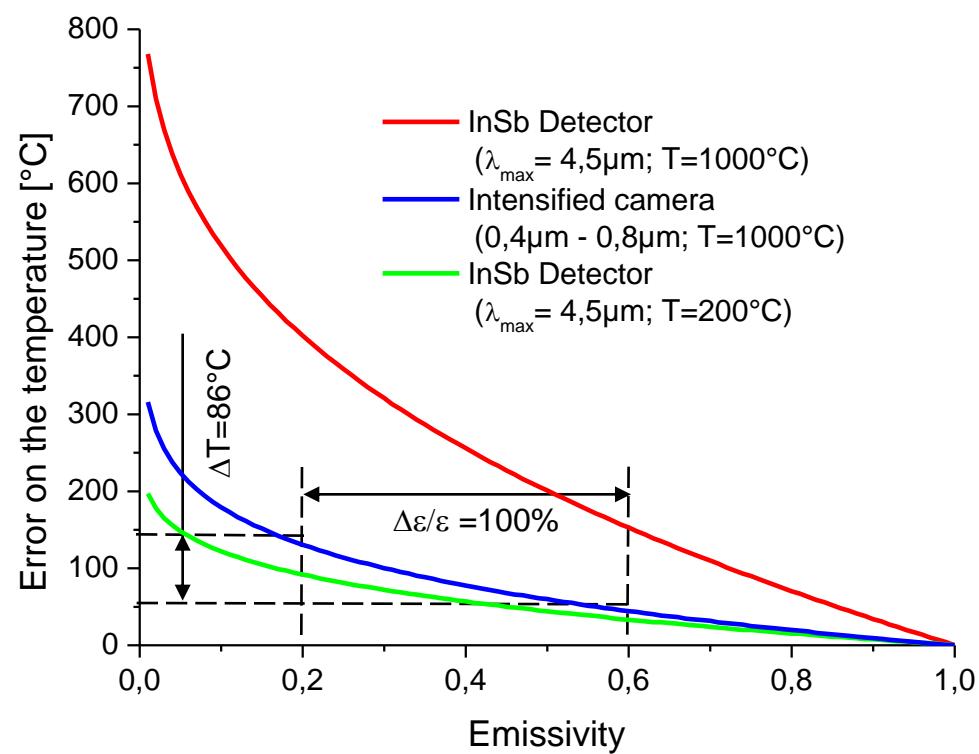
Calibration on a blackbody

Case of the “high temperatures”



Error on the temperature due to emissivity

Balckbody assumption $\varepsilon(\lambda, T) = 1$: luminance temperature



For $T = 1000^\circ C$ (High temperatures) :

- intensified camera ($0.4\mu m - 0.8\mu m$), coarse estimate of ε at 0,40 with $\Delta\varepsilon/\varepsilon = 100\%$: error on the temperature: $86^\circ C$ (7%)
- InSb detector ($4.5\mu m$), coarse estimate of ε at 0,25 with $\Delta\varepsilon/\varepsilon = 100\%$: error on the temperature: $313^\circ C$ (25%)

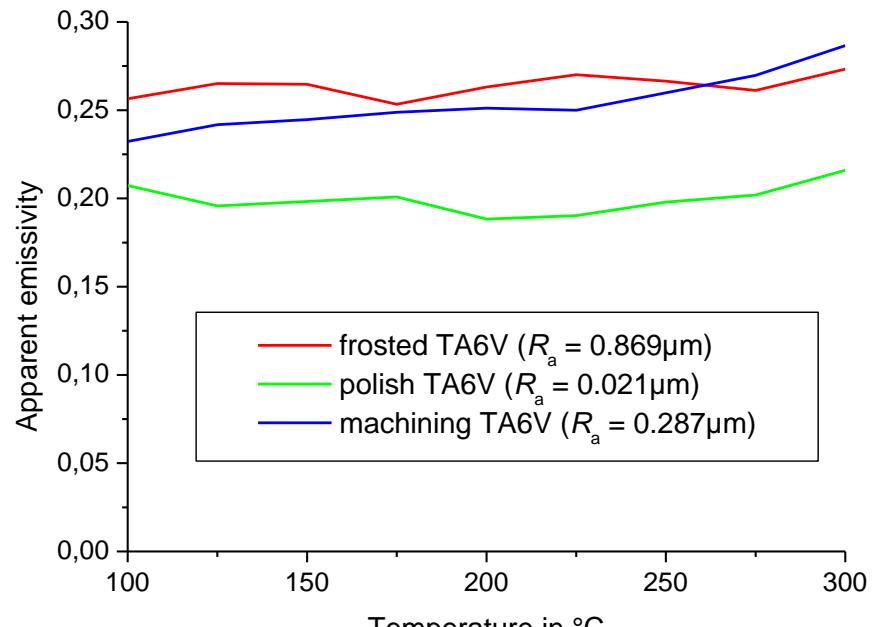
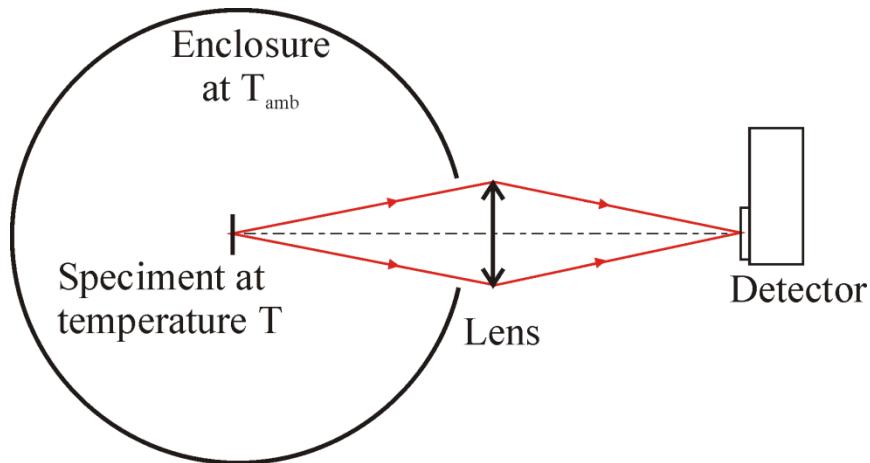
For $T = 200^\circ C$ (Low temperatures) :

- InSb detector ($4.5\mu m$), coarse estimate of ε at 0,25 with $\Delta\varepsilon/\varepsilon = 100\%$: error on the temperature: $158^\circ C$ (33%)
- InSb detector($4.5\mu m$), measure of ε at 0.250 ± 0.025 ($\Delta\varepsilon/\varepsilon = 20\%$) : error: $9^\circ C$ (1,6%)

→ Need to measure emissivity for the “low temperatures”

Measurement of the surface emissivity in the IR domain

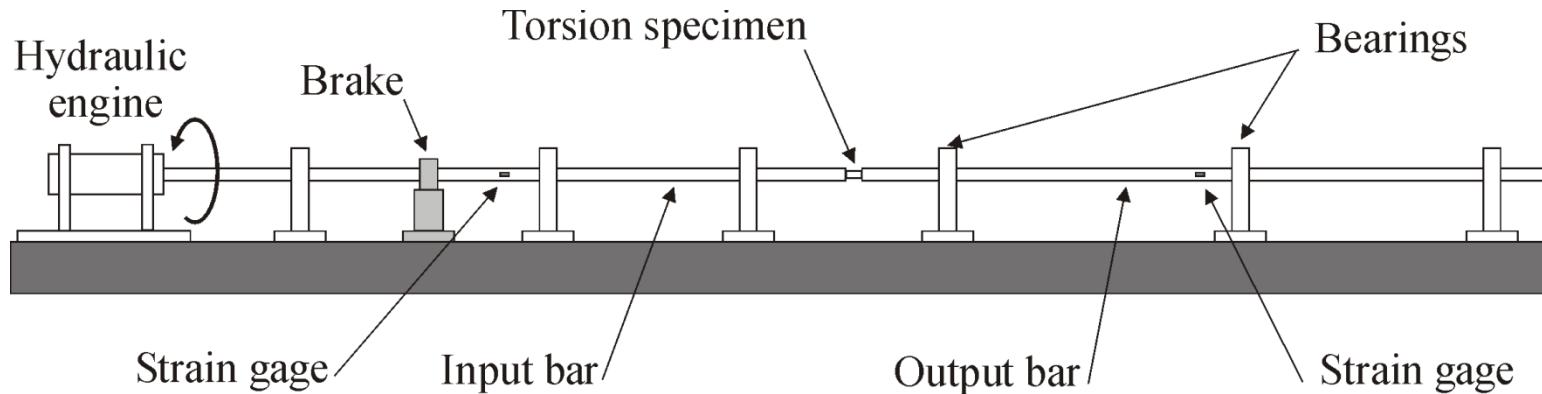
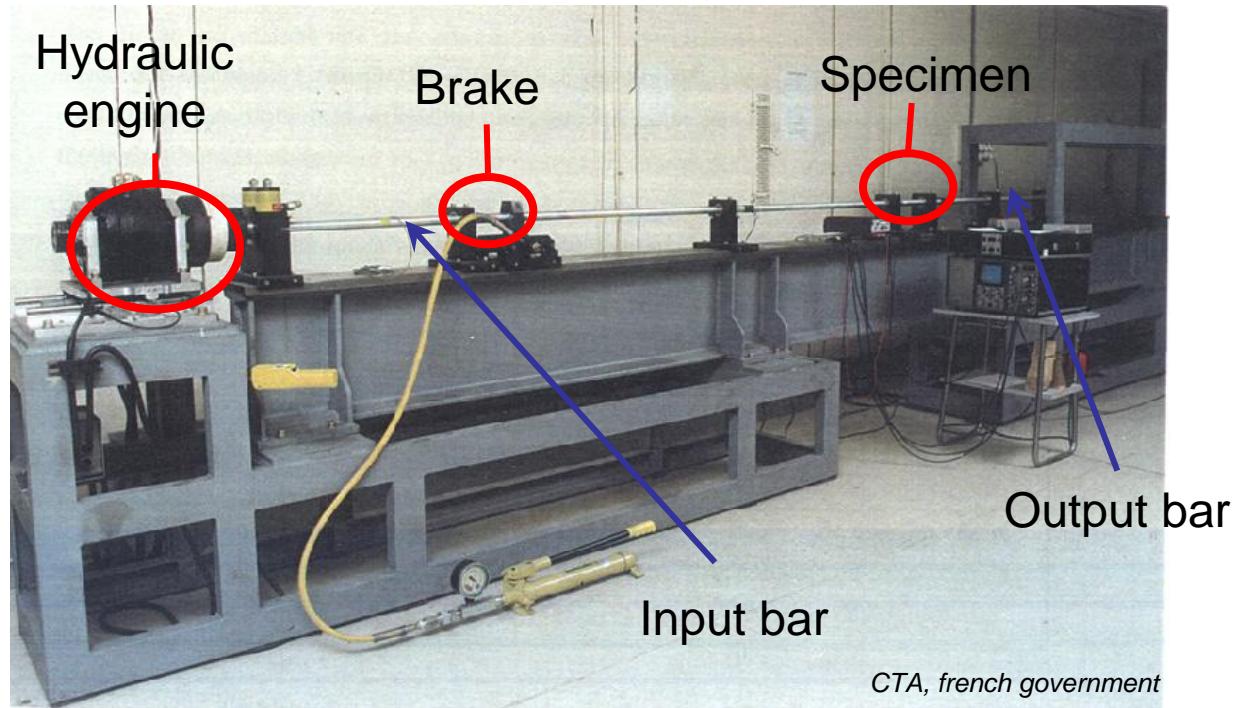
- Device of emissivity measurement
- Emissivity for various surface roughness according to the temperature



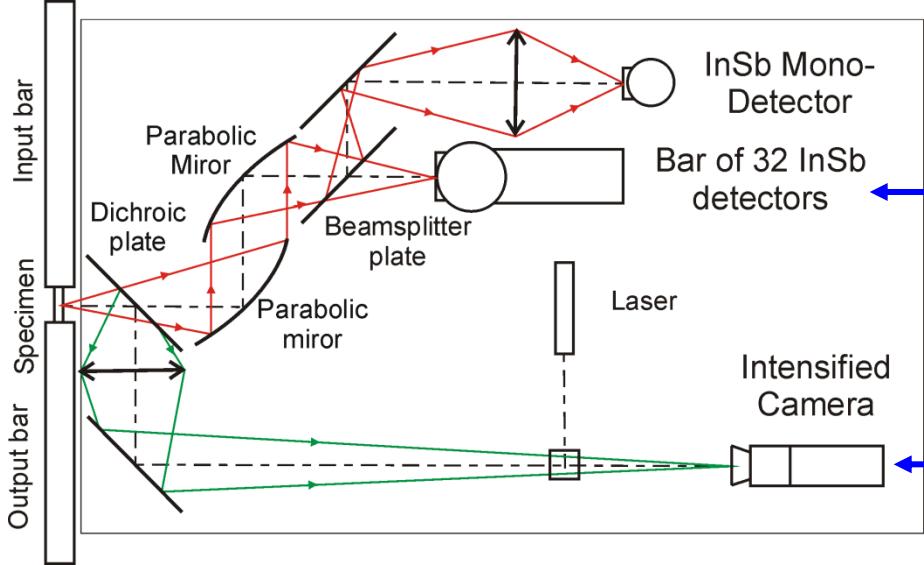
$$\varepsilon = 0.250 \pm 0.025$$

Device associated with
adiabatic shear band study

Torsional Hopkinson bars



Temperature measurement device



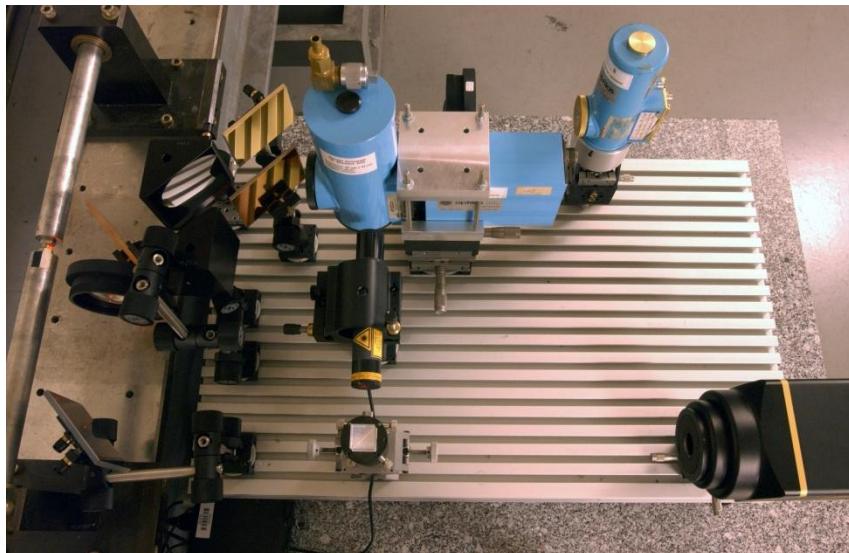
Trigger device

"Low temperature" device
(20°C to 300°C) :

- wavelength : 1 à 5,5 µm
- spatial resolution : 43 µm
- temporal resolution : 1 µs

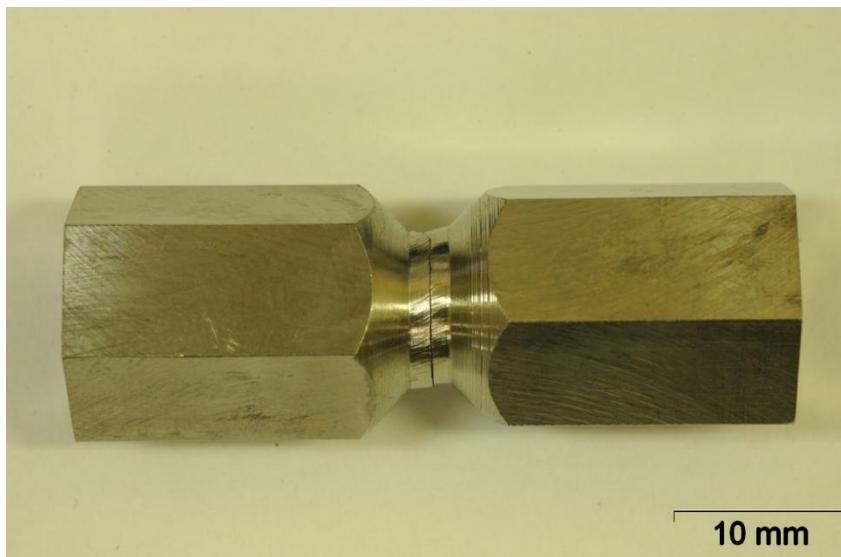
"High temperature" device
(600°C to 1500°C) :

- wavelength : 0,4 to 0,8 µm
- spatial resolution : 5 µm
- temporal resolution : 10 µs

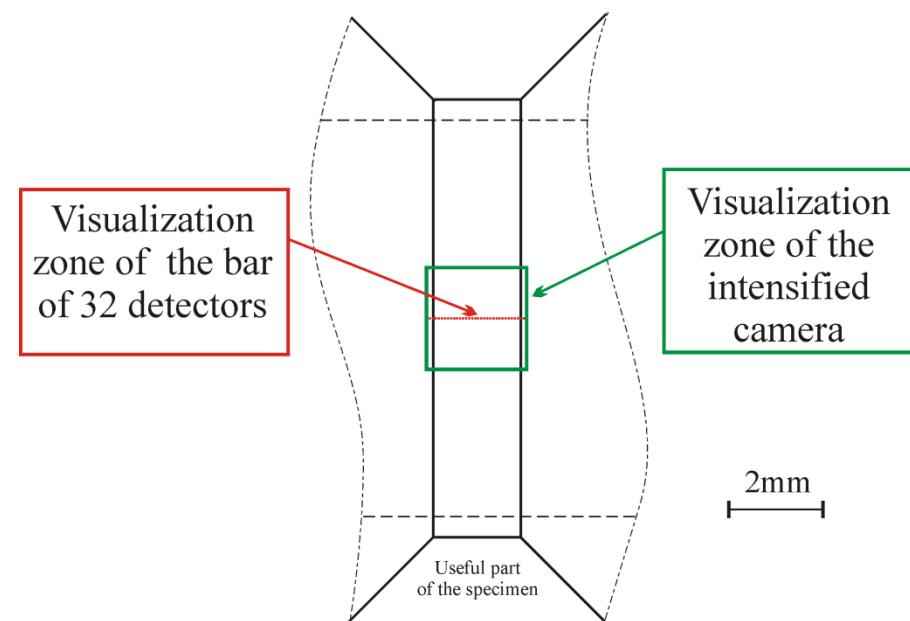


Torsion specimen

Specimen after ASB formation

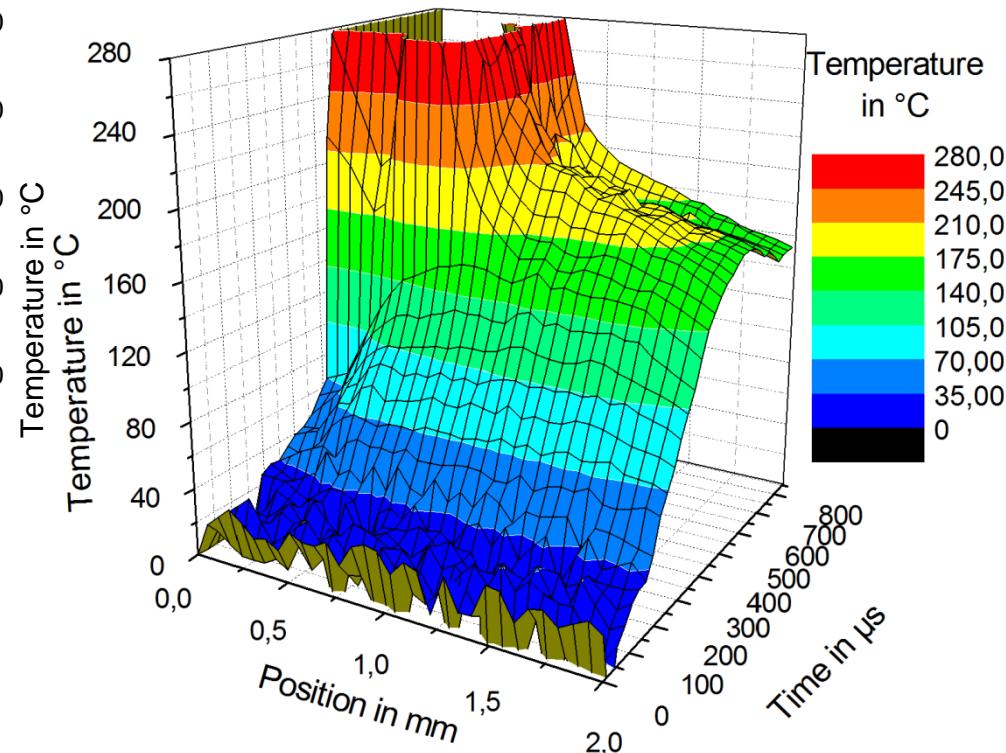
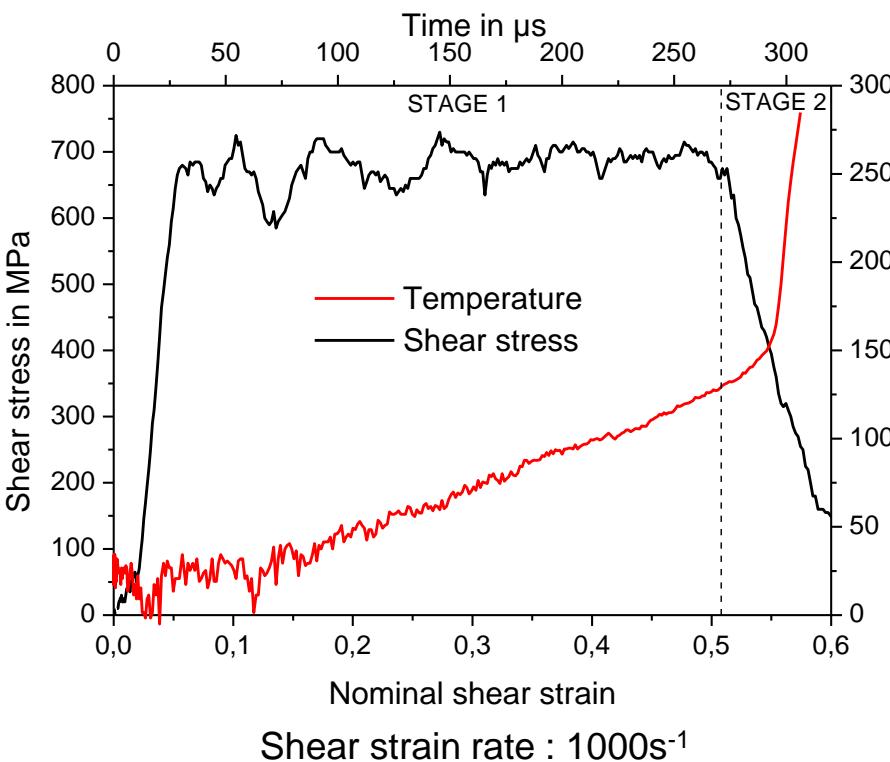


Visualization zones of the bar of detectors and the intensified camera on the specimen



Results

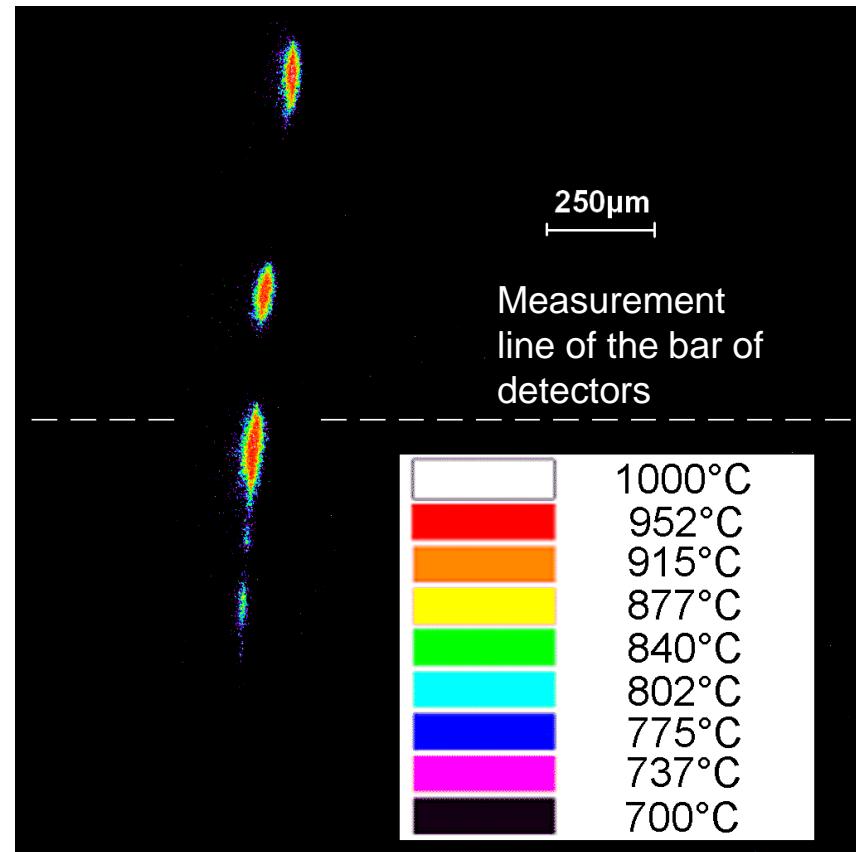
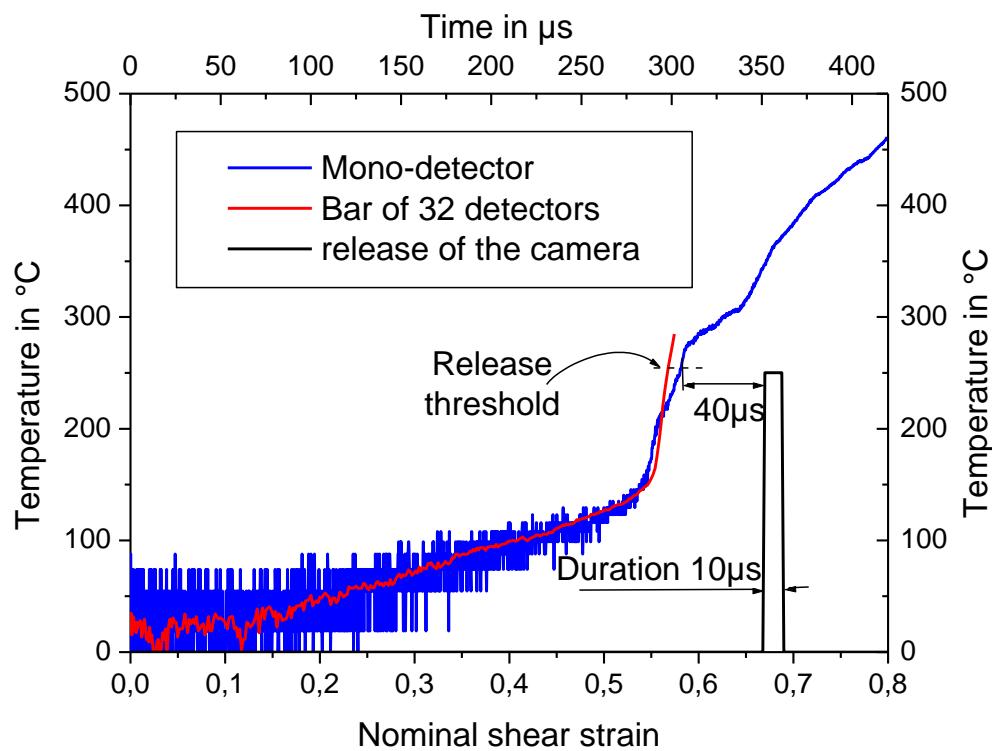
Results : low temperature



PHASE 1 : homogeneous temperature field

PHASE 2 : decrease of the stress, heterogeneous temperature field

Results : high temperature



Aperture time 10μs; $T_{\max} \approx 1000^{\circ}\text{C}$

temperature heterogeneity in the ASB

Conclusion

- **Study of adiabatic shearing**
 - High speed and very localised phenomenon
- **Choice of the adapted detector**
 - Higher sensibility : shortest possible wavelength
 - to check if the emitted signal is not too weak (fluctuations, signal to noise ratio)
- **Case of visible pyrometry** : possibility to measure simultaneously a displacement and a temperature fields with the same camera and the same optical device