Ultrasonic monitoring of material using reverberation techniques

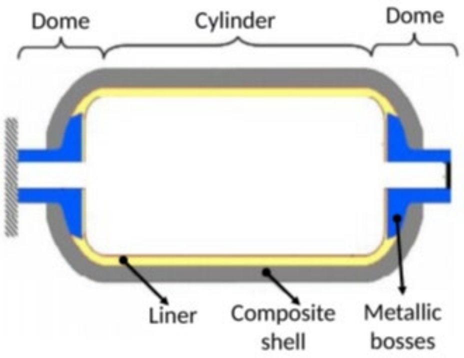
Hossep Hachdjian , Julien Bustillo, Jerome Fortineau

Context : Monitoring of a material's state

Non-destructive monitoring of a material's state during its physico-chemical transformations is of interest for several industrial fields including *food processing*, *cosmetics* and *polymers.*







Non-destructive monitoring → ***using acoustic waves***

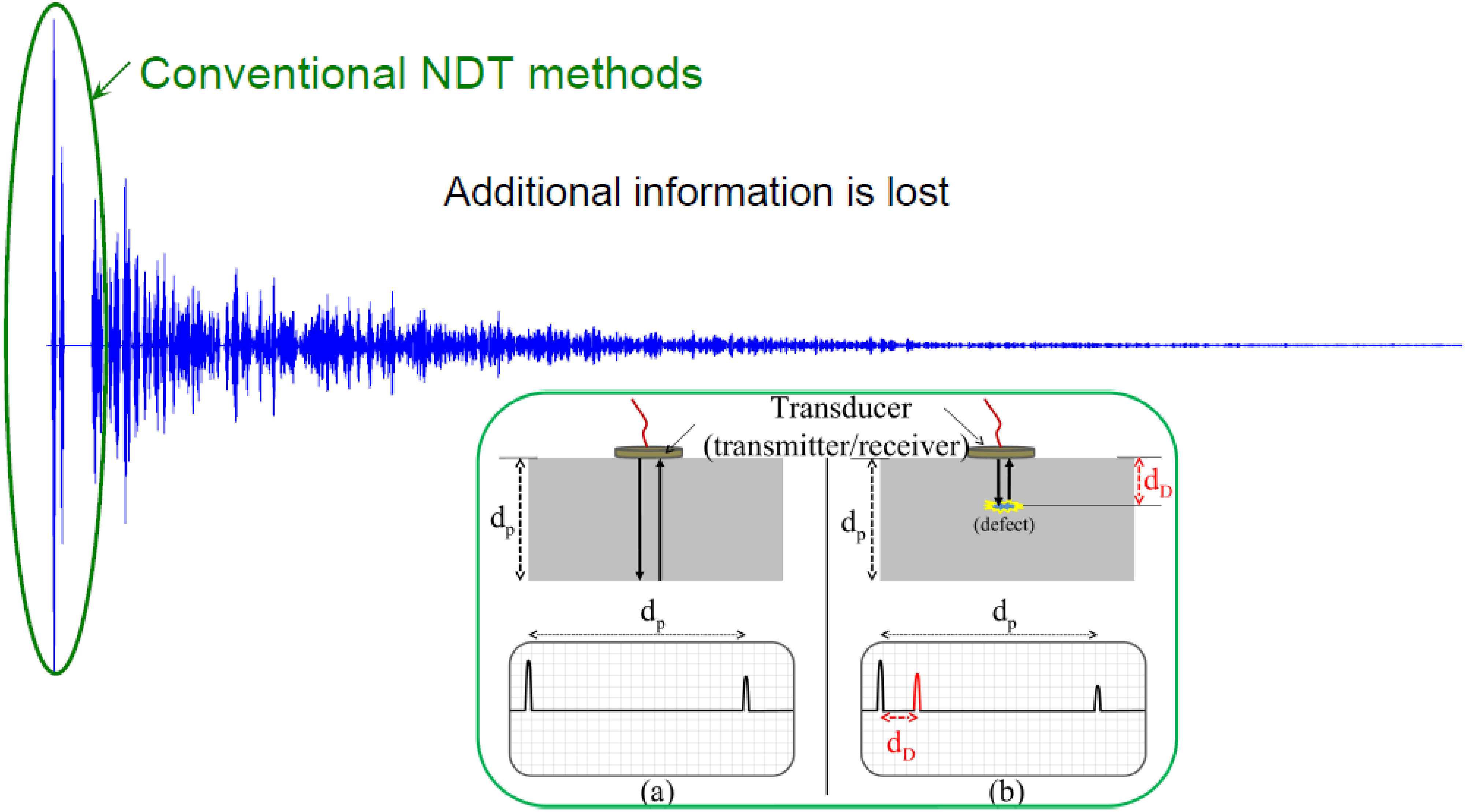
Acoustic Parameters (reverberation time, wave velocity, acoustic impedance)

Linked to

Defaults, cracks, sol-gel transition (density, viscoelasticity, gelling time)

Problematic and objective

- NDT in solid media :



Problematic and objective

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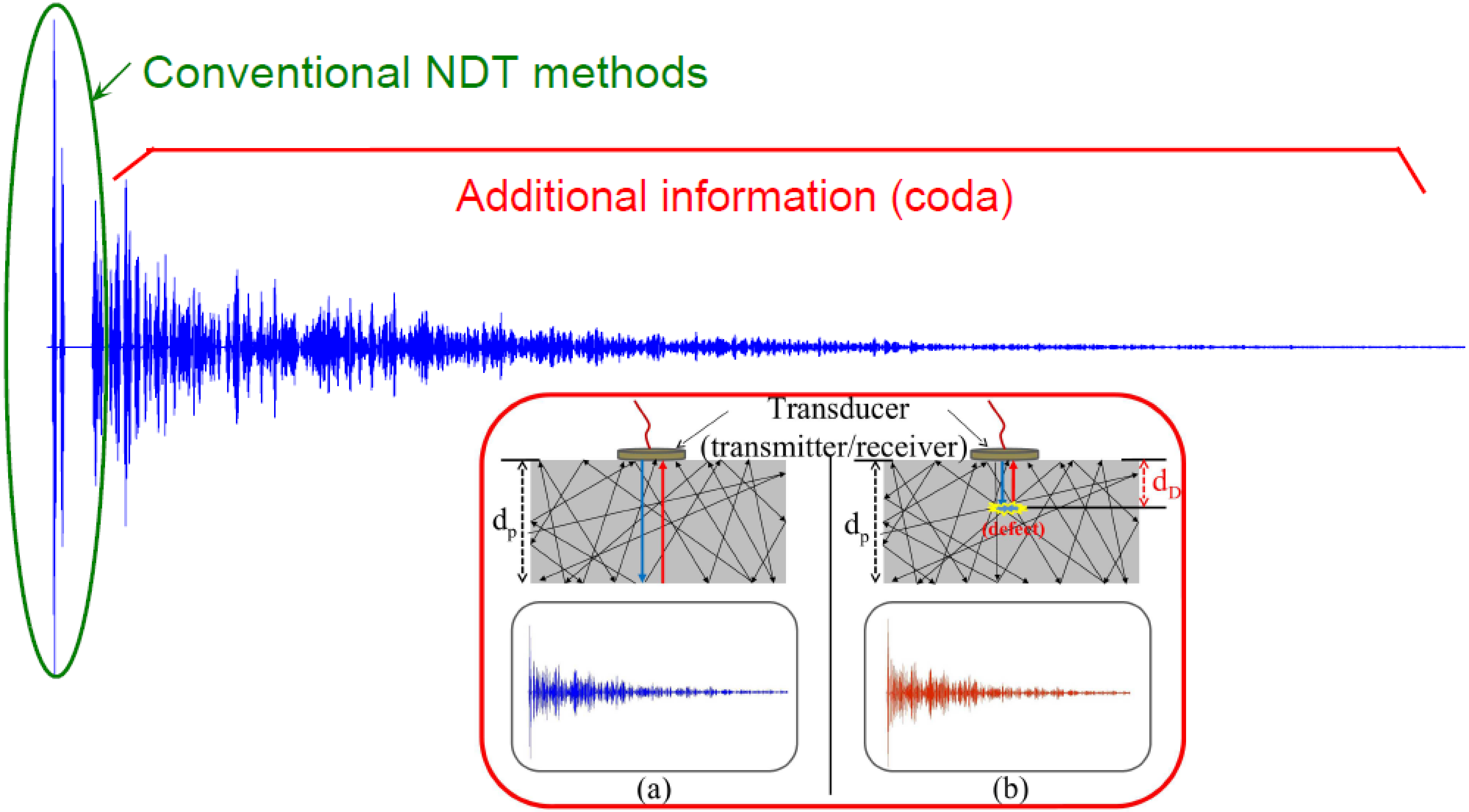
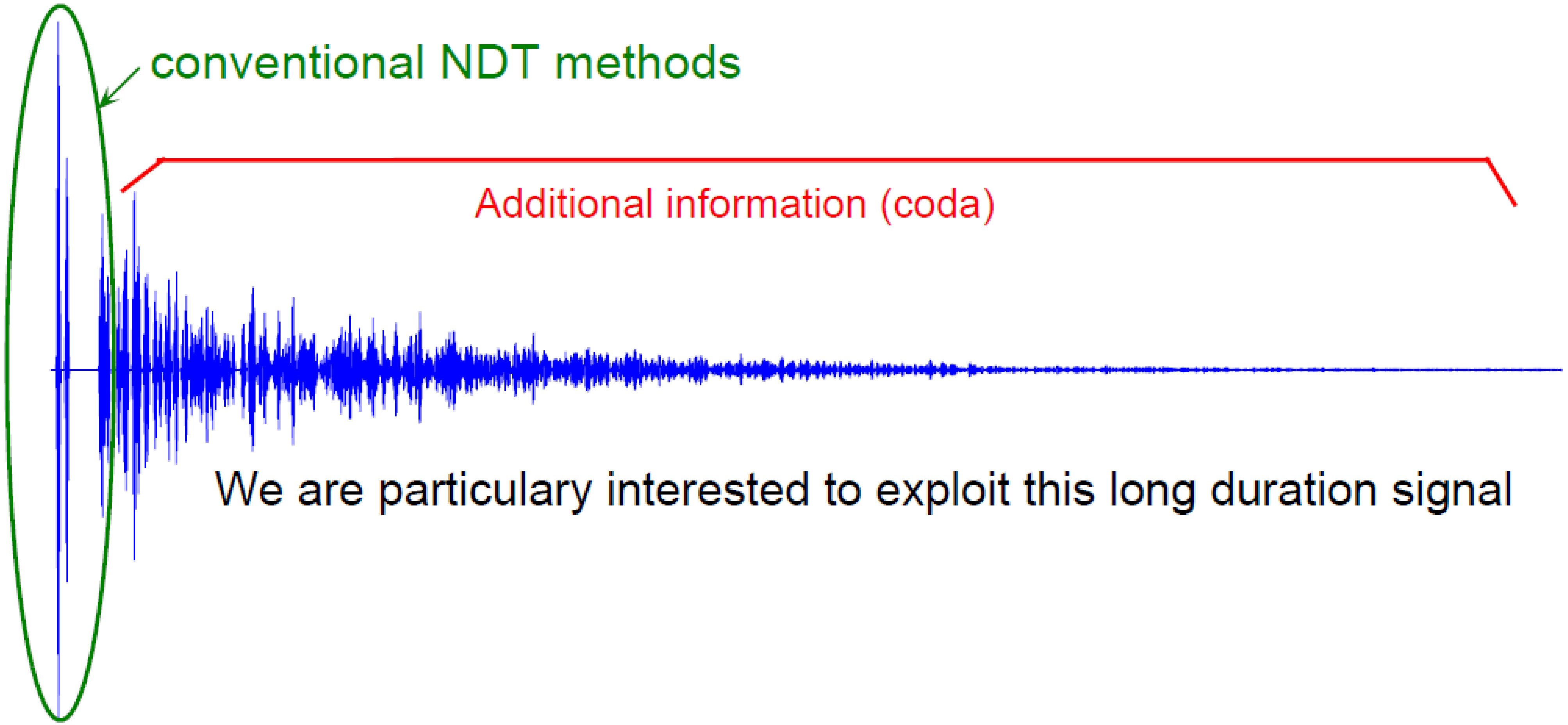


Problematic and objective

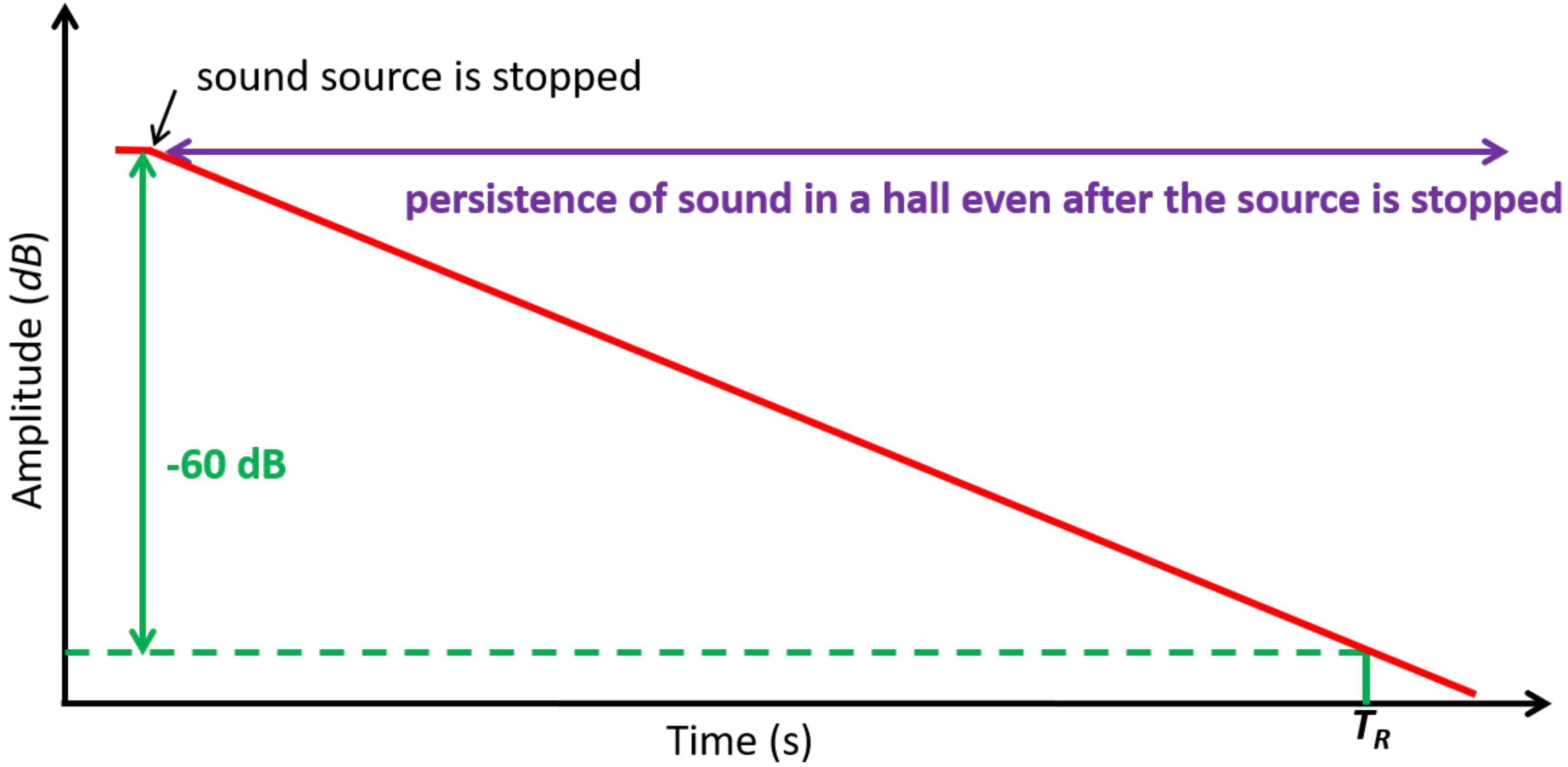
- NDT in solid media :



Hypothesis : The coda signal's information linked to the media properties

Such complex acoustic signals are frequently used in room acoustics but they are not so common in NDT.

- Room acoustics illustration :



Sabine and Eryring formula : $RT_{(-60dB)} = 0{,}16\,\frac{V}{S\,\alpha}$

⇒ Estimation of sound absorption coefficients of walls and/or characterization of acoustic absorption coatings.

Exploitation of multiple reflections in solid medium

Recent techniques:

Time-reversal acoustics (ex: Source localization)
Applications: medical, seismic, data processing. . .

Coda interferometry (ex : characteristic variations in a complex media)
Applications: seismic, NDT in solid media. . .

Field correlation (ex : imaging)
Applications: seismic, medicine, biology, transport. . .

They use deterministic relationships between two measuring points

Our proposed method:

Ensemble-averaging of reverberated signals

- ✓ Extraction of additional information
- ✓ Simple data processing
- ✓ Few sensors
- ✓ Time synchronization is not required

Adaptation of Sabin’s formula

$$RT_G = \frac{4(-G/10)\ln(10)}{c}\frac{V}{A}$$

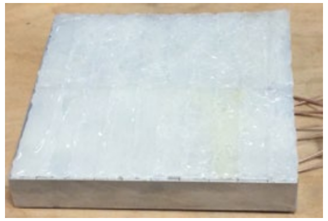
RT : Reverberation time (s)
G : Energy decreasing level (dB)
V : Volume of studied medium (m^3)
c : Wave velocity in medium (m/s)
A : Absorption coefficient between 2 media with $\neq Z_a$ (dB/m^2)

Room acoustics :theater

Air ⇔ Aluminum

Walls ⇔ Polymer

Adhesion level



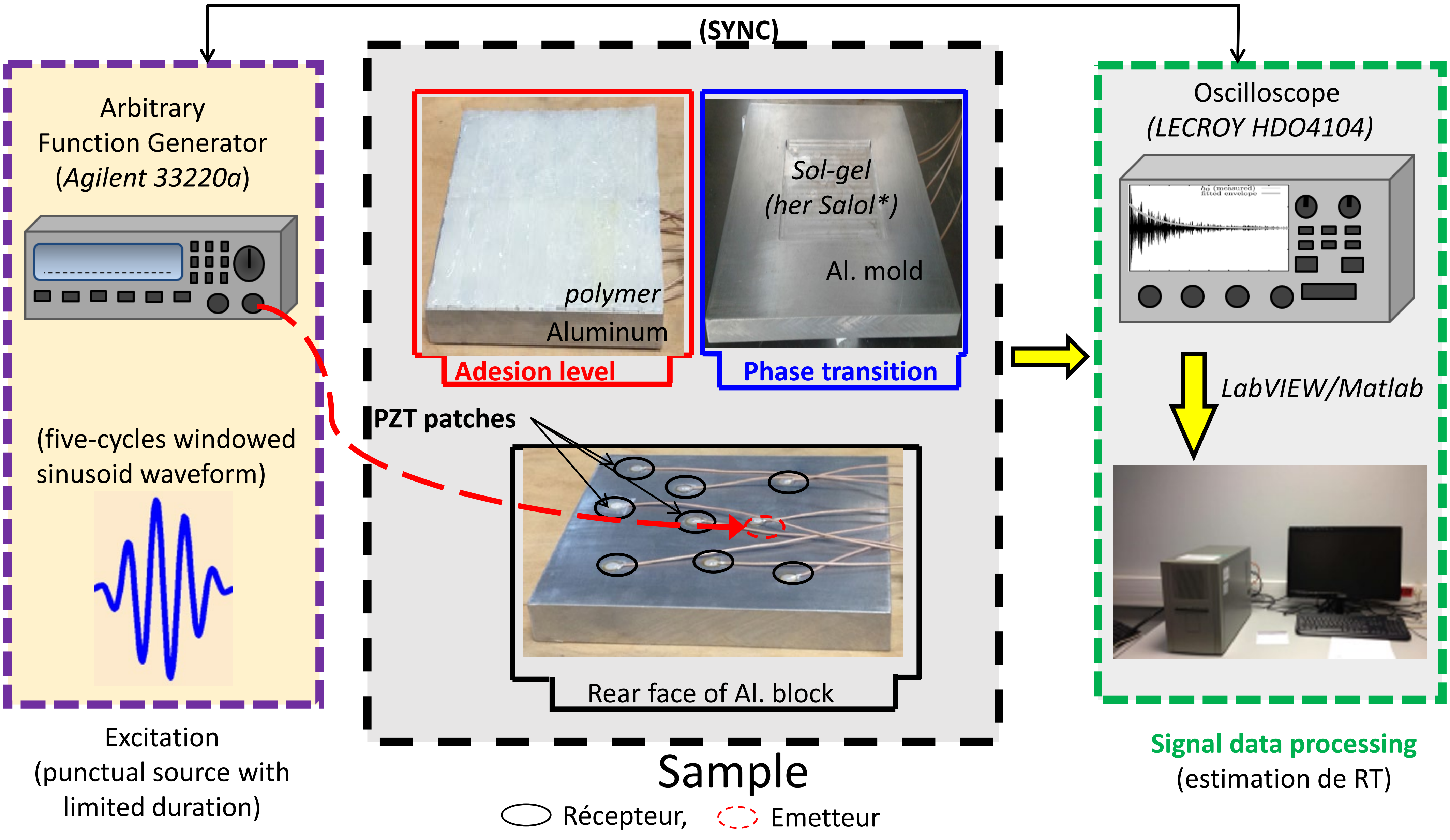
Air ⇔ Al. Mold

Walls ⇔ Sol-gel

Phase transition

Room $(G = -60\ dB)$	Our samples $(G = -10dB)$
$RT_{-60dB} = 0{,}16\frac{V_{room}}{A}$ $0{,}16 = f(G = -60dB, c_{room})\ with\ c_{room} = 340\ m/s$	$RT_{-10dB} = 0{,}00145\frac{V_{Al}}{A_s}$ $0{,}00145 = f(G = -10dB, c_{Al})\ with\ c_{Al} = 6320\ m/s$

Experimental Setup

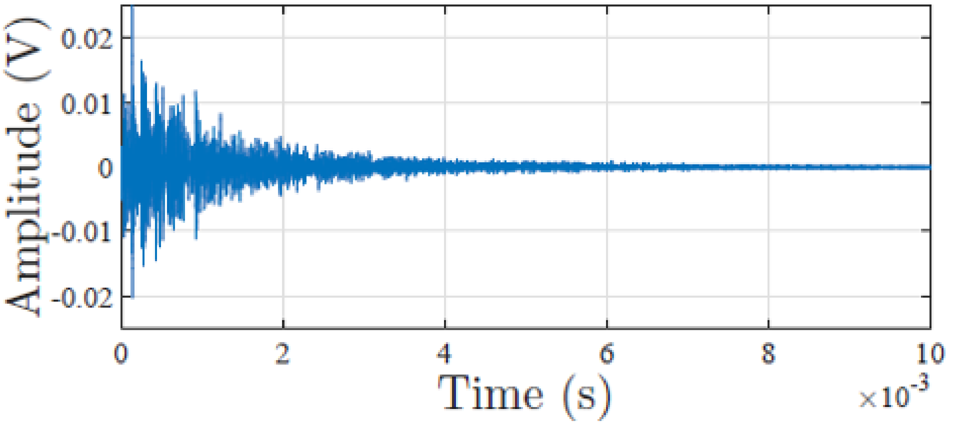


Excitation
(punctual source with
limited duration)

Sample

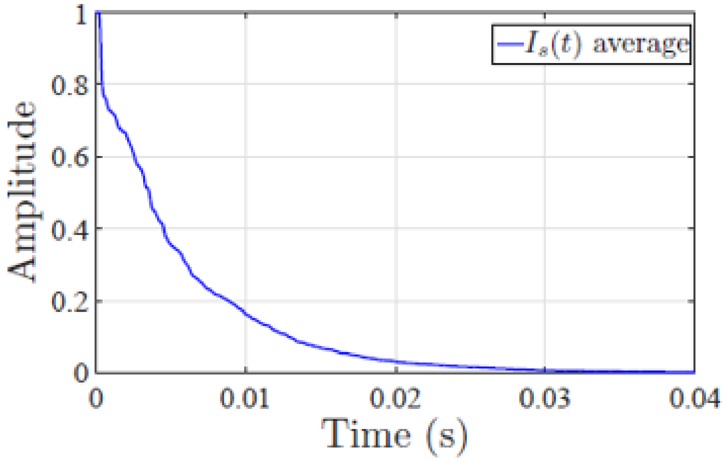
Signal data processing
(estimation de RT)

Parameter identification :

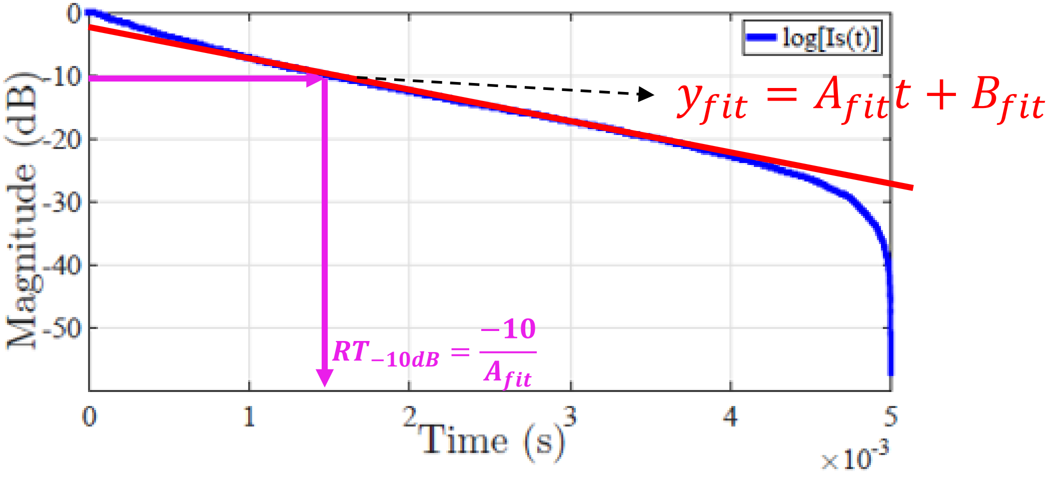


- Estimation of A_s through linear curve-fitting
- Schroeder's Integral

$$I_s = \int_t^{+\infty} [h(u)]^2 \, du$$



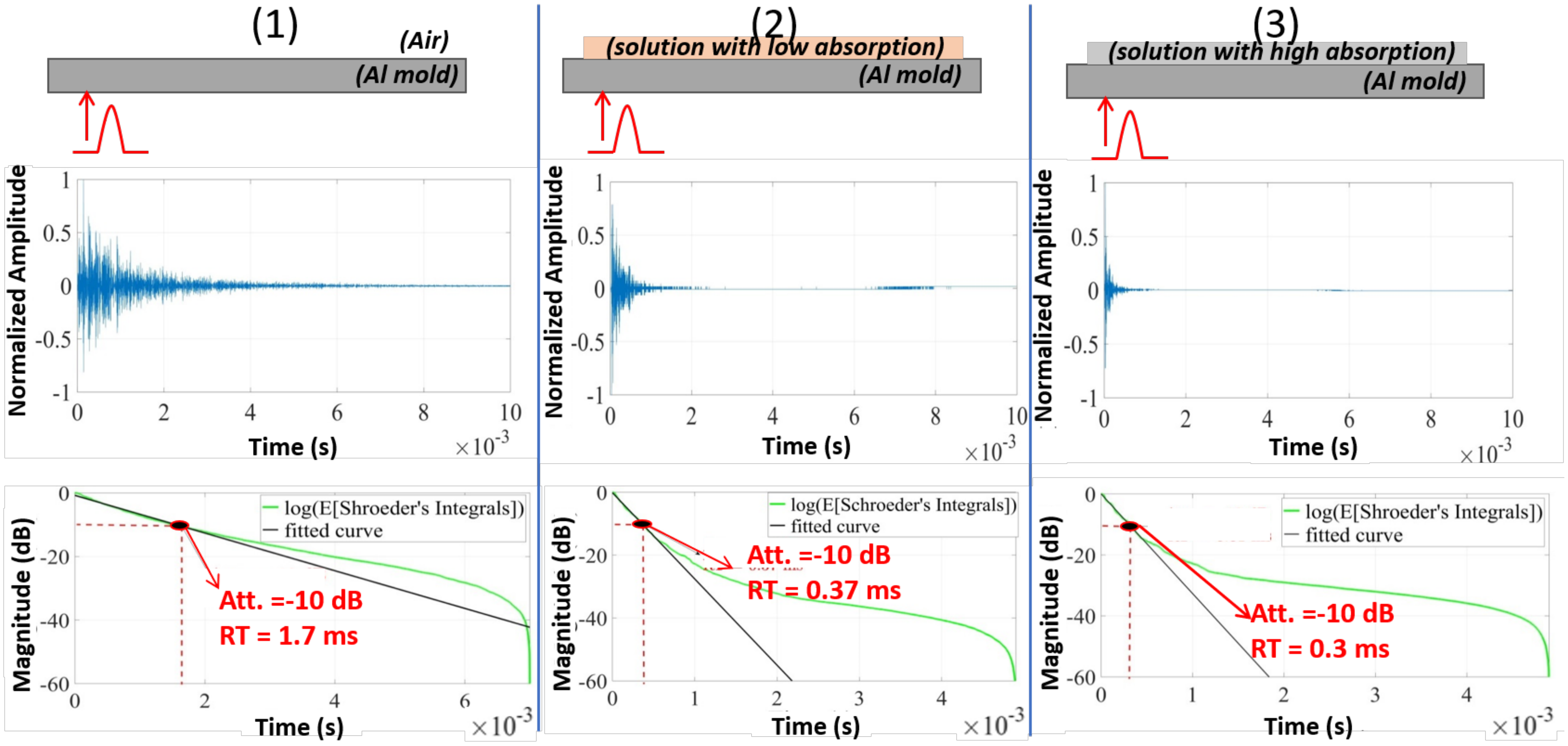
- Average over 4 sensor positions



RT → Absorption coeff. between 2 media ⇒ Estimate boundary conditions (surface fraction of polymer, phase transition, viscoelasticity…)

Parameter identification

Principle : Samples in different conditions

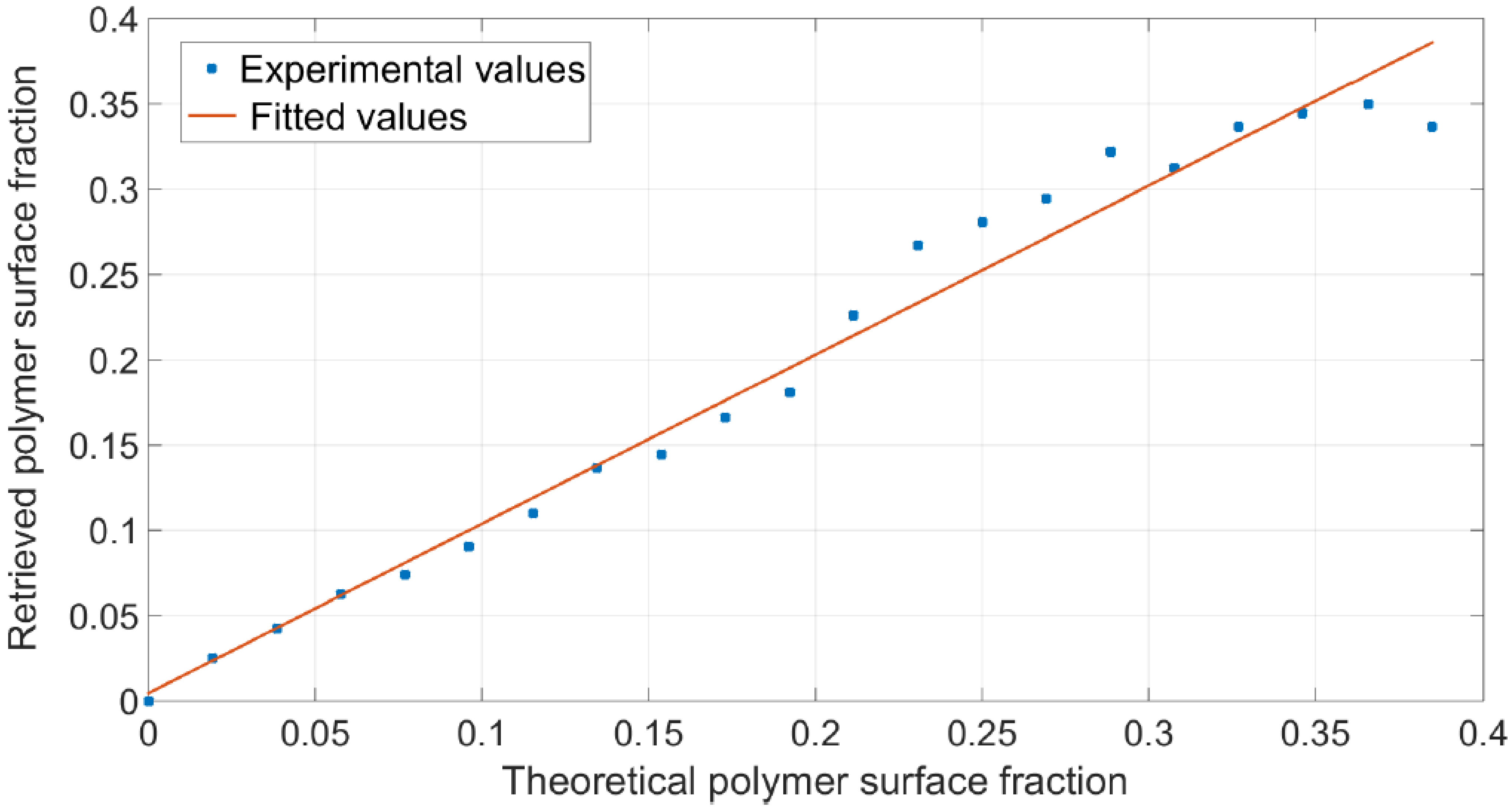


RT ↘ when absorption ↗

Using theoretical relation → calculation of absorption coefficient.

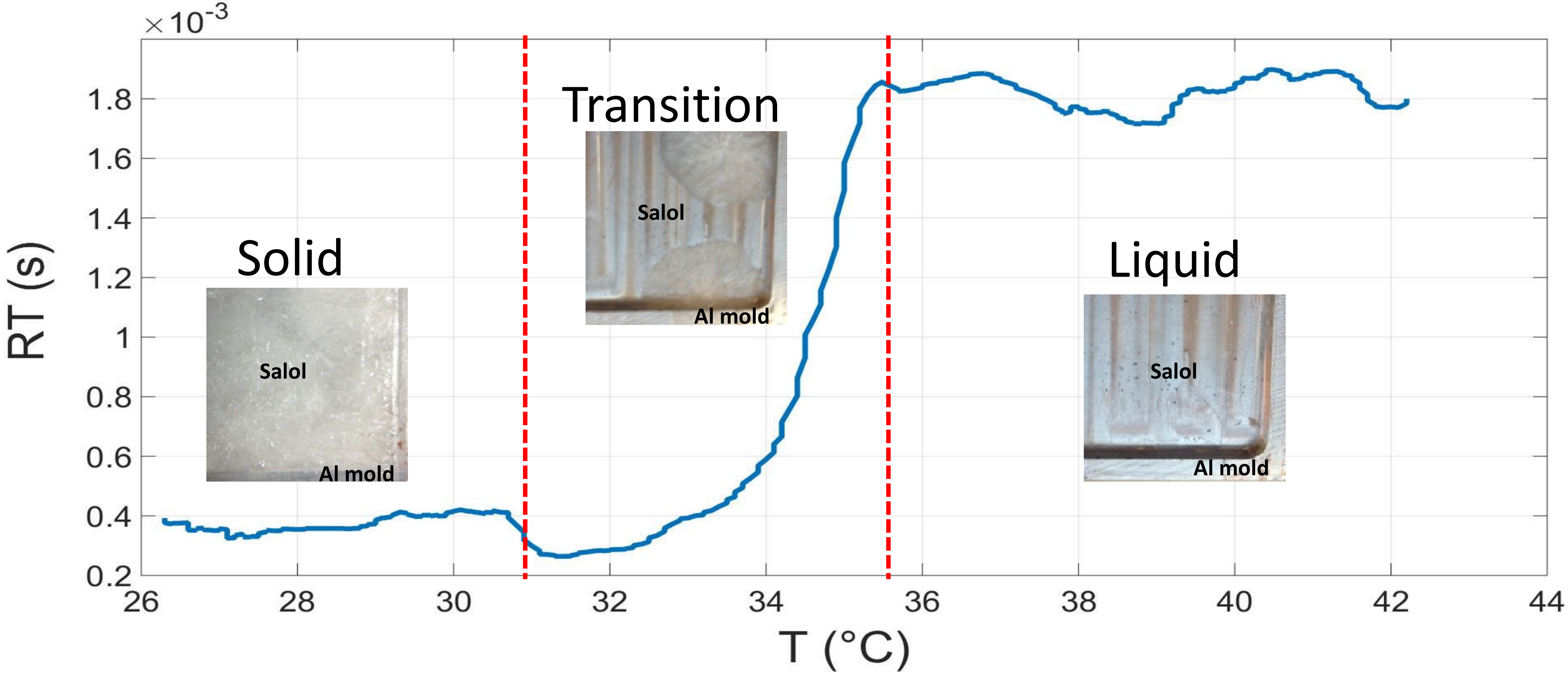
Application 1 : Contact surface fraction evaluation between aluminum and polymer

$$RT = fct(f_{poly}) \qquad f_{poly_{Estim.}} = fct\,(f_{poly_{Theo.}})$$



Application 2 : Phase transition

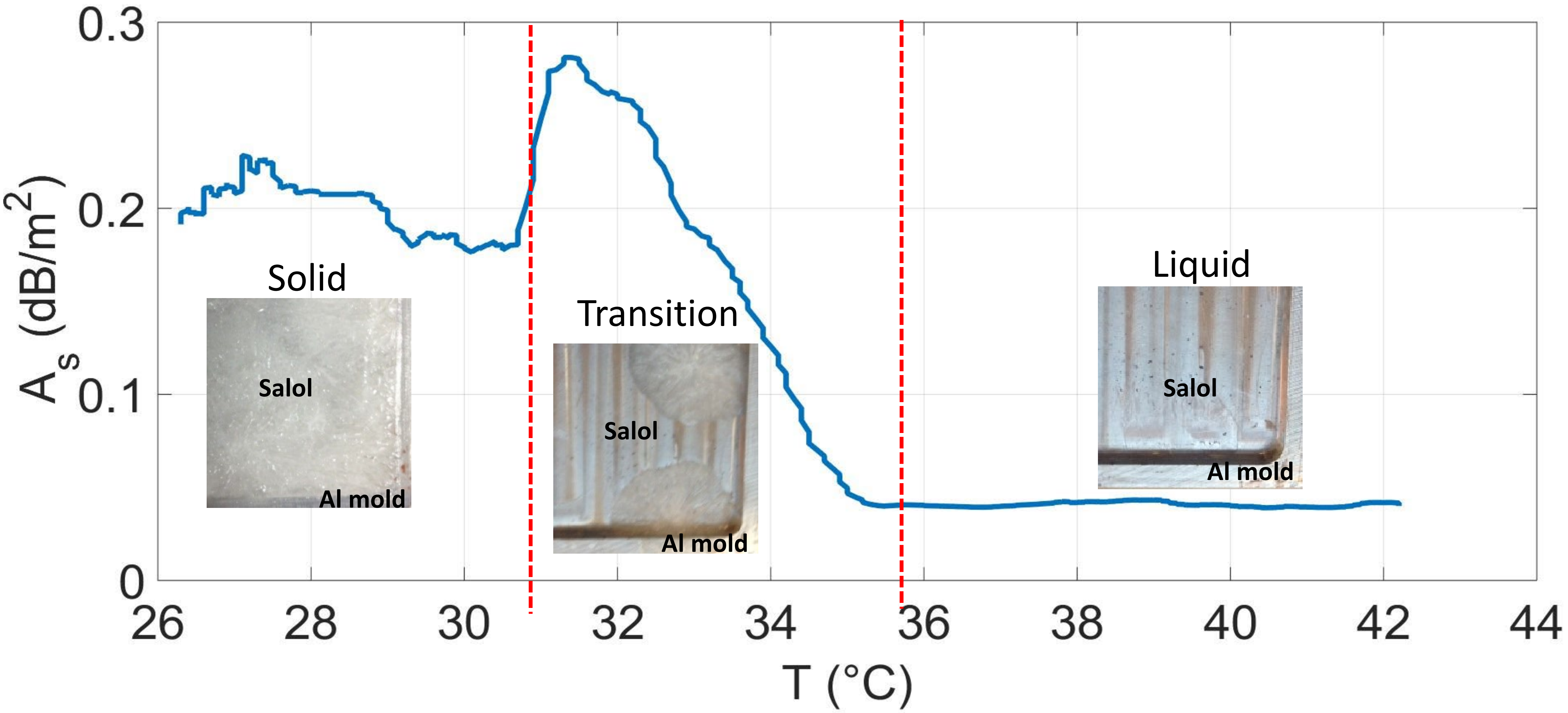
Estimated reverberation time $RT = fct(°C)$



Once RT Known ⇒ we deduce absorption coefficient

Application 2 : Phase transition

Absorption coefficient : $A_s = fct(°C)$



Conclusion & Perspectives

- Establishment of a direct relationship between boundary condition variations and the behavior of reverberant signals
- Sabine's formula is used and adapted to solid media in order to estimate absorption coefficient and surface fraction of polymer.
- Experimental validation of the hypothesis.
- We show the possibility to apply a room acoustics technique to solid media (NDT).

- Advantage:

✓ **No** time of flight measurement.
✓ **No** synchronization between the input channels.
✓ **No** shape identification.
✓ **+** low hardware constraints.

- Future works: apply this method to industrial products, estimation of acoustical parameters, such as velocity and acoustic impedance.