2008 IEEE

19-21 Mai 2008

Acoustic characterization of thin polymer layer for love mode surface acoustic waveguide

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OUTLINE

- Introduction
- Surface acoustic wave devices
- Simulation settings & validation
- Experimental monitoring of photo-resist characterization & results
- Conclusion

INTRODUCTION

Love mode acoustic sensors → detection sensitivity in layered viscous media

Quantitative physical properties → acoustic velocities & insertion losses

Validation of a simulation approach based on:

- transducer analysis → FEA / BEM
- dispersive propagation for viscous effects → Green's function
- delay line simulation → results inserted in a mixed-matrix model

Addressed problem: evaluation of the physical properties of a resist layer:

- mass density, elastic coefficients, viscosity coefficient, thermal dependence

↳ Since the layer contributes to the Love mode guiding

→ identify the mode characteristics at different curing temperature

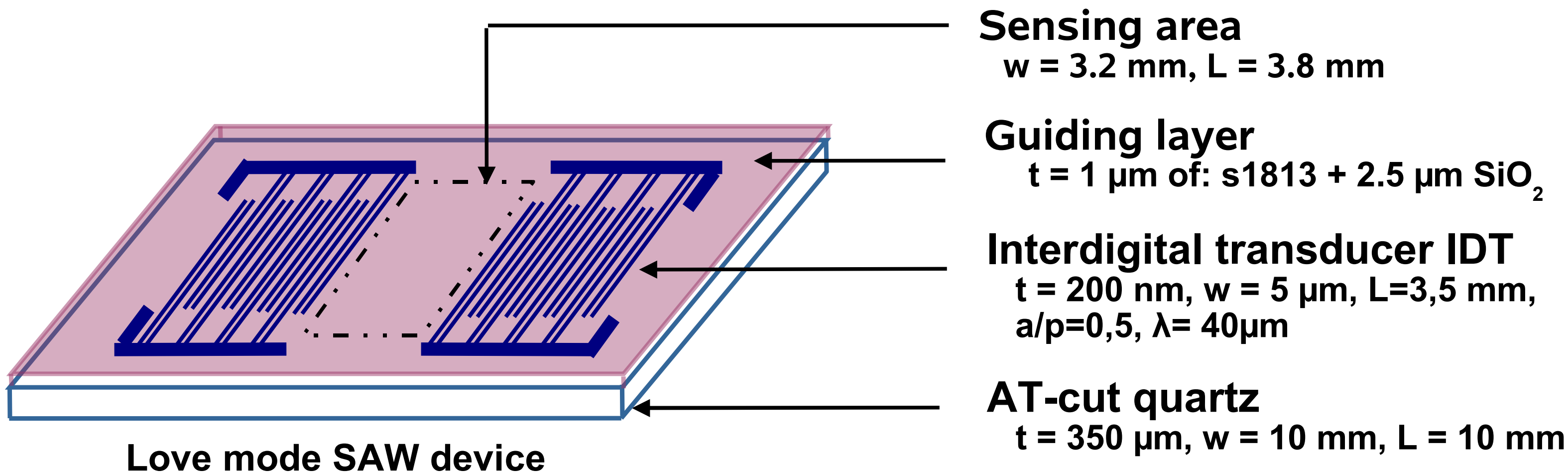
→ extract resist physical coefficients

Love-Wave Delay Line Design

➢ **Love mode surface acoustic wave (SAW):**

- Guided shear acoustic wave: thin S1813 and SiO_2 layers
- Interdigital transducers (IDTs) on a piezoelectric substrate

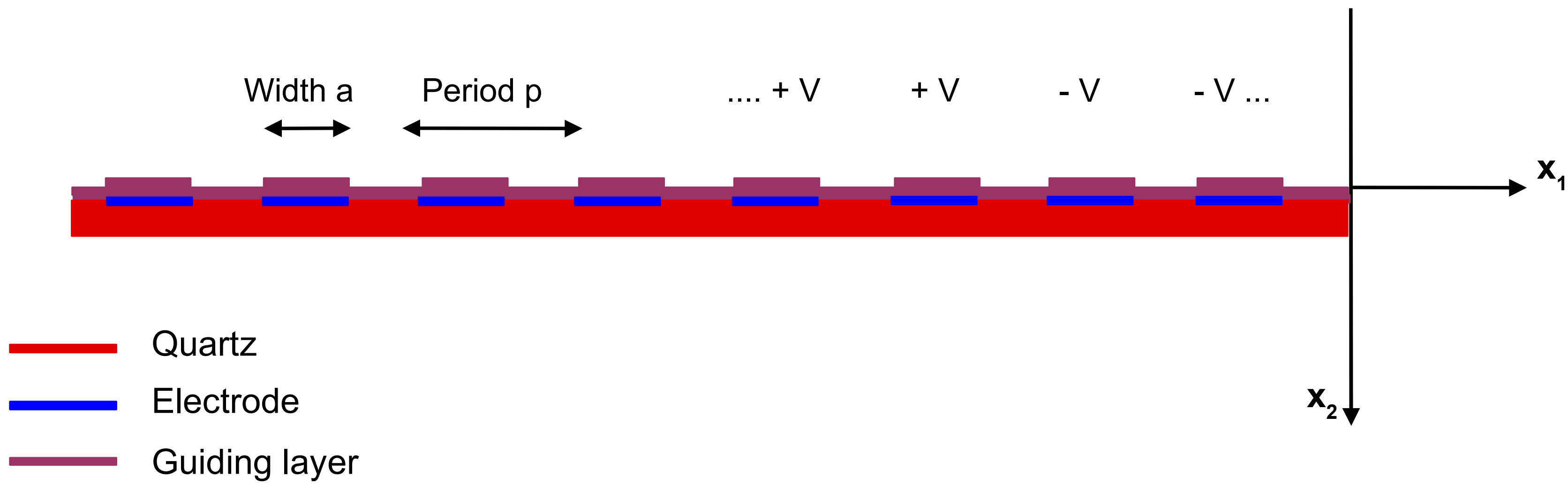
➢ **Basic structure of the sensor:**



↳ Sensor = a two-track delay line: the reference and the sensing line

Simulation of the IDT grating (I)

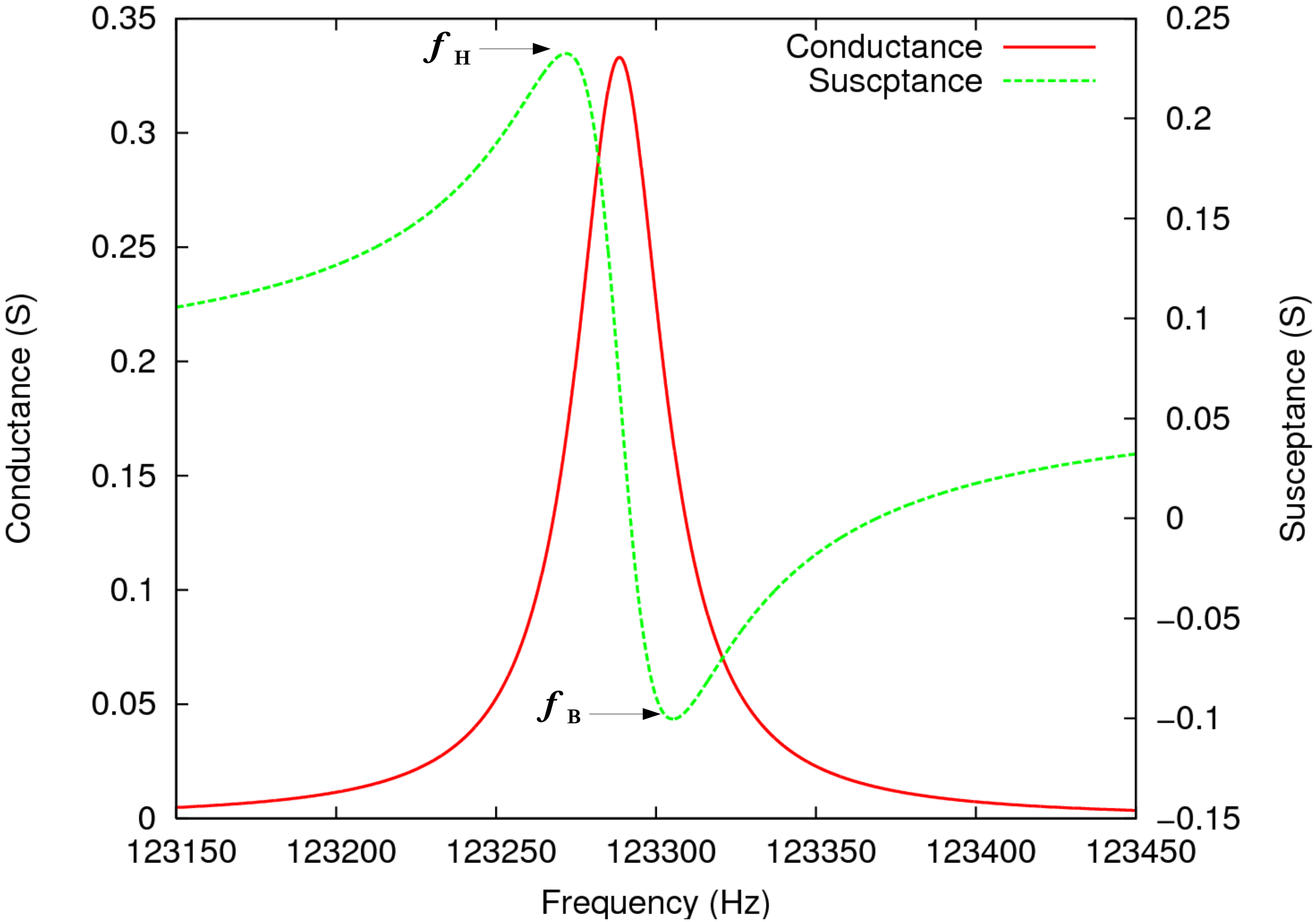
- **IDTs (4 finger-per-wavelength): Finite Element Method**
  - Typical IDT geometry:



  - Lab-made FEA-BEM software used to calculate the Harmonic Admittance at $\gamma = 0.25$

Simulation of the IDT grating (II)

- Harmonic Admittance, p = 10µm, a/p = 0.5, h/2p = 0.5%



$$V = f_{res} . \lambda$$

$$k_s^2 = 1 - \left(\frac{f_{res}}{f_{ares}} \right)^2$$

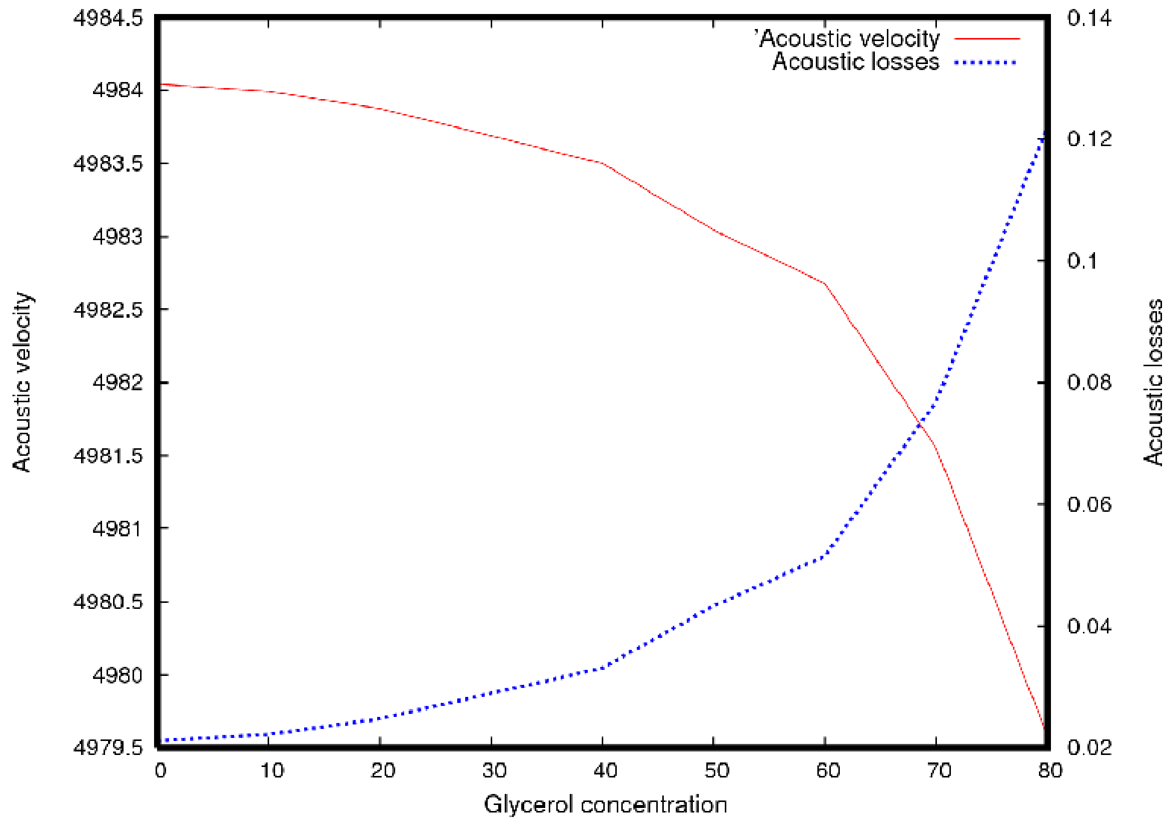
$$G = p . \pi . \frac{f_B - f_H}{f_B - f_H} \left(Y \left(f_H \right) + Y \left(f_B \right) \right)$$

$$\chi = 40 . \log e . \pi . \frac{f_B - f_H}{f_B + f_H}$$

Simulation of the propagation

- **Surface between IDTs: Green's function-based calculations**

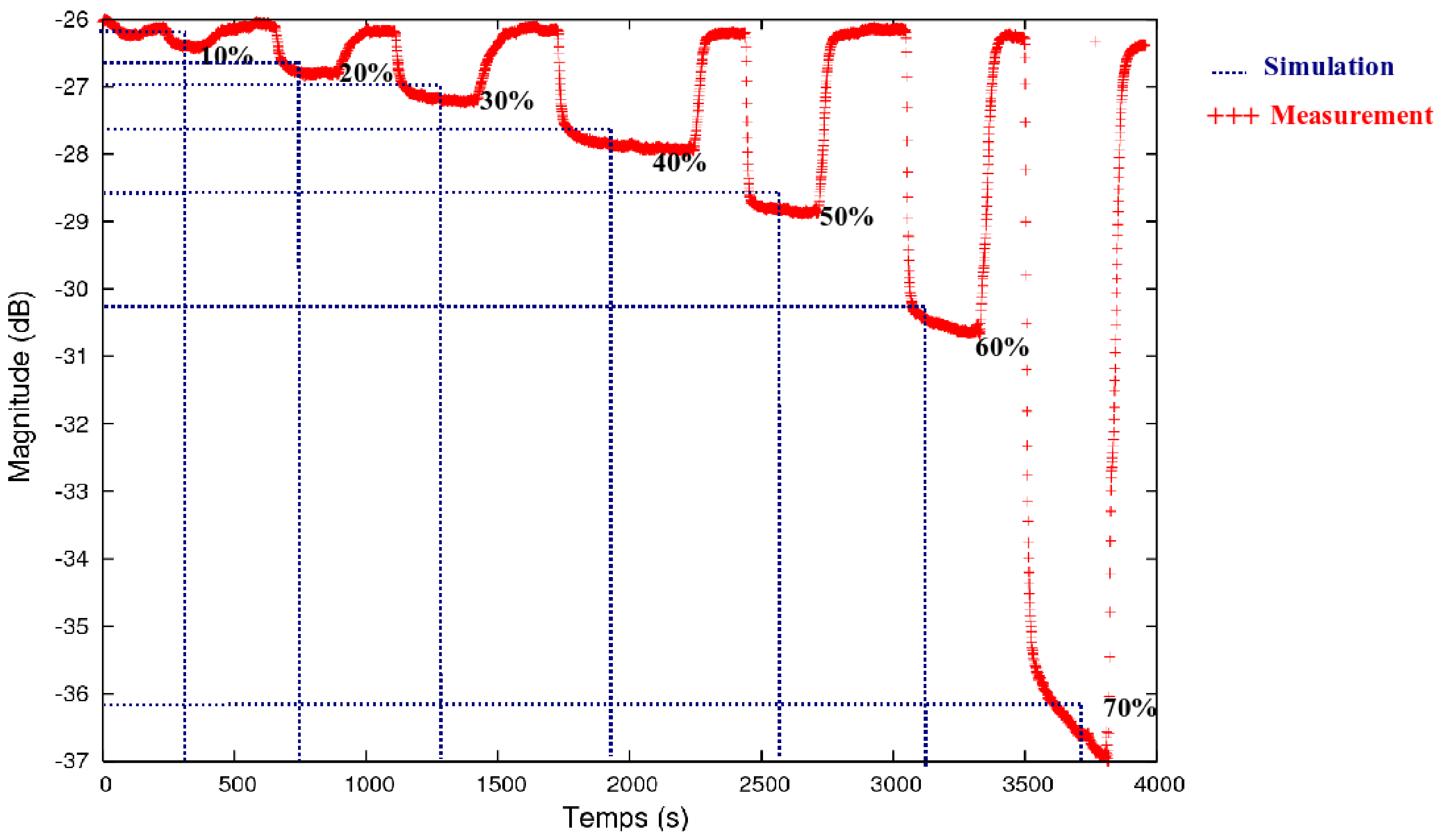
↳ Green's function of viscous-fluid-loaded devices allows for estimating velocity and losses of the wave



Acoustic velocity & acoustic losses versus glycerol concentration

Theory & experiment assessment

- **Love-wave device simulation: Mixed-Matrix model**



Time resolved simulation & measurements of the magnitude shift of glycerol solution

Resist layer characterization

• Experimental set-up:

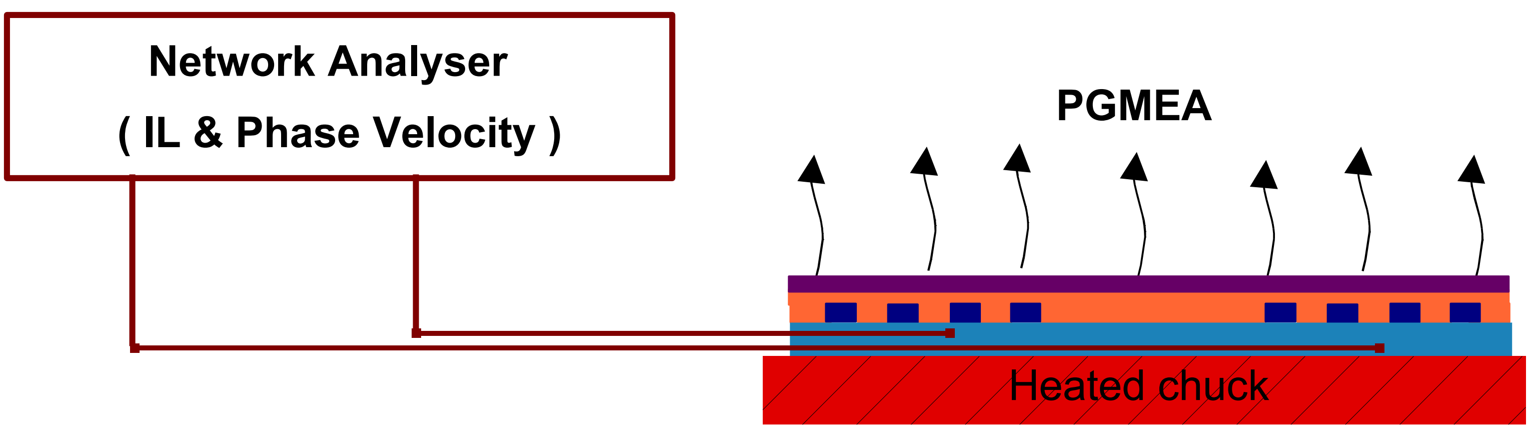
➢ Monitor the viscosity & solvent concentration of S1813 photo-resist:

- SiO_2 + S1813: guiding layer

→ Two experimental steps:

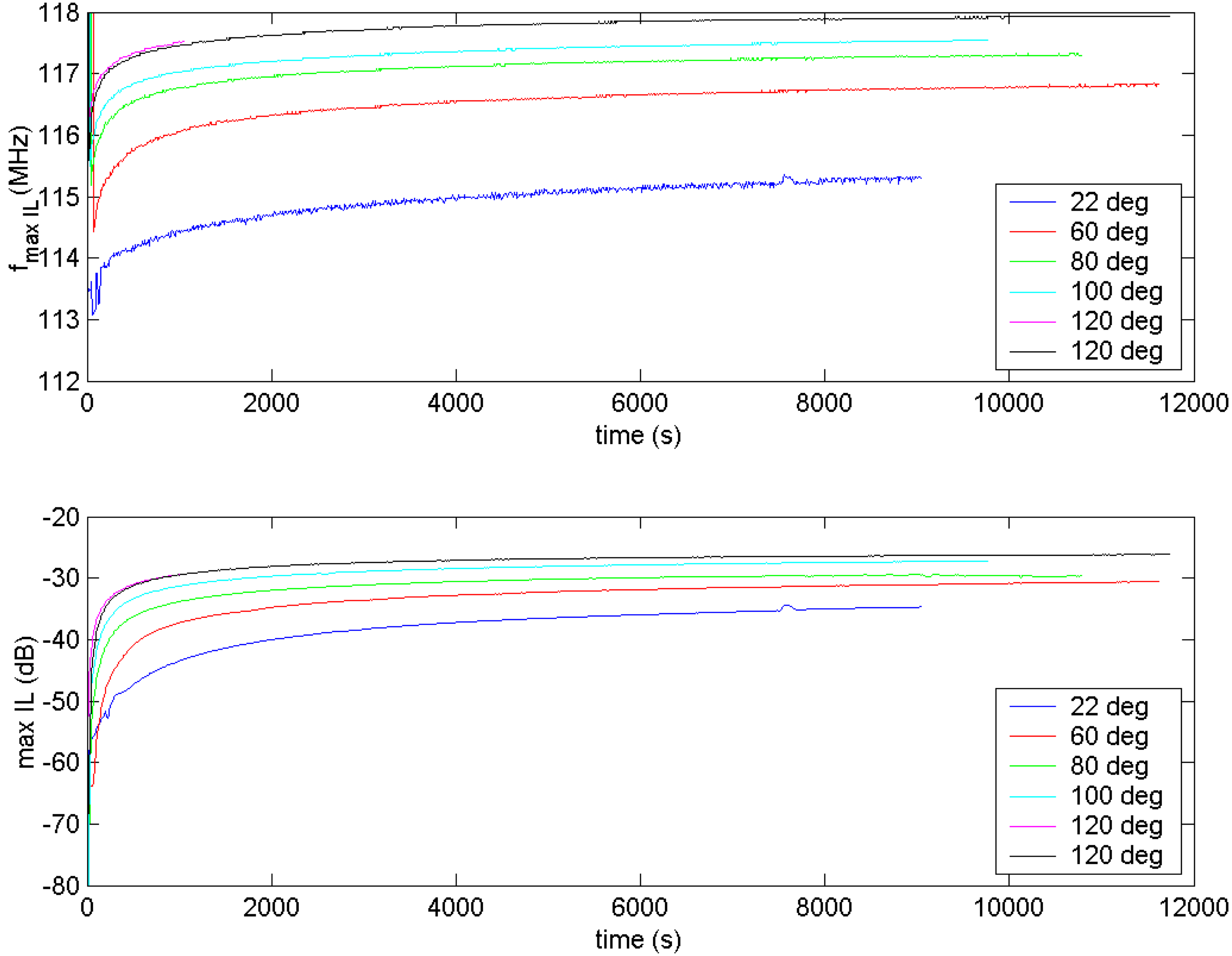
- Evaluate the specific IL & phase velocity when curing the guiding layer

- Record the solvent concentration within the layer using Infrared spectroscopy



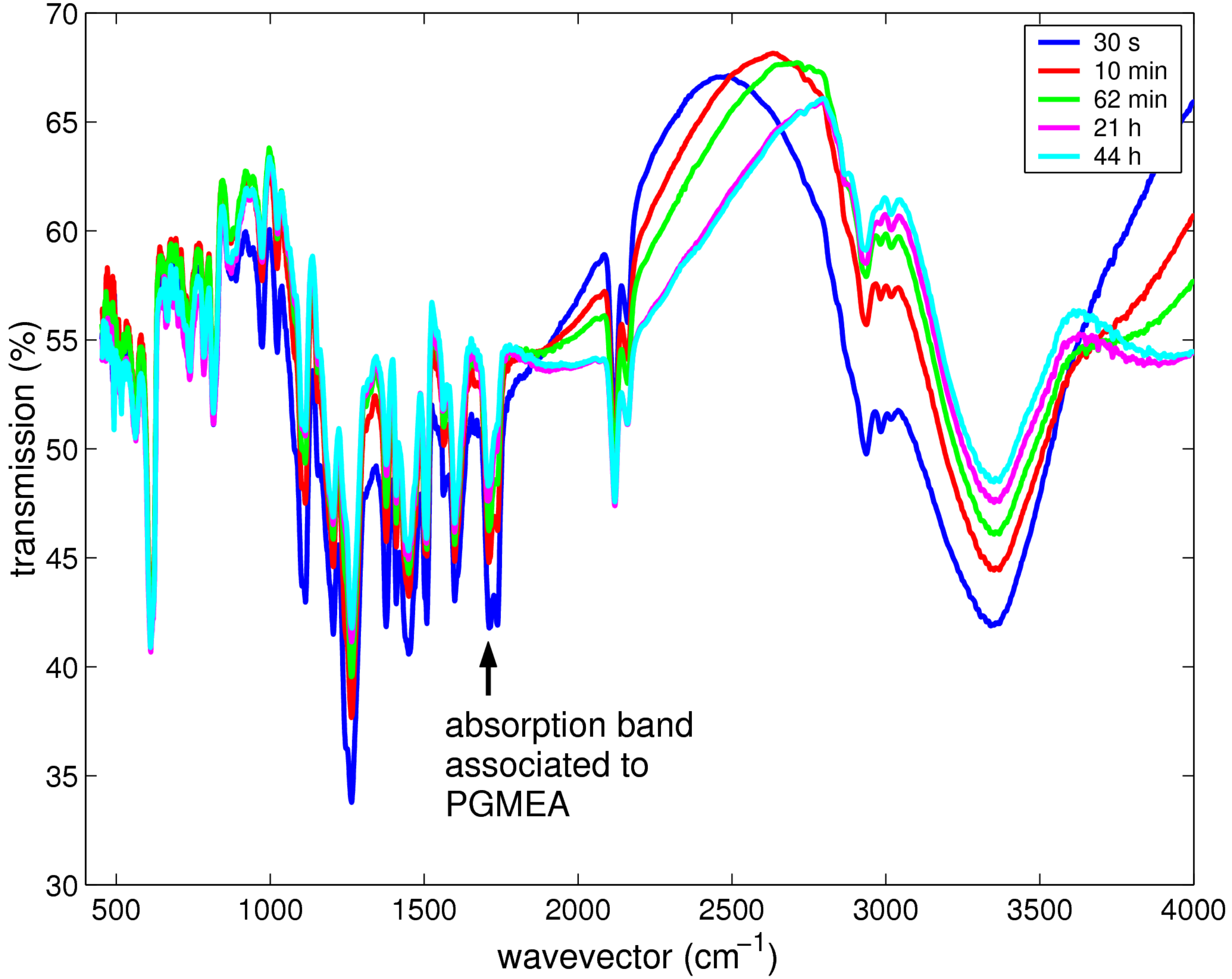
Measurement assessment: acoustics (I)

Evolution of experimental frequency & insertion losses monitored for different temperatures with the SiO_2+ S1813 guiding layer



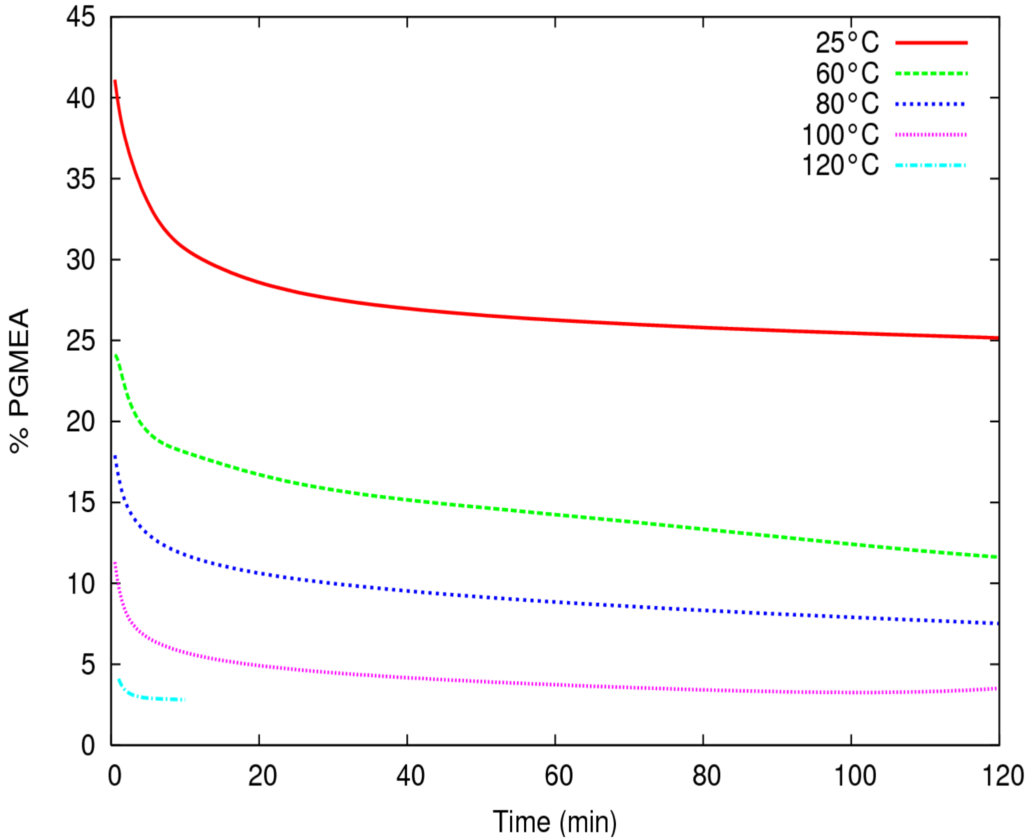
Measurement assessment: FTIR (II)

Spectrum localizing the exploited PGMEA absorption band

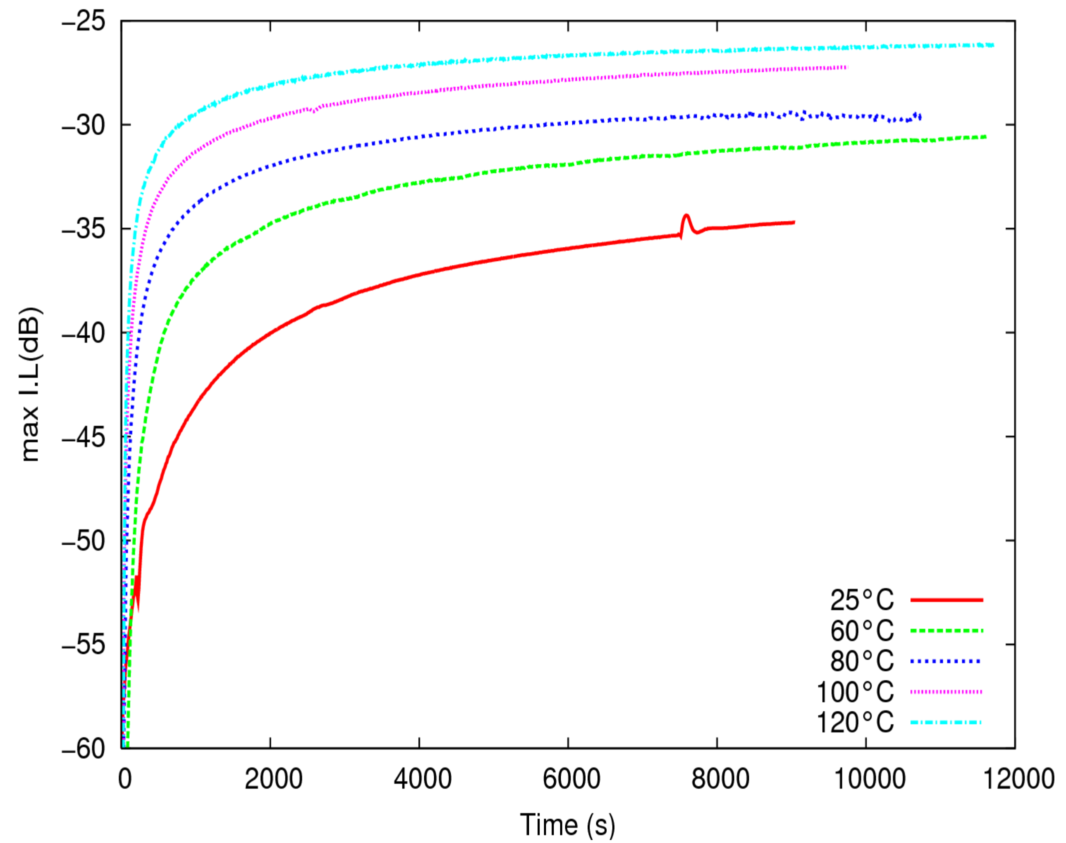


Measurement assessment (III)

Evolution of solvent concentration in the resist for different temperatures using Infra-Red spectroscopy



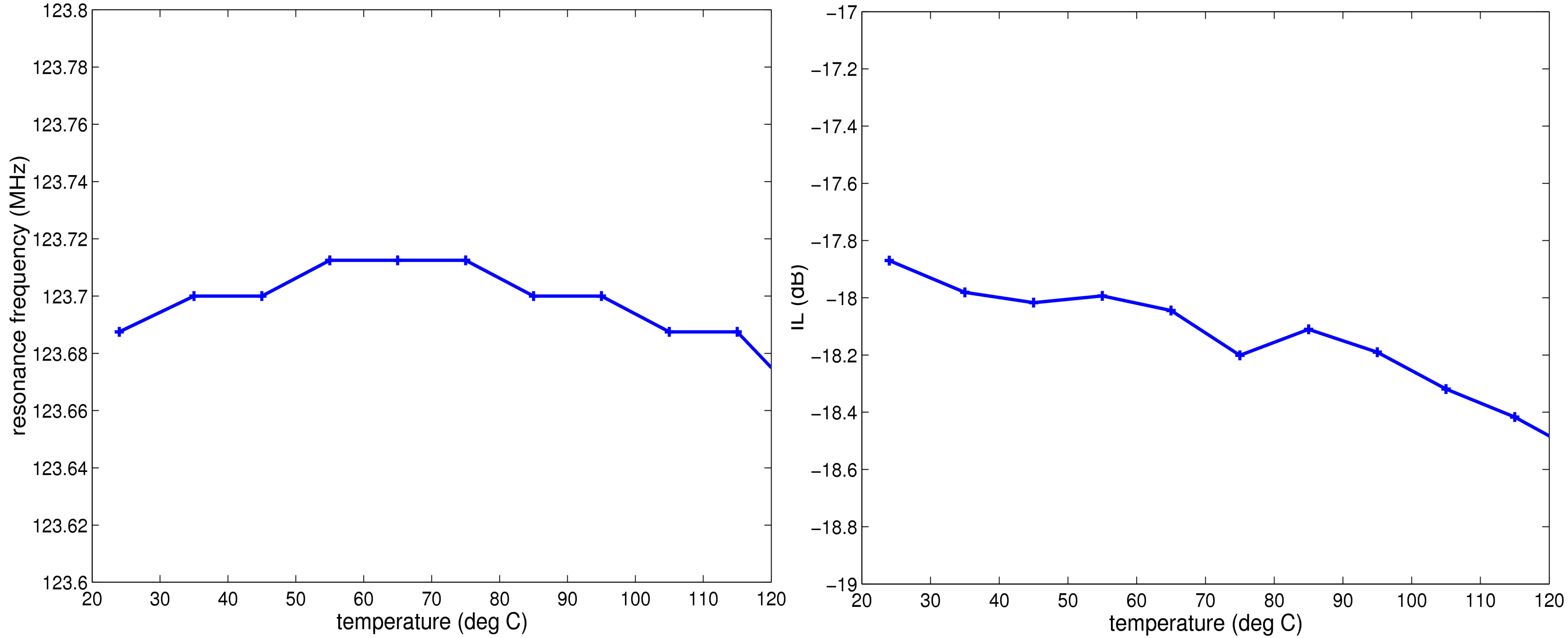
Evolution of experimental IL monitored for different temperatures with the SiO_2+ S1813 guiding layer



- Correlation between the temperature dependent acoustic signatures & Infra-Red spectroscopy results

Theoretical Results (I)

Evolution of experimental frequency & insertion losses monitored for different temperatures without the photo resist layer



- Neglect effect of temperature on insertion losses and frequency of the SAW device (Quartz + SiO_2)

Theoretical Results (II)

➔ Using Green's function: assume the resist layer behaves like a **viscous fluid**

$$C_{66}=0$$

→ identify viscosity from measured IL (for each temperature)

Problems:

- Variations of the frequency shift induced by the viscosity are negligible compared with the measurements
- Variations of the layer thickness & density have no impact on the propagation velocity

➔ Modify model to assume the resist behaves like a ***quasi-fluid*** (elastic):

$$C_{66}\neq 0$$

→ extraction of the temperature dependent shear elastic constant

Theoretical Results (III)

For each temperature we can determine:

- the thickness of the layer: $e = e_0(1+(T-T_0)\alpha_{11})$

$\alpha_{11} = 150\ ppm/K \qquad T_0 = 25C°$

- the mass density: $\rho(T) = \rho_0 / V_{me}(T)$

V_{me}*: thermal expansion coefficient of the elementary mesh*

- keeping previously determined viscosity

➔ Using Green's function $\rightarrow$ temperature dependent shear elastic constant

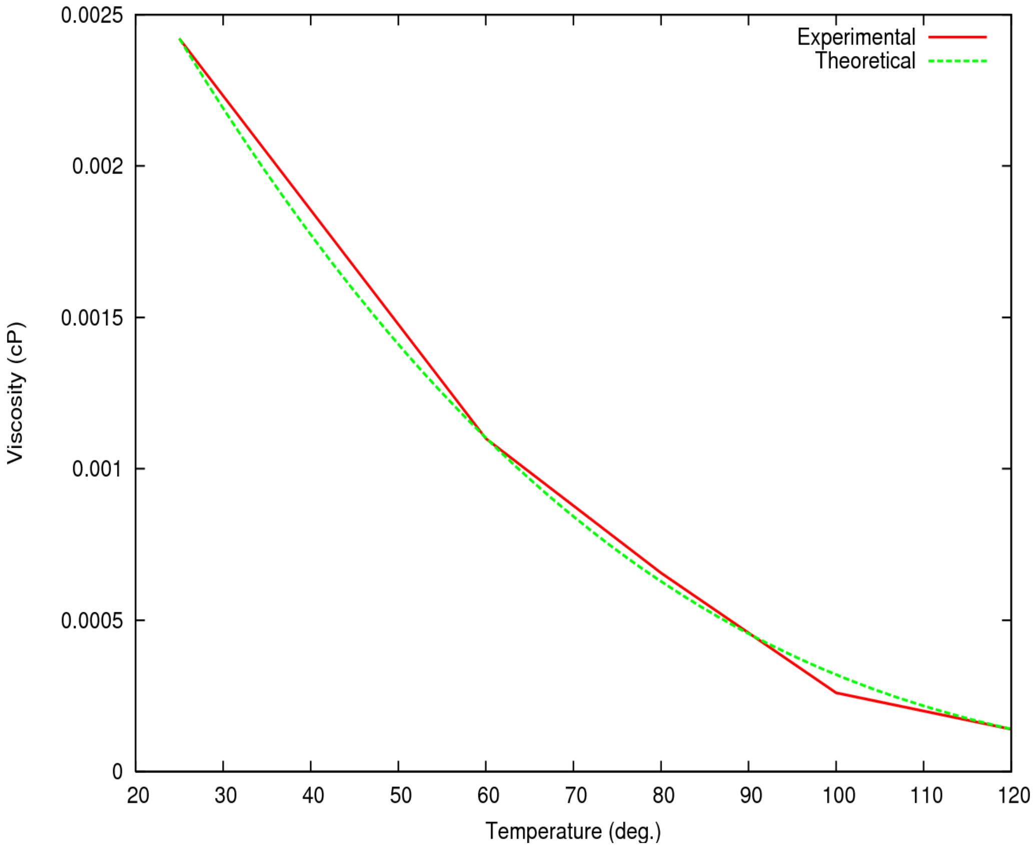
$$C_{ij}(T) = C_{ij_0}(1+(1/C_{ij_0})*(dC_{ij}/dT)*(T-T_0))$$

linear fit of the effective temperature coefficients of elasticity v.s temperature curve

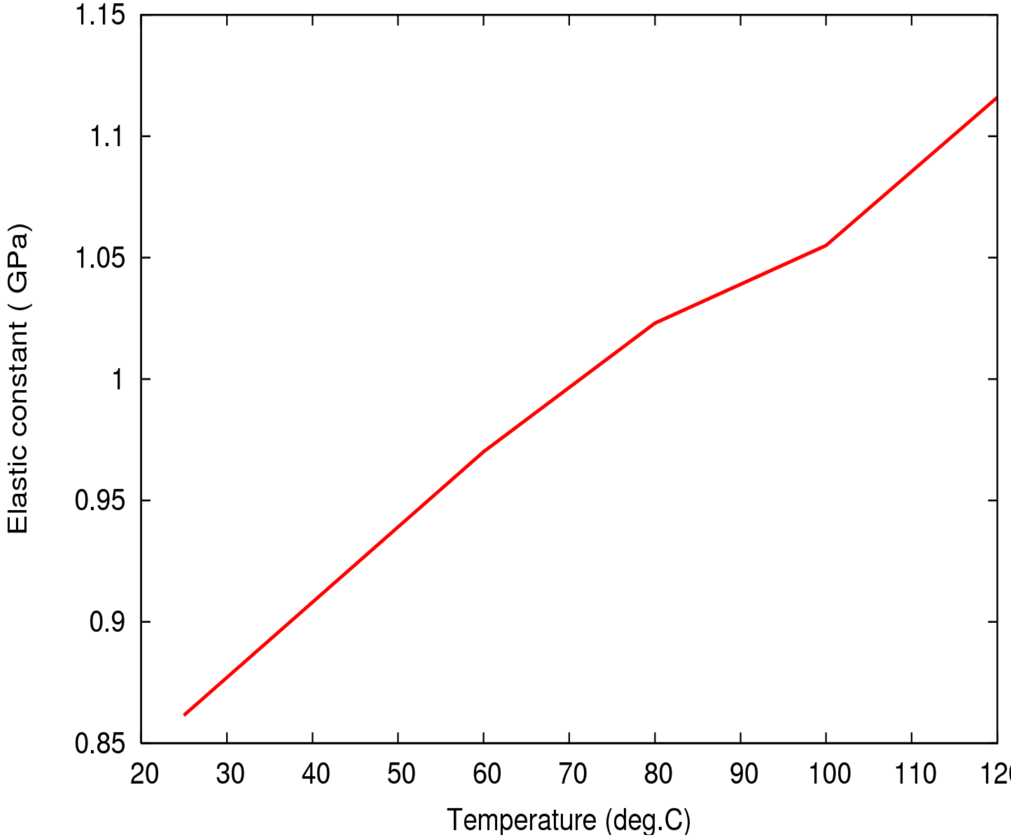
↳ these parameters are dominant in the variation of the frequency

Theoretical Results (III)

Evolution of experimental & theoretical viscosity for different temperatures



Evolution of elastic constant for different temperatures



Williams-Landel-Ferry model :

$$\mu(T)=\mu_0 \exp(-C_1(T-T_r)/(C_2+T-T_r))$$

C1 = -8.2; C2 = -179.4 K;
Tr=Tg: glass transition temperature

Shear elastic constants:

$$C_{44}=C_{55}=C_{66}$$

$$dC_{ij}/dT=3{,}110\,e^{-5}\,GPa/K$$

Conclusion

- SAW device system can be used to quantitatively evaluate viscous properties of liquids deposited atop the sensing track

↳ was used to characterize the acoustic behavior of a thin photo resist layer

→ the insertion losses give an indication on the viscosity of the layer

→ the property changes of the photo resist layer result primarily in:

- the evolution of the viscosity (I.L)
- the elastic behavior (Frequency)

while layer thickness and density are mostly unchanged during curing

↳ This approach is applicable to any type of film thinned by spin coating