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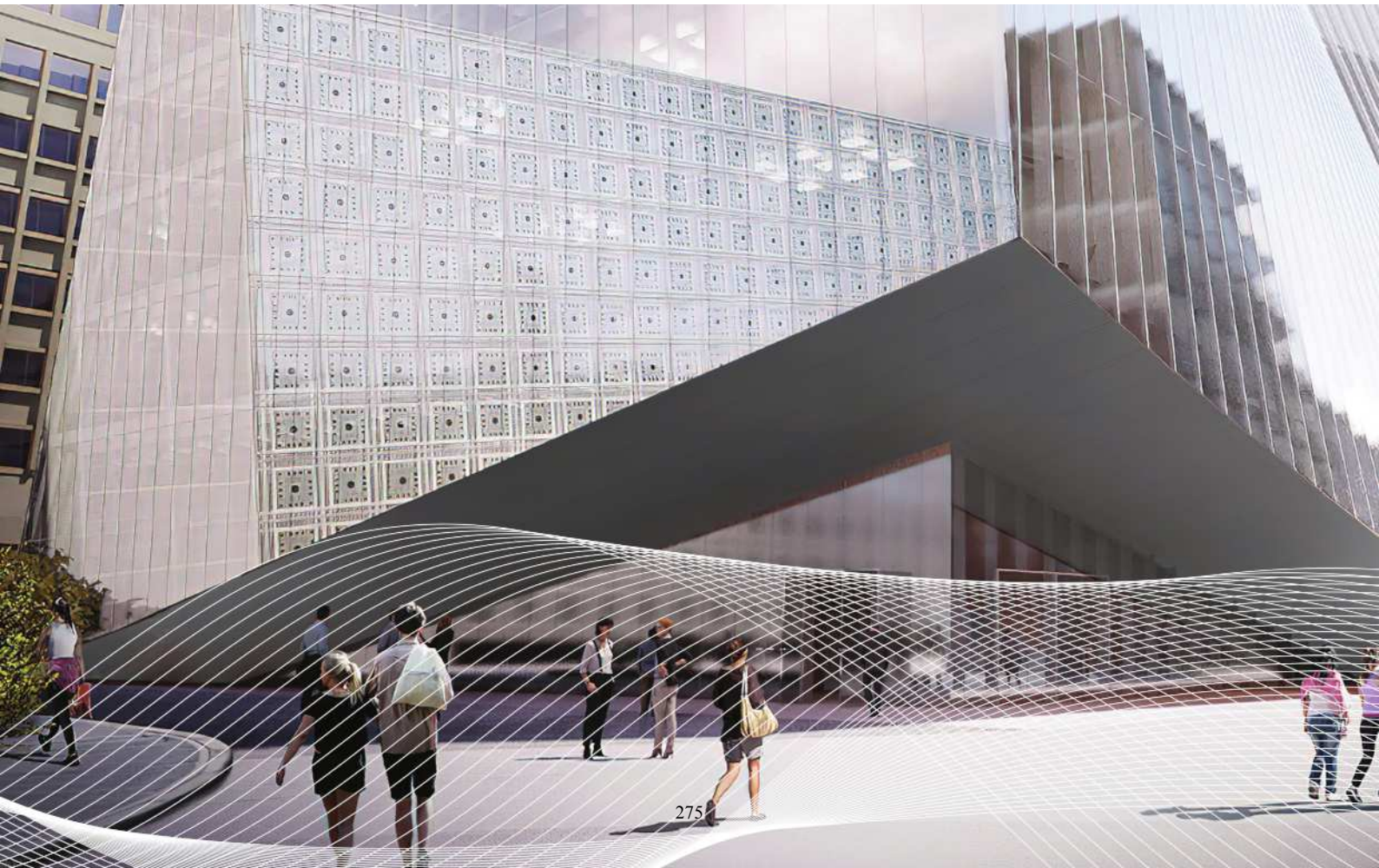
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Analysis of viscoelastic bilayer structure using a Scanning Acoustic Microscope at 200 MHz

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This work explores the application of scanning acoustic microscopy (SAM) using a 200 MHz plane-wave transducer for high-resolution materials characterisation. As a non-destructive technique, the SAM operates in pulse-echo mode, i.e. transmitting high-frequency acoustic waves into a sample, and then analysing the subsequent reflected echoes. The studied sample is a bilayer sample composed of a thin resin film deposited on a Glass substrate, which is a common configuration in coatings and microelectronics. The A-Scan signal has been investigated to provide a high-resolution measurement. The signal processing provides a characterisation, including density, acoustic velocity and acoustic attenuation. The use of a 200 MHz plane-wave transducer ensures high sensitivity for analysing the thin thickness of the resin layer. Key topics include the experimental setup, the use of appropriate model, which can be either TLM (transmission line model) or DSM (Debye series model), and considerations for achieving effective acoustic coupling. The analysis focuses on Epoxy-resin (100 μm) film deposited on a Glass substrate using a spin-coater. Characterization is performed using the Transmission Line Model (TLM) and visual decomposition of echo on film. Experimental and numerical results are compared, demonstrating the efficiency of different methods in characterizing viscoelastic parameters. The ability of the plane-wave transducer to discriminate between the acoustic properties of the resin and Glass is highlighted. The analysis of the A-Scan signals, and their characteristics, such as variations in amplitude and time-of-flight, provides an information on the acoustic and mechanical properties of the studied film. Those acoustic properties are identified throughout a nonlinear fitting of a given model to the SAM experimental data. The effectiveness of the technique in determining material properties is demonstrated, showing its potential applications in quality control and characterisation of thin films. The obtained results are promising for future developments in signal analysis to extend SAM's capabilities to multilayer systems. This presentation underlines the importance of the SAM as a precise and versatile tool for material analysis in scientific and industrial contexts.

1. Introduction

Non-destructive testing (NDT) using scanning acoustic microscopy (SAM) is used as an investigation tool for the characterization of a deposited layer on a substrate. This work focuses on the analysis of the electroacoustic response of an Epoxy film deposited on a Glass substrate. In this view, a high frequency piezoelectric transducer was chosen at 200 MHz without focusing. As an investigation tool, the Debye Series Model (DSM) [1], [2] has shown its ability to be adapted viscoelastic materials under the assumption of a linear dependence of the attenuation [3], [4], [5] and [6]. In this work, the Transmission Line Model (TLM) is used for the modelling of the measured echoes. Then the viscoelastic parameters of epoxy-resin are calculated by inverse problem solving *via* a nonlinear fitting of simulated model with identified parameters to the experimental signal. In a complementary approach, an alternative method has been applied with the electroacoustic decomposition method (EDM).

2. Methodology

2.1. Sample preparation

An Epoxy film was fabricated as follows:

An Epoxy film was deposited on a Glass substrate (thickness of 1.6 mm) using spin-coater. The thickness of resulting film was measured and evaluated at 100 μm thick, using a roughness meter.

2.2. Acoustic microscopy setup

- A scanning acoustic microscope (SAM) equipped with plane transducer at 200 MHz is used. The SAM is an industrial model PVA TEPLA SAM 301.
- Time-domain reflected echoes are recorded separately on a Glass substrate and on an Epoxy film.
- The frequency-domain analysis is performed using Fast Fourier Transform (FFT).

2.3. Characterization models

2.3.1. Transmission Line Model (TLM)

In a first approach, the TLM was implemented. This model is based on the recursive assimilation of the acoustic multilayer structure as a cascade of constitutive layers. Each of the quadrupole element is representing a fragment of electrical transmission line calculated by a (2×2) matrix. Each matrix represents acoustic wave proportion in that segment. The cascaded matrixes are multiplied by each other, in bottom-up direction. The total acoustic impedances intercepted at top layer 1 is calculated as shown in equations (1) and (2), resulting in a global reflection coefficient $R_{1inTotal}$:

$$Z_{in} = \frac{A.Z_{out} + B}{C.Z_{out} + D} \quad (1)$$

$$R_{1inTotal} = \frac{Z_1 - Z_{in}}{Z_1 + Z_{in}} \quad (2)$$

2.3.2. Echoes Decomposition Method (EDM)

As an analysis tool, the total echo on the film is considered as a composition of the incident reference signal $s_{ref}(t)$ and an additional contribution resulting from the sum of an image of this reference echo but shifted and resized. This could be represented in terms of equation **Erreur ! Source du renvoi introuvable.** as follows:

$$\begin{cases} s_{Glass}(t) = A_{Glass} \cdot s_{ref}(t - \tau_{Glass}) \\ s_{Epo}(t) = K_1 \cdot s_{ref}(t - \tau_1) \end{cases} \quad (3)$$

A detailed analysis of possible values for the set of parameters $\{K_1, \tau_1\}$ is carried out and the resulting optimum values are discussed. The final set of $\{K_1, \tau_1\}$ parameters, gives an information on the acoustic impedance and velocity in the studied film denoted as $\{Z, C_L\}$, respectively. From this set of values, a writing of the plane wave propagation equation leads to deduce the thickness of the Epoxy film:

$$\begin{cases} s_{ref}(t) = \frac{Z_{Glass} - Z_{Water}}{Z_{Glass} + Z_{Water}} \cdot s_0(t - \tau_{Glass}) \\ s_{final}(t) = \frac{Z_{Epo} - Z_{Water}}{Z_{Epo} + Z_{Water}} \cdot s_{ref}(t - \tau_{Glass} + \tau_{Epo}) \end{cases} \quad (4)$$

As a result, we get:

$$\begin{cases} K_1 = \frac{Z_{Epo} - Z_{Water}}{Z_{Epo} + Z_{Water}} \cdot \frac{Z_{Glass} + Z_{Water}}{Z_{Glass} - Z_{Water}} \\ \tau_{Epo} = \frac{2d_{Epo}}{c_{Water}} \end{cases} \quad (5)$$

We deduce the following properties:

$$\begin{cases} Z_{Epo} = Z_{Water} \cdot \frac{1 + K_1 \cdot \frac{Z_{Glass} - Z_{Water}}{Z_{Glass} + Z_{Water}}}{1 + K_1 \cdot \frac{Z_{Glass} - Z_{Water}}{Z_{Glass} + Z_{Water}}} \\ d_{Epo} = \frac{C_{Water} \tau_{Epo}}{2} \end{cases} \quad (6)$$

3. Experimental results

3.1. Echoes of interest

On the basis of the roundtrip echoes obtained on the Glass substrate by itself, the acoustic properties of the substrate have been identified. The echo of interest is having a duration of 45 ns. As a reference echo, the echo from the upper face of the Glass substrate is illustrated in Fig. 1.

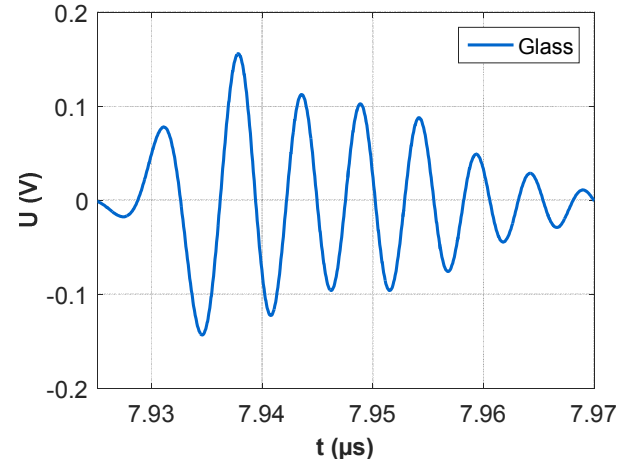


Fig. 1 : Echo on the Glass substrate.

Additionally, the echo on the Epoxy film is shown in Fig. 2. It could be seen that this echo is arriving earlier than that from the Glass. This time-of-flight τ_{Epo} (equation (5) and 6)) gives an estimate of the thickness of the Epoxy film.

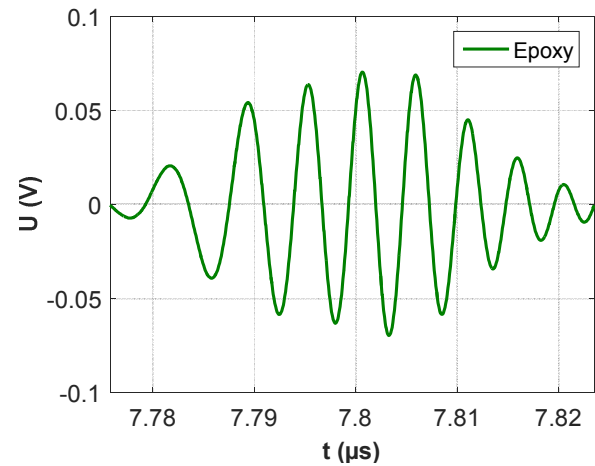


Fig. 2 : Echo on Epoxy film.

3.2. Echoes analysis

As a result of the echoes adjustment illustrated in Fig. 3, the final set of $\{K_1, \tau_1\}$ parameters gives an information on the acoustic impedance and velocity in the studied film denoted as $\{Z_{Epo}, C_{Epo}\}$, respectively.

$$\begin{cases} K_1 = 0.302 \\ \tau_1 = 148.68 \text{ ns} \end{cases} \quad (7)$$

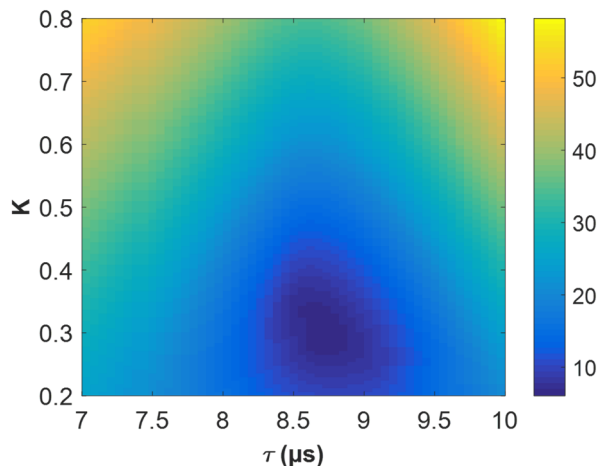


Fig. 3 : Test of possible values for the $\{K_1, \tau_1\}$ parameters.

From the final set of $\{K_1, \tau_1\}$ parameters, the following properties of the Epoxy film are deduced:

$$\begin{cases} Z_{Epo} \approx 2.56 \text{ MRa} \\ d_{Epo} \approx 110 \text{ }\mu\text{m} \end{cases} \quad (8)$$

3.3. Roundtrip echo identification

As explained in section 2.3.2, the echo from the Epoxy film is considered to be composed of the 1st reflection of incident signal plus the contribution from the deposit, *i.e.* including an additional contribution $\{K_2, \tau_2\}$ from the deposit. As described in equations (3) to (5), the additional echo resulting from the deposit is mixed with the reference one, with the amplitude coefficient K_2 and time shift by the delay τ_2 . Then a range of possible combinations of $\{K_2, \tau_2\}$ parameters have been investigated to find the best match between the desired parts of echo, here in the tail of echo. From the $\{K_2, \tau_2\}$ parameters, the velocity parameter C_{Epo} can be deduced, and the $\{\rho_{Epo}, C_{Epo}\}$ set of acoustic properties can be deduced from the acoustic impedance $Z_{Epo} = \rho_{Epo} \cdot C_{Epo}$ in the studied film respectively.

As shown in Fig. 4, this adjustment is operated on the tail of the electroacoustic response the of the Epoxy film, where the contribution of the roundtrip echo in the Epoxy film is clearly observed. As a result, the time-of-flight in the Epoxy film can be evaluated from the processing of the difference between those Glass and Epoxy echoes. The time-of-flight for a roundtrip in the Epoxy film is estimated at $\tau_2 = 7.86 - 7.77 = 90$ ns, and the velocity in the Epoxy film can be deduced:

$$C_{Epo} = \frac{2d_{Epo}}{\tau_2} \approx 2445 \text{ m/s} \quad (9)$$

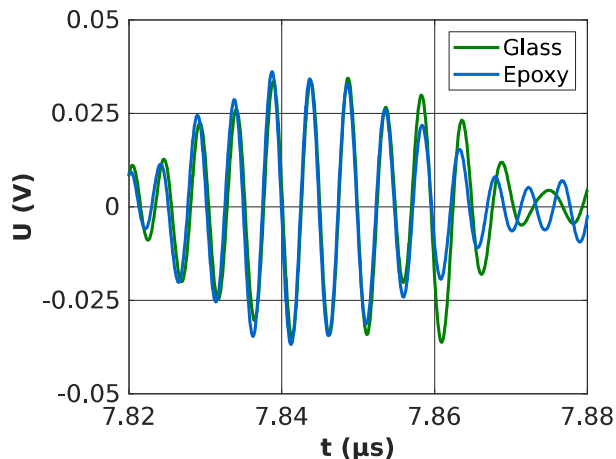


Fig. 4 : Superimposition of the tail echoes from the Glass substrate and from the Epoxy film

3.4. TLM methods

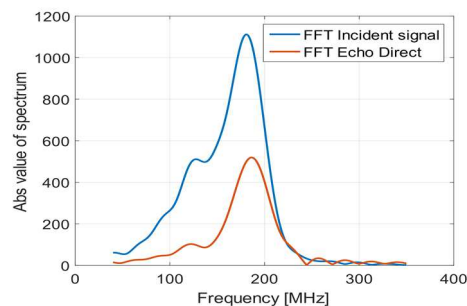


Fig. 5 : FFTs of incident signal (blue) and (b) FFT of echo on the Epoxy-Resin film.

The incident signal is estimated by dividing the FFT of the 1st reflection of the echo on the Glass substrate by the reflection coefficient of between water (coupling medium) and Glass substrate. Both FFTs of incident signal and 1st reflection of the echo on the Epoxy film are represented in Fig. 5.

A comparison between the echoes resulting from the Glass substrate by itself, and that obtained from the deposit on the Glass substrate are superimposed and compared.

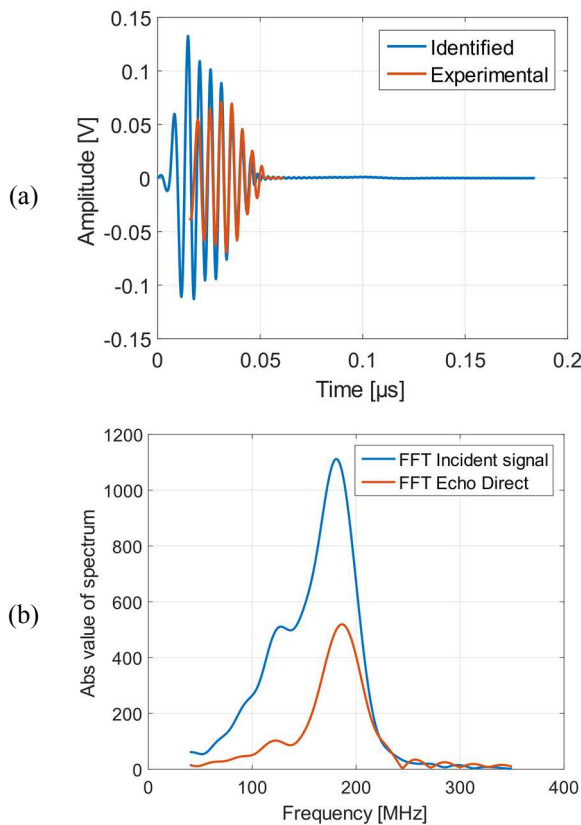


Fig. 6 : Reference substrate echo versus deposit-on-substrate (a) electroacoustic response and (b) associated spectrum.

By solving the inverse problem, involving the nonlinear fitting identification of the TLM parameters, the fitted electroacoustic response is obtained. The resulting fit to the experimental signal is illustrated in Fig. 6.

3.5. Comparison of characterization methods

The solving of inverse problem by identification as explained in sections 2.3 and 3.1, resulted in a set of viscoelastic parameters for the Epoxy resin that are summarized in Table 1. In an alternative approach, the electroacoustic decomposition method (EDM) resulted in the identification of the properties of the Epoxy film, *i.e.* its thickness d_{Epo} , acoustic impedance Z_{Epo} , wave velocity C_{Epo} and density ρ_{Epo} . Those results are reported in Table 1. Although the velocities are close to each other but the densities show higher differences.

Table 1 : Identified Epoxy film parameters

Identification method	C_L [m/s]	ρ [kg/m ³]	α_0 [Np/(m.MHz)]
TLM	2473	1584	333.4
EDM	2445	1047	N.A.

4. Conclusion

The results highlight the efficiency of SAM using plane high frequency transducer in characterizing thin viscoelastic layers. The TLM at 200 MHz provides precise parameter estimation, whereas signal decomposition method allows for effective characterization with different error margins. Future work will explore optimization techniques for enhancing model accuracy.

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