Development of a differential photoacoustic system for the determination of the effective permeability coefficient

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Background – Photoacoustic (PA) is a technique that has been applied to different fields in materials science to study their electronic and thermal properties, [1] the determination of thermal diffusivity of metals, process monitoring, food science, and water vapor permeability. Changes in PA signal (PAS) can be produced by different physical or chemical processes such as water vapor permeability and the in-situ monitoring of electrochemical reactions, among others. In PA developments, the influence of electronic components for transducing the signal and the effect of the geometry cell was not considered. Water permeability in ceramics,[2] water-diffusion in hydrogels,[3] and a model of the relaxation process depending on water-vapor applied have been studied using a single PAC cell. Non-instrumental function considerations in these works included the instrumental noise when the signal is processed, so that their calculations lack the physical sense since the noise is too high compared with the real sample measurement. As an alternative to avoid the noise in the real measurements, progress in the implementation of new PA systems has been made. Differential PA (DPC) systems are the arrangement most used for removing the noise of the real response.

The aimed work was to develop a Differential Photoacoustic Cell to determine the effective permeability coefficient in office paper film and polystyrene thin film, studying the signal changes within the PAC in relation to the amount of vapor that passes through the thin films and the pressure changes in the cell. The use of a differential cell is to do accuracy the results of the permeability coefficient. The implementation of the second cell has the function of measuring the instrumental contribution and calibrating the instrumental components and comparing the DPC and the reported permeability coefficient in the literature.

Methods – Electronic instrumentation filters out the signal to avoid noise produced by stray frequencies; nevertheless, the total signal measured is composed of the instrumental response and the sample one. To eliminate the instrumental function of the measured signal to obtain the real signal sample is enough to divide the measured signal (given by cell 1) by the instrumental function signal (provided by cell 2). Eqs. (1) and (2) deliver the way to correct amplitude and phase of the real signal sample.

$$S_{sample} = S_m(t) \cdot F_i(t) \qquad \text{Eqn. 1}$$

$$\varphi_{sample} = \varphi_m(t) - \varphi_i(t) \qquad \text{Eqn. 2}$$

S_{sample} is the real sample PA signal, $S_m(t)$ corresponds to the PA signal measured, and $F_i(t)$ represents the instrumental function. φ_{sample} corresponds to sample PA signal phase, $\varphi_m(t)$ represents the PA signal measured phase, and $\varphi_i(t)$ is the instrumental PA signal phase.

Results – Figure 1(a) and 1(b) shows the measure PA amplitude and phase signals, respectively, as a function of the time for a paper foil to determine the effective water permeability coefficient. The PAS increase by the vapor diffusion through the sample changing the absorption coefficient. The PAS tends to stabilize for a long time because the vapor diffused in the confined gas saturates the sample. Phase signal of the sample decreases, indicating changes in the film owing to moisture content and radiation/matter interaction. Figure 1(c) and 1(d) corresponds to the measured PA amplitude and phase for cell 2 (aluminium foil) used as an instrumental function, because there is not water diffusion through it. Figure 1(e) and 1(f) shows the real sample amplitude and phase signals corrected using Eqs. (1) and (2).

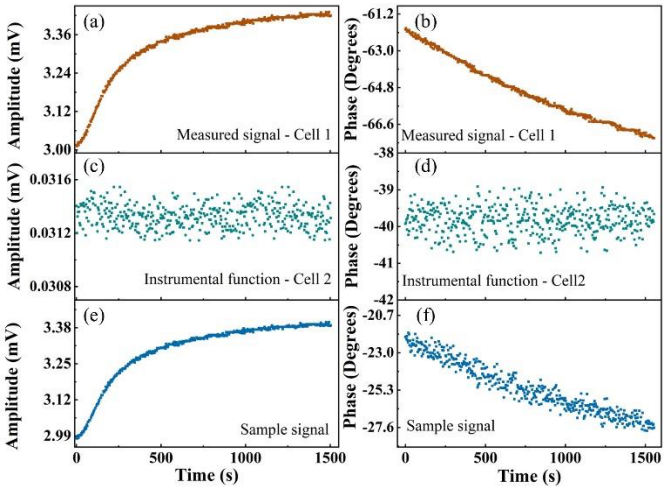

Fig. 1. (a) PA amplitude signal as a function of time. **(b)** PA phase signal as a function of the time. For aluminium as instrumental function: **(c)** PA amplitude signal as a function of the time. **(d)** PA phase signal as a function of time. **(e)** PA corrected amplitude signal as a function of time. **(f)** PA corrected phase signal as a function of time.

Figure 2(a) and (b) shows the office paper PAS. The water vapor diffusion time (τ_D) was determined. The red line corresponds to the best fitting for the PAS, and the black squares represent experimental data. τ_D value in paper was 332 s, and τ_D vapor diffusion time in polystyrene was 142 s. The permeability coefficient (Π) value using Eq. 8, for paper was 458×10^{-13} cm^{-2} s^{-1} Pa^{-1} and for polystyrene, Π value was 334×10^{-13} cm^{-2} s^{-1} Pa^{-1}.

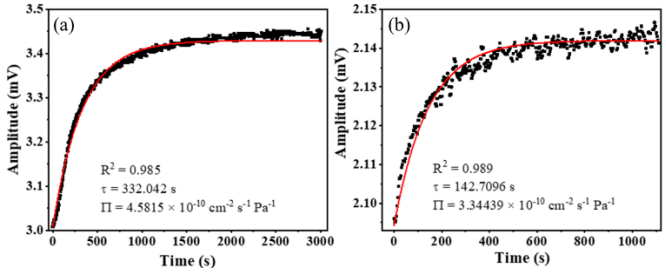

Fig. 2. (a) Office paper PAS

Conclusions – The methodology and metrology proposed in this work allowed to determine the effective water vapor permeability by the correction of the signal using a differential photoacoustic system. As perspectives stay to change the permeant atmosphere environment in the chamber with different gasses modifying the pressure. Electronic noise was reduced by effect of the instrumental function, geometry, and design of the PAC giving more accuracy values. Measured signal for the sample is composed by the instrumental function and the sample contribution, by correction measures have physical sense and it is important to consider the region work where RH is stabilized.

References

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