Development of models for the study of heat transport in ultra-thin layers by transient grating spectroscopy

Aguilar-Jimenez JA(1)*, Pech-May NW(2), Forereo-Sandoval IY(3), Alvarado-Gil JJ(1)

(1) Deparment of Applied physics, CINVESTAV Mérida, Yucatán, México
(2) Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany
(3) Institut Pprime, CNRS, Université de Poitiers, Futuroscope Chasseneuil, France

Corresponding author's email: arturo.aguilar@cinvestav.mx

Background – In Transient Grating Spectroscopy (TG), short laser pulses impinging on a sample, create a diffraction pattern on the surface. By analysing, the temporal decay of the temperature in the grating allows to analyse heat transport of the material. Previous studies have shown how thermal decays are sensitive to the grating period size for semi-infinite opaque materials [1,2]. In this work, the development of models to analyse the dynamical heat transport properties (thermal diffusivity and thermal effusivity) in opaque solid materials, using Transient Grating Spectroscopy, is presented. This approach allowed us to determine which thermal properties could be measured, using a specific configuration for thermal contrast, time scale, thermal properties of the layers, as well as grating period for multi-layered systems.

Methods – Heat transport equation for multi-layered systems were solved using appropriate boundary conditions and using the Fourier and Laplace transforms. As a result of complexity of the obtained solutions in Laplace space, the analysis of the temperature in time space was performed applying numerical algorithms to calculate the inverse Laplace transform of the solutions. Using this method, simulations of the thermal profiles in two and three-layer systems, were performed. The special case of glass, molybdenum, stainless steel, polyester-resin were considered.

Results and Conclusions – Figure 1 shows a simulation for two layer system with TG period of 25 μm and a first layer of 50 nm for materials with different themal diffusivities, polyester resin (left), stainless steel (center) and molybdenum (right). The parameter R12 represent the effusivities rate between the first and second layer given by the expression $R_{12} = (e_1 - e_2)/(e_1 + e_2)$. It is possible to observe as the thermal diffusivity of the first layer increases, the technique loses sensitivity in measuring smaller thicknesses, as in the case of molybdenum, where only the substrate is observed figure 1 (right).

Additionally, figure 2 (right) present a thermal decay for three-layer system of gold as a first layer, glass as a second layer and a substrate of stainless steel where it is possible to notice the system's sensitivity of the second layer for thermal diffusivity, where the peak of maximum sensitivity is at 10 ns in figure 2 (left).

Our results how the thickness of the illuminated layer and the kind of substrate affect the thermal decay signal giving us an idea of how the transient grating experiments should be performed to be able to reliably measure the thermal properties for ultrathin layer deposited on different kinds of substrates. It is important to emphasize how the technique is blind for materials with high thermal diffusivity. Therefore, these materials can be used as a coating for non-opaque materials and thus use the models shown in this work.

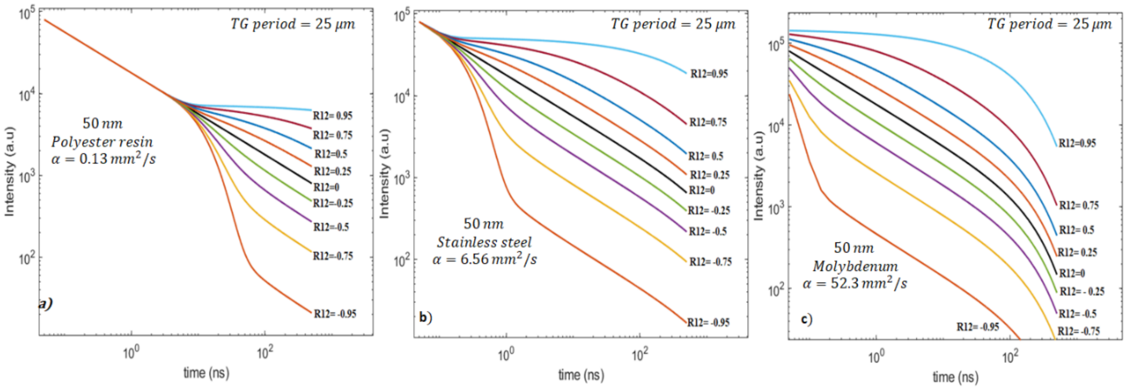

Fig. 1. Thermal decay for 50 nm of Polyester (left), Stainless steel (center) and Molybdenum (right). The parameter R21 goes from -1 to 1 showing the thermal contrast between the thin film and the substrate. Molybdenum is not visible for the technique.

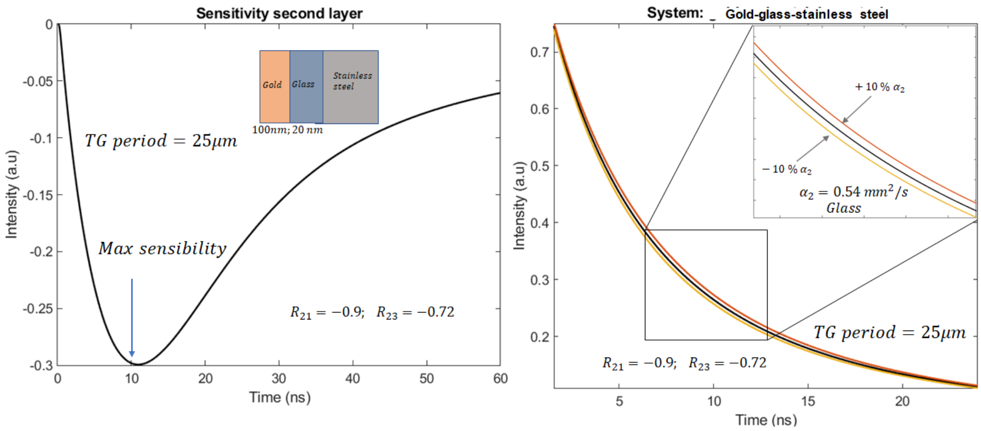

Fig. 2. Thermal decay of three layers system gold(100nm)-resin(20nm)-stainless steel, the first layer has no contribution and allows sensibility for the second layer (thermal diffusivity). (Left) shows the maximum peak of sensibility is between 50 and 100 ns.

References

[1] Vega-Flick et al., Thermal transport in suspended silicon membranes measured by laser-induced transient gratings, AIP Adv. 6:12 (2016) 1–23.

[2] J.A. Johnson et al., Phase-controlled, heterodyne laser-induced transient grating measurements of thermal transport properties in opaque material, J. Appl. Phys. 111:2 (2012).