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

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Introduction

Transient grating spectroscopy TG is a non-destructive, non-invasive technique that is suitable for studying transport in very thin films. A material is illuminated with very short pulses of laser light generating a thermal grating on material surface allowing the study of heat transport in the material. For thin layers the substrate could play an important role in the thermal transport. Therefore, it is necessary to develop models for TG in order to study multilayer systems and analyze the possibility of measuring this type of systems to determine the characteristics that they must fulfil in order to be sensitive to thermal changes and contrasts.

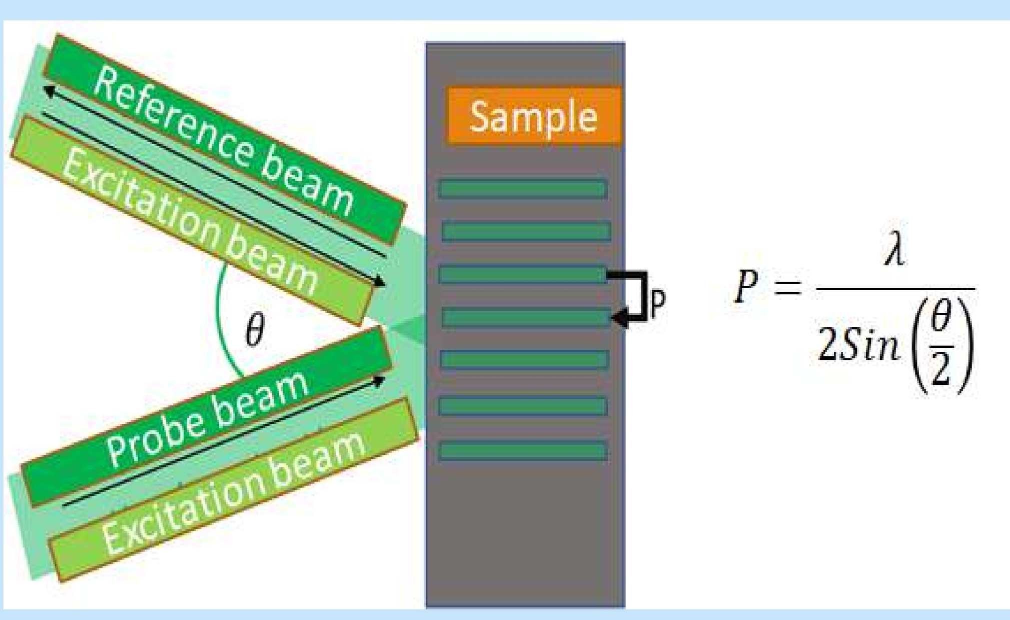


Figure 1. *Schematic of a transient grating on the surface of a sample. The green beams excite the sample generating a transient interference pattern.*

Objectives

- Develop mathematical models for the transient grating spectroscopy technique for multilayer systems for opaque samples.
- Establish the appropriate parameters for each type of system to be measured, taking into account the thermal properties and transient grating parameters

Metodology

Firstable we solved the heat equation in 2D on the Surface sample

$$(1) \qquad \alpha_x \frac{\partial^2 T_1}{\partial x^2} + \alpha_z \frac{\partial^2 T_1}{\partial z^2} = \frac{\partial T_1}{\partial t}$$

Initial conditions:

$$T_1(x,z,0) = \frac{Q}{\rho c} Cos(qx)\theta(z)$$

q:wave vector
Q:Heat given by the laser pulse

To find $\theta(z)$ we solve for single-layer, finite, semi-infinite and two-layer (finite-semi-infinite and two-layer finite and three layers systems) systems in Laplace space

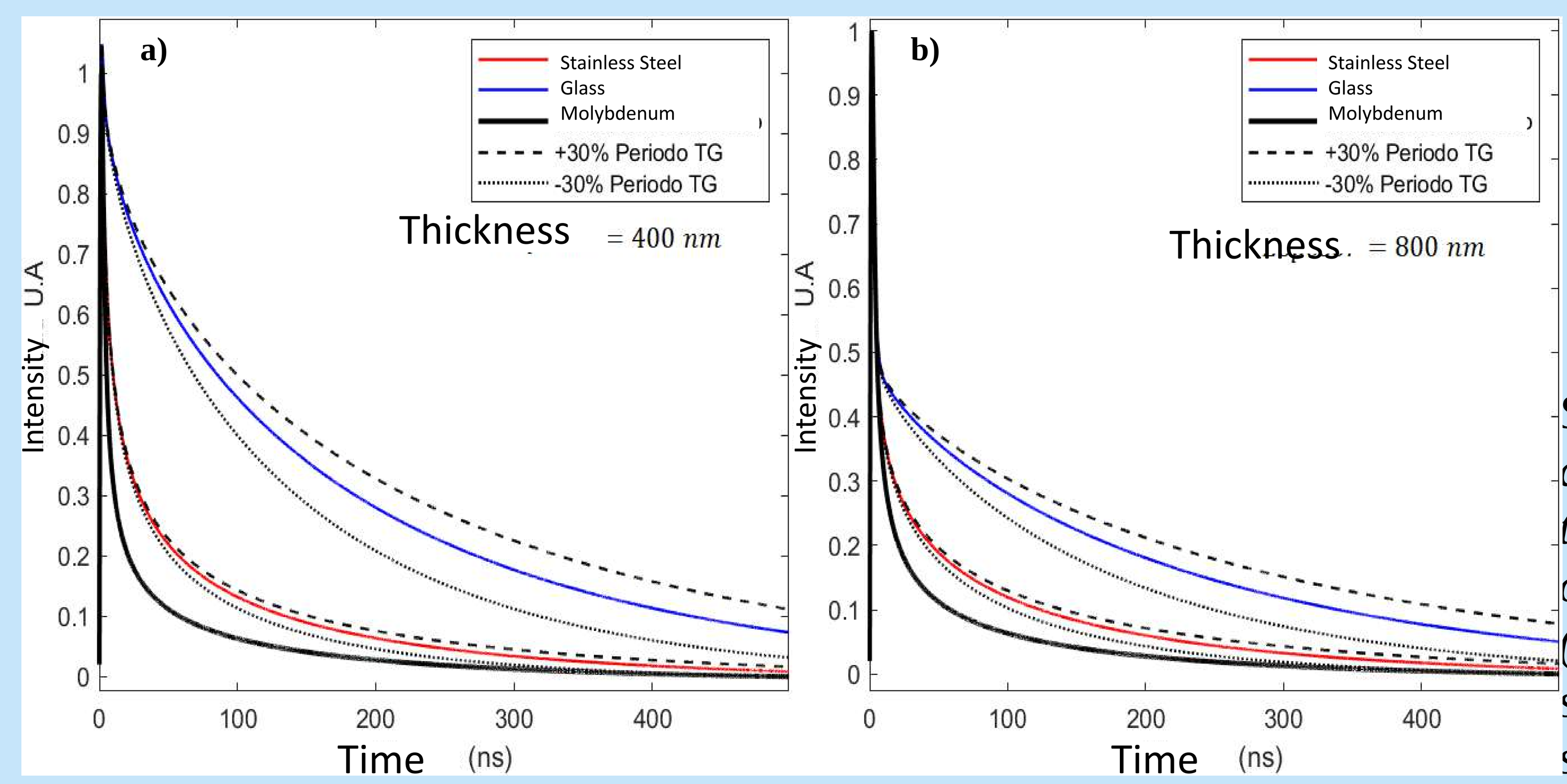
	Initial and and boundary conditions in real space	Initial and and boundary conditions in Laplace Space
(a)	$\theta_i(z,0) = 0$	
(b)	$-k_1 \frac{\partial \theta_1}{\partial z}\Big\|_{z=0} = \delta(t)$	$-k_1 \frac{\partial \tilde{\theta}_1}{\partial z}\Big\|_{z=0} = 1$
(c)	$-k_i \frac{\partial \theta_i}{\partial z}\Big\|_{z=L_i} = -k_{i+1} \frac{\partial \theta_{i+1}}{\partial z}\Big\|_{z=L_i}$	$-k_1 \frac{\partial \tilde{\theta}_1}{\partial z}\Big\|_{z=L_1} = -k_2 \frac{\partial \tilde{\theta}_2}{\partial z}\Big\|_{z=L_1}$
(d)	$\theta_i(z=L_i) = \theta_{i+1}(z=L_i)$	$\tilde{\theta}_i(z=L_i) = \tilde{\theta}_{i+1}(z=L_i)$
(e)	$-k_3 \frac{\partial \theta_3}{\partial z}\Big\|_{z=L_1+L_2+L_3} = 0$	$-k_3 \frac{\partial \tilde{\theta}_3}{\partial z}\Big\|_{z=L_1+L_2+L_3} = 0$

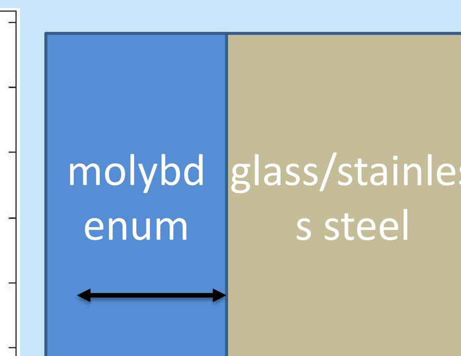
$$\tilde{\theta}_i(z,s) = A_i\, e^{q_i z} + B_i e^{-q_i z}$$

$$q_i = \sqrt{\frac{s}{\alpha_{z_i}}} \qquad i = 1,2,3$$

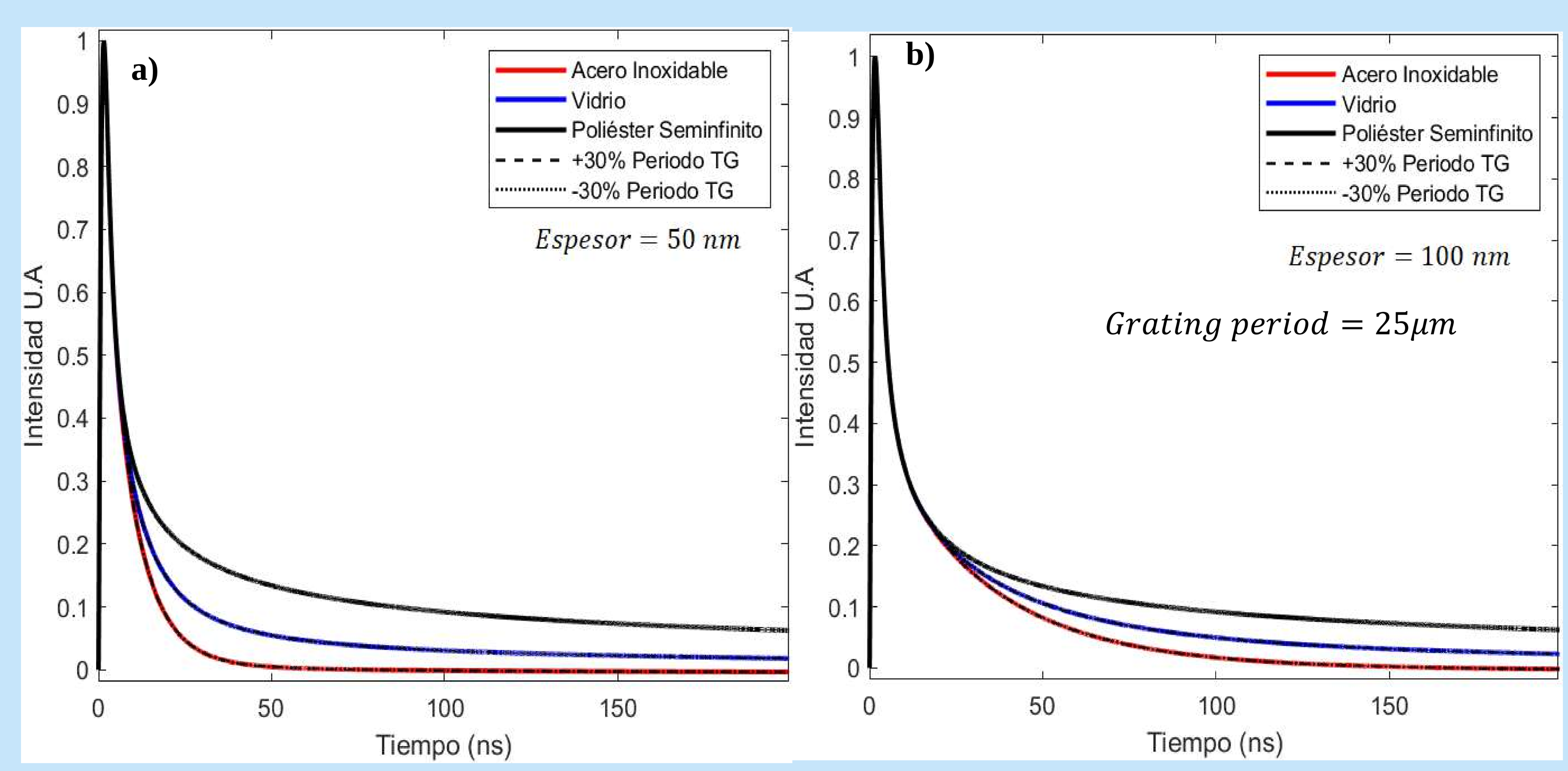
Results

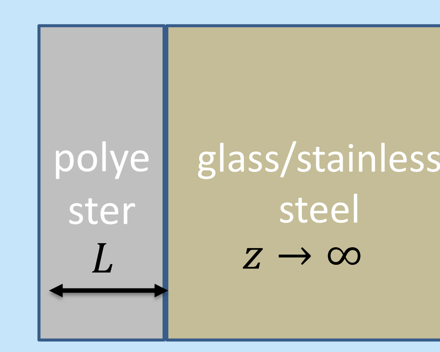
Two layers system. Finite-semi-infinite





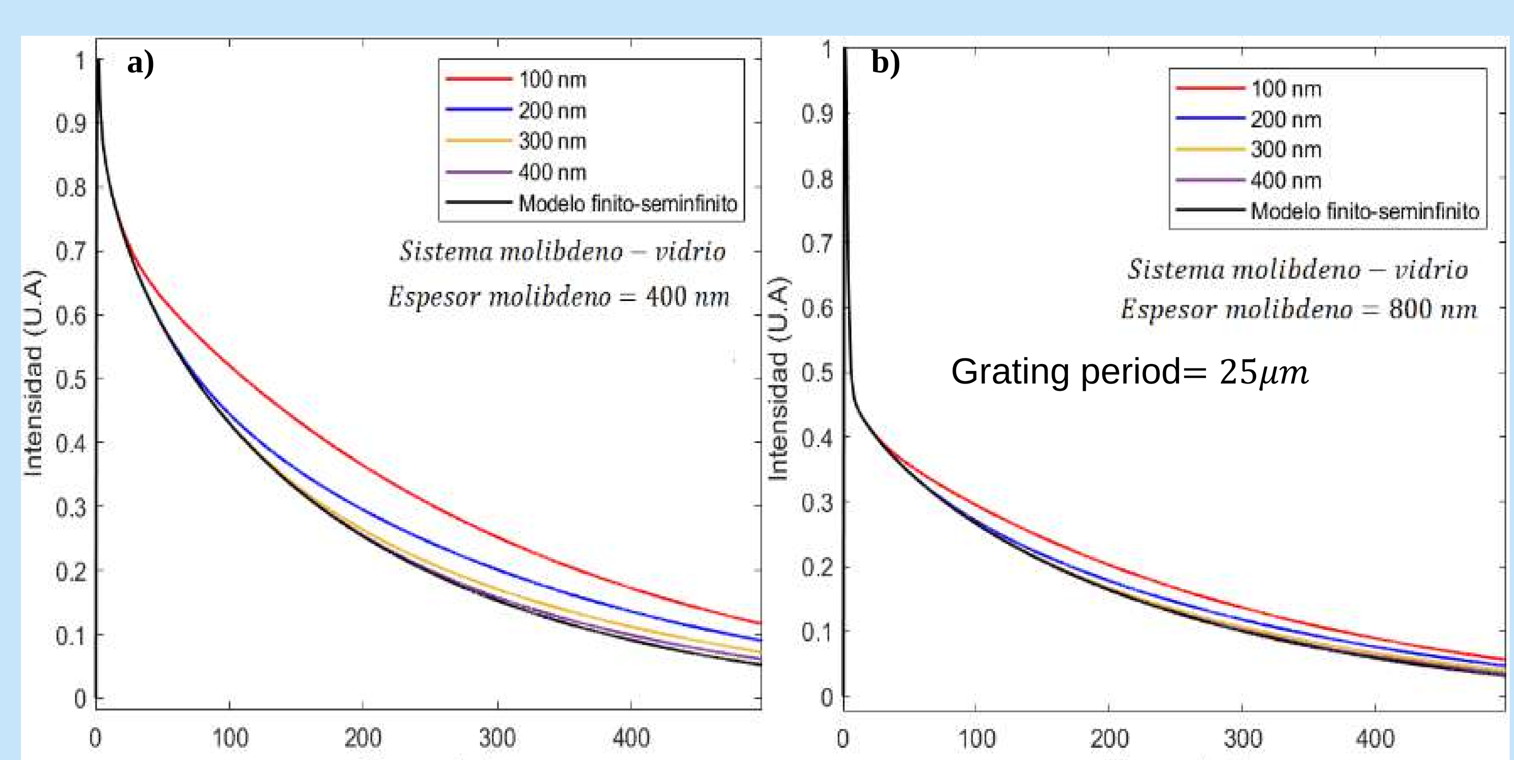
Simulation of thermal decay of a molybdenum thin film with thicknesses of 400 nm (a), 800 nm (b) using glass and stainless steel as substrates.

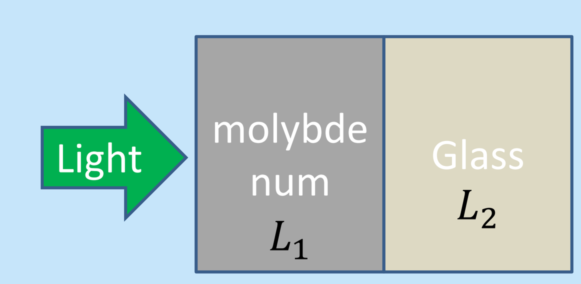




Simulation of the thermal decay of a polyester resin thin film with thicknesses of 50 nm (a), 100 nm (b) using glass and stainless steel as substrates.

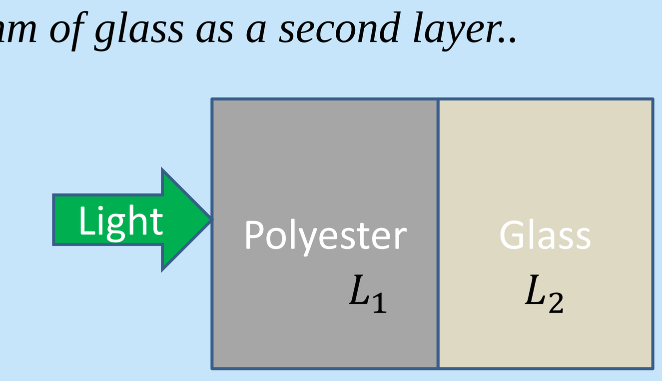
Two finite layers system

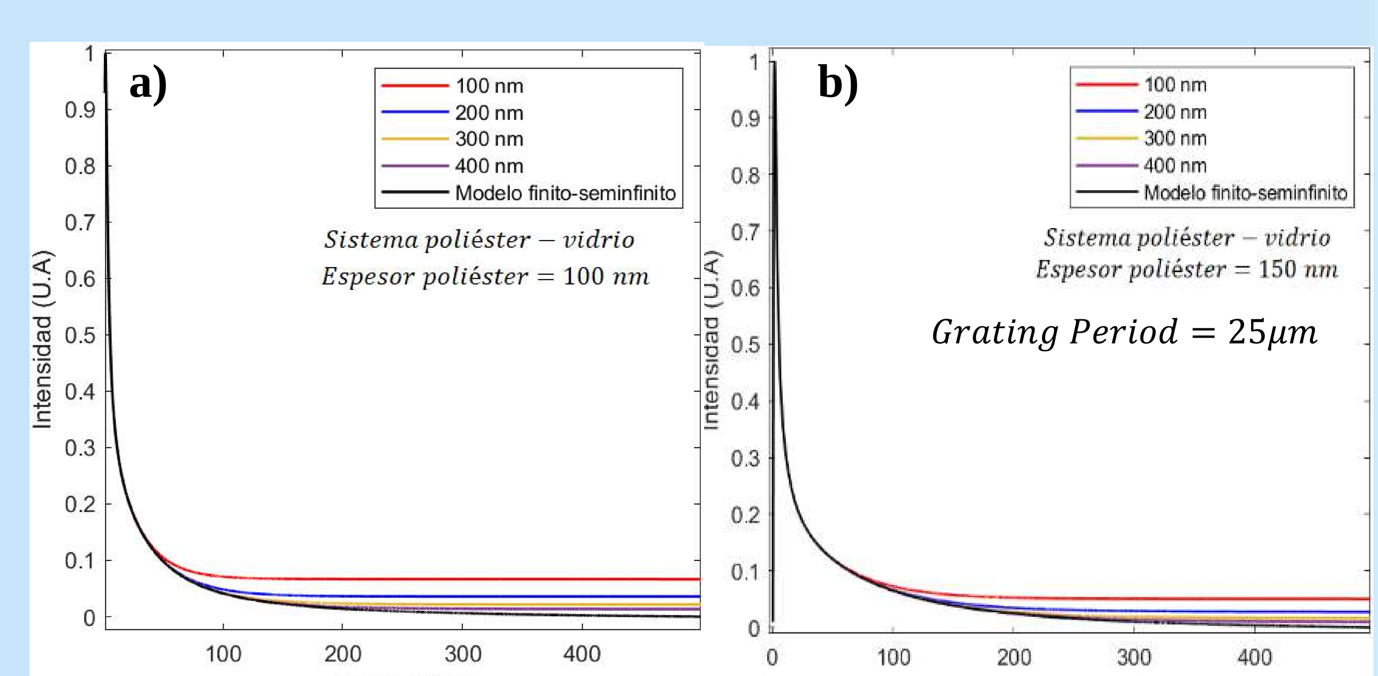




Simulation of the thermal decay signal of a finite molybdenum layer with thicknesses of 400 nm (a), 800 nm (b) with scanning thicknesses of 100, 200, 300, 400 nm of glass as a second layer.

Simulation of the thermal decay signal of a thin layer of polyester resin with thicknesses of 100 nm (a), 150 nm (b) with a scanning thickness of 100, 200, 300, 400 nm of glass as a second layer..





Conclusions

- Not all systems have the same sensitivity to changes in grating period; the sensitivity to this parameter depends strongly on the thermal properties of the material interacting with the laser pulse, which explains the higher sensitivity in molybdenum than in polyester resin. For ultrathin layers of the order of nanometres, there is an influence of the substrate on the thermal profile of the systems, which can allow us to perform a thermal contrast and to be able to measure both thermal effusivity and thermal diffusivity.