MEASURING THERMAL DIFFUSION AND SOUND VELOCITY INSIDE NIOBIUM THIN FILMS BY PUMP-PROBE SPECTROSCOPY

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WHAT WE LEARNED

1 **Time-domain thermoreflectance (TDTR) is a powerful technique for measuring the thermal diffusivity**

2 **Heat transfer studies in Niobium attract research interest due to the increasing demand in particle accelerator cavity.**

3 **Experimentally obtained thermal response is used in determining thermal diffusivity and sound velocity inside metallic films.**

BACKGROUND

- A Titanium: sapphire (Ti:Al2O3) femtosecond laser (wavelength = 800 nm, pulse width 110 fs, repetition rate 80 MHz) is used in developing an optical TDTR setup.
- Change in reflectivity due to change in temperature was recorded that contains information of material's diffusion ability.
- Thermal expansion generates acoustic waves of ultrasonic frequency.

OBJECTIVES

1. Thermal conductivity is measured by fitting the experimental data with the temperature profile derived from 1D heat diffusion model (TTM).
2. Using the period of acoustic oscillation, the longitudinal sound velocity inside niobium is determined.

METHODS

- Both free electrons and lattices contribute to thermal relaxation. The exchange of energy can be described by TTM:

$$C_e \frac{\partial T_e}{\partial t} = k_e \frac{\partial^2 T_e}{\partial x^2} - G(T_e - T_l) + S$$

$$S = I(t)A.\alpha.exp(-\alpha z)$$

$$C_l \frac{\partial T_l}{\partial t} = G(T_e - T_l)$$

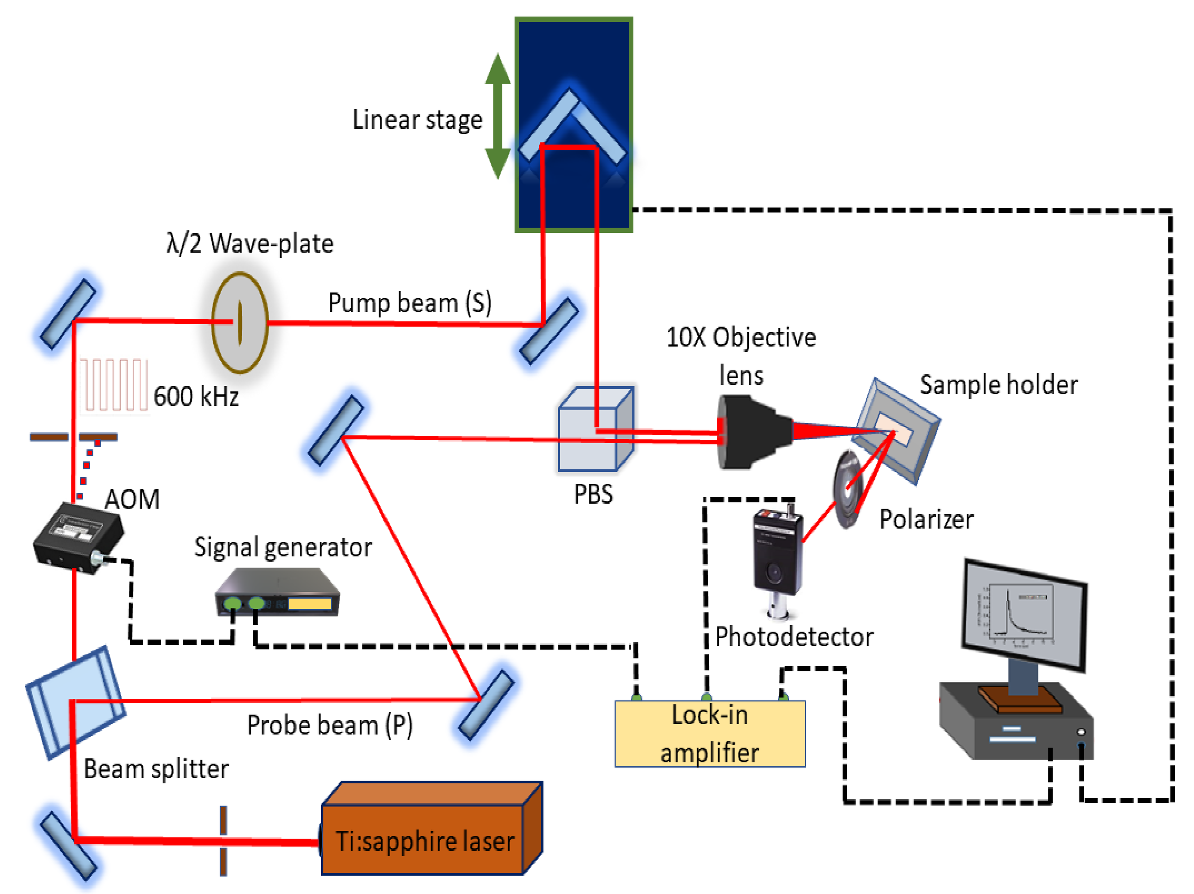
k_e = thermal conductivity (W/m K)
C_e= electron heat capacity (J/m^3 K)
C_i = lattice heat capacity (J/m^3 K)
T_e =electron effective temperature (K)
T_l = lattice effective temperature (K)
G =e-ph coupling coefficient (W/m^{3}K)
α = the optical penetration depth
z = film thickness (m)
$I(x,t)$ = pump laser intensity (Wm^{-2})

- Strain due to absorption of short pulse laser causes acoustic stress pulses that results in regularly spaced bumps on the TDTR scan.
- The period of the acoustic echoes varied linearly with the film thickness.
- Longitudinal component of sound velocity obtained from:

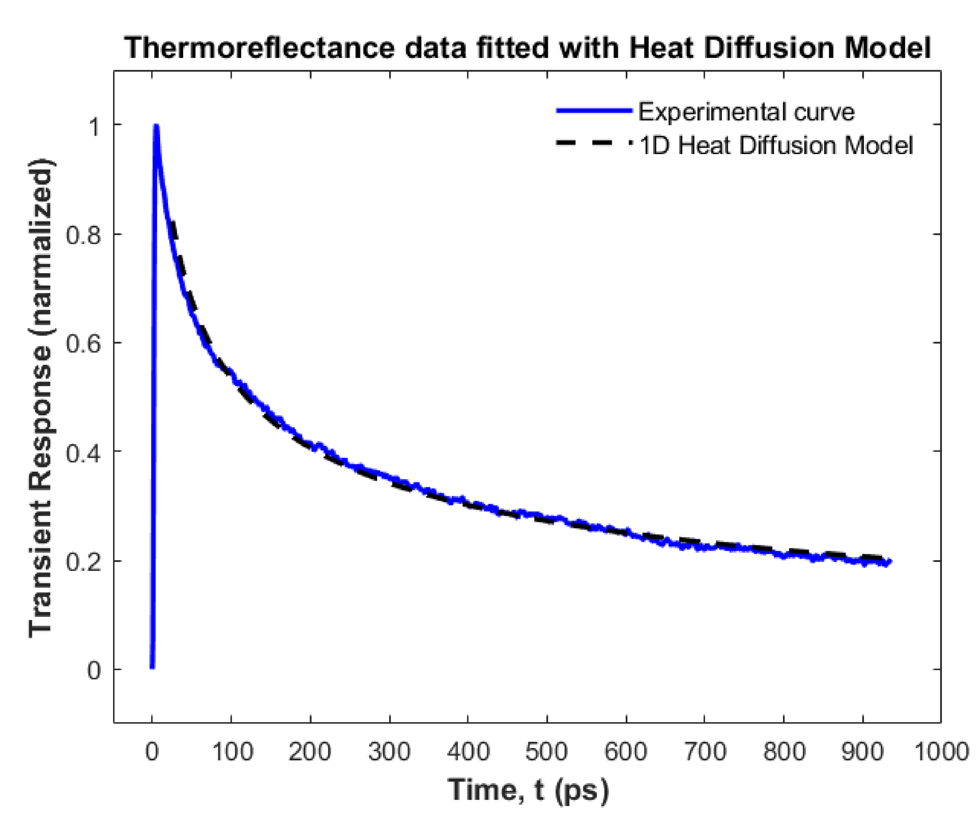
$$v = {}^{2d}/_{t}$$

here d is the film thickness and t is the measured period.

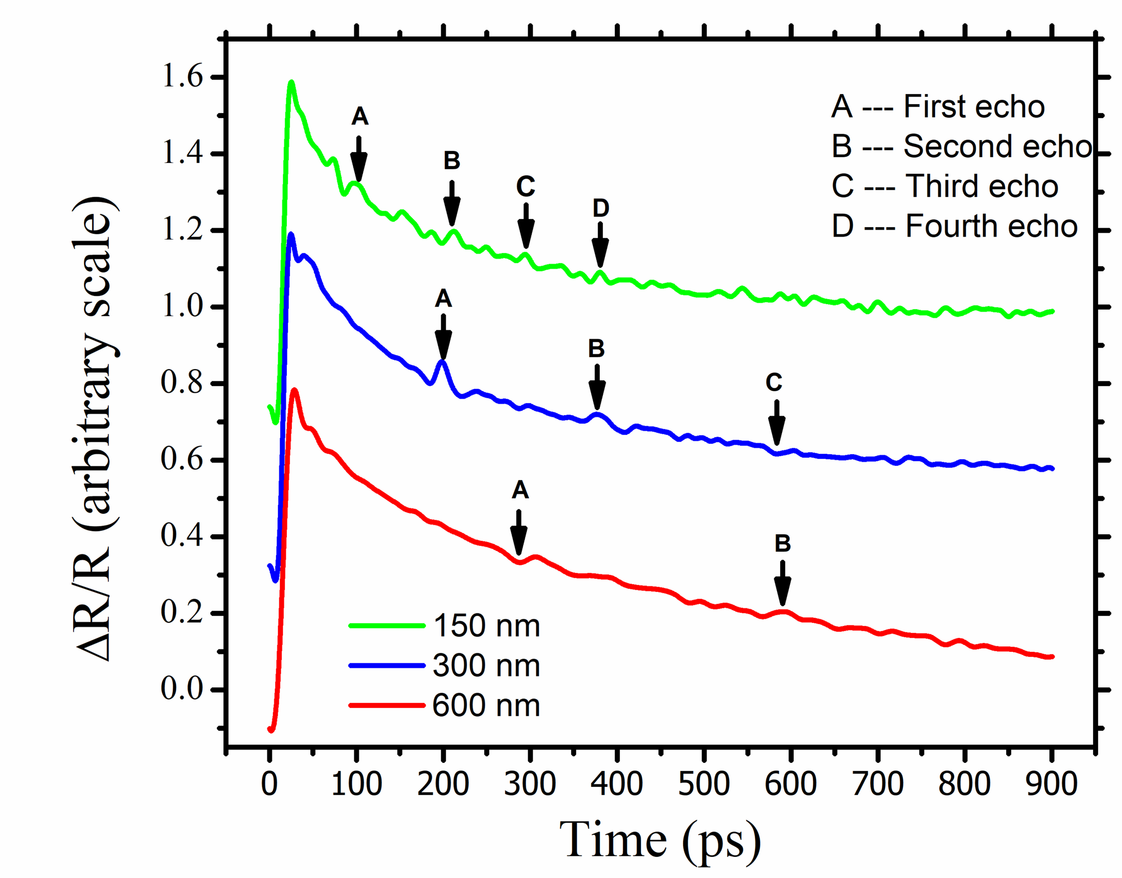
RESULTS



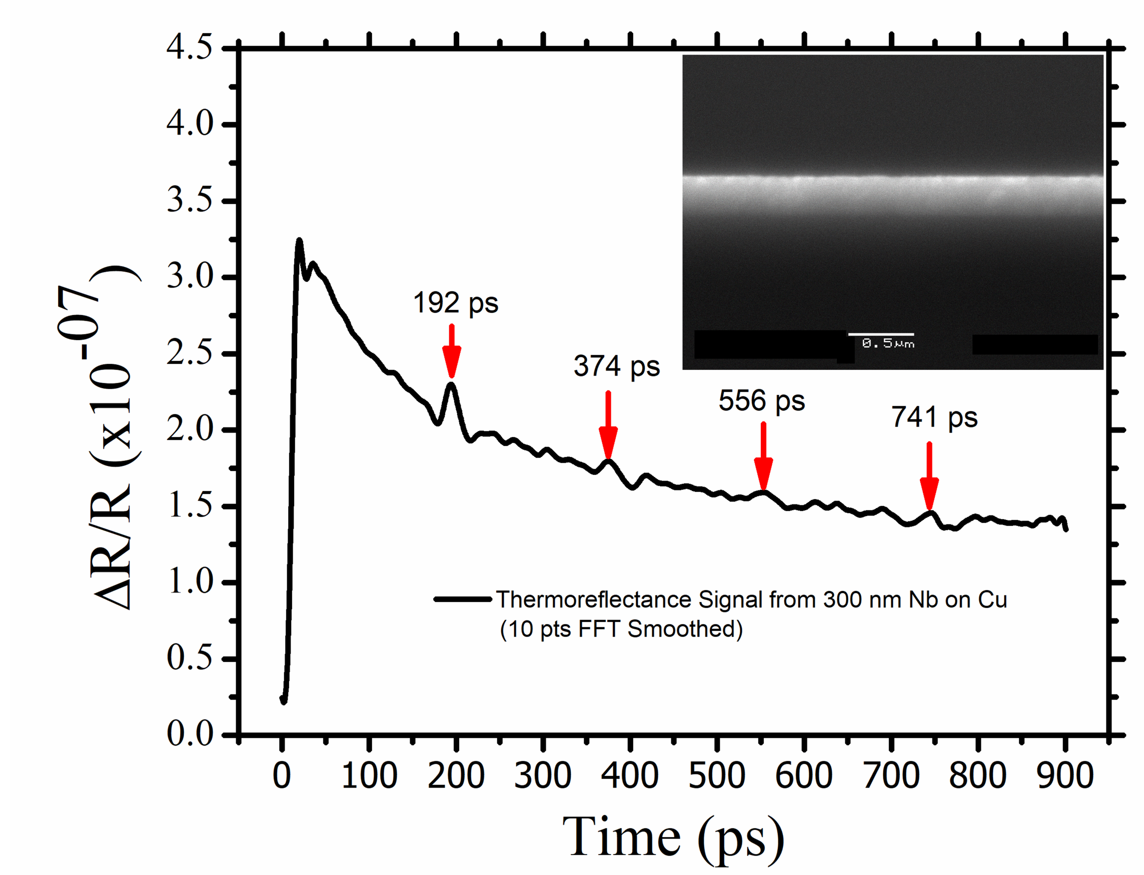
A Ti:sapphire laser releases ~110 fs pulses which are split into two beams at a ratio of 90:10. The AOM modulates the pump beam at 600 kHz. The linear stage sets the time delay between pump and probe beam. Lock-in amplifier measures the transient reflectivity changes.



Experimental TDTR scan fitted with TTM gives thermal conductivity of Nb (300 nm film) as $50.50 \pm 0.4\ Wm^{-1}K^{-1}$



Period of acoustic echoes increases as film thickness increases



For 300 nm film the period is measured as 182 ps. Using the measured value of period (t = 182 ps) and film thickness (d = 300 nm) the longitudinal sound velocity inside Nb is calculated as 3296.7 ms^{-1}. The inset is a cross-section SEM image of the film that confirms the thickness is about 300 nm.