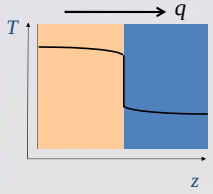
Interfacial Electron and Phonon Scattering Processes in High-Powered Nanoscale Applications

Sandia National Laboratories

Patrick E. Hopkins (Truman Fellow), Leslie M. Phinney (Mentor) & Daniel J. Rader (Manager)
Engineering Sciences Center (1500)
Microscale Sciences and Technologies (1513)

LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

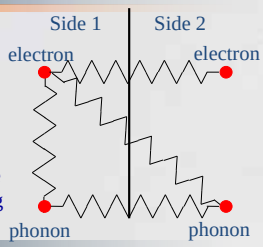
Problem



Thermal boundary conductance, h_K

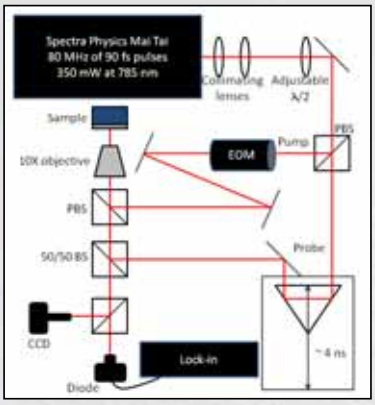
$$q = h_K \Delta T = \frac{1}{R_K} \Delta T$$

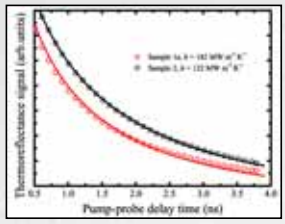
Change in material properties at interface gives rise to scattering events driving h_K

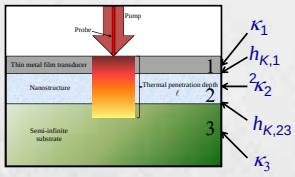


Approach

Time-domain thermoreflectance (TDTR) [1]



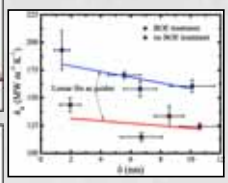




Results

Interfacial roughness and phonon scattering

Difference between "BOE" and "no BOE" samples is due to the native oxide layer on the Si substrate

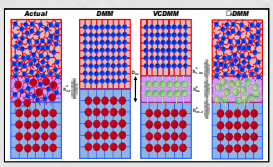


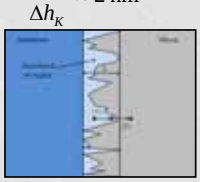
$$\frac{1}{\Delta h_K} \approx 1.74 \times 10^{-9} \text{ m}^2 \text{ K W}^{-1}$$

$$\kappa_{SiO_2} = 1.24 \text{ W m}^{-1}\text{K}^{-1}$$

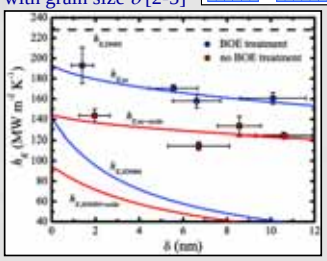
Native oxide layer thickness

$$d_{SiO_2} = \frac{\kappa_{SiO_2}}{\Delta h_K} \approx 2 \text{ nm}$$





Treat interfacial region as crystalline region with grain size δ [2-5]



$$h_{K,nc} = \left(h_{K,(1)}^{-1} + h_{K,(2)}^{-1}\right)^{-1}$$

$$h_{K,(1)} = h_{K,DMM}$$

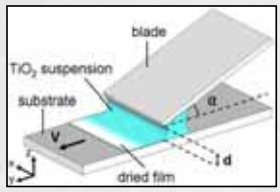
$$h_{K,(2)} = \frac{\kappa_{\text{disordered Al region}}}{\delta}$$

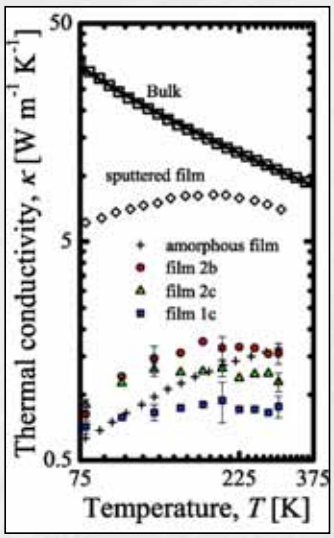
$$\kappa_{\text{disordered Al region}} \propto \left(\tau_{\text{Al gb}}^{-1} + \tau_{\text{Si mass}}^{-1}\right)^{-1}$$

Results (cont.)

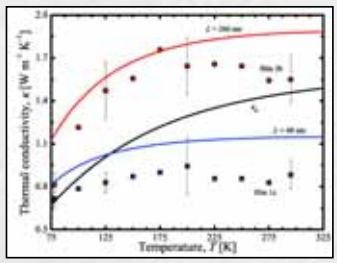
Tunable, ultralow thermal conductivity of TiO_2 crystalline, nanoparticle films

Electric field directed convective assembly [6]





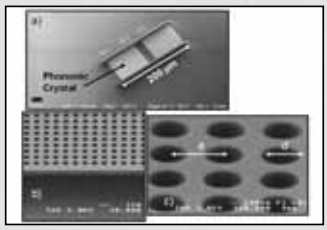
film 2b film 2c film 1c

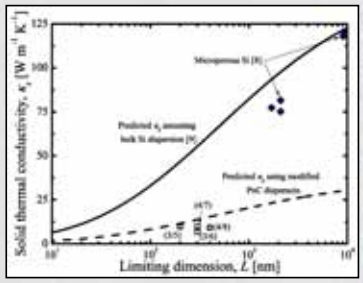


Phonon scattering at TiO_2 nanoparticle boundaries explains temperature trends and values of film thermal conductivity.

Reducing the thermal conductivity of Si through phononic crystal patterning

Phononic crystals are a unique method of controlling phonon dispersion [7].





Significance

Interfacial scattering can be used to control the thermal transport in nanosystems

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