Determination of Thermal Properties of GaAs Thin Film Semiconductor Devices

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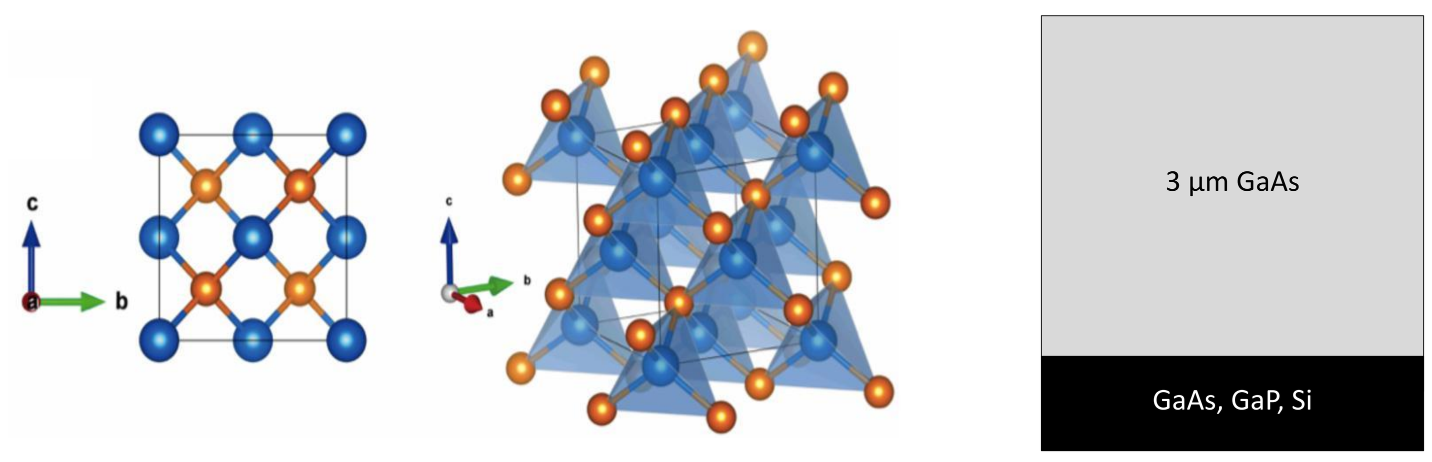
Introduction

In the filed of photonics, it is important to understand the effects of threading dislocations (TDs) and residual thermal stress on the heat dissipation of gallium arsenide, as this affects the efficiency of the photonic devices and their lifetime. Ordered multilayered structures of GaAs have been observed to have interesting and advantageous properties in fields like photonics and optoelectronics.

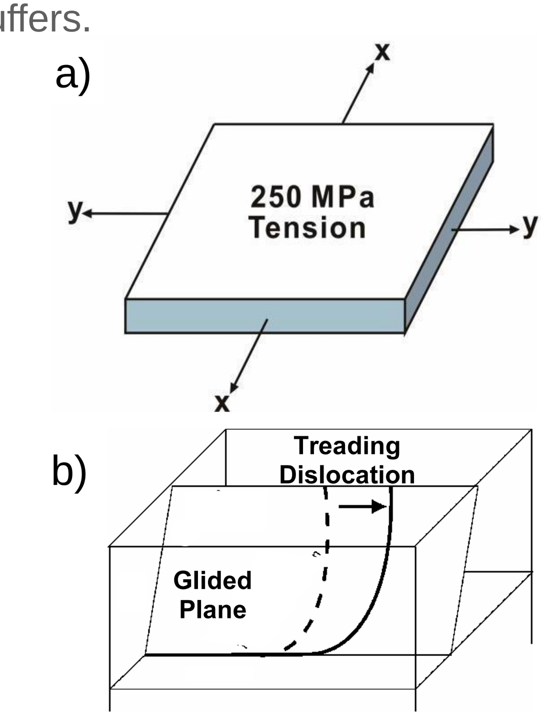
In this work, we execute a noncontact laser-induced transient thermal grating (TTG) technique to investigate properties like thermal conductivity and diffusivity of GaAs-based buffers.



GaAs atomic structure and GaAs based buffers.

Residual thermal stress arise when films are subjected to a temperature change that results in thermal expansion and imperfectly coherent interfaces with their substrates, due to a difference in the spacing of atoms.

It has been known that TDs can scatter phonons. When the unit cell of a crystal structure contains more than one atom, it will contain two types of phonons, acoustic and optical, with acoustic phonons being the main heat carrier.



Schematic of (a) in-plane biaxial tensile stress and (b) TDs

Methods – Transient Thermal Grating (TTG)

TTG is a technique used where two coherent laser pulses cross at an angle to make an interference pattern in a sample, producing spatially periodic material excitations pulses that give rise to thermal expansion.

The relaxation present is attributed to the thermal and acoustic response of the sample and is monitored through diffraction of a third laser beam. We control the spatial temperature profile by changing the period of the induced thermal grating, which in turn changes the thermal penetration depth probed by the laser.

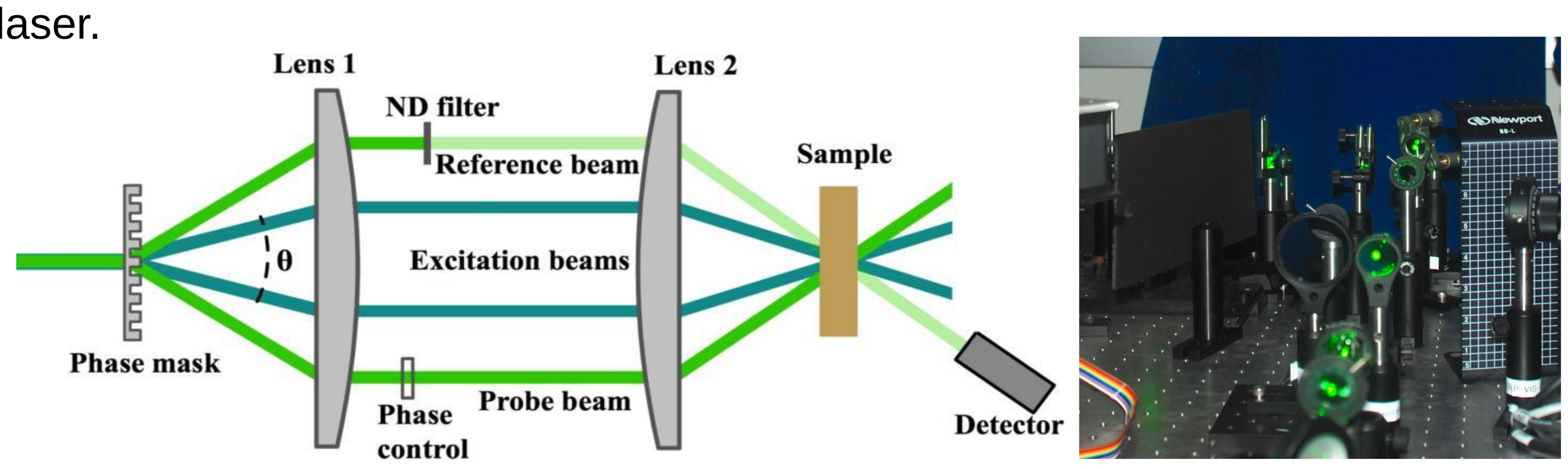
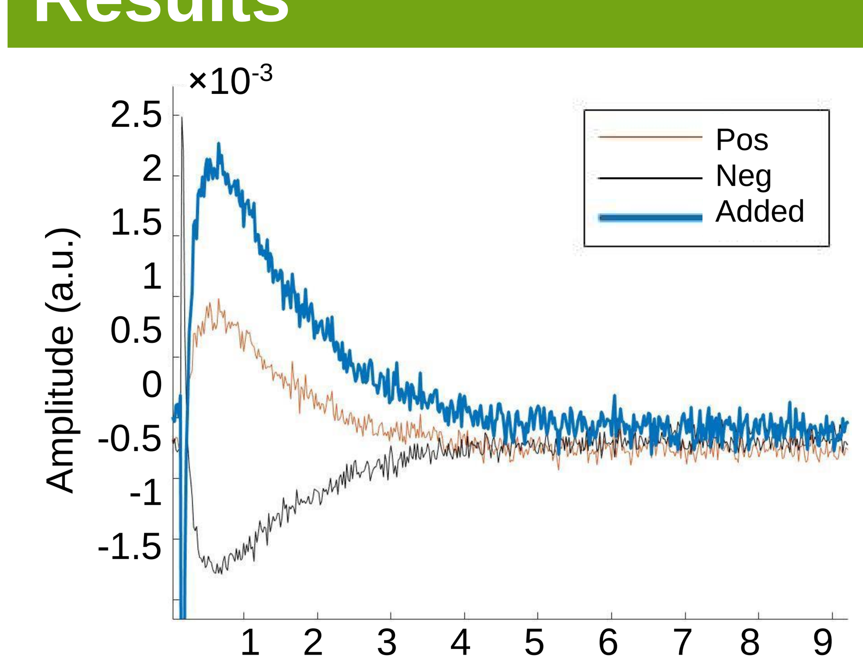


Diagram for TTG and lab setup.
Excitation Pump ~ (515nm) Probe + Reference ~ (532nm)

We measured GaAs films of 3 µm thickness grown on GaP and Si substrates with estimated in-plane biaxial stress of roughly 250 MPa. For TDDs analysis We measured three GaAs films of 3 µm thickness grown on Si substrates with different threading dislocation densities between 3×10^{6} dislocations/cm³ to 3×10^{9} dislocations/cm³ .

Results

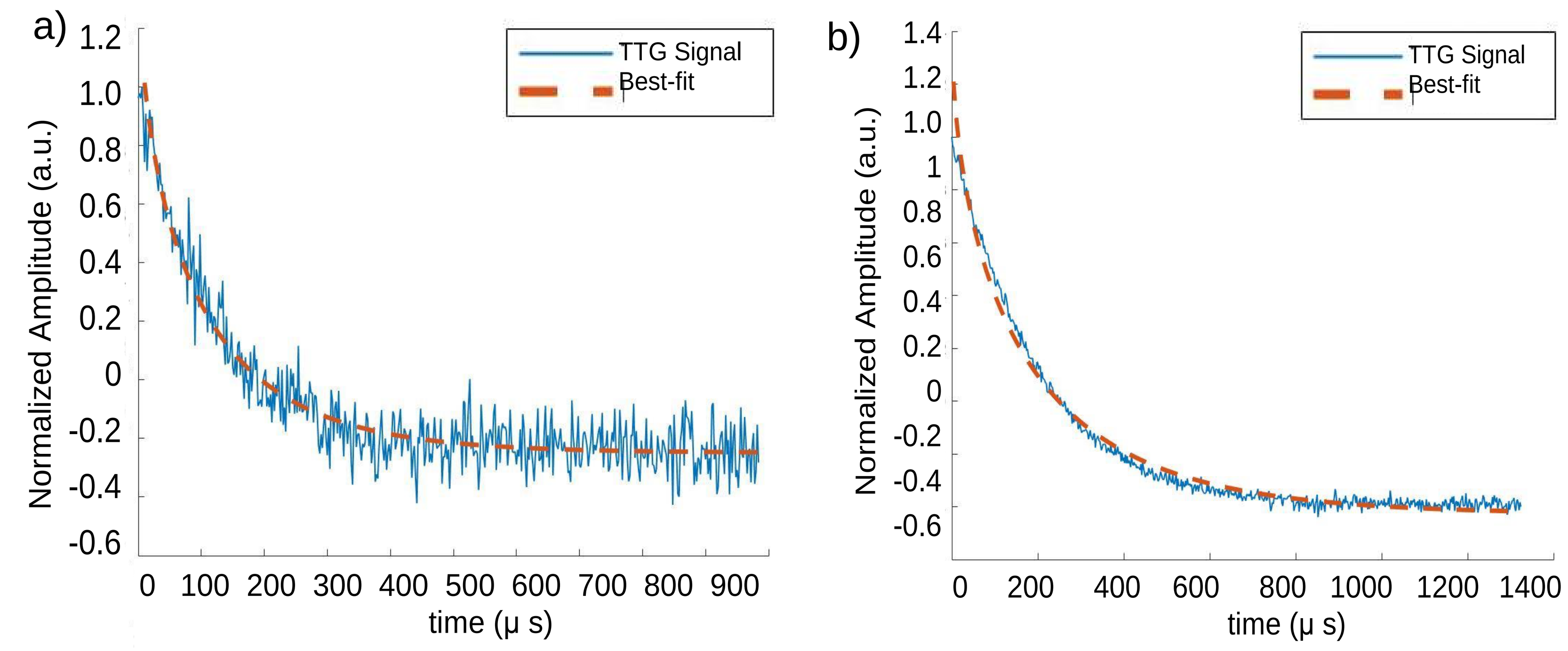


Plotted raw data

We must experimentally corroborate the increase of residual thermal stress and the increase of threading dislocation densities as main factors in the reduction of the thermal diffusivity.

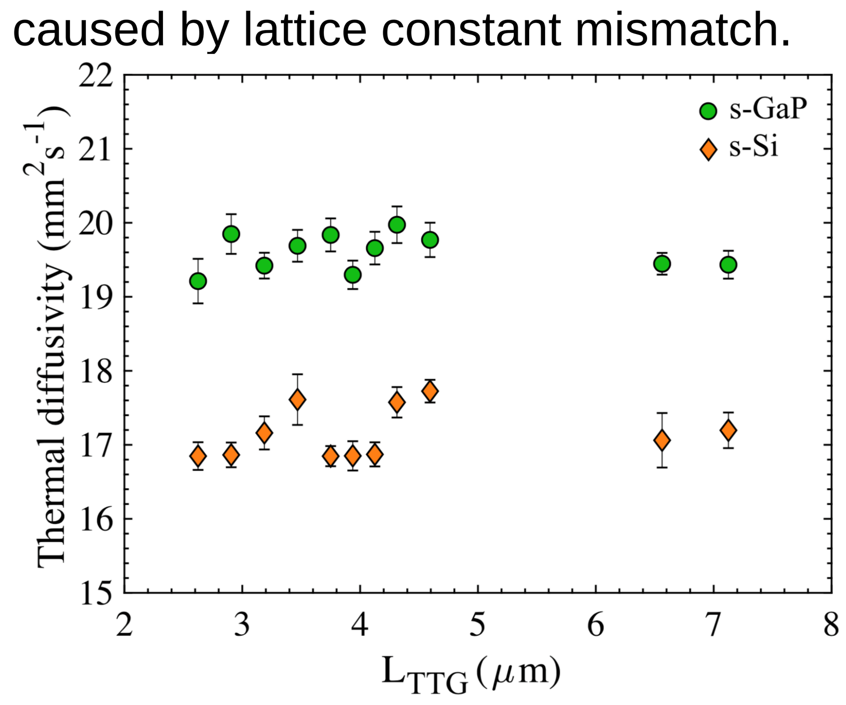
We add the two obtained relaxation times to reduce noise produced by the oscilloscope.

We analyze different grating periods ranging from 8.0 µm to 18.8 µm. The TTG time traces were normalized and analyzed using the complete solution to the thermo-elastic equation, we apply a best-fit with an error function.



Sample analysis for grating periods (a) 8.0 µm and (b) 18.8 µm

We plot results to make a relation between grating period and thermal diffusivity. Results showed that the obtained values are independent of the grating period. We observed a decrease on thermal diffusivity when growing on s-GaP compare to when growing on s-Si. This decrease in diffusivity is attributed to residual stress present in the GaAs layers in the s-Si samples, caused by lattice constant mismatch.



Obtained thermal diffusivity values as a function of the grating period

Sample	D (mm²/s)
s-GaP	19.6 ± 0.25
s-Si	17.1 ± 0.3
GaP	33.3 ± 1
Si	59.3 ± 0.8
GaAs	23.5 ± 0.3
GaAs(3 μm)/GaAs	18.7 ± 0.62
GaAs(3 μm)/GaP	18.5 ± 0.63

Thermal diffusivity values for substrates (First two rows) shown opposite behavior as literature values (Third and forth rows).

Conclusions

The multilayered structure dominates the thermal conductivity, the results indicate the absence of a substrate effect, and thus, we are effectively measuring the structure as a bulk semi-infinite material. Lattice constant mismatch results in residual stress in samples, which results in less efficient thermal transport.

Expected results for the analysis of TDs, attribute a decrease in thermal conductivity to an increase in phonon scattering due to a higher threading dislocation density.

These results indicate the importance of growing GaAs through rational design of applied residual thermal stress and with a significant reduction of TDD on device structures, all this to obtain a higher thermal conductivity and improve heat dissipation.

The significant reduction of the thermal conductivity of GaAs substrates on Si is detrimental to the heat dissipation capability of photonic devices, reducing the device lifetime.

TABLE II. Material properties used in the data analysis.

	GaAs	GaP	Si
α (K^{-1})[a]	5.7×10^{-6}	2.6×10^{-6}	4.7×10^{-6}
μ (GPa)[b]	32.4	62	39.2
ν[c]	0.31	0.27	0.31
ρ (kg m^{-3})[d]	5320	2329	4138
C (J/K)[e]	330	704	430

a) Thermal diffusivity, b) Shear modulus, c) Poisson's ratio, d) Density, e)Heat capacity

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