Pump-Probe Measurement of Coherent Phonons in Ge, GaAs, and MoS_2

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Abstract Using a pump-probe system the thermal, electrical, and optical properties of semiconductors including germanium (Ge), gallium arsenide (GaAs), and molybdenum disulfide (MoS_2) were explored. Phase and magnitude data was analyzed by fitting to simple mathematical models and results were compared to established material properties. The phase fit results in GaAs were used to yield a theoretical longitudinal sound velocity of 4755 m/s. Our analysis found that oscillation amplitude of the phase signal increased with pump power.

Pump-Probe Measurement

- We are able to generate coherent phonons in Ge, GaAs, and MoS_2 by using an ultrafast (<1 picosecond) laser.
- Using a pump-probe measurement system the reflectivity of our sample materials are modulated. Coherent phonons can be detected by monitoring a reflected or transmitted time-delayed probe light.

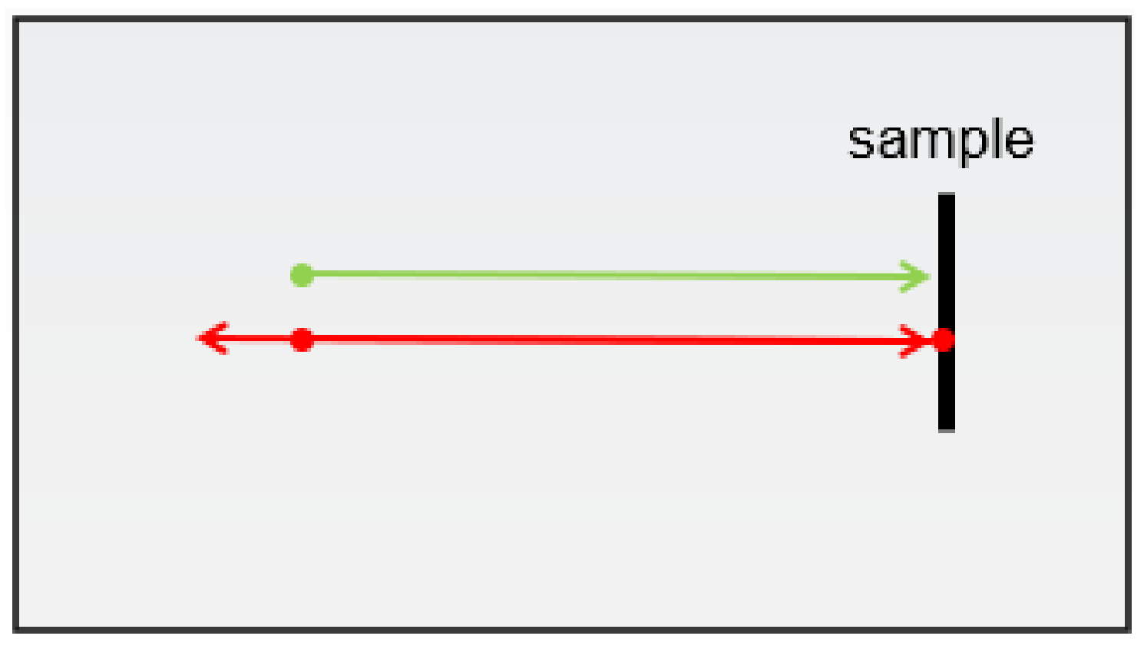

Fig. 1: A pump pulse (green) strikes the sample, a time delayed probe pulse (red) measures the temperature. Source: Sarah Warkander

- Using a lock-in amplifier the magnitude and phase are recorded.

Data Fitting

- The Coherent phonons generated by the pump-probe measurement system can be seen as a clear oscillatory signal.

$$A_0 + A_1 e^{\frac{-t}{\tau_1}} + A_2 e^{\frac{-t}{\tau_2}} \sin\left(\frac{2\pi t}{T} + \varphi\right)$$

A_0	Offset
A_1	Decay Amplitude
t	Delay Time
τ_1	Time Constant for Background
A_2	Oscillation Amplitude
τ_2	Time Constant for Oscillation Amplitude Decay
T	Oscillation Period
φ	Phase

Fig. 2: Fitting equation with variables

- Using a simple mathematical model we are able to fit these signals and generate fitting parameters.
- Here is an example of raw phase data with our fit model overlayed. During this research we were able to fit and analyze over 40 curves.

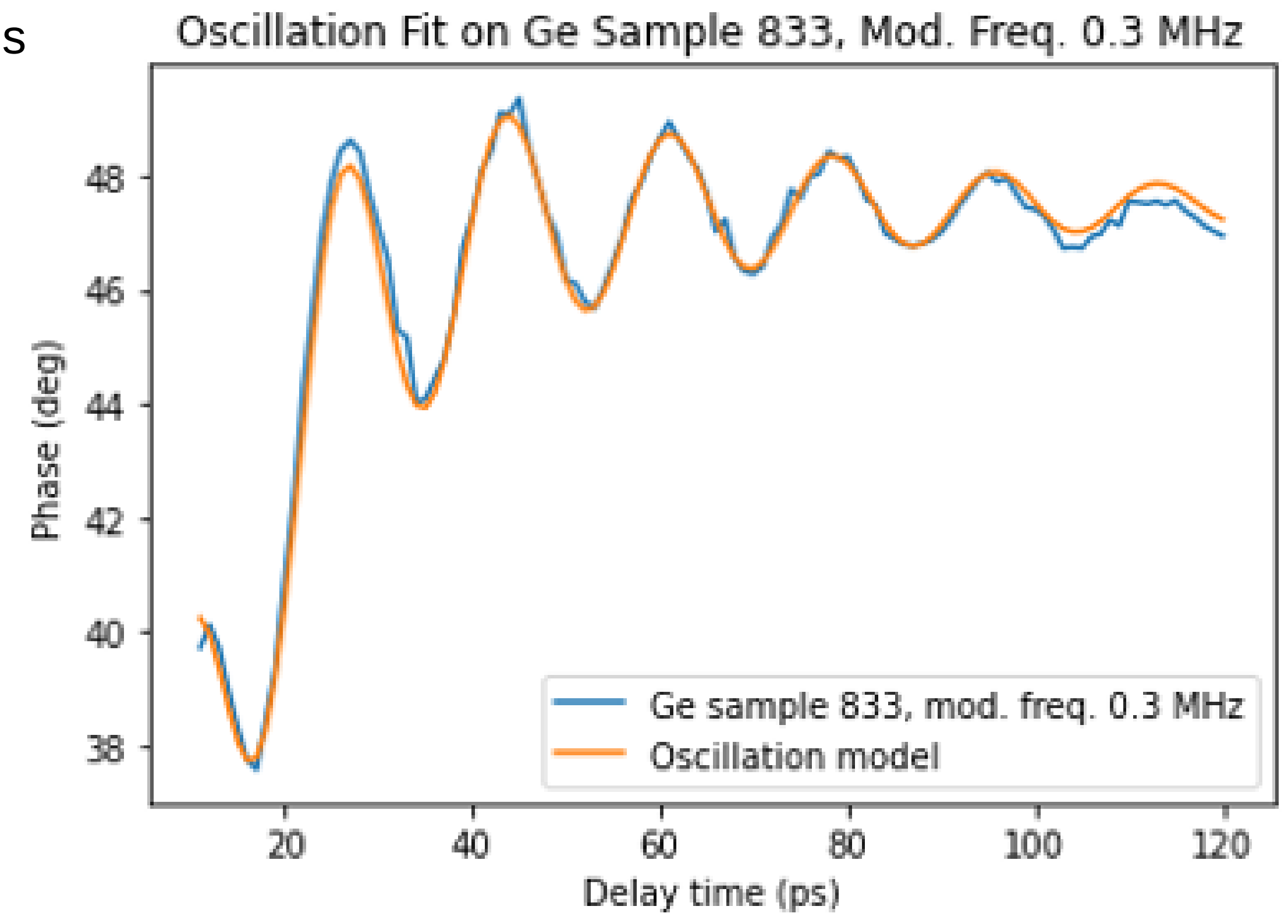

Fig. 3: Phase signal with our fit overlayed.

Trends in Fit Parameters

- Using Fig. 4 with our GaAs phase period of oscillation we found a theoretical longitudinal speed velocity of 4755 m/s.

	$v = \frac{\pi c_0}{\omega n T}$
v	Longituduinal Sound Velocity
c_0	Light Velocity in a Vacuum
ω	Light Frequency in a Vacuum
n	Refractive Index
T	Period of Oscillation

Fig. 4: Longitudinal sound velocity equation

	$k = \frac{c_0}{2\omega\tau v}$
k	Extinction Coefficient
c_0	Light Velocity in a Vacuum
ω	Light Frequency in a Vacuum
τ	Damping Time
v	Longituduinal Sound Velocity

Fig. 5: Extinction coefficient equation

- Using Fig. 5 with our GaAs phase damping time we found a theoretical extinction coefficient value of 0.227.
- As pump-power is increased in Ge, the oscillation amplitude of it's phase signal increases linearly.

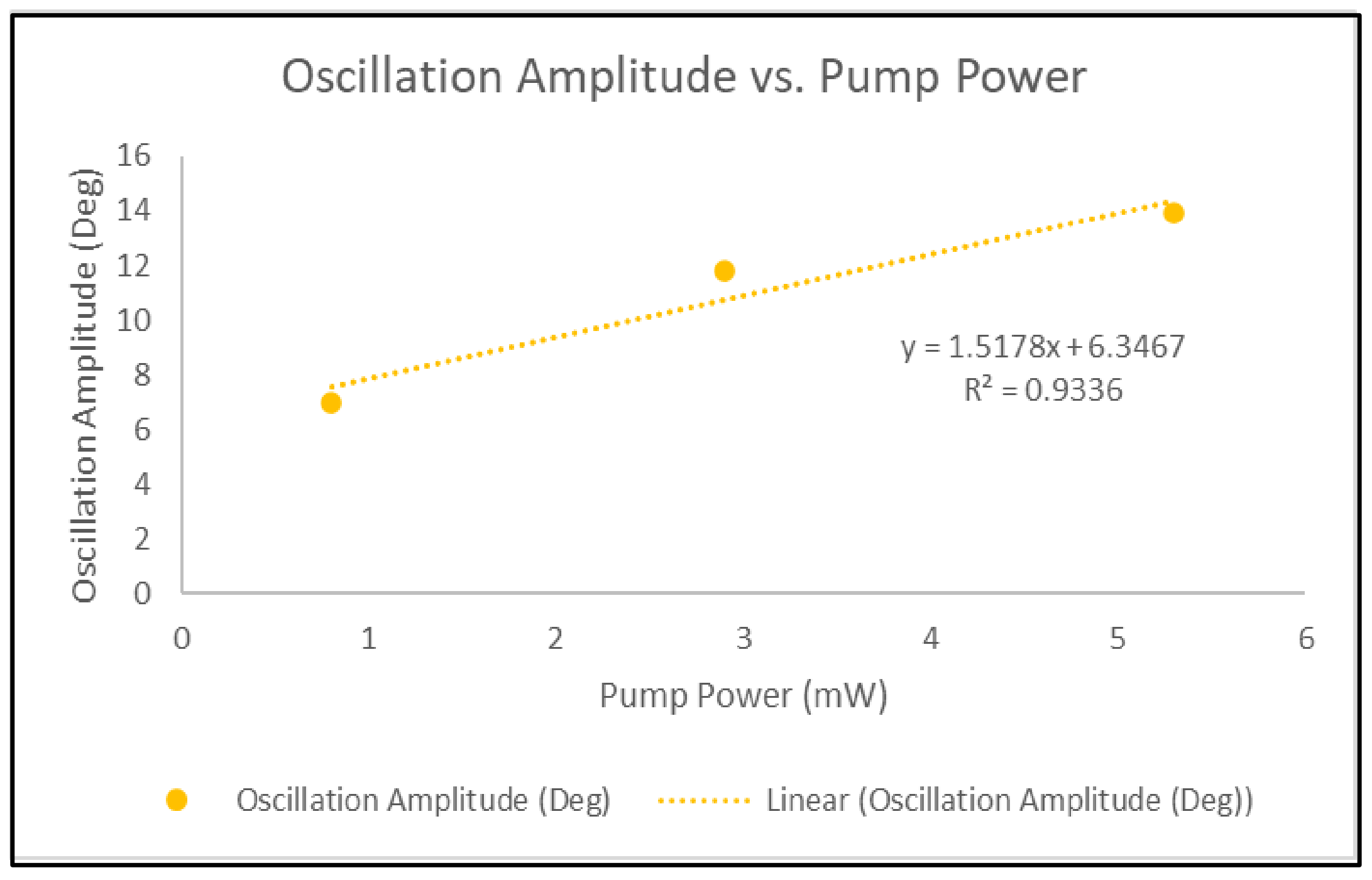

Fig. 6: Linear relationship between phase signal oscillation amplitude and pump power.

Conclusion

Using Phase and magnitude data of coherent phonons generated by a pump-probe measurement system we were able to Identify:

- The longitudinal speed of sound in GaAs, Ge, and MoS_2
- The extinction coefficient in Ge
- A pump-power vs. oscillation amplitude trend is observed

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