THE $C_{33}$ ELASTIC CONSTANT OF MoS$_2$ AS A FUNCTION OF PRESSURE AND
THE DEPOSITION OF MULTILAYER THIN FILMS BY SPUTTERING

BY

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THESIS

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ABSTRACT

The $c_{33}$ elastic constant of exfoliated MoS$_2$ flakes was measured up to 11 GPa using a diamond anvil cell and picosecond interferometry. The resulting elastic constants were similar those predicted by hybrid density functional theory calculations by Peelaers and Van de Walle, but lower than those calculated from lattice constant measurements by Fan. However, due to the failure of the Lorentz-Lorenz relationship between index of refraction $n$ and density, the change in $n$ was not compensated for. This means that the actual $c_{33}$ constants are lower than those that have been reported here.

A two source sputtering chamber for deposition of [Co,Pt] multilayer transducers for use in time-resolved magneto-optical Kerr effect (TR-MOKE) experiments is also discussed, along with the preliminary film and transducer characterization. Four-point probe measurements of the thin films indicated high resistivities corresponding to roughness or small grain size. A multilayer transducer was tested on a SiO$_2$ reference wafer and had a $d\theta_K/dT$ of the same order of magnitude as similar [Co,Pt] transducers.
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# TABLE OF CONTENTS

Chapter 1  Elastic Constant of MoS$_2$ Under High Pressure ...........................................  1  
  1.1  Introduction ...........................................................................................................  1  
  1.2  Methods ...............................................................................................................  2  
  1.3  Results and Discussion ......................................................................................  8  

Chapter 2  Two Source Sputtering Chamber .................................................................  12  
  2.1  Introduction ...........................................................................................................  12  
  2.2  Characterization of Films ..................................................................................  13  
  2.3  [Co,Pt] Multilayer ...............................................................................................  15  

References .....................................................................................................................  18
CHAPTER 1

ELASTIC CONSTANT OF MoS$_2$ UNDER HIGH PRESSURE

1.1 Introduction

Molybdenum disulfide (MoS$_2$) is a hexagonal layered material comprised of layers of Mo atoms covalently bonded between planes of S atoms. These S-Mo-S layers are weakly bound together by Van der Waals forces. It has long been understood to be a good lubricant due to this weak interlayer bonding[1], and has more recently has attracted attention for use in optoelectronic[2] and electronic applications[3, 4].

The mechanical and electrical properties of materials are known to change under pressure, which can be useful for tuning physical properties for different applications. There have been multiple theoretical and experimental studies investigating crystal and electronic structural changes[5, 6, 7]. One important property that has received less focus is the elastic behaviour of MoS$_2$.

The elastic constants for a material relate its deformation to the applied stress. This is important for understanding the mechanical behavior of a material[8] and the thermal transport. The number of independent elastic constants depend on the structure of the material. For material with hexagonal symmetry there are five independent elastic constants[9]. While there have been some measurements of the MoS$_2$'s elastic constants under ambient conditions[10, 11], there has been limited experimental work under pressure. Here I have measured the out of plane Young’s modulus $c_{33}$ using Brillouin scattering.

Feldman used neutron and x-ray scattering data to calculate the approximate elastic constants of MoS$_2$, and found $c_{33}$ to be 52 GPa[10]. More recently Zhao also measured $c_{33}$ as 52.0 GPa in few-trilayer MoS$_2$ using Raman spectroscopy[11].

From x-ray diffraction studies of the lattice constants it is known that the lattice constant $c$ is more compressible than $a$ and that it is most easily compressed when pressure is first applied, but as the interlayer spacing decreases and the atoms are forced into closer proximity the interaction strength increases and the rate of change with pressure decreases[5, 6]. The changes in the lattice constants lead to the expectation that the stiffness of the MoS$_2$ will rapidly increase. The hybrid density functional theory calculations by Peelaers predict an order of magnitude increase in $c_{33}$ over 40 GPa[12].
1.2 Methods

Diamond Anvil Cell and Sample Preparation

A diamond anvil cell (DAC) is a common tool for investigating the properties of materials at high pressures. There are several types of DACs, but they all have the same basic principle of operation[14]. A DAC holds two diamonds mounted so that their flat culets are aligned and parallel. To use it a soft metal gasket is first indented by the two parallel diamond faces. A hole drilled is drilled in the center of the gasket which is then placed back on the diamond face which acts as the bottom of the sample chamber formed by the hole. The sample and a pressure medium are placed in the chamber and the diamond faces are brought into contact with the gasket, deforming it, and sealing the chamber as shown in figure 1.1. The pressure medium is there to ensure that hydrostatic pressure is applied to the sample. The pressure in the chamber depends on the force $F$ applied and the area of the diamond culets $A$ as $P = F/A$. The force on the diamonds can be changed by adjusting the screws holding them together. In this manner it is easy to generate several GPa of pressure in the chamber of the DAC.

One of the advantages of using diamonds is that they are transparent in the visual, infrared, ultraviolet, and x-ray regions of the electromagnetic spectrum, which allows a great number spectroscopic techniques to be performed in situ on a sample inside a DAC, including X-ray diffraction, Brillouin scattering, and Raman scattering.

I used a Boehler-Almax Plate DAC with diamond culets of 400 µm with 0.01 inch thick rhenium gaskets from H Cross. The gaskets were indented to 0.073-0.079 inches and a 190 µm diameter hole was drilled using
an electrical discharge machining tool (EDM).

The samples were prepared from natural MoS$_2$ from SPI by micromechanical exfoliation onto 500 nm SiO$_2$ wafer pieces. To exfoliate the flakes, adhesive tape is used to cleave the MoS$_2$ sample until it is very thin. The clean surface is then pressed onto a substrate and light pressure is applied. When the tape is removed flakes remain adhered to the substrate though Van der Waals forces. This produces a wide range of flake size and thickness making it necessary to identify flakes of suitable size and thickness. MoS$_2$ on SiO$_2$ exhibits a color change towards gold as the number of layers increases becoming completely gold at greater than 50 layers, so an optical microscope was used to identify flakes 100-150 $\mu$m wide and at least 50 layers thick. An optical profilometer was used to determine the smoothness of the flake’s surface and to establish the approximate thickness. The flakes used were between 1-10 $\mu$m.

Loading the MoS$_2$ flake into the diamond anvil cell requires the use of microtools and a stereoscopic microscope in order to see and manipulate the small flakes. I initially tried to move the flakes using SiC microtools, but I discovered that the force required to dislodge the flakes from the substrate tended to break them. In order to avoid damaging the flakes I used isopropanol to detach the flake from the substrate and a flexible tungsten needle to move the flake into the sample chamber. A silicone oil (octamethyltrisiloxane) from Sigma-Aldrich was used as a pressure medium. A syringe was used to add it to the sample chamber after the sample had been place.

![Experimental set ups for measurements](Figure 1.2: Experimental set ups for measurements)
Brillouin Spectroscopy and Raman Spectroscopy

Brillouin spectroscopy is a non-destructive optical technique that detects the change in frequency of light inelastically scattered from acoustic phonons in a material. It is commonly used for the measurement of elastic constants and acoustic velocity[16]. There are two basic types of Brillouin scattering: spontaneous and stimulated. In spontaneous scattering the thermal fluctuations in the intensity of the acoustic wave while in stimulated scattering an acoustic pulse is generated and intensity of the measurement is proportional to its amplitude[17]. The signal in stimulated scattering is larger[18].

![Periodic oscillations detected using picosecond interferometry on a MoS$_2$ flake inside the DAC at 8.8 GPa. The high frequency oscillations at short delay times are from the MoS$_2$, and the lower frequency oscillations are from the silicone oil pressure medium.](image)

In order to measure the Brillouin frequency $f$ in the diamond cell, a type of stimulated Brillouin spectroscopy know as picosecond interferometry was used[19]. A pulsed femtosecond Ti:sapphire laser mode-locked at 785 nm with a repetition rate of 80 MHz was split into a pump and probe beam, and the probe beam was sent through a mechanical delay stage. The pump and probe beam are both focused onto the same spot on the sample and the signal from the reflected probe beam is measured using a Si photodiode. The full experimental setup is shown in figure 1.2a. When the pump beam is incident on the sample it causes
a rapid rise in temperature which creates a longitudinal strain pulse due to thermal expansion. The probe beam weakly reflects from the moving acoustic pulse which causes constructive or destructive interference with the stronger reflections from the rest of the sample[19, 20]. The photodiode detects this as a periodic oscillation that has the Brillouin frequency.

Inside the DAC the thermal expansion of the sample can also create a strain wave in the pressure medium. This allows the detection of the Brillouin frequency of the pressure medium and the sample. An example of this is shown in figure 1.3.

For my experiments a 20x objective lens with a numerical aperture of 0.28 was used to focus the pump and probe beam onto the MoS$_2$ sample, and data was taken from both sides of the DAC. In order to maximize the signal from the DAC, pump and probe powers between 9 and 13 mW were used. Multiple sets of data were taken and used to average out the noise to ensure a very clear signal using the principle that the noise will vary in each data set while the actual signal will not. Taking the average thus reduces the noise without changing the signal.

Low frequency Raman scattering was also done using a 488 nm solid state laser. The experimental set up is shown in figure 1.2b. Raman measurements were only taken from the front side of the DAC.

![Figure 1.4: Raman peak shift of MoS$_2$ with pressure.](image-url)
Pressure Determination

I tried two methods to determine the pressure in the diamond cell: using the Brillouin signal from the silicone oil which had previously been calibrated by Greg Hohensee[13] and Raman shift of the MoS$_2$ which was measured at low pressures by Sugai[7].

The Raman spectra for MoS$_2$ is shown in figure 1.4. From the spectra it can be seen that the peaks all increased in response to pressure and that the intensities decreased. Although variations in peak intensity with pressure were seen in the measurements by Chi, it did not consistently decrease as pressure increased[21]. The Raman system was realigned and calibrated between the lower two measurements in order to reduce the Rayleigh scattering being detected. In order to avoid any zero off-set calibration errors the Stokes and Anti-Stokes peaks were measured and averaged to be symmetric. The uncertainty in the measurements found using Si and bulk MoS$_2$ reference samples was 0.5 cm$^{-1}$. I used the $E^2_{2g}$, $E^1_{2g}$, and $A_{1g}$ peaks that I measured to find the pressure by comparing them to the values measured by Sugai[7]. The results of this and the Brillouin frequencies from the silicone oil are shown in 1.5.

Figure 1.5: The DAC pressure measured using the Brillouin scattering from the pressure medium and the Raman shift of the MoS$_2$. The x-axis refers to each time the pressure in the diamond cell was increased. The y-ais shows the pressure calibration of my data to Hohensee and Sugai’s results.
The error bars for the Raman shift were calculated by combining the uncertainty in my measurements with that in the calibration data for each peak. For the uncertainty in the Brillouin frequency I similarly combined the uncertainty in the frequency measurements with the uncertainty in the calibration data. However, the calibration done by Hohensee in this pressure range had a lot of data and had a relatively small uncertainty[13]. At higher pressures the uncertainty is significantly larger due to fewer data points being available.

![Graph](image)

Figure 1.6: Measured Raman shift compared with data from Sugai[7]. The y-axis is the pressure measured from the Brillouin frequency. Literature values for ambient MoS$_2$ peaks are from [22, 23].

The $E'_{2g}$ shift indicated a lower pressure than the $A_{1g}$ shift and the Brillouin scattering from the silicone oil. However, the pressures indicated by the $A_{1g}$ and Brillouin scattering were very similar. Surprisingly, the $E'_{2g}$ mode is the most dissimilar. However, part of this discrepancy in pressures could be because the Raman shift I measured is lower at all pressures than Sugai. This is shown in figure 1.6. Even at ambient pressure I measured all the modes except $E'_{2g}$ as being significantly lower. This suggests that there is a systematic offset in the data. Established literature values for the Raman peaks agree more closely with my data than with Sugai’s measurements. Given this, combined with the fact that the Brillouin signal from the silicone oil was very clear, with the exception of the data taken when the DAC was first loaded, and provided a more precise measure of the pressure than the Raman shift, I chose to use it as my method of determining the
1.3 Results and Discussion

Brillouin Signal Strength

As the pressure was increased inside the DAC, the Brillouin signal from the MoS$_2$ increased in strength. This effect exists independently of variations in the probe power used to take the measurements, which also increase the signal strength. The signal strength, corrected for different pump and probe powers and normalized to the signal strength of the flake under ambient conditions, is shown in figure 1.7.

![Figure 1.7](image)

Figure 1.7: The normalized amplitude of the Brillouin signal from MoS$_2$ in the DAC at different pressures. The amplitude for the same MoS$_2$ flake at ambient pressure when not loaded in the DAC is shown for comparison.

Inelastic light scattering is comprised of three basic processes: an incoming photon excites an electron-hole pair, the electron-hole pair is scattered by the lattice creating a phonon and another electron-hole pair, this electron-hole pair decays and produces a new photon. The final photon produced will have the energy of the initial photon shifted by that of the phonon. The first process mentioned dominates the scattering cross-section[17].
MoS$_2$ is an indirect semiconductor with bandgap that has been experimentally measured as 0.8 eV, 1.29 eV, and 1.2 eV\cite{24}. The band-gap in most semiconductors is sensitive to strain, and DFT calculations of the band structure for MoS$_2$ have shown that the band-gap of MoS$_2$ decreases with pressure\cite{12, 25}. This would cause an increase in the scattering cross-section by increasing the number of electron-hole pairs excited and could account for the observed increase in signal strength. The decrease in bang-gap energy is also predicted to be non-linear. As the band-gap continues to decrease at higher pressures I expect the Brillouin signal to increase as well, but it will be interesting to see if the rate of change tracks that of the band-gap energy.

Elastic Constant Calculation

The Brillouin frequencies were extracted by taking the FFT of the oscillations. Because the backscattering geometry was used, the Brillouin frequency ($f$) is related to the longitudinal speed of sound ($v_L$) in the material by

$$f = \frac{2n v_L}{\lambda} \quad (1.1)$$

where $n$ is the index of refraction and $\lambda$ is the wavelength of the incident laser\cite{16}.

The $c_{33}$ elastic constant is related to $v_L$ by Christoffel’s equation for a hexagonal system along the Z axis

$$v_L = \sqrt{\frac{c_{33}}{\rho}} \quad (1.2)$$

where $\rho$ is the density of the material\cite{9}.

Combining these equations gives the direct relationship between the Brillouin frequency and $c_{33}$

$$c_{33} = \rho \left( \frac{\lambda f}{2n} \right)^2 \quad (1.3)$$

To get the change in $\rho$ with pressure I used the bulk density of 5.06 $g \text{ cm}^{-3}$\cite{26} and a third order Birch-Murnaghan fit to Aksoy’s data on the change of unit cell volume with pressure\cite{5}. The change in density also corresponds to a change in the refractive index. In order to model this I tried to use the Lorentz-Lorenz relationship

$$\frac{n^2 - 1}{n^2 + 2} = \frac{4\pi}{3} \alpha \rho \quad (1.4)$$

where $\alpha$ is the polarizability of the material. I used $n$ and $\rho$ at ambient pressure to find $\alpha$, then assuming $\alpha$ remained constant, graphically solved for $n$ at different pressures. However, I found that the relationship does not hold in this situation: $n$ increased rapidly from 4.7\cite{27} at ambient pressure to $>10$ by 11 GPa. At only 20.5 GPa it becomes unsolvable.
Figure 1.8: The $c_{33}$ elastic constant for MoS$_2$ at different pressures. The DFT calculation by Peelaer and the elastic constants from the pressure derivative of Fan’s measurement of the $c$ lattice constant are shown for comparison[28]. The $c_{33}$ error bars do not include the uncertainty from the change in $n$ with pressure.

The resulting elastic constants are shown in figure 1.8. Error bars are shown for the pressure and the elastic constants. The uncertainty in the pressure in the same as what is shown in figure 1.5. As the Brillouin signal becomes larger the uncertainty in the Brillouin frequency decreases. The uncertainty shown for $c_{33}$ stems from error propagation of the uncertainty in the measurements of the Brillouin frequency, the index of refraction, and the density. The uncertainty in the density is taken from the uncertainty values reported in [5] for the volume of the unit cell. The values of the index of refraction for MoS$_2$ reported in the literature vary widely[29], but there are only two reported values for the light wavelength used in my experiments[30, 27]. I estimated the uncertainty in the index of refraction from them.

Slightly different MoS$_2$ Brillouin frequencies were measured at different positions on the sample, which leads to $c_{33}$ varying by as much at 14 GPa. This indicates that there might be local pressure gradients in the material. However the overall trend is that $c_{33}$ increases linearly as the material is compressed and stiffens.

This is what is predicted by the hybrid density functional theory (DFT) calculations performed by Peelaer and Van de Walle using the screened hybrid functional of Heyd, Scuseria, and Ernzerhof along with the semiempirical Grimme D2 correction[12]. My results show a similar rate of change, but are higher than
those predicted by Peelaers. This could be partially due to the uncompensated change in the index of refraction. Since the index of refraction will have increased with pressure the elastic constants shown should be slightly lower, which would make them more similar to those predicted by Peelaers.

I also calculated $c_{33}$ from the finite element pressure derivative of the $c$ lattice constants reported by Fan[28] for comparison. These values show a similar trend as the ones I measured and Peelaer’s calculations, but are significantly higher. I attribute this to the large amount of uncertainty for this type of calculation. Under ambient conditions $c_{33}$ has been reported as 52 GPa using neutron scattering data with an uncertainty of 20%[10]. However, more recent studies of $c_{33}$ measured with Raman scattering report values of 52.0 GPa[11], and 59.2 GPa[31] for MoS$_2$, which is in agreement with my value of 53.4 GPa.

A way to model the change in $n$ with pressure will be need to be determined in order to more accurately measure $c_{33}$, as well as gathering data over a wider range of pressures in order see if the linearity holds. However, thus far the measured $c_{33}$ is in agreement with the available work in the literature.
CHAPTER 2

TWO SOURCE SPUTTERING CHAMBER

2.1 Introduction

One of the experimental techniques used in the Cahill group is time-resolved magneto-optical Kerr effect (TR-MOKE), which can be used to measure the thermal properties of materials. A thin ferromagnetic transducer is deposited on top of the sample and the changes in the Kerr rotation with temperature are measured. In order to facilitate these experiments I built a two source sputtering chamber to deposit [Co,Pt] multilayers for use as transducers. A diagram of the chamber is shown in figure 2.1.

Figure 2.1: Schematic diagram of the sputter chamber. P1 is a convection gauge, P2 is a cold cathode ion gauge and P3 is a capacitive manometer.
Sputtering is a simple physical vapor deposition method that can be used to easily create thin metal films. An Ar plasma is used to remove atoms from a target of the desired thin film material. The released material is then deposited onto the substrate as long as the distance between the target and the substrate is smaller than the mean free path of the atoms. The deposition rate can be controlled by the distance between the target and the substrate, the Ar pressure, and the power of the plasma, but in practical terms only the latter two options are easily changed by the operator.

The chamber I built is similar in design to other sputter chambers used in the Cahill group for thin metal film deposition, with a few notable differences. The top flange of the chamber has two 1.5” target sputter sources mounted on it along with a viewing port that allows visual monitoring during deposition. The two targets makes it possible to deposit a multilayer film without exposing it to contamination. This is very important for materials that are prone to oxidation and need a capping layer before they are exposed to atmosphere to prevent the formation of native oxides that could change the properties of interfaces. Each source has a manual shutter that can be used to alternate deposition of the materials. A fast entry door allows for easy loading and unloading of samples onto the heated sample stage.

2.2 Characterization of Films

In order to calibrate the deposition rate of the chamber for each material 10 minute depositions were performed at 20 W and 1 mTorr of Ar with a base pressure better than $2 \times 10^{-7}$ mTorr. I attempted to measure the thickness of the films using picosecond acoustics. This technique uses the same configuration as the Brillouin scattering discussed earlier, but can only be done using an optically thick thin film on top of the sample[32]. The film propagates a strain wave through the sample that reflects off of interfaces and changes the reflectivity of the film when it reaches the surface. This is detected as a series of regularly spaced “pulses” in the data collected by the photodiode that correspond to twice the thickness of the material. The deposition times I used were not long enough to create optically thick films and instead these measurements resulted in Brillouin scattering.

The Brillouin scattering for the 10 minute deposition of the Co layer is shown in figure 2.2. The first set of oscillations has a period of 6.3 ps and is a breathing mode of the cobalt. This was used with the sound velocity calculated from the density $8.86$ g/cm$^3$[26] and $c_{33}$ 357 GPa[33] in the $<001>$ direction to calculate the wavelength of the breathing mode as 40 nm, which corresponds to the twice the thickness of the layer. The breathing mode oscillations are continue until 36.5 ps when the strain wave reaches the SiO$_2$ layer. This produces a much longer oscillation with a period of 51 ps. However, the layer is not thick enough to see a
Figure 2.2: Pump-probe measurement of a 20 nm Co film on 500 nm SiO$_2$ on Si. The breathing modes of the Co and Brillouin scattering of the SiO$_2$ and Si can be clearly seen.

full period. At 39 ps the wave reaches the SiO$_2$/Si interface, which results in short oscillations again. As the delay time increases the Co and Si scattering begin to cause interference with each other leading to mixed oscillations.

To further confirm the thickness of the layers I also used single wavelength ellipsometry. The Co film was about 20 nm thick and the Pt film was about 30 nm. Between the two methods of measuring the film thickness I established a deposition rate of 0.33 Å/s for the Co and 0.5 Å/s for the Pt. This is a deposition ratio of 1.51, which is higher than the ratio of 1.15 that has previously been found for 600 eV Ar$^+$ ions[34]. Part of the reason for this discrepancy is that the targets in this chamber are at slightly different distances and angles with respect to the substrate, which will change their deposition rate.

The individual Co and Pt films were further characterized by measuring the electrical resistivities using a four-point probe. The resistivities ($\rho$) for the Co and Pt films were $18 \times 10^{-8}$ Ωm and $17 \times 10^{-8}$ Ωm respectively. These are higher than the bulk values of $5.2 \times 10^{-8}$ Ωm and $10.6 \times 10^{-8}$ Ωm[35]. While this is not uncommon for very thin films due to scattering effects, previous studies of high quality Pt films have shown that $\rho$ approaches bulk values in films thicker than 10 nm[36][37]. This indicates that there could be high surface roughness or small grain size in the films I deposited. The surface roughness could be further
investigated and quantified using an optical profilometer. In the case of the Co film it is possible that oxidation has changed the resistivity since the four-point probe measurements were not done in a vacuum. Co is known to form a native oxide of 8-10 Å[38].

2.3 [Co,Pt] Multilayer

A magnetic transducer for TR-MOKE experiments requires a large enough Kerr rotation angle $\theta_k$ to be detected and needs to be perpendicularly magnetized. Both of these characteristics have been extensively studied for [Co,Pt] multilayers and depend on the ratio of Co to Pt layer thickness, number of bilayers, and total thickness of the multilayer as well as various growth parameters for the films[39]. It has been shown that the $\theta_k$ is increased for films thinner than 300 Å[40]. A higher Co content also increases the $\theta_k$, but too much Co can cause a loss of perpendicular magnetization in the films; 3-7 Å thick layers of Co are generally considered a good range[41]. An increasing number of bilayers also increases $\theta_k$ [42]. Using a thicker buffer layer of Pt on the sample can improve the texture of the multilayer, which enhances $\theta_k$[43]. When balancing all these factors there are a number of different structures that will work for a [Co,Pt] multilayer transducer. I chose to deposit a multilayer of [Pt (1 nm)/Co (0.5 nm)]x6/Pt(11 nm) on top of 500 nm SiO$_2$ on Si wafer (shown in figure 2.3). This structure is not near any of the extremes that can cause the transducer to lose perpendicular magnetization, which also makes it an appropriate test structure in case the deposition does not proceed exactly as planned. It has previously been used for TR-MOKE measurements[44], thus it makes
a good test of whether or not this sputter chamber can deposit usable [Co,Pt] multilayers.

The resulting TR-MOKE data is shown in figure 2.4. Since the properties of the SiO$_2$ wafer are known, it was possible to fit for the thickness of the transducer, which was 26 nm. For the fit the volumetrically averaged heat capacity 2.94 J/K-cm$^3$ of the Co and Pt layers was used. The thickness found was greater than the planned 20 nm stack, indicating either the deposition rates or the timing during the multilayer deposition were slightly off. The layers were deposited at 20 W for 15 s for each Co layers and 20 seconds for the Pt layers. The Pt buffer layer was deposited for 220 s. The deposition rate of the films could be decreased by lowering the power used in order to increase control. The deposition rate should change linearly with power, but in reality it would be better to actually measure the film thickness to determine the deposition rate at each power used. One possible source of the discrepancy is if the substrates used for the thickness depositions were not placed in the exact same position as the substrate used for the multilayer deposition. The uniformity of the flux for this chamber has not be tested, and it is possible that there is enough variation to account for part of the 6 nm difference.

![Figure 2.4: TR-MOKE data and fit for [Co,Pt] transducer on a SiO$_2$ reference sample](image)

This transducer is not optically thick, so it cannot be used for time domain thermo-reflectance (TDTR) measurements, which utilizes the change in the reflectance of the transducer with temperature to measure
thermal conductivity[15]. However, future multilayers could be made optically thick by increasing the buffer layer, which would allow the direct comparison of the two techniques.

The $\frac{d\theta_K}{dT}$ for this transducer was calculated to be about $5 \times 10^{-5}$ K$^{-1}$. This is the same order of magnitude for similar [Co,Pt] multilayers that have been previously used by our group. For this calculation I used the volumetric average of the absorption coefficients and the heat capacities for Co and Pt assuming the ideal structure shown in figure 2.3.

Further testing and optimization of the [Co,Pt] multilayers will need to be done, but preliminary results indicate that this sputter chamber is capable of producing usable transducers for TR-MOKE experiments. It also has the potential to be modified for cosputtering and the deposition of different multilayers in the future.
REFERENCES


