Applications of Raman Spectroscopy in Material Science: Material Characterization and Temperature Measurements

Yusuke N[1], Yongjie Zhan[2], Sina Najmaei[2], Jun Lou[2]

NanoJapan Program

1 Department of System Design Engineering, Keio University
2 Department of Mechanical Engineering and Material Science, Rice University

Raman spectroscopy is a powerful tool for characterizing materials and measuring temperatures. Synthesis of MoS2 films, a novel material with applications in semiconductor technology, requires accurate and robust characterization. We applied Raman spectroscopy to characterize CVD synthesized MoS2. This technique will provide information about existence and quality of these materials. In addition, we used Raman spectroscopy to measure and calibrate temperature in mechanical testing devices. These devices consist of a circuit designed for Joel heating of the samples and allow for mechanical measurements to be taken at elevated temperatures. Our aim is to correlate the input voltage or current to the temperatures reached in the samples.

Applications of Raman Spectroscopy in Material Science: Material Characterization and Temperature Measurements

Yusuke Nakamura[1,2], Yongjie Zhan[1], Sina Najmaei[1], Jun Lou[1]

[1]NanoJapan Program, Department of Mechanical Engineering and Material Science, Rice University

[2]Department of System Design Engineering, Keio University

Introduction

Raman Spectroscopy:

A powerful tool to characterize chemical and physical properties of materials.

Here I Have Applied This Technique to:

- **Molybdenum Disulfide (MoS_2)**
  Goal: Synthesis of single- and few-layered MoS_2 by Chemical Vapor Deposition (CVD) method.
  ---> Chemical and quality characterization of MoS_2
- **Mechanical Testing Device**
  Goal: Mechanical testing at elevated temperatures
  --->To correlate the input power to ohmic heating of the device by means of Raman shift analysis

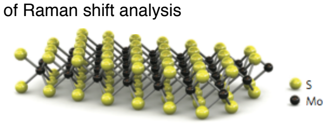


Fig. 1 3D representation of the structure of MoS_2[1]

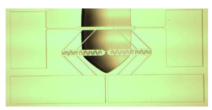


Fig. 2 Mechanical Testing Device [2]

Methods

CVD Method

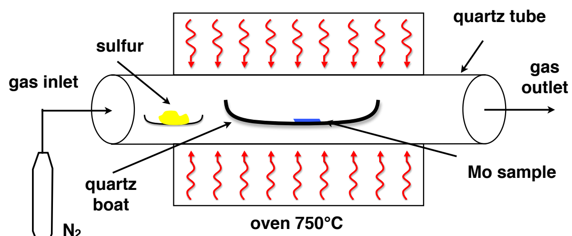


Fig. 3 A Simplified Schematic of CVD experimental system

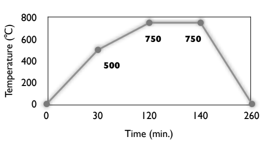


Fig. 4 CVD process

Au as a substrate :
- No reaction with S
- Tight bonding with Mo

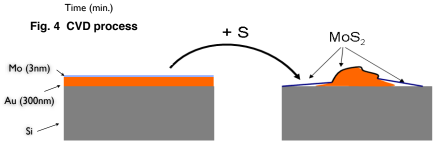


Fig. 5 Schematic of Synthesis of MoS_2

Methods (cont.)

Mechanical Testing Device Experiment

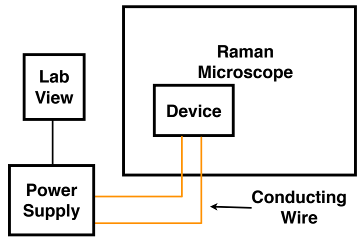


Fig. 7 A simplified schematic of an experiment

Experimental Procedures

1. Pass current through the device for Ohmic Heating
2. Scan the device via Raman Microscope after 90 sec. of heating and record the spectra
3. Turn off the power supply and wait for 2 min. (for the device to cool down)
4. Acquire similar data for different voltages
5. Quantify silicon band position for each voltage and

Data Analysis

$$\frac{I_{AS}}{I_S} = \left(\frac{\varpi_l + \varpi_p}{\varpi_l + \varpi_p}\right)^4 \gamma e^{(h\varpi_p/kT)} \quad (1)$$

↓

$$\Omega = \Omega_0 - \frac{C}{e^{[D(h\Omega_0/kT)]} - 1} \quad (2)$$

↓

$$T = \frac{Dh\Omega_0}{k\ln\left(\frac{C}{\Omega_0 - \Omega} + 1\right)} \quad (3)$$

I_{AS} : anti-Stokes intensity
I_S : Stokes intensity
ϖ_l : the frequencies of the laser
ϖ_p : the phonon of the laser
γ : constant
T : absolute temperature
h : Planck constant
k : Boltzmann constant
$c = 3 \times 10^8$
C, D: constant depending on materials
C = 10.53 /cm D = 0.587
Ω_0= 525 /cm (Raman line position at 0K)

The equation (3) is used to find the relationship between Raman shift and the corresponding temperature and input electrical current

Results and Discussion

Mechanical Testing Device

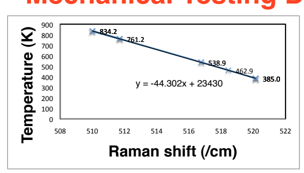


Fig. 8 Raman shift-temperature

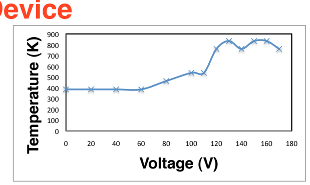


Fig. 9 Voltage-temperature relationship

Temperatures as high as 800K were achieved and temperature vs. voltage characteristics of the device was quantified.

Problem: Wire bonding due to weak Si Au adhesion

---> Solution: Deposit Cr on Si

Results and Discussion (cont.)

Single-layered or Few layered MoS_2

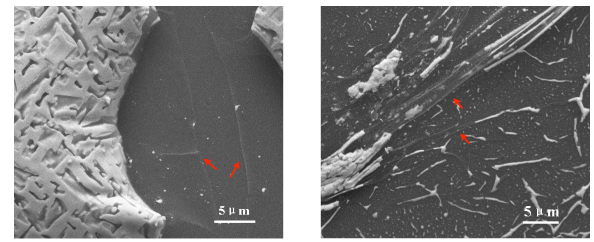


Fig. 10 SEM images of MoS_2 films (shown by red arrows) and gold particles on silicon substrate

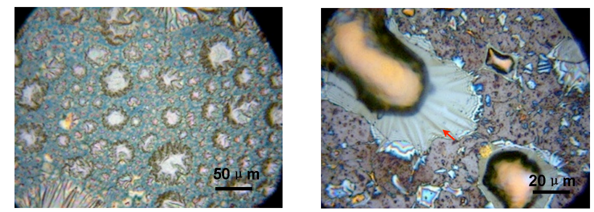
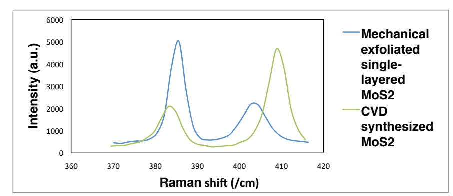


Fig. 11 MoS_2 films synthesized by CVD method on gold substrate

MoS_2 is on the whole surface. The red arrow shows the suspended MoS_2.
---> Easy to remove it from Au



Why is the discrepancy?
---> CVD synthesized MoS_2 is thicker than and suspended.

Fig. 12 Raman shift - intensity relationship

References

B. Radisavljevic et al., nature technology, 2011

Yezeng Cheng,Thermal MEMS Device Design, Simulation, Testing and Analysis, 2011

Acknowledgments: This research conducted at Rice University as a participant of NanoJapan 2011 program supported by the National Science Foundation under Grant No. OISE – 0530220. Special thanks to Prof. J. Kono, S. Phillips, Dr. Lou, Y. Zhan, S. Najmaei, and P. Dong.