Relation Between Phase Transition and Laser Irradiation Strength and Time Duration through Phase Patterning of MoTe$_2$

Trevor Shimokusu,$^{1,2}$ Kota Kamiya,$^3$ Nobuyuki Aoki,$^3$ and Jonathan Bird$^4$

1Department of Mechanical Engineering, The University of Hawai‘i at Mānoa, Honolulu, Hawai‘i, U.S.A
2Naktatani RIES: Research & International Experience for Students Fellowship in Japan, Rice University, Houston, Texas, U.S.A
3Graduate School of Advanced Integration Science, Chiba University, Inage-ku, Chiba, Japan
4Department of Electrical Engineering, University at Buffalo, The State University of New York, Buffalo, New York, U.S.A

An intriguing property displayed by transition metal dichalcogenides (TMDCs) known as polymorphism, is attractive for its application in future electronic devices. Molybdenum ditelluride (MoTe$_2$) is a TMDC with an energy difference of ~35 meV between its semiconducting 2H and metallic 1T’ phases, which is considerably less than the homologous energy differences of other TMDC materials [1,2]. By taking advantage of this smaller energy difference, we were able to feasibly observe polymorphism within MoTe$_2$. In this study, we fabricated MoTe$_2$ field effect transistors, and used laser-driven phase patterning to induce property changes in desired areas of the semiconducting channel [3]. While previous studies have confirmed successful 2H-1T’ phase transition at laser irradiated sites, we investigate the possibility of controlling semiconducting properties by controlling laser irradiation strength and time. We are particularly interested in p-n polarity and threshold voltage shifts (from normally-off to normally-on) of MoTe$_2$ upon phase patterning, as establishment of such relationships is essential for configuring electrical circuits within crystals of MoTe$_2$. Furthermore, we attempt to describe the mechanism behind the phase patterning induced phase transition. Although it is known that the formation of the Te-atom vacancy serves as the key origin for phase transition [3], the specific cause of this vacancy and other related causes of phase transition are still not confirmed. Realizing the previously stated relationships along with the driving mechanism of phase patterning opens the potential of fabricating circuit components, such as logic gates and transistors, with a uniform material.

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**Introduction**

- **Background**
  - Fabrication of a monolithic integration circuit is desirable
  - Requires different types of semiconducting and metallic areas

- **Objectives**
  - Change 2H-MoTe₂ semiconducting properties through laser irradiation
  - Investigate the mechanism behind laser-induced phase transition

**FET Fabrication and Testing Process**

1. **Mechanical Exfoliation**
   - Multilayer flakes onto SiO₂/Si substrate
2. **Electrode patterning**
   - Wire/metal mask method (n-type sample)
   - Photolithography method (p-type sample)
3. **Electrode deposition**
   -PD/Au (5/75 nm) top contact
4. **Laser Irradiation**
   - Irradiate samples with 532 nm CW laser under various laser powers and times
5. **Evaluation**
   - Raman spectroscopy to understand phase shifts
   - Electronic property changes

**Results**

**A. Control of Semiconducting Properties**

**Photolithography FET sample**

- Gate Dependence ($V_D = 0.05 \text{ V}$)

**B. Irradiation Time Dependence**

**Photolithography FET sample**

- Gate Dependence ($V_D = 0.1 \text{ V}$)

**C. Threshold Voltage Shifts of p & n Samples**

- p-type sample became more p-type-like upon laser irradiation
- n-type sample became more n-type-like upon laser irradiation

**Discussion**

- Successfully changed 2H-MoTe₂ semiconducting properties by using a weaker laser power density
- Observed systematic shifts in threshold voltage with increasing irradiation time
- Raman spectra broadening suggests irradiation induced Te-atom defects which is in agreement with previous studies
- Consistent threshold voltage shifts of p & n type samples suggests band gap narrowing (strains within the crystal)

**Future work**

- Identify the induced strains associated with MoTe₂ phase change (tensile or compressive) through further Raman spectra, band gap measurements, and simulation
- Explore the reversibility of 2H-1T' phase transition by studying the effects of MoTe₂ heat annealing
- Investigate the possibility of switching a sample’s characteristics from p-type to n-type and vice versa

**References**


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