Lithography for 2D Materials

CNF Project Number: 3035-22
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Primary Source(s) of Research Funding: The National Science Foundation, CBET-CAREER #2240944

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, SC4500 Odd-Hour & Even-Hour Evaporator

Abstract:

Intercalation is a reversible insertion of ions, atoms, and molecules into empty spaces in crystalline materials (Figure 1). For layered materials, intercalation can tune the materials properties greatly and even induce new phases. We electrochemically intercalate lithium ions into layered transition metal dichalcogenides and rare-earth tri-tellurides to induce new phases, change materials properties, and study nanoscale effects on the thermodynamics of lithium (Li) intercalation. For this, we fabricate electrochemical cells on individual nanodevices using exfoliated flakes, which allows us to measure the changes in the structure and electrical properties of the host material as we controllably intercalate lithium.

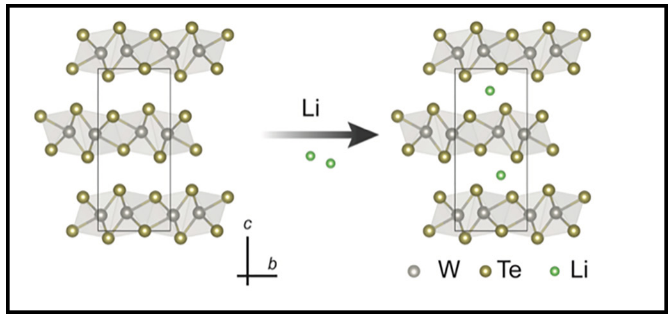

Figure 1: Schematic of lithium intercalation into tungsten ditelluride (WTe_2).

Summary of Research:

We discovered that semimetallic molybdenum ditelluride ($MoTe_2$) becomes semiconducting when enough lithium gets intercalated. The intercalation-induced semiconducting phase takes on a new crystal structure not found in existing polymorphs of $MoTe_2$, observed by Raman spectroscopy (Figure 2). We constructed electrochemical cells that are compatible with *in situ*, single-crystal X-ray diffraction experiments so that we can identify the new crystal structure. X-ray data were successfully obtained, and we are currently analyzing them. Further, we observed that the intercalation-induced phase change in these layered materials can be affected greatly by the interactions with the substrate; this is clearly observed by the intercalation-induced phase change getting delayed for thinner samples, where the substrate effects will be more enhanced. Finally, we observed that lithium intercalation into lanthanum tritelluride ($LaTe_3$) modifies the uni-directional charge density wave (CDW) that is present in $LaTe_3$. From Raman spectroscopy, it appears that uni-directional CDW gets suppressed with increasing concentrations of lithium intercalation into $LaTe_3$.

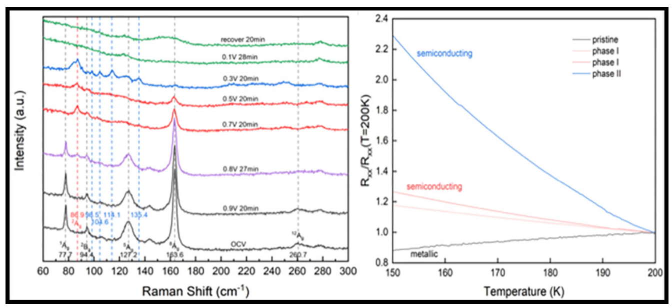

Figure 2: (Left) New structure is observed by intercalating lithium into molybdenum ditelluride ($MoTe_2$), which we denoted as Phase I and Phase II. (Right) These new phases are semiconducting, as confirmed by increasing resistance with decreasing temperature, in contrast to the initial metallic $MoTe_2$.

Conclusions and Future Steps:

Three manuscripts are in preparation to report our findings regarding lithium intercalation into layered materials: (1) new semiconducting phase in $MoTe_2$ by lithium intercalation, (2) thickness effects in intercalation-induced phase transition in WTe_2, and (3) changes in CDW in $LaTe_3$ by lithium intercalation. We will continue investigate the origin for the apparent suppression of the CDW phase in $LaTe_3$ with lithium intercalation. We will extend the study by including other rare-earth tritellurides that also have CDW phases. Transport measurements will also be carried out as a function of lithium intercalation, *in situ*.