TMD Superlattices for Phase Change Memory: Growth and Thermal Characterization

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Introduction
Superlattices are mainly studied for use in phase change memory, because their nanolaminate structures allow for heat confinement, lower switching energies while also preventing resistance drift [1]. From a broader perspective, superlattices are a playground for material properties, especially when considering thermal conductivity.

Material Choice and Growth
Transition metal dichalcogenides (TMDs) encompass a broad set of materials with a large array of properties. A subset of TMDs are studied as candidates to be used in PCM superlattices. Their structure, consisting of 2D sheets separated by Van der Waals gaps make them compatible with van-der-Waals gap bound phase change materials like Sb_2Te_3. A selection of 9 TMDs is studied, all from the 3 by 3 element grid between titanium and tungsten. These metals are predicted to have a MTe_2 crystal structure resembling CdI_2. The growth of these materials is performed through magnetron sputtering from elementary pure targets. In order to create the correct stoichiometry, the sputtering power of each target is individually tuned, while the sample is rotate through the flux of the two material. This method resembles the method of modulated reactants [2]. The materials deposited through this method crystallize in the CdI_2 structure after anneal, with some materials already crystalline upon deposition. The CdI_2 structure with texture of the 00L plane parallel to the substrate is evident from the XRD patterns in Fig. 1. The texture of these materials is further substantiated by rocking curve analysis.

Thermal Conductivity
When heat, intended to drive the phase change, diffuses into the surroundings, this is detrimental for the power consumption of the device. Typical phase change materials, such as Sb_2Te_3, GST and GeTe typically demonstrate not only a high thermal conductivity, but also a high contrast between amorphous and crystalline state. Superlattices prevent this by lowering the cross-plane thermal conductivity. This can be measured through time-domain thermoreflectance (TDTR). Using TDTR, the TMDs are studied individually before studying them in a superlattice. At room temperature, the intrinsic thermal conductivity is extracted, as shown in Fig. 2, leading to a broad spread of values. The superlattices, however, all demonstrate a low thermal conductivity, both in as-deposited as well as in crystalline phase.

Optothermal Cycling
Phase change material performance is typically quantified through electrical devices. Although this method is very application-relevant, results are typically heavily dependent on device parameters. In order to get a more device-independent metric, a laser based method is presented. Fig. 3 shows an example of repeatable switching that was obtained with this method on a Sb_2Te_3 thin film. The beam and scanning electronics of a confocal microscope are used to locally heat the phase change material. By tuning the parameters, both crystallization as well as amorphization are possible, in a process called optothermal cycling [3].

Conclusions
Sb2Te3/TMD superlattices are studied. Deposition of the TMDs is done through magnetron sputtering through a method resembling the method of modulated reactants. Thermal conductivity measurements show that metal choice is important for the high-temperature behaviour of the superlattices. At room temperature, the interfaces in the system dominate the thermal resistance. Optothermal cycling is presented as a more fundamental, device independent method of functional characterization.

References

1. K. Ding et al., *Science* **366**, 210–215 (2019).
2. M. Noh et al., Science **270**, 1181 (1995)
3. E. Seabron *et al*., *Opt. Mater. Express* (submitted, 2026)

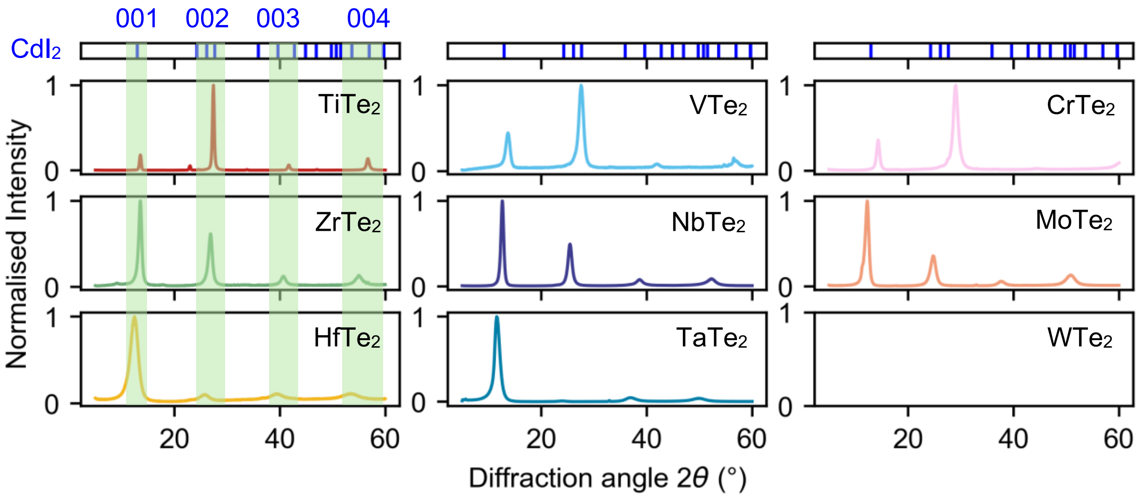

Figure 1. XRD results for deposited MTe_2 films with M one of the elements in the 3 by 3 grid between Ti and W. All but WTe_2 crystallize into the CdI structure with 00L planes parallel to the substrate after anneal.

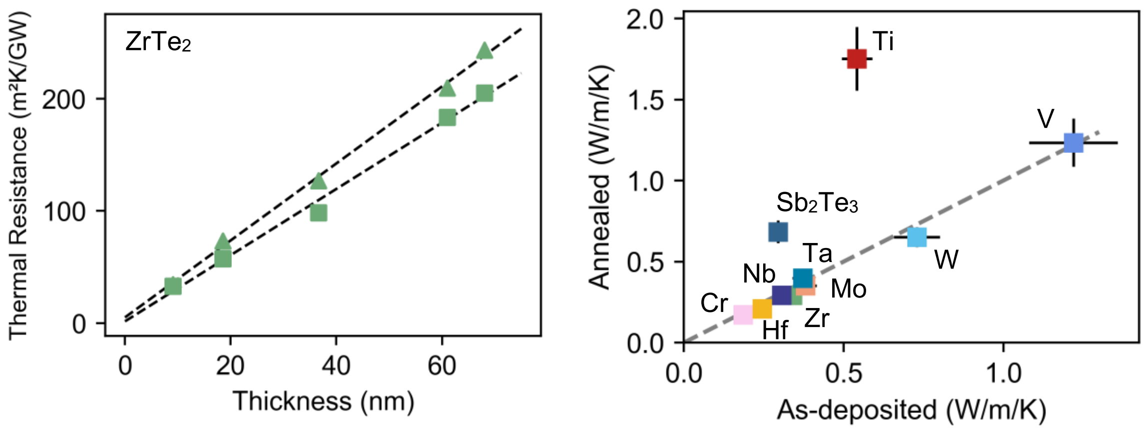

Figure 2 (left) By depositing a thickness series, the intrinsic thermal conductivity of a material is measured. The thermal resistance because of the interfaces in the system can be calculated through extrapolation. **(right)** The room temperature thermal conductivities of all studied TMDs, only the metal is noted for clarity. The dotted line signifies no contrast between the as-deposited and amorphous state. Most TMDs lie in the lower left corner, signifying a low thermal conductivity.

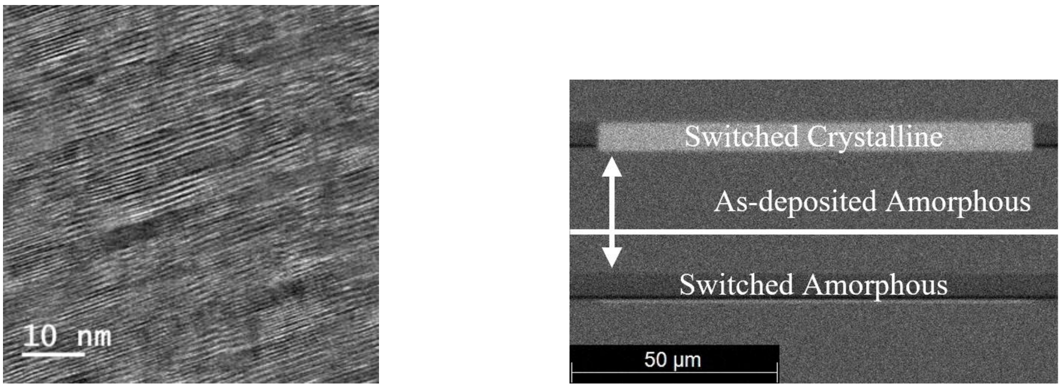

Figure 3 (left) A high resolution TEM micrograph of an annealed $TiTe_2$/Sb2Te_3 superlattice shows the highly textured nature of both materials. There is a clear preferred orientation parallel to the substrate. **(right)** Optothermal switching results for a Sb_2Te_3 thin film. Through this method, the material can consistently be switched between the two states.