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van der Waals (vdW) materials: towards heterostructures

Abstract

Phase change materials (PCM) are a technologically important materials class. There are two mature main application areas for PCM. The first deals with their use in optical discs for data storage. The second application area is in electronics and is known as phase change random access memory. These memory elements exploit the resistance contrast between the amorphous and crystalline phases. The prototype phase change material $Ge_2Sb_2Te_5$ displays a cubic and a trigonal crystalline phase. In our group we pioneered the epitaxial growth of PCM using molecular beam epitaxy and studied the ordering of the crystalline phases.[1-5] Such materials are lamellar and display a pronounced bond hierarchy, featuring strong bonds within quasi 2D building blocks, while weak bonds link adjacent blocks.

These weak bonds are frequently referred to as van der Waals (vdW) bonds. The weak interlayer interaction – which causes the 2D nature of these materials – is both a blessing and a curse. On the one hand, it allows the growth of heterostructures and superlattices of dissimilar 2D materials without epitaxial guidance (vdW epitaxy). Yet, it also creates adverse side-effects such as poor adhesion and wetting. More importantly, the weak coupling impedes strain engineering. Clearly, in the limit of zero coupling across vdW gaps, it should be impossible to introduce any strain in the growing 2D film. Yet, if enough coupling prevails across these gaps, strain engineering should be possible, too. The engineering of strain is an elegant concept to tailor physical properties without changing composition.

Here I will discuss two examples of strain engineering in PCMs. The first method is to induce strain at the interface in the vdW epitaxy of GeTe-Sb_2Te_3 alloys by the employment of Silicon vicinal surfaces.[6] The epitaxial layer is tilted along the growth direction with respect to the substrate; due to the out-of-plane lattice mismatch which introduces strain at the step edges, whereas the in-plane component is weakly bonded to the surface. Within the second method I will present evidence that p-bonded GeTe/Sb_2Te_3 superlattices (SLs), V_2VI_3 as well as their alloys devise a gap of non-pure vdW nature between the two chalcogenide atoms.[7]

Moreover, the larger coupling across the gap allows the tuning and engineering of strain. Most importantly, SLs of this class of materials develop a tunable distribution of in-plane lattice constants. Such a distribution of lattice constants within one solid has no precedent and is clearly beyond reach in classical 3D coupled solids.

Host: Jonas Johansson (Solid State Physics)

Biography

Dr. Calarco is with the PDI since September 2010. Her current research interests include on the one hand epitaxy of III-nitride nanostructures and layers on the other hand epitaxial growth of phase-change materials for memory applications. She has about 4099 citations as author or co-author of about 127 publications, 27 proceedings, 63 invited talks, 4 book chapters, 6 invited review papers, and 2 patents. She She received the Ovshinski Lectureship Award 2017 - Prize for Excellence in Chalcogenides for her exceptional work on epitaxial phase change materials.

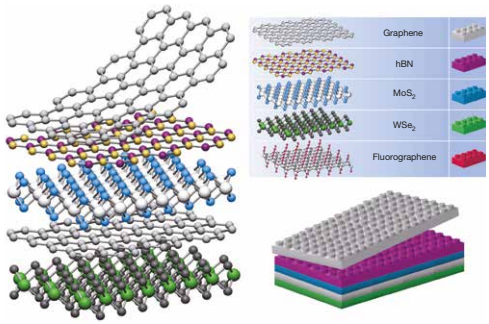

Figure 1 (from "van der Waals heterostructures", Nature, v. 499, 2013): Building van der Waals heterostructures. If one considers 2D crystals to be analogous to Lego blocks (right panel), the construction of a huge variety of layered structures becomes possible. Conceptually, this atomic-scale Lego resembles molecular beam epitaxy but employs different 'construction' rules and a distinct set of materials.

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