Ultimately Thin Sliding Ferroelectric Tunnel Junctions for Artificial Neural Networks

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Biological neural networks (NNs) use electric signals which are carried and stored by rapid electronic flows and relatively slow, non-volatile, ionic rearrangements. Artificial NNs (ANNs) aim to expand the natural NNs' logic and storage capabilities while using the outstanding technological capabilities to control crystalline materials developed over decades of fundamental and engineering efforts. So far, however, semiconducting ANNs systems control the flow of electrons with great precision and speed, whereas switching non-volatile atomic arrangements remains a great challenge. Our research focus on a novel van der Waals (vdW) sliding mechanism, allowing us to control pristine periodic crystalline arrangements within the thinnest possible ferroelectric material – only two atoms thick [1]. This artificially stacked layered boron-nitride crystal slides between two configurations with opposite vertical polarizations, switching its surface potential by 0.25 Volt. Similar response appears in synthetic ferroelectric crystals assembled from layered transition metal dichalcogenides [2] , with internal polarizations that accumulate in fixed steps with each additional layer. The minute depolarization observed and the substantial tunneling current in this ultimately thin polar limit enables Sliding Ferroelectric Tunnel Junctions (SFTJ) with outstanding performance and versatility.

The talk will focus on a novel design concept of SFTJ in nm-scale islands which are embedded is a super-lubricant medium [3]. Each interconnecting island can switch between two metastable polytype configurations with a range of electronic dispersions, optical responses, and magnetic orders [4]. By optimizing the junction's geometry and spread, we achieve a better than Femtojoule switching energy at a faster than nanosecond switching speed. Notably, we anticipate outstanding junction to junction uniformity and unlimited switching endurance compared to FTJs based on thin films of 3D crystals which are inherently sensitive to depolarizations. Compared to other non-volatile memristive technologies that rely on stochastic atomic motions (like arrays of phase change alloys or formations of conducting filament in degraded 2D crystals), the SFTJs switch pristine crystalline configurations and hence expected to improve substantially with the crystals quality as the technology matures.

I will discuss the diverse landscape of vdW polytypes, their stacking-dependent orbital overlaps, characteristic adhesion energies, discrete symmetries, and overall properties, with emphasis on our ongoing efforts to expand the "Slide-Tronics" paradigm using Super Lubricant Arrays of Polytypes (SLAP) for wider applications.

References

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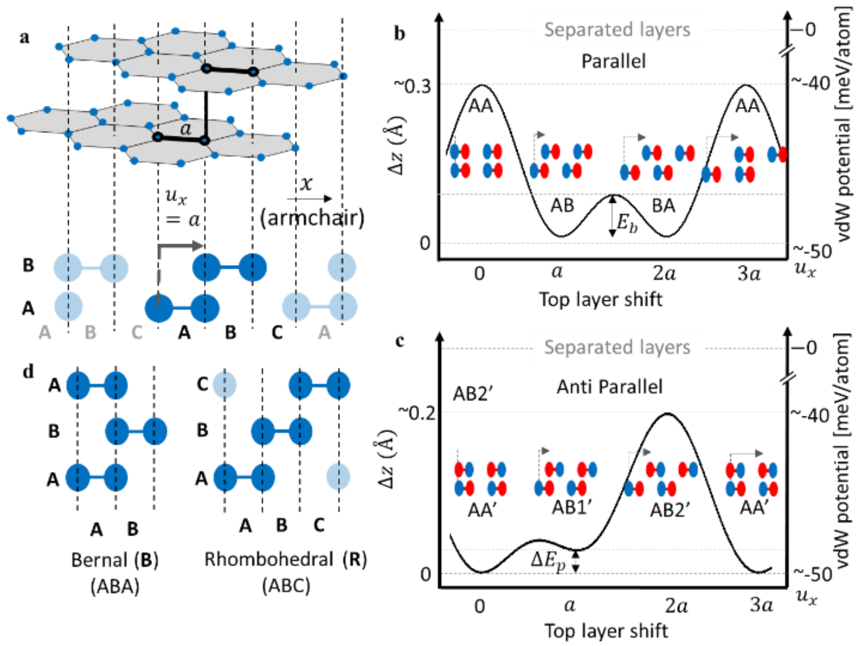

Figure 1: vdW Polytypes and stacking potentials (a) AB polytype illustration showing interlayer shift by a, the inter-site distance, along the armchair direction. A unit cells with two atoms per layer is emphasized (b) Typical stacking energies (right axes) and vertical separation variation Δz (left) as a function of the planar shift u_x. The depth of the potential well E_b is marked by arrows (c) Interfacial stacking potential in antiparallel binary compounds. (d) ABA and ABC polytypes of trilayer graphene.

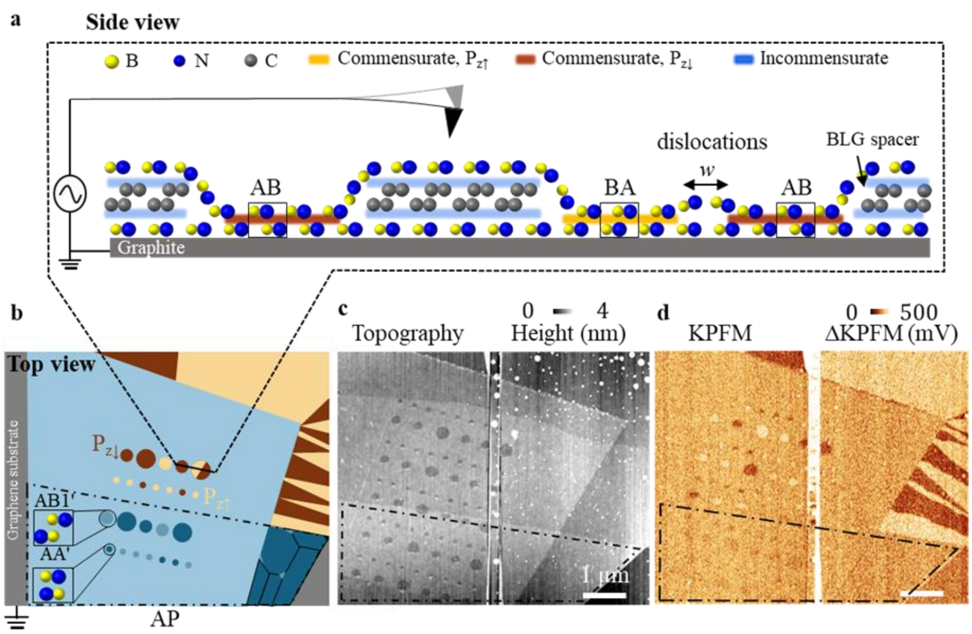

Fig. 2: Super-Lubricant Array of vdW Polytypes (SLAP). a,**b**, Sideview, and Top view device illustrations. The line cut shows a pair of cavities etched in a bilayer graphene spacer (identical carbon spheres) and encapsulated by two parallel *h*-BN layers (yellow and blue spheres). Commensurate *h*-BN interfaces of AB/BA polytype configurations at the cavities are shaded with dark/bright brown color for down/up internal polarizations. Lubricant incommensurate interfaces with the spacer are cyan-shaded. The right-side cavity island shows mixed BA/AB domains separated by a *w*-wide partial dislocation strip. The dashed-dotted line borders a region of antiparallel AA' and AB1' polytypes[46] islands marked by dark blue/bright blue colors, respectively. **c**, Topographic image of Device 1 with two nm thick parallel *h*-BN flakes. Note the brighter (one layer thicker) surface below the dashed-dotted line. **d**, Corresponding electric surface potential map by Kelvin probe force microscopy (KPFM).