Electronic Materials: Physics and Applications

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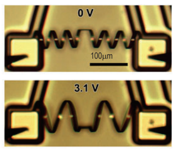
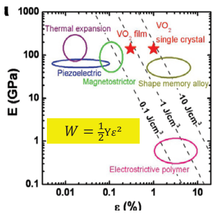
Introduction

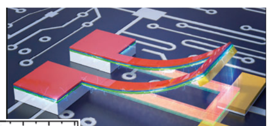
The Wu Group explores fundamental physics and new applications of low-dimensional materials, layered transition metal dichalcogenides (TMDs), strongly correlated materials, and their heterostructures. We aim to understand the influence of defects, doping and external stimuli on the electronic and structural properties and performance of these materials, for potential applications in thermoelectrics, photovoltaics, memory, NEM switches, actuators, infrared sensors, thermal management, etc.

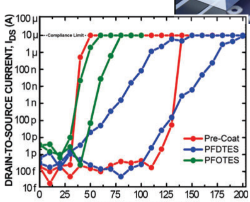
Electromechanical Properties



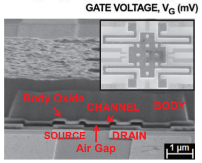


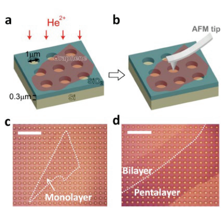
By utilizing the 1% lattice expansion in VO_2's thermally driven structural phase transition at 67°C, we build micro-actuators and mechanical metamaterials with high energy efficiency and rewritable functionalities.





Friction and stiction forces between solid surfaces are explored for nano-electromechanical switches. Self-assembled molecular coating and 2D materials are exploited for adhesion reduction.

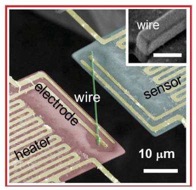


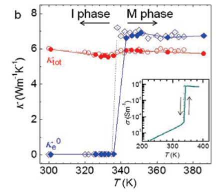


Mechanical, adhesion, friction and elastic properties of TMDs are investigated in response to defects, gating and interlayer coupling.

Adv. Mater. 27, 6841 (2015); IEDM, Dec. (2016); Adv. Mater. 26, 1746(2014); Adv. Mater. Int., 3, 1500388 (2016); Nature Comm., 5, 4986 (2014); Nano Lett., 14, 5097 (2014); Small, 14, 1703621 (2018)

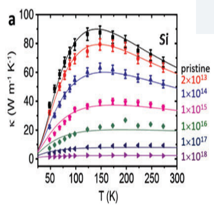
Thermal and Thermoelectric Properties

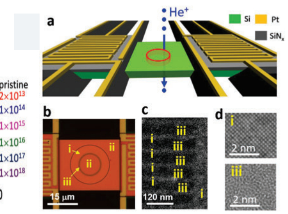




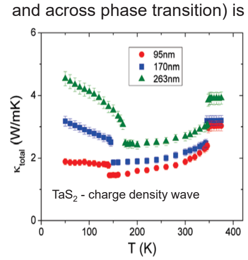
$\kappa_{tot} = \kappa_{electron}+\kappa_{lattice};\ \kappa_{electron} = L_0\sigma T$

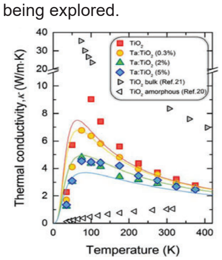
Using suspended micro-fabricated devices, thermal, electric and thermoelectric properties of nanowires are measured simultaneously. Shown here is violation of the Wiedemann-Franz law in the metal-insulator transition of VO_2.

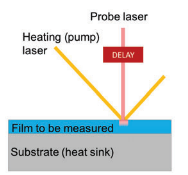


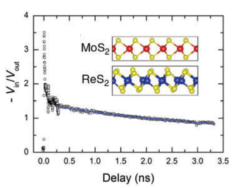


Thermal conductivity and electrical conductivity of black-phosphorus are found to be highly anisotropic in the basal plane; Thermal conductivity of crystalline Si membrane is extremely suppressed by ion irradiation, creating a platform to write programmable thermal metamaterials. Other thermal conduction physics (such as of charge density wave and across phase transition) is being explored.





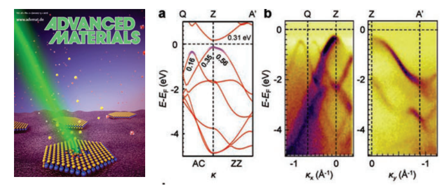




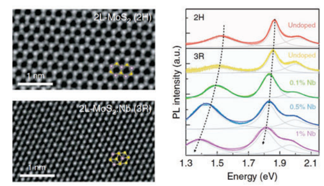
Time-domain thermo-reflectance (TDTR) is used to probe cross-plane thermal conductance of layered materials and thin films of various structures.

Science, 355, 371 (2017); Appl. Phys. Lett., 113, 022103 (2018); Nature Comm., 6, 8573 (2015); Adv. Mater. 27, 3681 (2015); Nano Lett., 14, 4867 (2014); Nano Lett., 14, 2394(2014).

Defects, Doping and Alloying

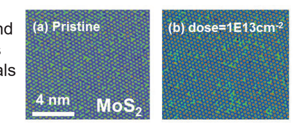


Laser-assisted site-selective annealing, doping, reaction and alloying of new layered materials (eg, black As).



Engineering band structures in 2D TMD alloys.

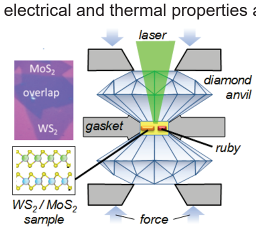
Engineering point and line defects in TMDs for improved materials performance and understanding.

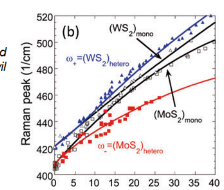


Nature Commun. 9, 199 (2018), Nature Commun., 6, 7993 (2015); Nature Physics, 13, 127 (2017); Adv. Mater., 28, 341 (2016); Adv. Mater. 27, 6841 (2015); Nano Lett., 14, 6976 (2014)

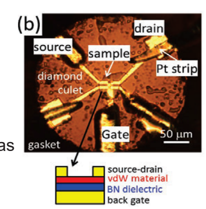
High Pressure Modulation

Diamond anvil cells (DAC) are used to apply hydrostatic pressures up to 50 GPa (~ 500k atm); under these pressures, many solid materials exhibit new properties or structures that otherwise do not exist. Optical, Raman, electrical and thermal properties are probed within DAC.





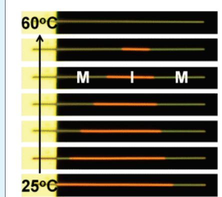
Interlayer coupling in van der Waals heterostructures is modulated to host new properties and stabilize new states.

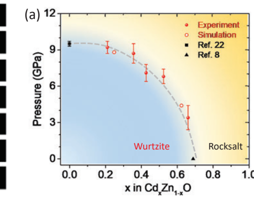


Pressure-tuned physics in 2D materials and structures, such as TMD FETs and graphene/h-BN heterostructures.

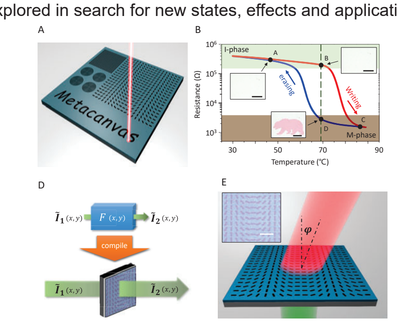
Nature Comm. 5, 3252 (2014); Phys. Rev. B, 92, 241408(R)(2015); Phys. Rev. B, 91, 104110 (2015); Nano Lett., 17, 194 (2017)

Phase Transitions and Applications

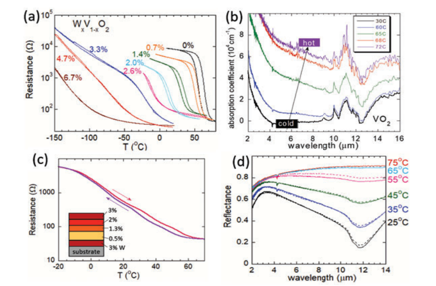




Structural and electronic phase transition in solids are explored in search for new states, effects and applications.



Hysteresis in metal-insulator phase transition in VO_2 is exploited for rewritable metamaterials, memories, and optical modulators.



Unprecedented physical properties from doping and graded doping of VO_2 structures enable smart infrared technologies.

Nature Chemistry, 6, 151-158 (2014); Adv. Mater., 30, 1703878 (2018); J. Am. Chem. Soc. 135, 4850 (2013); Phys. Rev. Lett., 109, 166406 (2012); Phys. Rev. Lett., 108, 096102 (2012).

Acknowledgments

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