The 3rd International Workshop on Scanning Probe Microscopy

2022년 8월 29일(월)~31일(수)

포항 라한호텔

Organized by

apctp 아시아태평양이론물리센터

과학기술정보통신부 BrainLink 한양대 사업단

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고려대학교 기초과학연구원

vdWMRC Van der Waals Materials Research Center

BeCaP Center for Berry Curvature based New Phenomena

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The 3rd International Workshop on Scanning Probe Microscopy

Venue : Lahan Hotel, Pohang, Korea

Period : August 29 (Mon) ~ 31 (Wed), 2022

Overview

The 'International Workshop on Scanning Probe Microscopy(IWSPM)' focuses on interesting science and engineering research using scanning probe microscopy. The conference topics includes semiconductors and metals, magnetic systems, 2D materials and devices, superconductors and topological materials, biological systems, surface reactions, novel instrumentations, and theory and simulations.

Workshop Website : https://apctp.org/wb.php?id=IWSPM2022

Invited Speakers:

Myung-Hwa Jung (Sogang), Woo Seok Choi (SKKU), Joong Il Choi (IBS), Seungbum Hong (KAIST), Junho Suh (KRISS), Taekyeoung Kim (HUFS), Won-Jun Jang (IBS), Kab-Jin Kim (KAIST), Gyung-Min Choi (SKKU), Joonho Jang (SNU), Hyobin Yoo (Sogang), Hyung-Joon Shin (UNIST), Sunghun Kim (KAIST), Jong Hun Kim (SNU), Sangmin An (JBNU), Junghoon Jahng (KRISS)

Organizers:

Jeehoon Kim (POSTECH), Jeong Young Park (KAIST), Jae-Hyuk Choi (KRISS), Jungdae Kim (Ulsan), Donghun Lee (Korea), Hyo Won Kim (Samsung), Doohee Cho (Yonsei), Sang Mo Yang (Sogang), Jewook Park (IBS), Sangjun Jeon (CAU), Kyoung-Duck Park (POSTECH), Daesu Lee (POSTECH), Tae-Hwan Kim (POSTECH)

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So-Jin Park (sjpark@apctp.org)

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Program

Day 1

Date	Session	Time	Speaker
Monday, August 29	Opening	14:00	Jeehoon Kim (POSTECH)
	Chair		Jeong Young Park (KAIST)
	Invited Speaker 1	14:15 - 14:40	Joong Il Choi (IBS) Ambient pressure studies on water-induced surface degradation of MAPbBr3
		14:40 - 15:05	Sangmin An (JBNU) Research on 0D and 2D nanomaterials by using atomic force microscope
		15:05 - 15:30	Jong Hun Kim (SNU)
	Oral	15:30 - 15:45	Jinyoung Yun (POSTECH) In-plane field angle dependence of London penetration depth using a vector-field cryogenic magnetic force microscope
		15:45 - 16:00	Geunyoung Kim (POSTECH) A cryogenic magnetic force microscope with a vector field and its application
	Break	16:00 - 16:30	Break
	Chair		Donghun Lee (Korea)
	Invited Speaker 2	16:30 - 16:55	Kab-Jin Kim (KAIST) Spin pumping induced by magnetic phase transition
		16:55 - 17:20	Joonho Jang (SNU) Scanning quantum sensors to study low-dimensional superconducting and magnetic quantum materialst
		17:20 - 17:45	Gyung-Min Choi (SKKU) Optical detection of spin Hall effect and orbital Hall effect
		17:45 - 18:10	Won-Jun Jang (IBS) Direct observation of multiband charge density waves in NbTe2

Day 2

Date	Session	Time	Speaker
Tuesday, August 30	Chair		Hyo Won Kim (Samsung)
	Tutorial 1	09:10 - 09:50	Sang Mo Yang (Sogang) Piezoresponse force microscopy: from single frequency to band excitation
	Break	09:50 - 10:20	Coffee Break and Workshop picture
	Chair		Jungdae Kim (Ulsan)
	Invited Speaker	10:20 - 10:45	Taekyeong Kim (HUFS) Mapping Fermi-level hysteresis in nanoscale bubbles of few-layer MoS2
		10:45 - 11:10	Seungbum Hong (KAIST) Discriminating osteoconductive surface charge effects from piezoelectric motion in hydroxyapatite using piezoresponse force microscopy
		11:10 - 11:35	Hyung-Joon Shin (UNIST) Catalytic reactions of single molecules on TiO2 surface
	Oral	11:35 - 11:50	Nguyen Huu Lam (Ulsan) Tailoring the type-II Dirac band of NiTe2-xSex via spin-orbit coupling
		11:50 - 12:05	Yongman Kim (KAIST) In Situ Electrochemical STM Imaging of an Au Electrode Identifying the Active Sites during the Electrocatalytic Process
		12:05 - 14:15	Lunch
	Chair		Jae-Hyuk Choi (KRISS)
	Invited Speaker	14:15 - 14:40	Myung-Hwa Jung (Sogang) Better understanding the phase transition of FeRh
		14:40 - 15:05	Hyobin Yoo (Sogang) Operando TEM investigation on domain dynamics in 2D ferroelectric materials
		15:05 - 15:30	Junho Suh (KRISS) Microwave cavity optomechanical force sensors in the quantum regime
	Oral	15:30 - 15:45	Hyoungkug Kim (POSTECH) Layer-Dependent Charge Order in Strongly Coupled IrTe2
	Break	15:45 - 16:00	Break
	Poster	16:00 - 17:30	Poster Session
		18:30 - 20:00	Banquet

Day 3

Date	Session	Time	Speaker
Wednesday, August 31	Chair		Doohee Cho (Yensei)
	Tutorial 1	09:10 - 09:50	Sangjun Jeon (CAU) Scanning Tunneling microscopy and spectroscopy of topological materials
	Break	09:50 - 10:20	Coffee Break
	Chair		Jewook Park (IBS)
	Invited Speaker	10:20 - 10:45	Sunghun Kim (KAIST) Two-dimensional quantum electron system revealed by k-space microscopy
		10:45 - 11:10	Woo Seok Choi (SKKU) Tunable spin exchange splitting in a graphene/LaCoO3 heterostructure
		11:10 - 11:35	Junghoon Jahng (KRISS) Linear and nonlinear spectroscopic nanoimaging by using photo-induced force microscopy
	Closing	11:35 - 11:50	Jeehoon Kim (POSTECH)

Abstract

Tutorial speaker

Piezoresponse force microscopy: from single frequency to band excitation

Sang Mo Yang*

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This is a tutorial talk for students who have basic knowledge of scanning probe microscopy, especially atomic force microscopy (AFM). In this talk, I will introduce piezoresponse force microscopy (PFM), which is a special AFM mode to detect electromechanical response of the materials. Electromechanical response, i.e., mechanical displacement change induced by external electric field, is an intriguing phenomenon, which is widely observed in many material systems. Typical examples range from piezoelectric responses in piezoelectric and ferroelectric materials and flexoelectric responses in dielectric materials to electrochemical strain in ionic systems. In this tutorial, I will introduce the basic principle of PFM and its development history and details from single frequency PFM to band excitation PFM.

Scanning Tunneling microscopy and spectroscopy of topological materials

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Topologically protected states and their application to novel electronic and optical devices have been mainstream in condensed matter physics for a decade. The recent theoretical progress fully classified the topological materials from the symmetry arguments. However, the direct experimental observation and characterization of topological states are ongoing research topics. Here I introduce a method to visualize topological materials' band structure and protected boundary states by utilizing scanning tunneling microscopy (STM) and spectroscopy (STS). This tutorial includes the determination of band dispersion from a quasi-particle interference (QPI) measurement, Berry phase from a Landau level fan diagram, and topological boundary states from a localization length. The STM/STS methods introduced in this tutorial can be extended to exotic superconducting, magnetic, and correlated states that can be emerged with topological states.

Invited Speaker

Ambient pressure studies on water-induced surface degradation of MAPbBr3

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While organic-inorganic hybrid perovskites are emerging as promising materials for next-generation photovoltaic applications, the origins and the pathways of the instability of perovskites remain speculative. Herein, we employ ambient-pressure atomic force microscopy1 (AP-AFM) to carry out surface characterization and atomic-scale analysis of the reaction mechanisms for methylammonium lead bromide (MA(CH3NH3)PbBr3) single-crystal surfaces in environments ranging from ultra-high vacuum (UHV) to ambient pressures. MAPbBr3 single crystals grown in a solution process are mechanically cleaved at UHV to obtain an atomically clean surface.2 We observe surface inhomogeneity on the freshly cleaved MAPbBr3 surface: the coexistence of MA-terminated layers with cubic lay-er heights, and full and partial coverage of PbBr2-terminated defective layers with lower layer heights.3 Consecutive topography and friction force measurements in low pressure water (pwater $\approx$ 10 − 5 mbar) show the creation of degraded patches that are one atomic layer deep, gradually increasing their coverage until fully covers the surface at water exposure of 2 × 106 Langmuir. We ob-served high-friction perimeters of the degraded patches which are equivalent to MABr-flat surface where methylammonium ligand establish strong interaction to the AFM tip, enhancing local friction. We show that exposure to high pressure water (pwater = 0.01 mbar) depletes the organic ligands from the surface of MAPbBr3.

Research on 0D and 2D nanomaterials by using atomic force microscope

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Atomic force microscope (AFM) is the essential tools for revealing intrinsic properties of the low dimensional (-D) materials (0D, 1D, or 2D) along with a high-resolution topographical imaging. In this work, I introduce a news for advanced AFM including studying of 0D/2D nanomaterials by using the AFM. Additionally, I introduce progress of the nanoscale water (liquid) as 0D [1,2] and 2D materials (graphene and MoS2), 3D printing techniques [3] by using the advanced AFM.

References

[1] Phys. Chem. Chem. Phys. 23, 12387-12394 (2021).
[2] Phys. Rev. X 8, 041046 (2018).
[3] Nano-Micro Lett. 14, 13 (2022).

Spin pumping induced by magnetic phase transition

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We propose a novel method to generate a large spin current via spin pumping. We utilize a FeRh which undergoes a magnetic phase transition from an antiferromagnet (AFM) to ferromagnet (FM) around 370 K.[1] The magnetic phase transition of FeRh from AFM to FM accompanies the change of total angular momentum from zero to finite. The change of angular momentum generates a spin current into a neighboring non-magnetic layer, and is converted to the charge current through the inverse spin Hall effect (ISHE). We find that the ISHE voltage is generated exclusively during the phase transition. Furthermore, the measured signal is found to depend on the sign of spin Hall angle and the direction of magnetization of FeRh, confirming that the observed signal indeed originates from the phase transition-induced spin pumping and ISHE. The generated spin current density is at least 3 orders of magnitude higher than those in previous spin pumping reports,[2,3] and is comparable to that generated by the spin Hall effect.[4] Our work provides a novel way to generate spin current, which could be utilized in potential spintronics applications.

References

[1] S. Maat, et al. Phys. Rev. B 72, 214432 (2005).
[2] H. L. Wang, et al. Phys. Rev. Lett. 112, 197201 (2014).
[3] Y. Wang, et al. Nat. Commun. 11, 275 (2020).
[4] L. Liu, et. al. Science 336, 6081, 555-558 (2012).

Scanning quantum sensors to study low-dimensional superconducting and magnetic quantum materials

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Low-dimensional superconductors and quantum magnets are expected to provide crucial information on quantum matters driven by strong interactions. However, the delicate nature of the quantum systems renders problems in conventional measurement techniques. In this talk, I will present our experimental efforts to study these low dimensional quantum matters using the techniques of scanning quantum sensor microscopes, whose quantum mechanically enhanced sensing elements play a key role in achieving detection of delicate signals from various quantum systems.

Optical detection of spin Hall effect and orbital Hall effect

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Spintronics aims an electrical control of the spin degree of freedom in materials. Recently, spin Hall effect and orbital Hall effect have been considered as an efficient mechanism to convert charge current to spin or orbital current in non-magnetic materials. To investigate spin Hall effect and orbital Hall effect, one can detect a spatially non-uniform distribution of spin or orbital on non-magnetic materials or torque on ferromagnet in non-magnet/ferromagnet heterostructures. Optical methods based on the magneto-optic Kerr effect has advantages for these experiments in sensitivity, vector resolution, and time resolution. In this presentation, I will show our recent works for optically detection of the spin and orbital Hall effect.

Direct observation of multiband charge density waves in NbTe2

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Charge density wave (CDW) is the phenomena of charge accumulation accompanied with the periodic modulation of atomic structure due to the instability of Fermi surface. The Peierls model explains CDW formation in a one-dimensional (1D) system owing to electron-lattice instability. However, CDWs formation and its physical properties in two dimensional layered materials could not be simply explained by 1D Peierls model and the explanation using Fermi surface nesting, which is the generalized model of 1D Peierls model, was also still not enough. Recently, the possibility of multiband CDW in the layered material, NbSe2 has been suggested as an alternative explanation for unusual CDWs. Here we report the direct observation of multiband CDWs in NbTe2 using low temperature scanning tunneling microscopy (STM) and spectroscopy (STS). The striped periodic lattice distortions with (3 × 1) and (1 × 9/2) superstructures were characterized in real and reciprocal space. The simultaneous formation of momentum-specific suppressions in the spectral weight and phase shifts of the CDWs related to the superstructures were observed at multiple energies. These unusual energy dependencies are well agreed with the CDWs formed in the multiband electronic structure of NbTe2. Fermi surface nesting and reconstruction of the reciprocal lattice were suggested in developing the multiband CDWs in NbTe2.

Mapping Fermi-level hysteresis in nanoscale bubbles of few-layer MoS2

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Nanobubbles are formed inevitably in transferring process of two dimensional (2D) layered materials onto a substrate and heavily affect the 2D material-based device performance. Here, we report a Fermi-level (Ef) hysteresis imaging strategy based on Kelvin probe force microcopy with gate voltage (Vg) sweeps to study origins and mechanisms of local charge trapping in nanobubble of MoS2 on SiO2. We observe that the Ef-hysteresis is larger in nanobubbles than that in flat region and increases with the height in a nanobubble. We find that the band bending in the dielectric layers owing to the water (H2O) molecules trapped in nanobubble is added to the oxide trap band bending in downward at positive Vg, resulting in the increase the number of oxide traps below Ef and the larger Ef-hysteresis in nanobubbles. The Vg dependent emission time constants extracted from the Ef-hysteresis also confirm that the Ef-hysteresis in nanobubbles could be larger than that in flat regions. Furthermore, we perform the local transfer curve measurements to demonstrate the feasibility of the nanobubble structure with high trap density on the memory device applications, which exhibits the larger current (I)-hysteresis windows compared to those of the flat and reliable programming/erasing operations. Our results provide fundamental knowledge on the local charge trapping in nanobubbles of MoS2 on SiO2, paving the way for practical applications in 2D material based nonvolatile memory devices.

Discriminating osteoconductive surface charge effects from piezoelectric motion in hydroxyapatite using piezoresponse force microscopy

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Here, we present multi-eigenmode piezoresponse force microscopy via Pearson correlation and conducted multiscale material analysis to independently measure the piezoelectric coefficient and the surface charge density of hydroxyapatites (HAp). Quantitative comparison between the measured surface charge density and the conceptual values computed for all possible candidates of the surface charging such as piezoelectricity, chemically induced surface charging, flexoelectricity, and defect dipole moment will be explained and discussed. We found that calcium ions released during local calcium orthophosphate phase transition at the surface act as the main source of the surface charging. We further show that the ion concentration can be tuned using a charged conductive tip. This means that the interstitial ions are mobile within the HAp matrix. In summary, we developed a novel method to measure the effective surface charge density of arbitrary material systems, thereby facilitating the investigation of biophysical phenomena related to surface electromechanics [1].

References

[1] Y. Han et al., J. Appl. Phys. 129, 094902 (2021).

Catalytic reactions of single molecules on TiO2 surface

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The scanning tunneling microscopy (STM) is a unique technology that can resolve the atomic-scale structure and electronic structure of surfaces and single molecules. STM studies on model catalyst systems have enabled us to understand a lot of fundamental and important questions by direct observation of the relevant systems. I will introduce our recent STM studies on TiO2 catalysts. Among various applications of well-known photocatalyst TiO2, advanced oxidation process (AOP) is the technology that generally uses the hydroxyl radicals (• OH), the strong oxidants for degradation of organic contaminants in wastewater. We can produce • OH with the help of primary oxidants such as H2O2 and catalysts. When H2O2 and TiO2 is used together, the concentration of the • OH generated becomes much higher than when used separately, even without UV light. The understanding of this synergistic reaction process would be essential for the further development of AOPs, while very little has been revealed experimentally with respect to H2O2 at the single-molecule level yet. Here, we successfully elucidated the intermediate step of AOP upon adsorption of H2O2 molecules. We found that Ti-O-O-Ti peroxides were formed on the surface of TiO2(110) by dissociative adsorption of aqueous H2O2. TiO2 absorbs UV light and decomposes the water molecule into • OH in aqueous condition. One of the drawbacks of using a photocatalyst for water purification is that photocatalytic efficiency is dependent on the amount of available light. We found that modification of TiO2 surface could enhance the catalytic activity of TiO2 surface. Due to the increased electronic hole density at the TiO2 surface from modifications, water molecules were dissociated into • OH even without the irradiation of UV light. The gap states and charge transfer at the interface played an important role in enhanced catalytic performance.

Better understanding the phase transition of FeRh

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FeRh has attracted much interest because of the first-order phase transition from the antiferromagnetic to ferromagnetic state above room temperature, which is accompanied with a large change in electrical resistance. However, such large resistance change cannot be understood solely by the change in magnetization, i.e., magnetic scattering mechanism between antiferromagnetic and ferromagnetic spin alignments. Recently, we obtained a high-quality FeRh films with a sharp phase transition, which shows no residual magnetic moment in the antiferromagnetic phase. We confirmed that the FeRh films are epitaxially grown with the 45o orientation relationship between FeRh[100] sample and MgO[100] substrate and the magnetic domains follow the crystalline orientation. In this study, we present the electrical transport properties of FeRh through the Terahertz time-domain spectroscopy measurements. From the analysis based on the Drude model, we obtained two important parameters; extrinsic parameter of scattering time, t and intrinsic parameter of charge density divided by effective mass, n/m^*. Since n/m^* abruptly changes at the phase transition temperature, compared to the monotonic increase of t with temperature, we propose the band structure change between the two magnetic phases is a major factor causing the phase transition of FeRh.

Operando TEM investigation on domain dynamics in 2D ferroelectric materials

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Control of interlayer stacking angle in two-dimensional (2-D) van der Waals (vdW) heterostructure enables one to engineer the crystal symmetry to imprint novel functionality. By stacking two layers of transition metal dichalcogenides (TMD) with designed twist angle, one can break the inversion symmetry and thereby develop vertical electric polarization. The direction of the electric polarization can be switched electrically, suggesting that the twisted bilayer TMD can host ferroelectricity. Such ferroelectricity reported in twisted bilayer vdW system is distinguished from conventional ferroelectrics in that the lateral sliding of the constituent layers induces vertical electric polarizations. Due to the reduced dimension, the ferroelectric domains do not require forward growth along the third dimension, suggesting unconventional 2-D domain dynamics under an applied electric field. Here we employ operando transmission electron microscopy (TEM) to investigate the domain dynamics in 2-D vdW ferroelectrics. Operando TEM technique enables one to examine the structural change in the environment that mimics the device operating condition. On a thin SiN based TEM compatible platform, we fabricated double capacitor structure on 2D vdW ferroelectrics. Electrical gating in double capacitor structure and real time observation of structural change in a simultaneous manner provides an insight onto the switching mechanism of the 2-D vdW ferroelectrics.

Microwave cavity optomechanical force sensors in the quantum regime

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Mechanical force sensors such as the microscale silicon cantilevers are essential in scanning force microscopy. The recent advances in the cavity optomechanical systems allow such mechanical sensors to function in the quantum regime, where the fundamental quantum noise of mechanical oscillator becomes relevant in their performance. The optomechanical interaction originates generally from the radiation pressure of light on a movable object, therefore it enables an access to the mechanical quantum oscillator with light at a wide range of frequency spanning from GHz to THz. When one utilizes microwaves at GHz range, it is possible to implement the optomechanical system as a compact superconducting circuit device suitable for cryogenic force sensing near quantum-limit. I introduce the basics of cavity optomechanical systems and discuss recent results from superconducting niobium circuits harnessing the optomechanical interactions[1-2]. These devices demonstrate improvements in operating temperature and magnetic field compared to the previous aluminum devices and present important routes in developing cryogenic, quantum-limited force sensing techniques.

References

[1] J. Cha et.al., Nano Lett. 21, 1800-1806 (2021).
[2] J. Shin et.al., Nano Lett. 22, 5459-5465 (2022).

Two-dimensional quantum electron system revealed by k-space microscopy

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Pure electrons spread in two-dimensional (2D) space can have several different phases of gas, liquid, and even solid − so called Wigner crystal, determined by their kinetic energy and Coulomb potential. In quantum regime, it is expected to have diverse intermediate phases between Fermi liquid and Wigner crystal phases rendered by the quantum fluctuation in addition to electron-electron interactions. In this regard, there have been many efforts to realize pure electron system in quantum regime and to unveil its intriguing physics. However, the requirements to realize such quantum electrons at solid systems set a huge hurdle that the most of the experimental investigations have been limited in the classical regime so far. In this presentation, I report the discovery of pure 2D quantum electron liquid formed on solid 2D electride and its phase transition. By virtue of k-space microscopy, so-called angle-resolved photoemission spectroscopy, we characterized the dense surface electrons decoupled from the top-most layer that means free from lattice and orbital degrees of freedom. By reducing the density of 2D electron system, we observed dynamics change to that of non-Fermi liquid along with anomalous band deformation. The band deformation indicates conserved translational symmetry and reduced rotational symmetry which suggests a phase transition to the hexatic liquid crystal phase. These results can provide further opportunities to study the role of electron-electron interaction which can drive Wigner crystal and various intermediate phases in quantum regime.

Tunable spin exchange splitting in a graphene/LaCoO3 heterostructure

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The heterostructure composed of 2D layered materials and complex oxides serves as a prominent playground in which various synergistic physical and chemical behaviors become evident [1]. Particularly, heterostructures composed of graphene and perovskite oxide thin films have shown the importance of the electronic and chemical interactions between the distinctive material systems, such as large voltage scaling in the quantum Hall effect [2] and quantum sensing of the oxygen vacancy concentration in SrTiO3 [3]. In this talk, we show that the spin degeneracy in graphene can be effectively lifted by the interfacial interaction with ferromagnetic LaCoO3 epitaxial thin film. We demonstrate a giant spin exchange splitting in graphene ranging from 152 to 310 meV, which is further tunable by the gate electric field. The interfacial magnetic proximity effect including effective charge transfer has been identified as the origin of the giant exchange splitting. Our discovery might lead to the spintronics applications of electrically tunable spin polarization using the heterostructure approach.

References

[1] Kang et al. Adv. Mater. 31, 1803732 (2019).
[2] Park et al. Nano Lett. 16, 1754 (2016).
[3] Kang et al. Adv. Mater. 29, 1700071 (2017).

Linear and nonlinear spectroscopic nanoimaging by using photo-induced force microscopy

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We present a theoretical and experimental analysis of linear and nonlinear optical responses for a low dimensional material with a 10 nm spatial resolution by using the novel type of microscopy – photo-induced force microscopy (PiFM). The photo-induced forces, strongly localized by the tip-enhanced field, depend on the local response of the media, which covers from induced dipole interaction to thermal expansion. This approach shows higher sensitivity and 1,000 times better spatial resolution than conventional ensemble averaged infrared microscopy, even under ambient and environmental conditions. The ability to apply AFM's for nanometer scale optical spectroscopic will open new opportunities in materials science and biology by investigating the linear and nonlinear optical response of individual structures.

Oral

In-plane field angle dependence of London penetration depth using a vector-field cryogenic magnetic force microscope

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Revealing the pairing symmetry of the superconductor is of importance for understanding the mechanism of superconductivity. So far a variety of measurements have been carried out using numerous techniques to unveil the pairing symmetry. Nevertheless, the gap symmetry of various superconductors is still under debate. Here we suggest novel technique to investigate the pairing symmetry using a cryogenic vector-field magnetic force microscopy (MFM), equipped with a 2-2-9-T vector magnet. A cryogenic MFM is one of sensitive local probes to measure the superconducting parameters such as London penetration depth and pinning force in the superconductor. Our method focuses on extracting the local variation of the penetration depth with respect to the in-plane field angle, which is closely linked to the pairing symmetry.

A cryogenic magnetic force microscope with a vector field and its application

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Cryogenic magnetic force microscope (MFM) with a vector field provides an opportunity to investigate unconventional phenomena in magnetic materials and superconductors. Here we present the construction of a low temperature MFM equipped with a 2-2-9 T vector magnet and its application for magnetic materials and superconductors. To demonstrate the capability of the MFM for low temperature and vector field, we performed the field-angle-dependent MFM experiments in a van der Waals magnetic insulator Cr2Ge2Te6. The result, showings a domain transition from the stripe to the bubble phase with respect to the magnetic field angle, may be related to the magnetic anisotropy of the Cr2Ge2Te6. As for superconducting materials, we obtained a pinning force in a single-vortex level by using the novel Meissner current induced manipulation (MCIM) in a Nb film, which is able to measure the pinning force of vortices by combining the MFM technique and Meissner current induced by an in-plane magnetic field. The results show that our vector-field cryogenic MFM is useful for investigating various anisotropic phenomena in magnetic materials and superconductors.

Tailoring the type-II Dirac band of NiTe2-xSex via spin-orbit coupling

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NiTe2 with type-II Dirac band has attracted widespread interest due to its interesting topological properties and potential applications. Here, in scanning tunneling spectroscopy measurements, the differential conductance spectra showed that the peaks near the Fermi level EF negatively shift, reflecting the evolutions of tilted Dirac bands in the NiTe2-xSex alloy. Indeed, using combined density-functional theory calculations and angle-resolved photoemission spectroscopy, we confirmed the movement of the bulk Dirac point moves from +0.1 eV above Fermi level EF (NiTe2) to −0.3 eV below EF (NiTeSe) depending on the Se concentrations, while the type-II Dirac band is preserved. Our work demonstrates an approach to tailor the type-II Dirac band in NiTe2 by controlling the spin-orbit coupling strength via chalcogen substitution. This approach expected can be applied to manipulate the topological character of other chalcogen materials.

In Situ Electrochemical STM Imaging of an Au Electrode Identifying the Active Sites during the Electrocatalytic Process

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Understanding the influence of surface structural features is important for guiding mechanistic proposals for electrocatalytic reactions of the electrode. However, atomistic knowledge of the actual active sites remains elusive, because of the complicated relationship between structural stability and catalytic activity. With this in mind, we have focused on the fundamentals of the electrocatalytic process, using in situ electrochemical STM, and on locating the real active sites, a longstanding issue. In this work, we present STM results on two-dimensionally well-ordered manganese porphyrin structures on Au(111). We show that manganese porphyrins are oxidized after water oxidation and promptly decompose into catalytically active species as bright protrusions. These newly formed active species have dramatically lost their catalytic activity, either by acid treatment, one of the oxide removal methods, or by deposition of phosphonic acid, one of the oxide−favoring materials. This confirms that the active species are composed mainly of manganese oxides as a water oxidation catalyst. We extended our study to examine the surface structural sensitivity of Au single crystals itself for electrocatalytic CO2 reduction as a simple model study. As the most active electrocatalyst for CO2 conversion into CO, Au(hkl) shows structural dependency on coordinated sites, such as the terrace of Au(111) and the steps of Au(332). Through real-time electrochemical STM measurements, we have confirmed that these are the actual active sites for CO2 reduction. A remarkable finding of our work provides the molecular evidence for Au and modified-Au electrode's active sites, providing impetus for future application in water oxidation and CO2 reduction catalysts, as the data establishes a relationship between catalytic activity and structural changes.

Layer-Dependent Charge Order in Strongly Coupled IrTe2

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Tuning dimensionality induces various phase transitions, such as superconductivity [1, 2], charge density waves [3, 4], and structural symmetry [5, 6]. A quasi-two-dimensional system with weak interlayer couplings and strongly bonded in-plane layers is an attractive playground to control the dimension by a simple mechanical exfoliation [7, 8]. However, the reduction of thickness up to monolayer regime in IrTe2, one of the widely studied van der Waals materials, is challenging because tellurium atoms between layers bond covalently [9]. Here, we employ an aluminum-oxide-assisted exfoliation technique to obtain the atomically thin IrTe2 flakes ranging from monolayer to seven-layer IrTe2. We use scanning tunneling microscopy and spectroscopy to demonstrate that stripe charge orders of IrTe2 evolve gradually as the thickness increases and the Coulomb gap at the Fermi level decays exponentially. Furthermore, the sensitivity of charge orders to layer number drives two different electronic density of states in an edge between an ordered and trivial phase. The thickness-dependent evolution of charge orders thus offers a powerful method to control the density of stripe charge orders in IrTe2 and further to tailor superconductivity in IrTe2 that may depend on its thickness.

References

[1] X. Xi, Z. Wang, W. Zhao, J.-H. Park, K. T. Law, H. Berger, L. Forro, J. Shan, and K. F. Mak, Nat. Phys. 12, 139 (2016).

[2] Y. Song, T. Ying, X. Chen, X. Han, X. Wu, A. P. Schnyder, Y. Huang, J. G. Guo, and X. Chen, Phys. Rev. Lett. 127, 237001 (2021).

[3] X. Xi, L. Zhao, Z. Wang, H. Berger, L. Forro, J. Shan, and K. F. Mak, Nat. Nanotechnol. 10, 765 (2015).

[4] P. Chen, Y. H. Chan, R. Y. Liu, H. T. Zhang, Q. Gao, A. V. Fedorov, M. Y. Chou, and T. C. Chiang, Phys. Rev. B 105, L161404 (2022).

[5] J. Lin, S. Zuluaga, P. Yu, Z. Liu, S. T. Pantelides, and K. Suenaga, Phys. Rev. Lett. 119, 016101 (2017).

[6] Z. Ni, H. Zhang, D. A. Hopper, A. V. Haglund, N. Huang, D. Jariwala, L. C. Bassett, D. G. Mandrus, E. J. Mele, C. L. Kane, and L. Wu, Phys. Rev. Lett. 127, 187201 (2021).

[7] S. Ghosh, W. Bao, D. L. Nika, S. Subrina, E. P. Pokatilov, C. N. Lau, and A. A. Balandin, Nat. Mater. 9, 555 (2010).

[8] W. Jin, P. C. Yeh, N. Zaki, D. Zhang, J. T. Sadowski, A. Al-Mahboob, A. M. Van Der Zande, D. A. Chenet, J. I. Dadap, I. P. Herman, P. Sutter, J. Hone, and R. M. Osgood, Phys. Rev. Lett. 111, 106801 (2013).

[9] S. Park, S. Y. Kim, H. K. Kim, M. J. Kim, T. Kim, H. Kim, G. S. Choi, C. J. Won, S. Kim, K. Kim, E. F. Talantsev, K. Watanabe, T. Taniguchi, S.-W. Cheong, B. J. Kim, H. W. Yeom, J. Kim, T.-H. Kim, and J. S. Kim, Nat. Commun. 12, 3157 (2021).

Poster

The correlation between in-gap states and the stacking order in the insulating phase of 1T-TaS2

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Although 1T-TaS2 has an odd number of electrons, it shows insulating characters at low temperatures with the formation of the charge density wave (CDW) cluster, so-called the Star of David (SD). This state has long been known as the Mott-insulating state, attributed to the charge localisation at the SD centre. Recent studies have reported that the surface electronic structure of 1T-TaS2 ¬is considerably affected by not only the on-site Coulomb repulsion but also the stacking configurations, which could result in a metallic, band-insulating or Mott-insulating state. Despite much progress, we lack an understanding of the bulk electronic structure governed by the stacking order in correlated layered materials. Here, we observe surface areas corresponding to the band-insulating state with the bandwidths of in-gap states varying with and without the presence of surface domain walls by conducting scanning tunnelling microscopy and spectroscopy measurements on the 1T-TaS2 surface. This indicates that their bandwidths could be a key hint to identifying the stacking order of 1T-TaS2. The analysis of the stacking order dependent electronic structure may lead to a better understanding of different insulating states driven by various external control parameters, such as doping, pressurisation and optical (electrical) pulses in the bulk 1T-TaS2.

Strain Induced Domain Switching in Two-Dimensional Topological Insulators, 1T'-MoTe and 1T'-WTe_2

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Topological insulators (TIs) show protected metallic states on their boundaries of insulating bulks that can be either edges, surfaces, interfaces or dislocations. Symmetry of the crystal structures further diversifies these boundary states and classifies TIs with different topologi-cal index. Although such topological states at the non-symmorphic boundary in two dimen-sional (2D) TIs, in particular, 2D transition metal dichalcogenides with 1T'-MX_2 chemical formula (M is Mo or W, and X is S, Se or Te.), have been experimentally observed [1], and created [2], fundamental understanding on the formation mechanism for those boundaries is still lacking. Here, we introduce a novel method for such structural redesign and report the experimental demonstration of controlled and reproducible ferroelastic domain switching be-tween three orientational variants of the 1T' phase of $MoTe_2$ and WTe_2, which can form sym-metry-dictated topological boundaries, using the tip of a scanning tunnelling microscope (STM).

References

[1] H. W. Kim et. al., Nano Lett. 20, 5837 (2020).
[2] Z. Pedramrazi et al, Nano Lett. 19, 5634 (2019).

Phase-Dependence on the Friction of Exfoliated MoX2 (X:S, Te) Layers

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Transition metal dichalcogenides (TMDs) 2-dimensional (2D) material is widely studied for its semiconducting nature. Among TMDs, the molybdenum disulfide (MoS2) monolayer is an atomically thin semiconductor with a bandgap of 1.8 eV, which makes it potentially suitable for applications in thin-film transistors. MoS2 is also getting attention as an anode for Li-ion batteries, because of its Li intercalation mechanism. Electron donations from Li induce a MoS2 phase transition from the stable semiconducting 2H phase to the metallic 1T phase. While MoS2 chemically exfoliated with Li showed friction at a similar level with mica, mechanically exfoliated MoS2 exhibits significantly lower friction than mica We turned mechanically exfoliated 2H-MoS2 into 1T-MoS2 by a lithiation process and measured atomic-scale tribological and electrical properties of MoS2, including friction, with atomic force microscopy (AFM). We report that the friction of MoS2 increased significantly with the phase transition of 2H to 1T. The friction proportion of 2H-MoS2 and 1T-MoS2 is 0.12:1.07, with normalization to the value of mica. We also measured the friction of molybdenum ditelluride (MoTe2), of which the pure 1T phase is commercially available, since it shows a stable 1T phase as well as a 2H phase. The friction proportion of exfoliated 1T-MoTe2 and 2H-MoTe2 is 0.18:1.09, normalized with the friction of mica. With density functional theory (DFT) calculation, we attribute the higher friction of 1T-MoX2 to the increased overlap of phonon density of states (DOS) with mica substrate, as well as the higher energy barrier in the potential energy surface of 1T-MoX2. The study suggests the intriguing possibility of tuning friction by a phase transition of 2D materials.

Observation of charge density wave (CDW) boundaries on a surface of vanadium-based Kagome magnets

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Various studies have been conducted on V-based Kagome magnets (AV3Sb5, A=K, Rb, Cs) in relation to charge density wave (CDW)[1], [2], unconventional superconductivity[3], and anomalous Hall effect[4]. The unusual electronic structures are proposed to be originated from the Dirac cone, van Hove singularities, and flat band inherent in the Kagome structure[5], [6]. Among the phenomena, CDW is considered essential in understanding the collective nature of electrical conduction in low-dimensional material and promoting strongly correlated interactions. CDW domain boundaries, where charge order is forced to break, have been suggested to generate emergent properties such as multiferroicity, superconductivity, and topological vortex[7]. This research investigated various CDW boundaries formed on a RbV3Sb5 by breaking in-plane and out-of-plane translational symmetries. The complicated structure of CDW with Rb reconstruction on a surface of RbV3Sb5 produces rich domain structures and boundaries. We suggest structural models of the boundaries and discuss a variation of an electronic structure near the boundaries formed on the surface of a Kagome magnet.

References

[1] H. Li et al., “Rotation symmetry breaking in the normal state of a kagome superconductor KV3Sb5,” Nat. Phys., vol. 18, no. 3, Art. no. 3, Mar. 2022, doi: 10.1038/s41567-021-01479-7.

[2] H. Zhao et al., “Cascade of correlated electron states in the kagome superconductor CsV3Sb5,” Nature, vol. 599, no. 7884, Art. no. 7884, Nov. 2021, doi: 10.1038/s41586-021-03946-w.

[3] H. Chen et al., “Roton pair density wave in a strong-coupling kagome superconductor,” Nature, vol. 599, no. 7884, Art. no. 7884, Nov. 2021, doi: 10.1038/s41586-021-03983-5.

[4] S.-Y. Yang et al., “Giant, unconventional anomalous Hall effect in the metallic frustrated magnet candidate, KV3Sb5,” Sci. Adv., vol. 6, no. 31, p. eabb6003, Jul. 2020, doi: 10.1126/sciadv.abb6003.

[5] N. J. Ghimire and I. I. Mazin, “Topology and correlations on the kagome lattice,” Nat. Mater., vol. 19, no. 2, Art. no. 2, Feb. 2020, doi: 10.1038/s41563-019-0589-8.

[6] L. Ye et al., “Massive Dirac fermions in a ferromagnetic kagome metal,” Nature, vol. 555, no. 7698, Art. no. 7698, Mar. 2018, doi: 10.1038/nature25987.

[7] S. Lim, J. Kim, C. Won, and S.-W. Cheong, “Atomic-Scale Observation of Topological Vortices in the Incommensurate Charge Density Wave of 2H-TaSe 2,” Nano Lett., vol. 20, no. 7, pp. 4801−4808, Jul. 2020, doi: 10.1021/acs.nanolett.0c00539.

Microscopic investigation on the charge density wave in bulk VTe2

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Vanadium ditelluride (VTe2) is a rare example of a material exhibiting CDW phase above room temperature. Here, we conducted a systematic study on the CDW phase of bulk VTe2 via scanning tunnelling microscopy (STM) combined with density functional theory (DFT) calculations. The STM topograph of bulk VTe2 shows a stripe modulation with 3 × 1 periodicity, which indicates the signature of CDW phase. Interestingly, the 3 × 1 CDW modulation undergoes contrast inversion between filled and empty state topographs. Atomistic features and contrast changes of CDW observed in STM are clearly reproduced in our DFT simulation images. Charge distribution calculation indicates that the spatial extension and density of Te 5p orbitals have strong variations with filled and empty states, explaining the fine structure of 3 × 1 CDW in VTe2. Our finding provides an inspirable insight for further research on yet less explored electronic structure of VTe2.

AFM Probing of Nanoscale Triboelectric Charge on Gamma-ray Irradiated Fluorinated Ethylene Propylene (FEP)

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Recently, the triboelectric nanogenerator (TENG) using triboelectrification has attracted interest in various fields due to its high output power and low manufacturing cost. Polymer materials have been used as a surface material of TENG because of its high energy conversion efficiency. However, while mechanisms of triboelectrification are well established in metal and semiconductors, mechanisms of triboelectrification in polymer, which is a nonconductor, have been continuously debated. In this study, we show the triboelectrification characteristics of fluorinated ethylene propylene (FEP) influenced by the amount and humidity of gamma-ray investigated to find out whether mechanochemistry contributes to the triboelectrification of polymer. Through the contact mode atomic force microscopy (AFM) and kelvin probe force microscopy (KPFM) analysis method, we observed the local triboelectric charge and charge decay phenomenon on the FEP surface, and found that there is a difference between the contact potential difference (CPD) value and charge decay tendency which is varied by the amount of irradiated gamma − ray, and humidity. We show that the triboelectrification properties of the FEP polymer change with the increased mechanochemical product by gamma − rays, and humidity, indicating that the mechanochemistry is closely related to the triboelectrification of the polymer.

Optical simulations for geometries of tip-enhanced cavity-spectroscopy

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Electromagnetic cavity modes in plasmonic resonators gives numerous properties of light−matter interaction. Here, we found that nano assembled two golden tips can localize light to a volume less than 1 cubic nanometer. Since picocavities with ultrasmall localization of light contain various plasmonic modes, we present a tip-force control combined with tip-enhanced photoluminescence (TEPL) simulations for optimized picocavities at the nanoscale.

Lubrication of Au(111) surface by Condensed Water Molecules and Reduction of Contact Stress

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Contact between surfaces is essential in tribology. Especially in atomic force microscopy (AFM) measurements, friction between tip and sample may vary when material of tip changes. Many parameters could change friction between tip and sample. For example, velocity of tip when scanning, shape of a tip, medium of surroundings like liquid or gas, etc affect friction measurements. In order to investigate the influence of water on the tribological properties, we conducted AFM measurements for friction detection in various humidity conditions: from UHV to 0.1mbar of water. At low humidity conditions, the plot of the friction force versus the normal load follows JKR-DMT model. However, when it comes to higher water pressure conditions, friction between conducting diamond tip and sample is reduced at the low load, suggesting the passivating role of water layers. At the higher load or low humidity condition, it fails to distribute stress effectively and higher lateral force is detected due to the penetration of the AFM tip through the water layer followed by the plastic deformation of Au (111). These experimental results may be helpful when understanding nanotribological characteristics when humidity condition is important.

All-optical control of excitonic conversion dynamics in atomically thin semiconductors

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The spatial control of the excitonic quasiparticles in 2D semiconductors has been extensively studied because it paves the way for developing a range of exciton-based optoelectronic devices and circuits. The recent study revealed the intrinsically low funneling efficiency of the neutral exciton (X0) at room temperature.

Investigation of epitaxial WS2 monolayer on zigzag Au substrate using scanning tunneling microscopy

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Monolayer transition metal dichalcogenides (TMDs) have been extensively investigated owing to their unique physical properties, such as atomically thin nature and tunable electronic properties. Furthermore, the presence of the substrates can induce drastic changes to the properties of such materials in various ways including charge doping and strain. Here, employing scanning tunneling microscopy and spectroscopy (STM/S), we characterize the epitaxial WS2 monolayer grown on the high-index Au surface which was recently introduced as a unique platform for single-crystalline TMD synthesis. High-resolution STM imaging reveals that intrinsic sulfur vacancies are predominant. Interestingly, alternating doping level of WS2 with atomically sharp boundaries is observed, and a direct correlation with the zigzag-like morphology of the Au substrate is revealed by STS mapping. From the Fourier analysis, two major superstructures between the WS2 and substrate are found, implying that different interlayer coupling may lead to the alternating doping level.

Direct observation of multiband charge density waves in NbTe2

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Charge density wave (CDW) is a low energy state that appears in systems with reduced dimensionality, and the lattice distortion affects the electronic ground state at low temperature. While plenty of materials host CDW and other correlated phases simultaneously, a lack of understanding of the mechanism and aspect of CDW hinders the interplay between CDW and other unconventional phenomena. In this work, the characteristics of multiband CDWs in NbTe2 were examined using low-temperature scanning tunneling microscopy/spectroscopy (STM/STS). (3×1) and (1×9/2) CDWs were identified and investigated with various analyses of STM/STS data. Momentum specific suppression in the spectral intensity of Fourier transformation of STS data was observed at multiple electronic energies. The spatial phase shift and amplitude suppression of CDW were extracted from the data and compared with a set of toy model simulations. With the comparison, we suggest that Fermi surface nesting and reconstruction of the reciprocal lattice play a crucial role in developing the multiband CDWs in NbTe2.

Electric Field-assisted Patterning of Few-layer MoTe2 by Scanning Probe Lithography

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The discovery of two-dimensional materials, such as graphene and transition metal dichacogenides (TMDs), and the novel properties of these materials have promoted research for the next generation of materials that may be essential for the development of new technologies such as ultra-thin, flexible, nanoelectronic, and optoelectronic devices. In particular, monolayer group VI two-dimensional (2D) transition metal dichalcogenides with 1T' phase, 1T'-MX2, where M is Mo or W and X represents S, Se, or Te have garnered much attention as notable 2D topological insulators (TIs). In order for these materials to be useful as next-generation devices, it is critical to precisely pattern and create the edge state of 2D TIs. Here, we present a surface patterning method to remove one or few top layers of 1T' MoTe2 at desired position and create a hole or trenches with step edges which can have topological edge states using by atomic force microscopy and scanning tunneling microscopy. By adjusting the pressing force and the magnitude of the applied voltage, we can control their depth and width.

Study on the classification of surface properties of fluorinated graphene via AFM

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Recently, many 2D materials have been widely used and studied in the field of nanotechnology due to their excellent properties. Therefore, it will also be important to fabricate 2D material samples at the nanoscale and to classify them according to their properties. We mechanically removed the surface doping of fluorinated graphene via contact mode AFM [1] and classified their surface properties through LFM and KPFM. In addition, the SVD method was used to remove noise from the measurement image to increase the image accuracy. This method using AFM with high resolution can be used to characterize nanomaterials with very small sizes or complex patterns in the future.

References

[1] J. R. Felts, A. J. Oyer, S. C. Hernández, K. E. Whitener Jr, J. T. Robinson, S. G. Walton and P. E. Sheehan, Direct mechanochemical cleavage of functional groups from graphene, *Nat. Commun.* **6**, (2015) 6467, https://doi.org/10.1038/ncomms7467

Temperature-dependent piezoresponse force microscopy study of Moiré superlattices in twisted bilayer WSe2

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Moiré superlattices in van der Waals heterostructures exhibits various physical properties such as superconductivity, magnetism, and topological edge states. Reconstruction of atoms within the individual layers occurs for small twist angles, yielding the periodic domain structures with different energy levels. Among these physical properties, ferroelectricity in the Moiré superlattices has recently attracted considerable attention for its potential applications, including nonvolatile memories. Here, we present our recent efforts to study temperature-dependent piezoresponse of two-dimensional Moiré superlattices in twisted bilayer WSe2. By taking a line-by-line snapshot of their temperature varied response, we cautiously insist that the domain wall of the Moiré structure gets blurry as the sample is heated. We discuss the origin of this thermal effect in terms of ferroelectric phase transition.

Effect of deposition parameters on sputtered ferroelectricity in hafnium-zirconium oxide thin film capacitors

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Recently, HfO2-based ferroelectric materials have attracted a lot of attention due to many advantages such as high tolerance of read and write, CMOS capability, and very small critical thickness. Especially, hafnium-zirconium oxide (Hf1-xZrxO2, HZO) is one of the extensively studied HfO2-based ferroelectric materials, with its relatively wide dopant range (x = 0.3 − 0.5) to exhibit ferroelectricity. RF sputtering method is a widely used deposition technique for HZO thin film capacitors due to better productivity and capability on current industrial deposition structure. However, sputtering technique has many process parameters, including RF power, argon flow rate, and operating pressure, and thus it is relatively difficult to grow high-quality HZO thin films. Also, it is well known that top electrode materials also affect ferroelectricity of HZO structure. In this work, we present our recent efforts to grow ferroelectric HZO thin film capacitors. We fabricated HZO thin film capacitors varying top electrode materials, HZO deposition power, operation pressure, and annealing temperature. We investigated the physical properties of HZO capacitors using GI-XRD, polarization-voltage hysteresis, PFM spectroscopy and so on. Especially, we discuss the effect of operation pressure ferroelectricity in HZO thin film capacitors.

Study on gelatin biomaterial for embryonic stem cell cultivation by measuring Young's modulus via an atomic force microscope

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Coating of biomaterials in culture plate such as gelatin is commonly used for culture of mammalian cells as a tissue to support the attachment and survival. Gelatin is typically derived from collagen-related extracellular protein, and the gelatin-coated glass template is commonly used for culturing of the embryonic stem cell (ESC) instead of other expensive biomaterials [1]. However, studies on the density or coating structure of gelatin used in cell culture are lacking depending on those mixing ratio. In this study, we employ an atomic force microscopy (AFM) to study the correlation between ESC growth and the density of gelatin by measuring its Young's Modulus [2]. We confirmed from the measurement that young's modulus decreases as the mixing ratio of gelatin increases. Through these results, we expected to optimize the ESC culture decent condition by determining the appropriate density range of gelatin. Finding a range of densities of gelatin that can maximize the rate and condition of ESC growth will help producing organoids in good conditions for 3-dimensional tissue culture using gelatin-coated culture matrix.

References

[1] Benjamin Stanley Platt, *Biochem J*, **21**(1), 16-18 (1927).

[2] Seongoh Kim, Yunkyung Lee, Manhee Lee, Sangmin An*, and Sang-Joon Cho*, "Quantitative Visualization of the Nanomechanical Young's Modulus of Soft Materials by Atomic Force Microscopy", *Nanomaterials* **11**(6), 1593 (2021).

Fast reconstruction of distortion-corrected quasiparticle interference patterns using machine learning

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Quasi-particle interference (QPI) patterns in scanning tunneling microscopy play a major role in understanding electrical properties of materials. In particular, QPI patterns have strong advantages in exploring the symmetry of 2D materials, superconducting natures, topological properties, etc [1-3]. However, it takes a lot of measurement time to obtain meaningful QPI data. Due to the long measurement time, thermally driven special distortion of the QPI data is unavoidable. Here, we introduce an alternative method to obtain QPI data by correlating scanning tunneling spectra with topography through machine learning with convolutional neural network [4]. This strategy easily corrects the unwanted distortion of QPI data and allows us to obtain reliable QPI data within a reasonable time. Furthermore, we can generally apply this method to any physical systems, where we can measure a relationship between topography and spectra.

References

[1] C. Fang et al., Phys. Rev. B 88, 125141 (2013).
[2] Y. Gao et al., Sci. Rep. 5, 9251 (2015).
[3] W.-C. Lee et al., Phys. Rev. B 80, 245439 (2009).
[4] S. Albawi et al., "Understanding of a convolutional neural network," in 2017 Int. Conf. on Engineering and Technology (ICET) (IEEE, Turkey, 2017) pp. 1 − 6.

3D microwire fabrication of CdSe quantum dot using Micropipette-combined QTF-AFM and in situ Raman spectroscopy

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Research on patterning and printing at the nanoscale has been actively conducted due to advances in photo, e-beam and dip-pen lithography. The aforementioned techniques are very fine, but there are some drawbacks. In the case of photolithography, diffraction occurs at the edge of the light source and the mask and the wafer. In the case of e-beam lithography, a large amount of voltage is required when operating it. Lastly, in the case of dip-pen, since the patterning after the tip and surface of the sample contact each other, multiple printing cannot be performed, and the tip is severely damaged. Above all, the common disadvantage among these three technologies is that only allow printing and patterning, but do not perform additional function such as measurement [1]. Therefore, in this study, we developed the new setup that overcome the disadvantage of dip-pen for tip damage and unlike e-beam, it does not require a large amount of voltage, and there is no worry about diffraction because it does not use a mask for patterning and it can measure Raman spectrum of the sample. So patterning is attempted using Micropipette-combined QTF-AFM [2]. This equipment will be used to print CdSe quantum dot 3D microwires on a glass surface [3]. And immediately after patterning, in order to obtain a Raman spectrum with information that can clearly understand the intrinsic properties of a material in one setup, a Raman spectroscopy setup is installed under the printing setup, and the Raman spectrum of the CdSe microwire is obtained immediately after printing [4].

References

[1] D. Cyranoski, Science education: Reading, writing and nanofabrication, *Nature* **460**, 171-17 2 (2009).

[2] A Fang, E Dujardin, T Ondarcuhu, Control of the Droplet Size in Liquid Nanodispensing. *Nano Lett.* **6**(10), 2368-2374 (2006).

[3] S. An et al., *Rev Sci. Instrum.* **85**, 0033702 (2014).

[4] A. Balandin, *Appl. Phys. Lett.* **76**, 137 (2000).

Construction of a low-temperature scanning tunneling microscope for studying 2D materials

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Scanning Tunneling Microscopy(STM) has been played a crucial role in determining the surface and the electronic structure of the condensed matter system. Especially 2low--dimensional hetero systems. have been shown interesting properties. Here we report the construction process of home-built low-temperature UHV STM for measuring studying 2D materials and devices. The microscope includes a sample stage with dual sample holders: one for a reference sample and another for a device sample with three electrodes. The long-range X-Y motion stage (7mm X 2mm) and position sensors (10 μm resolution) are installed to locate two samples and navigate micron-sized 2D flakes on a device sample. An external optical microscope is installed to guide the positioning of the tip, and an E-beam evaporator is placed for depositing individual atoms to functionalize the 2D devices. We also designed and built an attachable glove box to the load-lock chamber for transferring air-sensitive 2D devices. We can explore correlated electronic states of various hetero-structured 2D samples by utilizing this specially designed STM system. After constructing basis parts of STM such as STM head, sample stage with dual sample holders, gatable sample holder and cryostat, we added some equipment for supporting to measure the 2-D devices. For working under vacuum or inert gas conditions, we added glove box on prep camber. We design own evaporator in front of head to add defect on 2-D devices. Capacitance sensor will make us to know location of head without breaking experiments conditions. The spring damper installed on the top of inner Dewar improves noise condition. We could do more precise study of 2D hetero devices under UHV conditions. At present, we are measuring single crystal copper and Nbse2.

Pressure-induced superconductivity in Wely metal

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Owing to chiral anomaly, a Weyl metal shows negative MR and non-ohmic behavior. In this work, we show superconductivity under pressure in the Weyl state of Bi0.96Sb0.04. The superconductivity shows multi-band nature, which may result from the multi-band nature of the sample system. The close relation between superconductivity and negative longitudinal registivity suggests that the observed superconductivity may originate from the chiral anomaly.

Study of CO2 Reduction Reaction in Cu-Phthalocyanine on Au(111) using In-Situ Electrochemical Scanning Tunneling Microscopy

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Electrochemical CO2 reduction reaction (CO2RR) is essential to afford a promising solution for increase of CO2 concentration in atmosphere. To design effective electrocatalysts for CO2RR, the fundamental understanding of CO2RR mechanism is required. Metal-phthalocyanine is one of the attractive catalysts due to its structural uniformity and tunability. We fabricated adlayer of Cu-phthalocyanine (CuPC) molecules on Au(111) surface (CuPC/Au system) by immersion method, and investigated CO2RR in the CuPC/Au system using electrochemical scanning tunneling microscopy (EC-STM) to reveal CO2RR mechanism at the sub-molecular level. The CuPC adlayer on Au(111) surface showed the highly-ordered configuration. This configuration was also well maintained in the CO2-saturated 0.1M KHCO3 electrolyte solution. When applying cathodic electrode potentials, the ordered CuPC adlayer could not be found, but we detected the nanosized clusters. The size and density of cluster increased significantly at an electrode potential of −0.7 V vs Ag/AgCl, where CO2RR occurs actively, showing that the formation of cluster correlates to CO2RR on CuPC. In this work, we have confirmed the morphological change according to CO2RR on CuPC by the in-situ EC-STM measurements.

Anisotropic impurity states and electron scattering in Black Phosphorus

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Microscopic electronic phenomena can mediate macroscopic properties like electric conductance, resistivity, and band structure. Black phosphorus, which has puckered honeycomb lattice, has native vacancy defects that cause intrinsic p-doping. Low-temperature scanning tunneling microscopy/spectroscopy (LT-STM/STS) is widely applied to visualize the local density of states and the electron scattering patterns. Here, using LT-STM/STS, we unveil the existence of highly anisotropic impurity states and electron scattering close to the vacancies. In addition, we focus on the near-complete suppression of scattering along the (010) direction perpendicular to the higher conductive direction. The FFT spectra of the energy-dependent differential conductance maps will be compared with ARPES results and tight-binding calculations to characterize the impurity scattering potential.
Keywords: black phosphorus, electron scattering, scanning tunneling microscopy.

Anomalous ferroelectric domain switching in woken-up Si-doped HfO2 thin film capacitors

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The HfO2-based ferroelectric thin films have attracted a great of attention due to their potential applications, such as non-volatile memories and negative capacitance field effect transistors. Especially, compared to conventional ferroelectrics, the HfO2-based ferroelectrics have many advantages, including full CMOS compatibility, large bandgap, and very small critical thickness. The operation principle of ferroelectric-based memories is the polarization switching induced by the application of external electric field. Therefore, understanding ferroelectric domain switching dynamics is one of the most important prerequisites for the realization of HfO2-based memories. In particular, it is highly required to directly observe how ferroelectric domain nucleates and grows at the nanoscale in real capacitor geometry. Here, we present our recent efforts to study ferroelectric domain switching dynamics in Si-doped HfO2 thin film capacitors using piezoresponse force microscopy (PFM). In most regions, we observed normal domain switching; namely, the domains aligned along the applied electric field by domain nucleation and growth. However, in some regions, the domains aligned against the applied electric field, the-so-called “anomalous domain switching”. Using the stroboscopic PFM imaging and local PFM spectroscopy, we investigated the difference between normal and anomalous domains. We discuss the possible origin of the anomalous domain switching in the Si:HfO2 capacitors.

Effect of Water Vapor on Oxidation Process of Cu(111) Surface and Sublayer

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Copper-based materials are used for heterogeneous catalytic reactions, including CO oxidation, low-temperature water gas shift reactions, and CO2 hydrogenation. These applications could benefit from a better understanding of the transitions between different copper-based oxidation states, metallic Cu, Cu2O, and CuO. In this work, we directly observed different oxidation process-es on a Cu(111) single crystal, using near-ambient pressure scanning tunneling microscopy (NAP-STM) and X-ray photoelectron spectroscopy (NAP-XPS). The Cu(111) surface started to be oxidized at 0.01 Torr of pure O2 under dry oxidation conditions. Time-lapse NAP-STM and NAP-XPS results showed that dry oxidation started at the step-edges in the form of adsorbed oxygen atoms, O(ad), and progressed to the terrace in the Cu2O phase. In addition, independent oxidations on the metallic Cu(111) terrace provided a more collapsed Cu2O/Cu(111) surface structure. Under H2O/O2 mixed gas conditions, the humid oxidation of the Cu(111) surface occurred at 0.02 Torr. Time-lapse NAP-STM images demonstrated that the oxidation also proceeded from the step-edges to the terrace, but there were no independent oxidations on the terrace, leading to fewer defect sites on the Cu2O/Cu(111) surface. Time-lapse NAP-XPS results showed that the appearance of O(ad) and Cu2O peaks were similar to dry oxidation. Hydroxides were observed after the surface was completely saturated by the Cu2O phase. Furthermore, by analyzing the relative intensity and peak area of XP spectra, we found that the depth of Cu2O differed dramatically in the dry and humid oxidation processes. The Cu2O thickness of the dry oxidation was greater than that of the humid oxidation under all similar pressures. Water molecules from the humid oxidation caused a different oxidation mechanism from the dry oxidation, with a different degree of oxidation. Specifically, the water vapor molecules inhibited sublayer oxidation, inducing less coverage of the step-edges on the Cu(111) surface than under dry oxidation conditions.

Tunable Nucleation Morphology of Au on Monolayer Fluorinated Graphene

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Graphene has long been touted for its numerous exceptional mechanical and electrical properties, which have been further enhanced in various studies by mechanical modifications, such as folding and wrinkling, and surface treatments, such as hydrogenation and fluorination. More specifically, chemical modification of graphene has expanded its versatility to enable the investigation of hybrid materials such as Au nanoparticles (AuNPs) on graphene. AuNPs exhibit intriguing optical and electrical properties, with tunability of such characteristics largely dependent on nanoparticle size and shape; coupled with the versatility of graphene, investigation on the fundamental mechanism between Au-graphene interaction is highly valuable for effective exploitation of the two novel nanomaterials. In this research, we report a novel approach to achieving tunability in AuNP fabrication. We employ a customized contact-mode atomic force microscopy (AFM) to mechanochemically generate an in-plane chemical gradient of fluorinated graphene (FG) with a linear change in degree of fluorination. Then, we deposit a thin layer of Au on the surface of the chemically modified graphene (CMG) for an in-situ observation of the correlation between the geometry of AuNP and degree of fluorination of FG. Raman spectroscopy and lateral force microscopy (LFM) confirm successful gradient mechanochemical cleavage of fluorine atoms from FG. Characterization via AFM, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) reveal gradient-dependent variation in AuNP nucleation pattern from a ‘nano-dot’ nucleation of Au on FG with minimal F cleavage to a nano-triangular crystal formation of Au on nearly pristine graphene, and therefore precise tunability in AuNP geometry by optimization of the degree of fluorination. This research paves new potential for practical applications such as the utilization of optimally nucleated AuNPs in surface-enhanced Raman spectroscopy (SERS) and provides novel insight into the fundamental mechanism behind metal-graphene interfacial interactions in the atomic scale.