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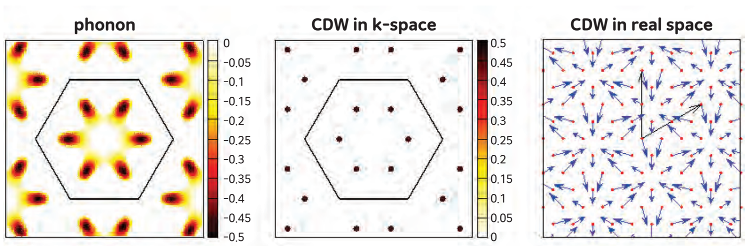
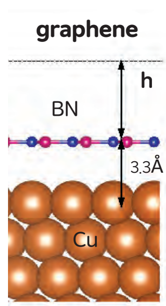
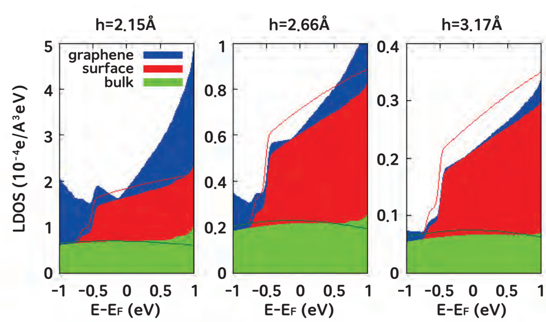
CALDES

Center for Artificial Low Dimensional Electronic Systems







Center for Artificial Low Dimensional Electronic Systems

CONTENTS

Message from Director

CALDES challenges the major physics problems of low dimensional electronic materials that have been the central issues of modern condensed matter physics since 1970's. In this long pursued discipline with the glory of quantum Hall effects, high temperature superconductors, and graphene, CALDES would pioneer new types of materials with state-of-the-art measurement technologies.

The new materials systems are low dimensional systems controlled and grown in atomic scale precision, such as atomic layers, atomic wires, atomic rods, and, in particular, their heterointerfaces. The state-of-the-art measurement technologies include scanning tunneling microscopy below 10mK, and ultra bright spin-and angle-resolved photoelectron spectroscopy.

These frontier instruments can address the electronic and spintronic properties of atomic-scale low dimensional systems in truly single atom and single spin precision. With the atomically controlled low dimensional materials under atomically-resolved probes, CALDES investigates and manipulates exotic electronic and spin channels and topological excitations such as solitons, quantum spin Hall edge states, non Fermi liquids, skyrmions, quantum spin liquids and so on. CALDES aims to establish full understanding of these low dimensional electronic phenomena and to discover new physics and new functionality emerging from atomically designed low dimensional electronic materials.

Han Woong Yeom
Director,
Center for Artificial Low Dimensional Electronic Systems,
Institute for Basic Science

Goal of CALDES

In this long-term research project, we aim to

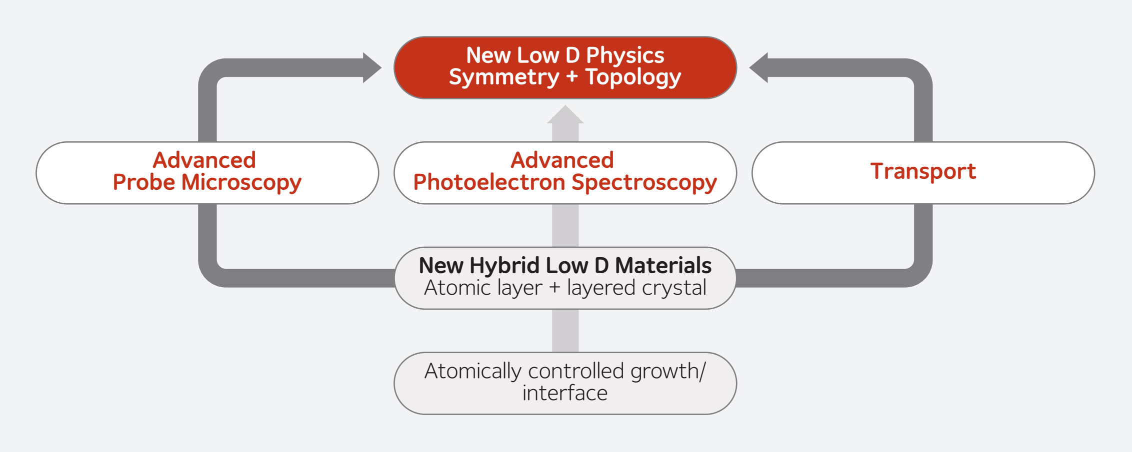
(1) create atomically controlled artificial materials such as wires, layers, ultrathin films, heterointerfaces, and multilayers, which can host novel low dimensional electronic systems,
(2) establish methods for the ultimate atomic scale measurement and control over these materials to manipulate their local and global electronic properties,
(3) discover new types of quantum matter originating from exotic symmetries, topology, and interactions of low dimensional electrons and challenge the grand problems of the quantum phase fluctuations, competitions, and transitions of low dimensional electrons.

To achieve the above goals, we propose an innovative approach through the combination of atomically controlled in- and ex-situ growth of new materials with the advanced spectroscopic and microscopic techniques such as spin-and-angle-resolved photoelectron spectroscopy and ultra-low-temperature-high-magnetic-field scanning tunneling microscopy.

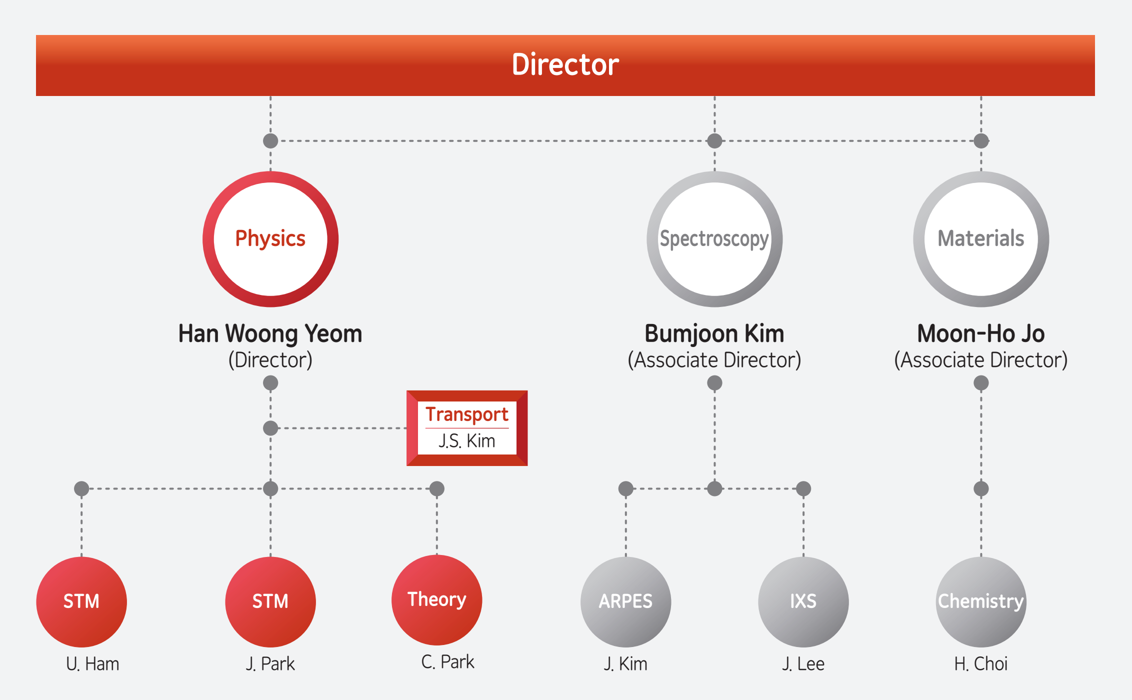
Finally, we hope to secure a route to revolutionary electronic or spintronic devices based on new types of quantum properties of electrons in low dimension.

Basically, our suggestion that various new low dimensional topological materials can be found and fabricated has been proved to be extremely successful during last five years. Together with existing topological materials, there is huge room for discoveries when we investigate their edge electronic channels, especially with atom resolution probes. We can further create various different types of heterointerfaces between topological materials and materials with distinct symmetries and interactions. The research on these heterointerfaces of atomic layer low dimensional materials are on its early stage and we have a great chance to become a leading group. In particular, while other major groups are still working basically on semiconductor heterostructures, we moved to more exotic heterointefacial systems with strong spin, orbit and electron interactions for new physics. The idea of proximity coupling of different interactions at such heterointerfaces is pursued throughout this project.

Since most of the current research on topological materials focuses 3D bulk materials or semiconductor quantum well structures, the current project on 1D/2D topological materials in atomic scale materials is rather unique. Moreover, the idea of proximity coupling in atomically controlled heterointerfaces to find new physics beyond the current scope of topological materials is original. We aim to make this idea successful and establish strong world leadership in this new field.



CALDES Structure



Director and Associate Directors

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RESEARCH AREA
- Atomic wires; self-assembled 1D metal and 1D topological insulator
- Atomic layers; epitaxially-grown single atomic layer 2D metals
- Atomic layer 2D topological insulators
- Atomic layer heteroepitaxy on strongly interacting systems

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RESEARCH AREA
- Atomic Scale Heteroepitaxy of Low-Dimensional Materials
  - Atomically thin semiconductor heterostructures and alloys
  - 2D polymorphism and isomorphism
  - van der Waals superlattices in wafer-scales
  - Atomic layer superconductors
- Nanoscale Device Physics
  - Charge transport in 2D heterostructures
  - Light-matter interactions at in 2D semiconductor heterostructures
  - Light-induced phase transitions in atomically thin materials
  - Laser transport spectroscopy
- New Device Technology
  - 2D electronics and photonics platforms in wafer-scales
  - Group IV optoelectronics
  - 2D thermoelectrics

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RESEARCH AREA
- Strongly correlated electron systems
- Unconventional magnetism and superconductivity
- Experimental detection of nontrivial electronic orders
- Interplay of spin, orbital, charge, and lattice degrees of freedom

Research Fellows

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RESEARCH AREA
- First-principles electronic structures calculation
- Charge density wave in 2D materials
- STM simulation of molecular assemblies and 2D materials

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RESEARCH AREA
- Electronic and magnetic structure of transition metal oxides
- 2D magnetic layers
- Interface of hetero structures

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RESEARCH AREA
- Functional probing of low dimensional materials
- Atomic level engineering of low dimensional electronic systems

Research Fellows

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RESEARCH AREA
- Structure and dynamics of unconventional superconductors
- Magnetism in heavy fermion systems
- Phase transitions under high magnetic field

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RESEARCH AREA
- Exotic superconductivity and magnetism in low dimensional quantum materials and their heterostructures
- Synthesis and single crystal growth of novel complex materials showing unusual quantum phenomena
- Electrical/thermal transport properties of condensed matters under extreme conditions

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RESEARCH AREA
- Scanning tunneling microscopy of single atoms and single molecules
- High resolution electron tunneling spectroscopy such as inelastic electron tunneling spectros-copy

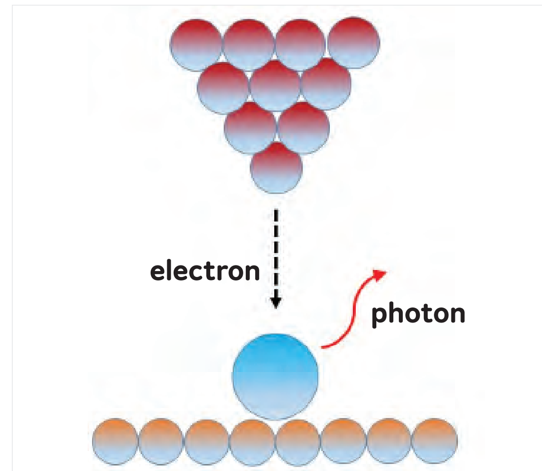
Research Groups

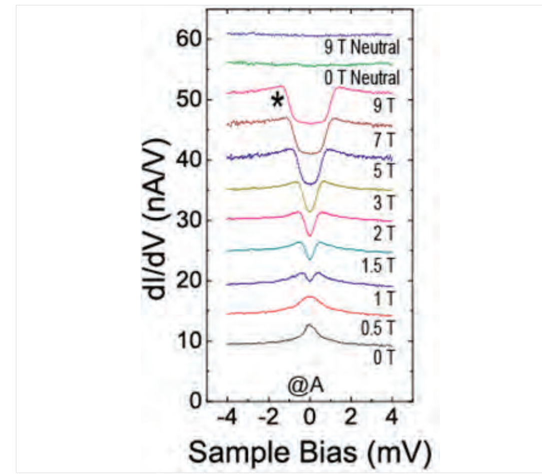
Physics group

Director: Professor **Han Woong Yeom**

Ultralow temperature high magnetic field scanning tunneling microscopy

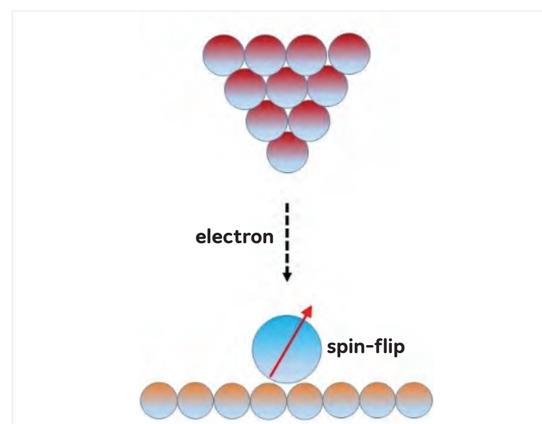
- Ultra high resolution electron tunneling spectroscopy
- Detection and control spin states of single spins
- Single magnetic metal atoms and single inorganic molecules as spin centers on decoupling layers
- 10 milli-Kelvin and high magnetic field

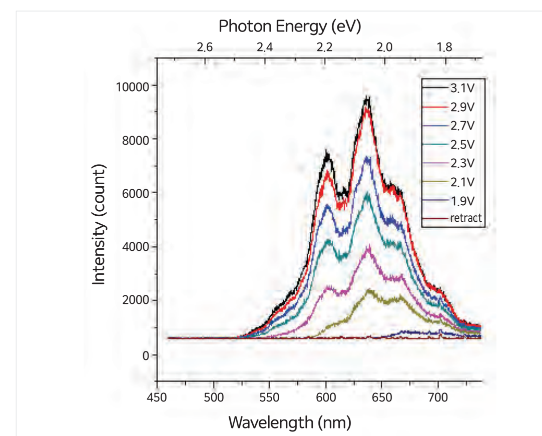




Photon collection capability into low temperature scanning tunneling microscope

- Photon spectroscopy with low temperature scanning tunneling microscopy
- Detection and control of single nanometer-sized light source
- Variable temperature (> 6 Kelvin) photon scanning tunneling microscope
- Sub-kelvin high magnetic field photon scanning tunneling microscope





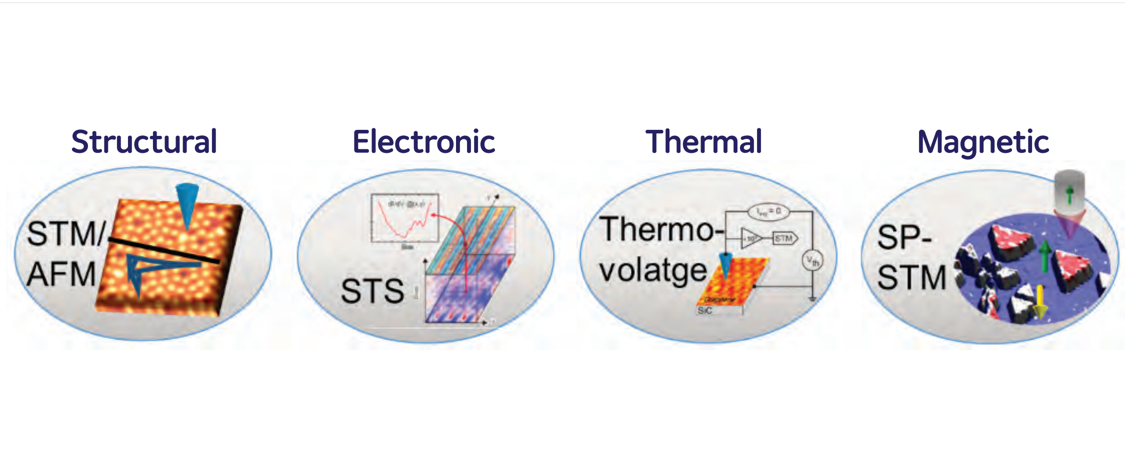
Research Groups

Physics group

Director: Professor **Han Woong Yeom**

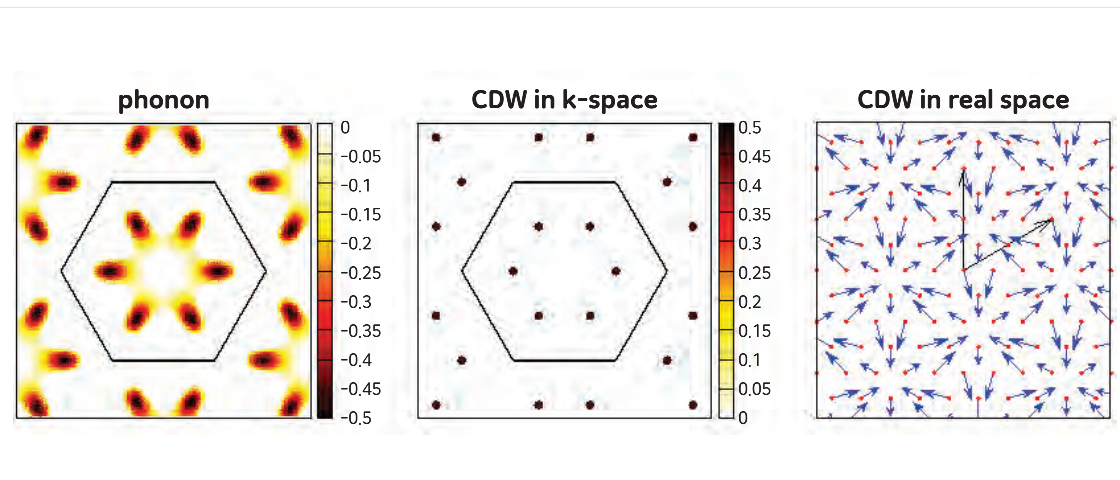
Functional probing with scanning probe microscopy

- Probing various physical properties: structural (STM/Low-temperature Atomic Force Microscopy), electronic (Scanning Tunneling Spectroscopy), thermal (Scanning Tunneling Thermovoltage Microscopy), and magnetic (Spin-polarized STM) properties.



STM and theoretical study of charge density wave in 2D materials

- Atomic potential approach to CDW transition beyond Landau theory
- Topology and electronic structures of CDW domain walls



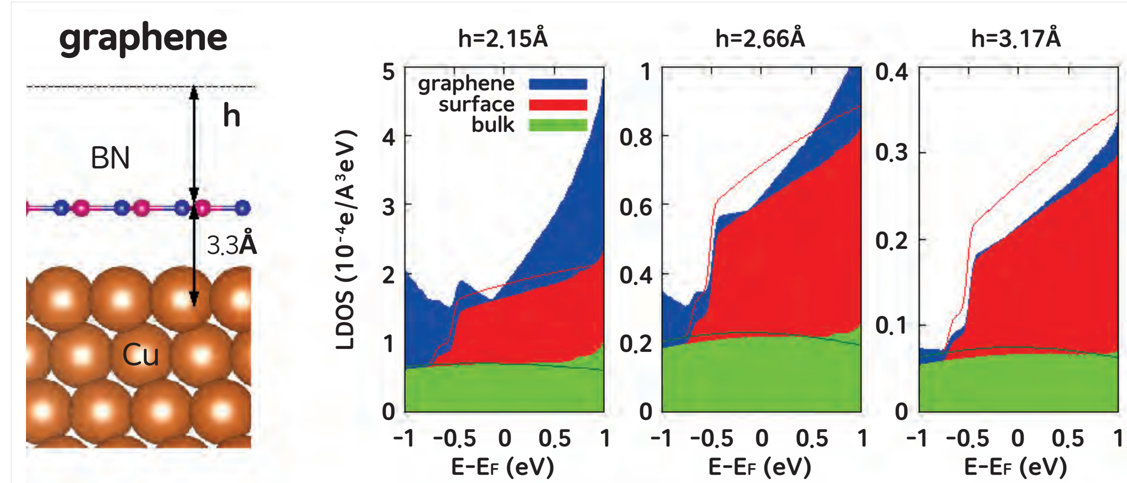
Research Groups

Physics group

Director: Professor **Han Woong Yeom**

STM simulation of molecular assemblies and 2D materials

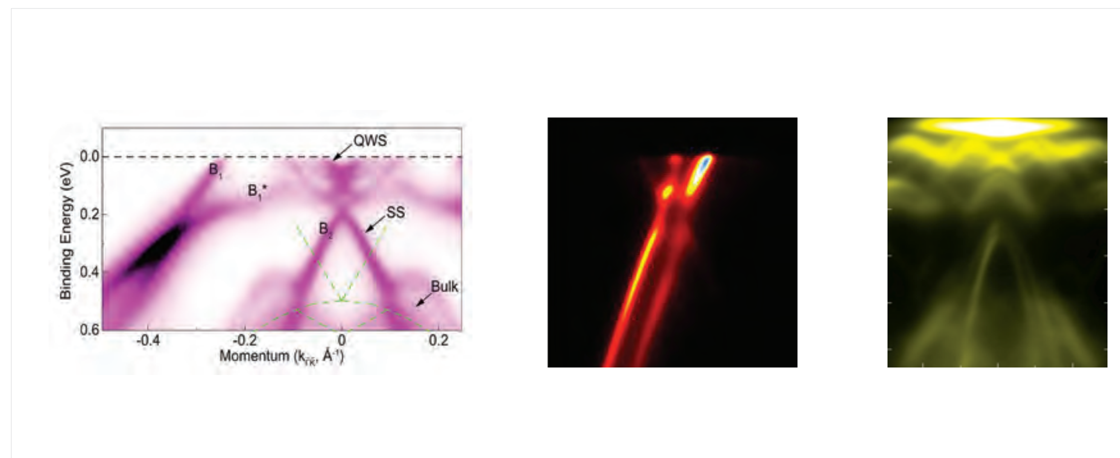
- Metallic tail effect on STM image and STS
- Finite-bias effect on charged defects or molecules on surface



Spin and angle-resolved photoelectron spectroscopy

Probing spin-resolved band structures of low-dimensional systems

- Band structures of new 1D and 2D topological insulators
- Low-energy excitations of homo- and hetero-interfaces of graphene



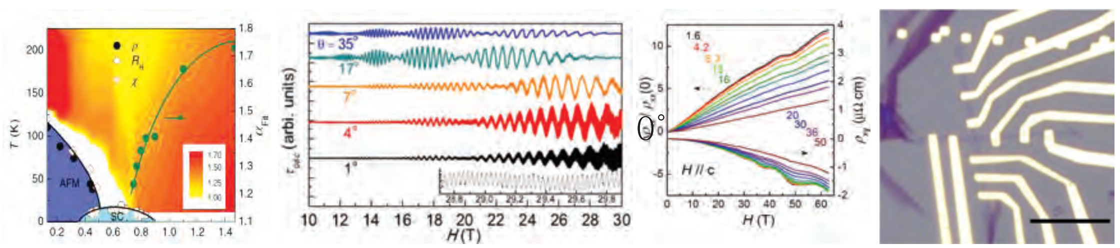
Research Groups

Physics group

Director: Professor **Han Woong Yeom**

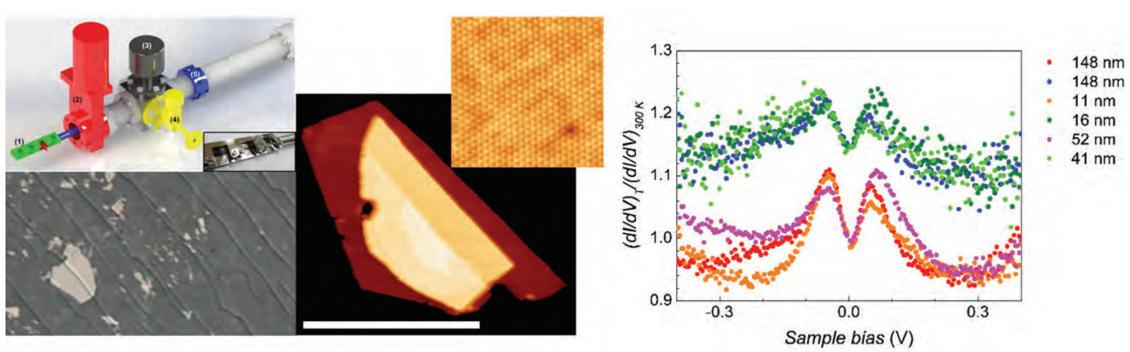
Quantum phenomena under extreme conditions

Physical properties of correlated/chiral electronic system under extreme conditions
- Quantum phase transition in low dimensional materials and their heterostructures
- Quantum oscillations and transport under extreme conditions



Thickness-dependent properties of 2D materials

- Preparing contamination-free surfaces of 2D materials
- Probing & manipulating electronic properties of 2D materials depending on their thickness



Research Groups

Materials Group

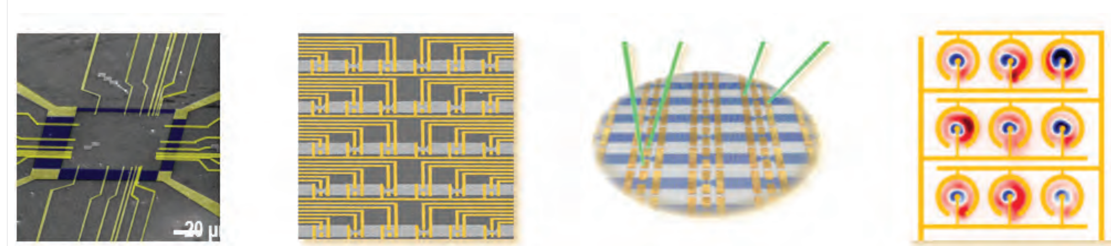
Associate Director: Muenjae Chair Professor **Moon-Ho Jo**

Atomic scale heteroepitaxy of low-dimensional materials

- Atomically thin semiconductor heterostructures and alloys
- 2D polymorphism and isomorphism
- van der Waals superlattices in wafer-scales
- Atomic layer superconductors
- 2D electronics and photonics platforms in wafer-scales
- Group IV optoelectronics
- 2D thermoelectrics

Novel electronic and photonic processes

- Charge transport in 2D heterostructures
- Light-matter interactions at in 2D semiconductor heterostructures
- Light-induced phase transitions in atomically thin materials
- Laser transport spectroscopy



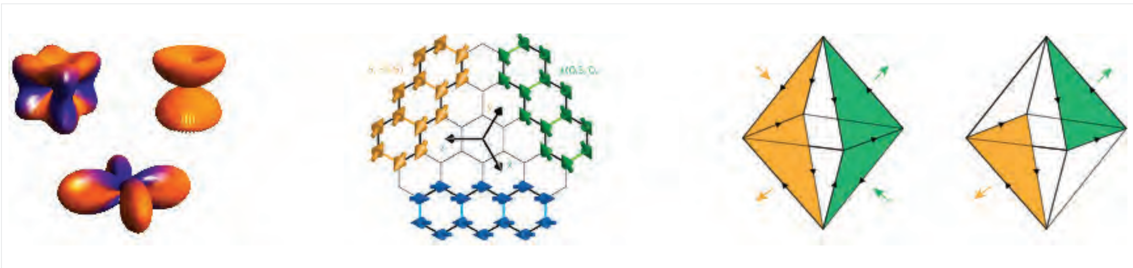
Research Groups

Spectroscopy group

Associate Director: Associate Professor **Bumjoon Kim**

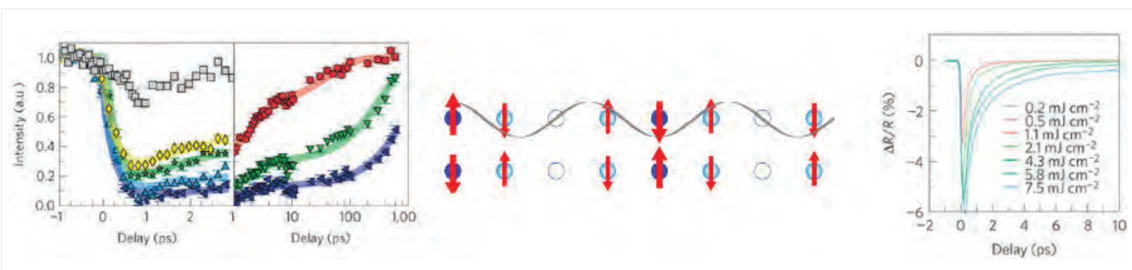
Light, x-ray and neutron scattering

- Spin and orbital orders and dynamics in transition metal oxides
- Detection of high order multipoles



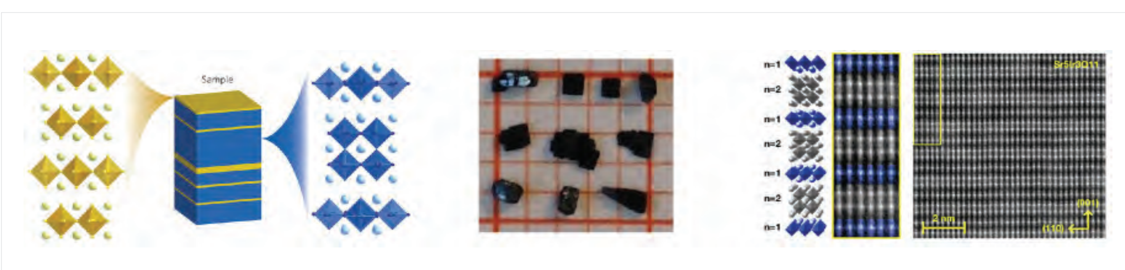
Time-resolved spectroscopy

- Destruction and recovery of magnetic order
- Fluctuating spin and charge density waves



Crystal growth

- Engineered samples for spectroscopy
- Naturally-stabilized heterostructures



CALDES Research Highlight

Physics Group

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- Chiral solitons in a coupled double Peierls chain, Sangmo Cheon, Tae-Hwan Kim, Sung-Hoon Lee, Han Woong Yeom, SCIENCE **350**, 182 (2015)
- Realization of a Strained Atomic Wire Superlattice, Inkyung Song, Han Woong Yeom et al., ACS NANO **9**, 10621 (2015)
- Electron Quantization in Broken Atomic Wires, Eui Hwan Do, Han Woong Yeom, Phys. Rev. Lett. **115**, 266803 (2015)
- Nanoscale manipulation of the Mott insulating state coupled to charge order in $1T\text{-}TaS_2$, Doohee Cho, Han Woong Yeom et al., Nature Comm. **7**, 10453 (2016)
- Impurity-Mediated Early Condensation of a Charge Density Wave in an Atomic Wire Array, Han Woong Yeom, Deok Mahn Oh et al., ACS NANO **10**, 810 (2016)
- Sublattice Interference as the Origin of σ Band Kinks in Graphene, Sung Won Jung, Keun Su Kim et al., Phys. Rev. Lett. **116**, 186802 (2016)
- Nanoscale superconducting honeycomb charge order in $IrTe_2$, Hyo Sung Kim, Han Woong Yeom et al., NANO LETTERS **16**, 4260 (2016)
- Switching chiral solitons for algebraic operation of topological quaternary digits, Tae-Hwan Kim, Sangmo Cheon, Han Woong Yeom, NATURE PHYSICS **13**, 444 (2017)
- Violation of Ohm's law in a Weyl metal, Dongwoo Shin, Jeehoon Kim et al., NATURE MATERIALS **16**, 1096 (2017)
- Correlated electronic states at domain walls of a Mott-charge-density-wave insulator $1T\text{-}TaS_2$, Doohee Cho, Han Woong Yeom et al., Nature Comm. **8**, 392 (2017)
- Frustration-driven C_4 symmetric orders in a naturally-heterostructured superconductor Sr_2VO_3FeAs, Jong Mok Ok, Jun Sung Kim et al., Nature Comm. **8**, 2167 (2017)
- Large anomalous Hall current induced by topological nodal lines in a ferromagnetic van der Waals semimetal, Kyoo Kim, Junho Seo, Han Woong Yeom, Jun Sung Kim et al., Nat. Mater., in press

CALDES Research Highlight

Materials Group

- Atomic layer-by-layer thermoelectric conversion in topological insulator bismuth/antimony tellurides, Ji Ho Sung, Hoseok Heo and Moon-Ho Jo, et. al., Nano Lett. **14**, 4030 (2014)

- Deterministic two-dimensional polymorphism growth of hexagonal n-type SnS_2 and orthorhombic p-type SnS crystals, Ji-Hoon Ahn, Myoung-Jae Lee and Moon-Ho Jo, et. al., Nano Lett. **15**, 3703 (2015)

- Interlayer orientation-dependent light absorption and emission in monolayer semiconductor stacks, Hoseok Heo, Hyunyong Choi, and Moon-Ho Jo, et. al., Nature Comm. **6**, 7372 (2015)

- Rotation-misfit-free heteroepitaxial stacking and stitching growth of hexagonal transition-metal dichalcogenide monolayers by nucleation kinetics controls, Hoseok Heo, Hyunyong Choi, Moon-Ho Jo, et. al., Adv. Mater. **27**, 3803 (2015)

- Enhancement of the anisotropic photocurrent in ferroelectric oxides by strain gradients, Kanghyun Chu, Moon-Ho Jo, and Chan-Ho Yang, et. al., Nature Nanotechnol. **10**, 972 (2015)

- 1s-intraexcitonic dynamics in monolayer MoS_2 probed by ultrafast mid-infrared spectroscopy, Cha S., Ji Ho Sung, Hyunyong Choi, and Moon-Ho Jo, et. al., Nature Comm. **7**, 10768 (2016)

- Ultra-high modulation depth exceeding 2,400% in the optically-controlled topological surface plasmons, Sangwan Sim, Ji Ho Sung, Soonyoung Cha, Seongshik Oh, Moon-Ho Jo, and Hyunyong Choi, et. al., Nature Comm. **6**, 8814 (2015)

- Thermoelectric materials by using two-dimensional materials with negative correlation between electrical and thermal conductivity, Myoung-Jae Lee, Ji-Hoon Ahn, and Moon-Ho Jo, et. al., Nature Comm. **7**, 12011 (2016)

- Selectively tunable optical Stark effect of anisotropic excitons in atomically thin ReS_2, Sangwan Sim, Soonyoung Cha, Ji Ho Sung, Moon-Ho Jo and Hyunyong Choi, Nature Comm. **7**, 13569 (2016)

- Coplanar semiconductor-metal circuitry defined on few-layer $MoTe_2$ via polymorphic heteroepitaxy, Ji Ho Sung, Hoseok Heo, Saerom Si, and Moon-Ho Jo, et. al., Nature Nanotechnol. **12**, 1064 (2017)

- Ultrafast quantum beats of anisotropic excitons in atomically thin ReS_2, Sangwan Sim, Soonyoung Cha, Ji Ho Sung, Moon-Ho Jo and Hyunyong Choi, Nature Comm. **9**, 351 (2018)

- Generation, transport, and detection of valley-locked spin photocurrent in WSe_2-graphene-Bi_2Se_3 heterostructures, Soonyoung Cha, Moon-Ho Jo, Jun Sung Kim, and Hyunyong Choi, et. Al., Nature Nanotechnol., in press (2018).

- Programmable writing of integrated circuits on a two-dimensional van der Waals semiconductor, Seung-Young Seo, Han Woong Yeom, Hyunyong Choi, and Moon-Ho Jo, et. Al., Nature Electronics, in revision (2018)

Spectroscopy Group

- Quartz-based flat-crystal resonant inelastic x-ray scattering spectrometer with sub-10 meV energy resolution, J. Kim, D. Casa, A. Said, R. Krakora, B. J. Kim, E. Kasman, X. Huang, T. Gog, Scientific Reports **8**, 1958 (2018)

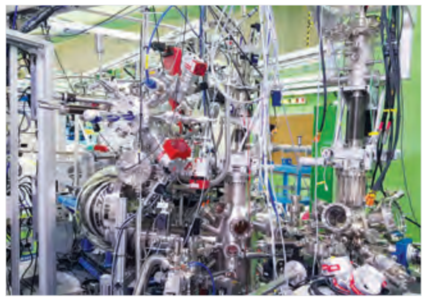
- Resonant inelastic x-ray scattering operators for t2g orbital systems, B. J. Kim, G. Khaliullin, Phys. Rev. B **96**, 085108 (2017)

- Raman scattering study of vibrational and magnetic excitations in $Sr_{2-x}La_xIrO_4$, H. Gretarsson, J. Sauceda, N. H. Sung, M. Höppner, M. Minola, B. J. Kim, B. Keimer, M. Le Tacon, Phys. Rev. B **96**, 115138 (2017)

- Raman Scattering from Higgs Mode Oscillations in the Two-Dimensional Antiferromagnet Ca_2RuO0, S.-M. Souliou, J. Chaloupka, G. Khaliullin, G. Ryu, A. Jain, B. J. Kim, M. Le Tacon, B. Keimer, Phys. Rev. Lett. **119**, 067201 (2017)

Equipment

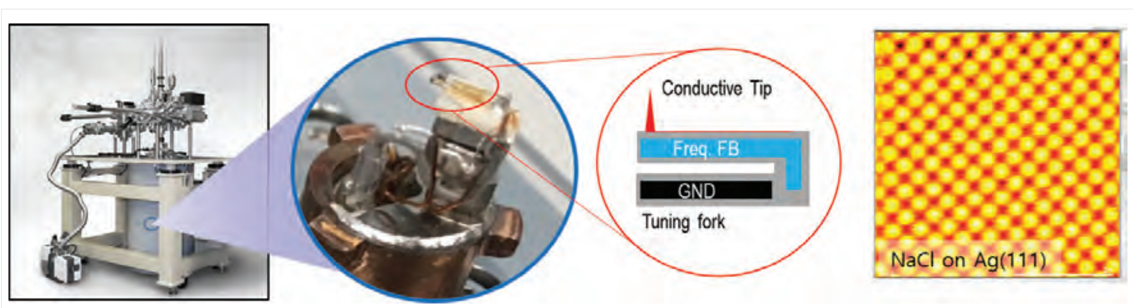
Spin and angle resolved photoemission beamline



Angle-resolved photoelectron spectroscopy is a powerful technique that measures the electronic structure of low D atomic crystals. We are constructing a spin and angle resolved photoemission beamline in collaboration with Pohang Light Source, which is based on new type of spin detector to achieve world top level performance in mapping out spin resolved band structures.

Low temperature atomic force microscopy (LT AFM 2 K 12 T)

AFM with tuning fork sensor facilitates atomic level investigation of insulators, where STM cannot work. The combination of STM and AFM study provides decoupling of electronic contribution in STM topography, which is essential to exploit localized electronic states. The AFM will explore structural, electrical, mechanical properties of new 1D/2D materials and their heterostructure regardless of local conductivity.

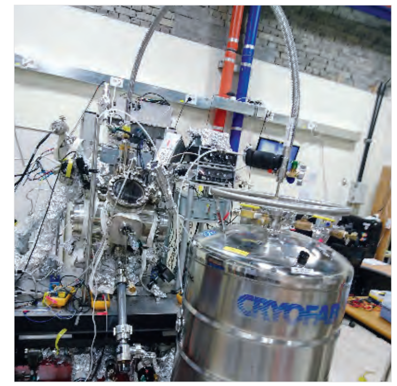


Variable temperature photon scanning tunneling microscope

This equipment has a unique feature of analyzing photon intensity and spectrum coming from STM junctions. Recently we have installed components for tip-enhanced Raman spectroscopy. We are studying optical properties of single nanometer-sized light sources, mainly, single planar inorganic molecules on decoupling layers.

Equipment

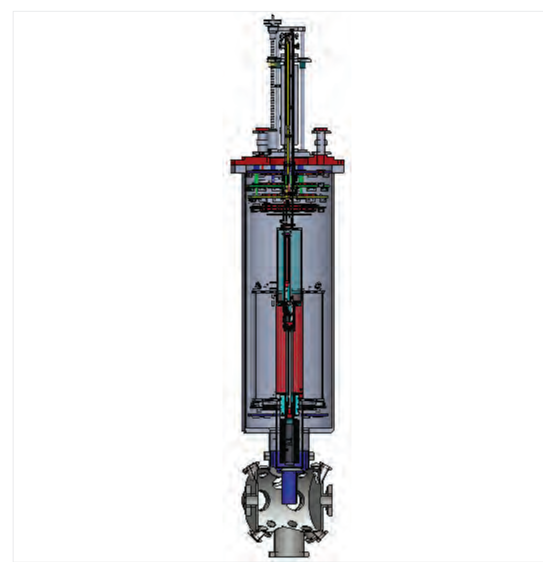
Variable temperature scanning tunneling microscope



This equipment can be said to be a sub-system of sub-Kelvin high magnetic field photon STM, which is under construction. 9 in-situ ports aiming the STM junction facilitates pre-study of single spin centers of single atoms and molecules.

Sub-kelvin high magnetic field photon scanning tunneling microscope

A homemade sub-Kelvin cryostat is being constructed. We use image guides, which is originally for endoscopes, to collect photons in the center of our superconducting magnet center. In this sense this system will be very unique in the world, and will give a strong impact on STM instrumentation.

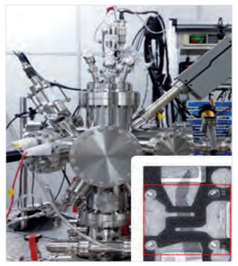


Milli-kelvin high magnetic field scanning tunneling microscope

This equipment is designed for single spin STM experiments. So, both ordinary 10 K STM routines with in-situ dosing and milli-Kelvin high magnetic field STM measurements are possible. Many unique features have been implemented to reach lowest electron temperature at sample surfaces.

Equipment

Variable-temperature scanning tunneling microscope with transport capability



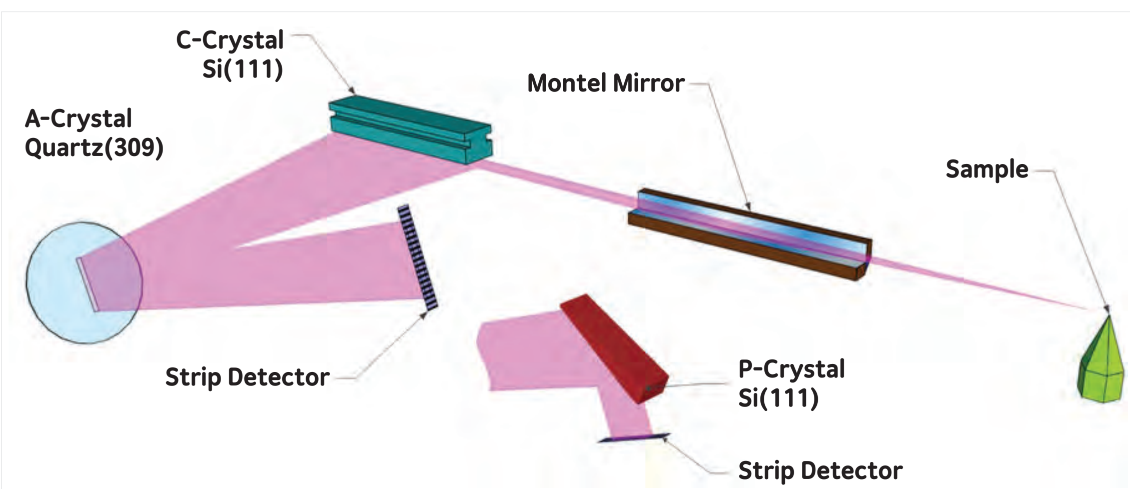
This equipment is designed for simultaneous STM and transport measurements at various temperatures from 10 K to 300 K. The STM is used to explore thin 2D materials as well as their heterostructures. To get contamination-free surfaces, it is carefully designed to be connected to the ultra-high vacuum suitcase, which contains well-prepared 2D materials without exposure to air.

High-resolution Raman spectroscopy

Raman scattering is widely used to study lattice, magnetic and electronic excitations in solids. Our system is capable of measuring small-energy excitations down to ~10 cm-1 with the selection of incoming and outgoing polarizations of the light that allows to disentangle contributions from different irreducible representations of the space group of the system.

Resonant inelastic x-ray scattering (RIXS) beamline

RIXS is a momentum-and energy-resolved technique that has access to charge, orbital, and spin dynamics over the full Brillouin zone and a very wide energy range. We are constructing a high-resolution hard x-ray RIXS beamline targeted for 5d transition-metal compounds in collaboration with Pohang Light Source.

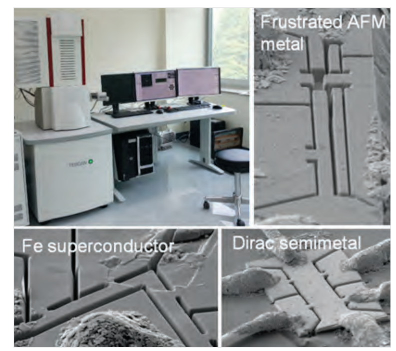


Equipment

Dilution refrigerator with high field magnet

The dilution refrigerator combined with high field magnet provides extremely low temperature (~10mK) and high magnetic field (~20T) conditions for investigating various interesting quantum phenomena in low dimensional materials

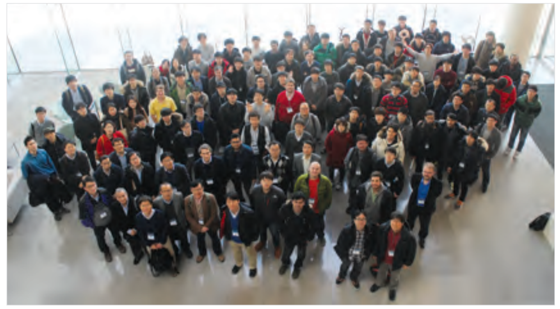
Electron-ion dual beam lithography and clean room



The electron-ion dual beam lithography system and clean room facility enable fabrication of various quantum materials. Precise control of electronic conduction is critical to observe new physical phenomena. We can tailor a small single crystal in a specific shape for a designed experiment in sub-μm scale by using focused ion beam (FIB) milling process. Furthermore, we can fabricate electron-beam resist-free device patterns with this lithography facility by combining the gas injection system (GIS).

Activities

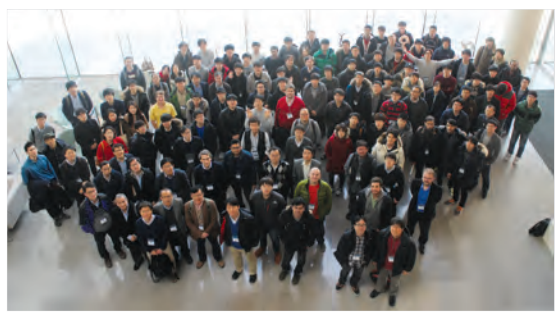

2016 CALDES Spring Workshop

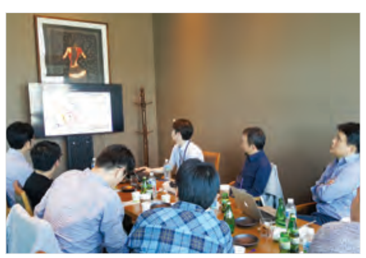

2016 Quantum Materials Symposium


2016 IBS Conference on Surface Atomic Wires

2018 CALDES Research Workshop


Student Visitors from The Radboud Univ., Nijmegen in 2016


The 9th International Workshop on Nanoscale Spectroscopy and Nanotechnology in 2017

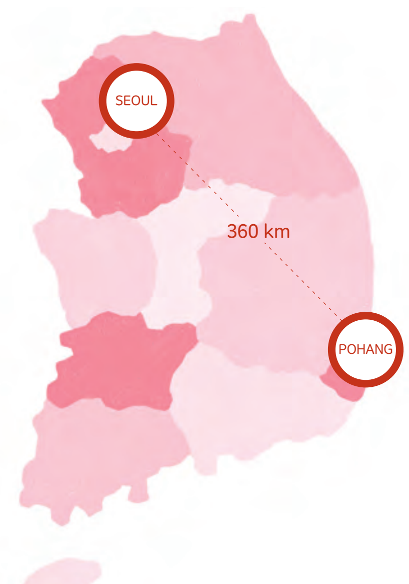

CALDES PI Meeting in 2016


Director Yeom, Inchon Prize for Science and Technology


The 8th International Conference on Recent Progress in Graphene and 2D Research in 2016

Location & Direction

Coming to POSTECH



The most convenient way to reach POSTECH from Seoul is either via Air (from Gimpo International Airport to Pohang Airport) or KTX fast train (from Seoul KTX Station to Pohang KTX Station).

FROM POHANG AIRPORT (KPO) TO POSTECH CAMPUS

POSTECH is located about 30 minutes away from Pohang Airport by car. Taxi service will charge about KRW 15,000.

FROM POHANG KTX TRAIN STATION TO POSTECH CAMPUS

The Pohang KTX Station is about 20 minutes away from the campus by car and taxi service will cost about KRW 10,000.

Institute for Basic Science

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