engineering the quantum future

CENTER FOR QUANTUM NANOSCIENCE

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Word from Our Director

Worldwide investments in quantum research are exploding as this nascent field takes shape. QNS is a young and ambitious center helping to shape and lead the area of quantum nanoscience. We are grateful to Korea's Institute for Basic Science for providing structure and funding to QNS. As we are enormously indebted to Ewha Womans University for our world-leading facility and ongoing operational support. The international community is coming to QNS and Korea (often for the first time!) to exchange techniques, people, and ideas with each other.

Andreas Heinrich
Director of Center for Quantum Nanoscience

We are very proud of QNS's developing role for the quantum nanoscience community; for our Scanning Probe Microscopy colleagues; as well as for our role in Korea.

Welcome to our exciting journey!

About us

The Information Technology industry's ability to shrink components to make computational devices more powerful is running into serious roadblocks.

The strong influence of quantum mechanical effects takes over as device components shrink to the atomic scale. As a result, harnessing quantum effects for computation potentially offers a powerful new route to solving real world computational problems.

The Center for Quantum Nanoscience (QNS) at Ewha Womans University aims to investigate quantum effects in solid state systems to further our understanding of this crucially important, but as of yet, poorly understood basic research field. Our goal is to become recognized as the best place to perform quantum research on the atomic scale in a solid-state environment and be a destination for leading domestic and international researchers.

QNS at Glance

Our Team

Group Leaders

Researchers

Engineers & Staff

Students

Where we are from

53% South Korea

29% Europe

13% Asia

5% North America

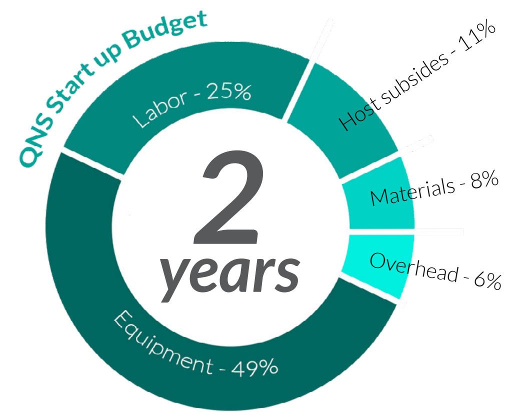
Equipment

8 STM Labs with lowest vibration level in Korea

2 control rooms and **4** clean rooms

6 STMs: ESR STM, 10mK STM, Optics STMs

Helium Recovery and Liquefier System



Numbers

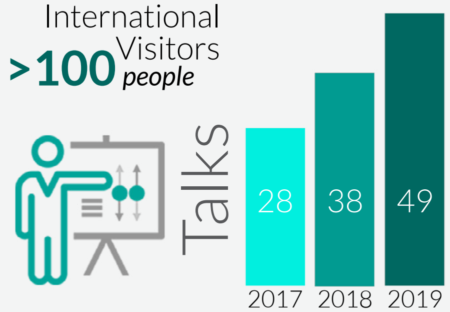
4 Academic Conferences and Workshops

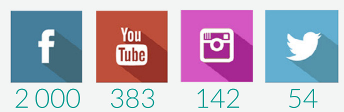
>60 Publications (Nature jornals, Science, Physics Review Letters, etc.)

6 International Awards Joseph F. Keithley Award 2017, Feynman Prize 2018, Max-Auwaerter Prize 2018, etc.

Visitors

International Visitors **>100** *people*





- @QNSscience

Research Groups

Each research group is made up of students, postdocs, and visiting scientists. Each team uses research equipment customized for QNS.

Quantum Properties of Individual Spin Systems on Surfaces

Quantum-coherent control of single atom and molecule spins on surfaces.

Ensemble Measurements of Spins on Surfaces

Quantum properties of molecules and atoms on surfaces with x-ray absorption spectroscopy and electron spin resonance.

Optics combined Scanning Probe Microscopy

Quantum-coherent manipulation of atoms and defects on surfaces combining optical spectroscopy and scanning probe microscopy (STM+AFM).

Development of NV Center-Based Scanning Magnetometry at Low Temperatures

Nanoscale quantum sensing using nitrogen-vacancy centers in a diamond.

Theory of Quantum Systems at Surfaces

Predictive computational methods based on density functional theory.

Research Highlights

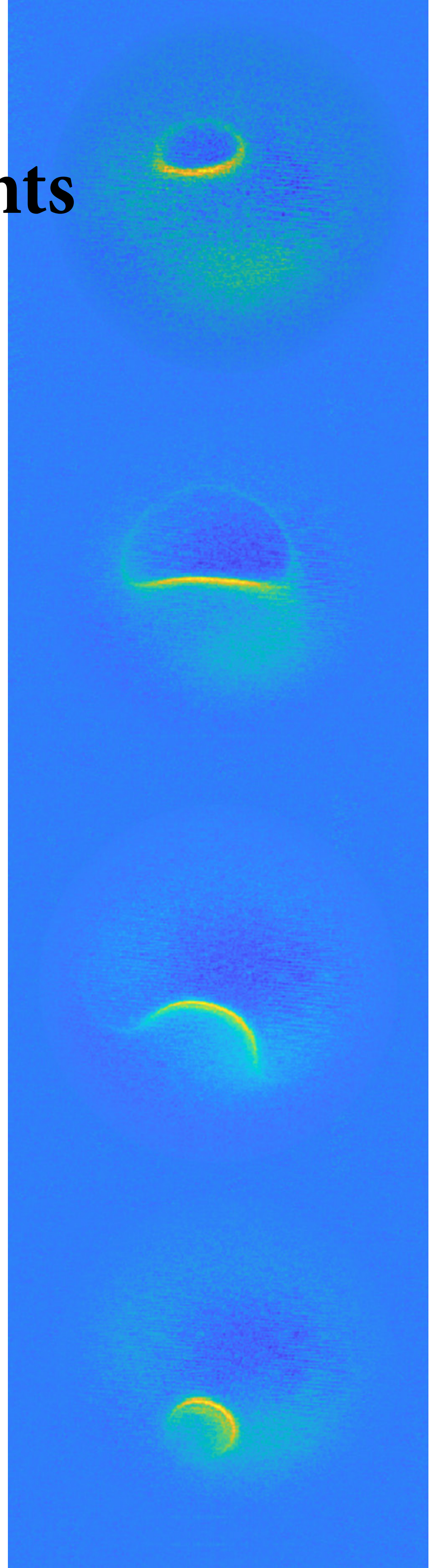
Magnetic Resonance Imaging of Single Atoms on a Surface

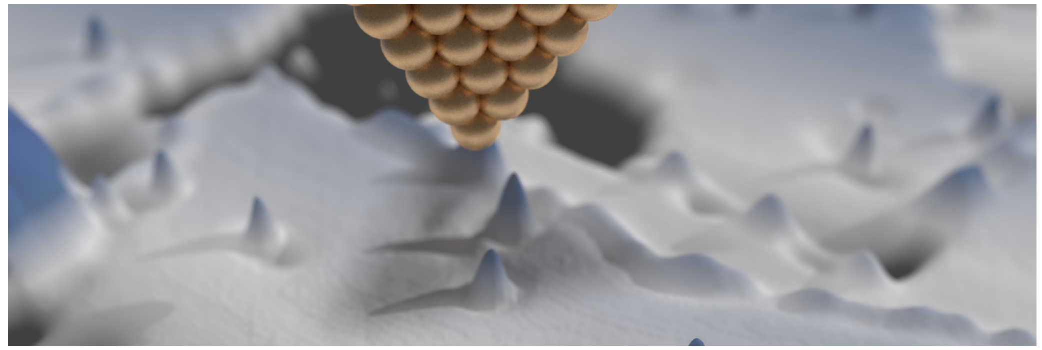
Our team showed that the MRI process is possible for an individual atom on a surface using an STM. QNS scientists in an international collaboration used this new technique to visualize the magnetic field of single atoms.

The two elements that were investigated in this work, iron and titanium, are both magnetic. Through precise preparation of the sample, the atoms where readily visible in the microscope. The researchers then used the microscope's tip like an MRI machine to map the three-dimensional magnetic field created by the atoms with unprecedented resolution. In order to do so, they attached another spin cluster to the sharp metal tip of their microscope. Similar to everyday magnets, the two spins attract or repel each other depending on their relative position. By sweeping the tip spin cluster over the atom on the surface, the researchers were able to map out the magnetic interaction.

Lead author, Dr. Philip Willke of QNS says: "It turns out that the magnetic interaction we measured depends on the properties of both spins, the one on the tip and the one on the sample. For example, the signal that we see for iron atoms is vastly different from that for titanium atoms. This allows us to distinguish different kinds of atoms by their magnetic field signature and makes our technique very powerful."

P. Willke et al. Magnetic Resonance Imaging of Single Atoms on a Surface, Nature Physics (2019)





A Step Closer to Single-Atom Data Storage

Physicists of QNS and EPFL used Scanning Tunnelling Microscopy to successfully test the stability of a magnet made up of a single atom. Despite the rise of solid-state drives, magnetic storage devices such as conventional hard drives and magnetic tapes are still very common. But as our data-storage needs are increasing at a rate of almost 15 million gigabytes per day, scientists are turning to alternative storage devices.

One of these is single-atom magnets: storage devices consisting of individual atoms stuck ("adsorbed") on a surface, each atom able to store a single bit of data that can be written and read using quantum mechanics. And because atoms are tiny enough to be packed together densely, single-atom storage devices promise enormous data capacities. But although they are no longer science fiction, single-atom magnets are still in basic research, with many fundamental obstacles to be overcome before they can be implemented into commercial devices.

F. Natterer et al. Thermal and Magnetic-Field Stability of Holmium Single-Atom Magnets, Physical Review Letters (2018)

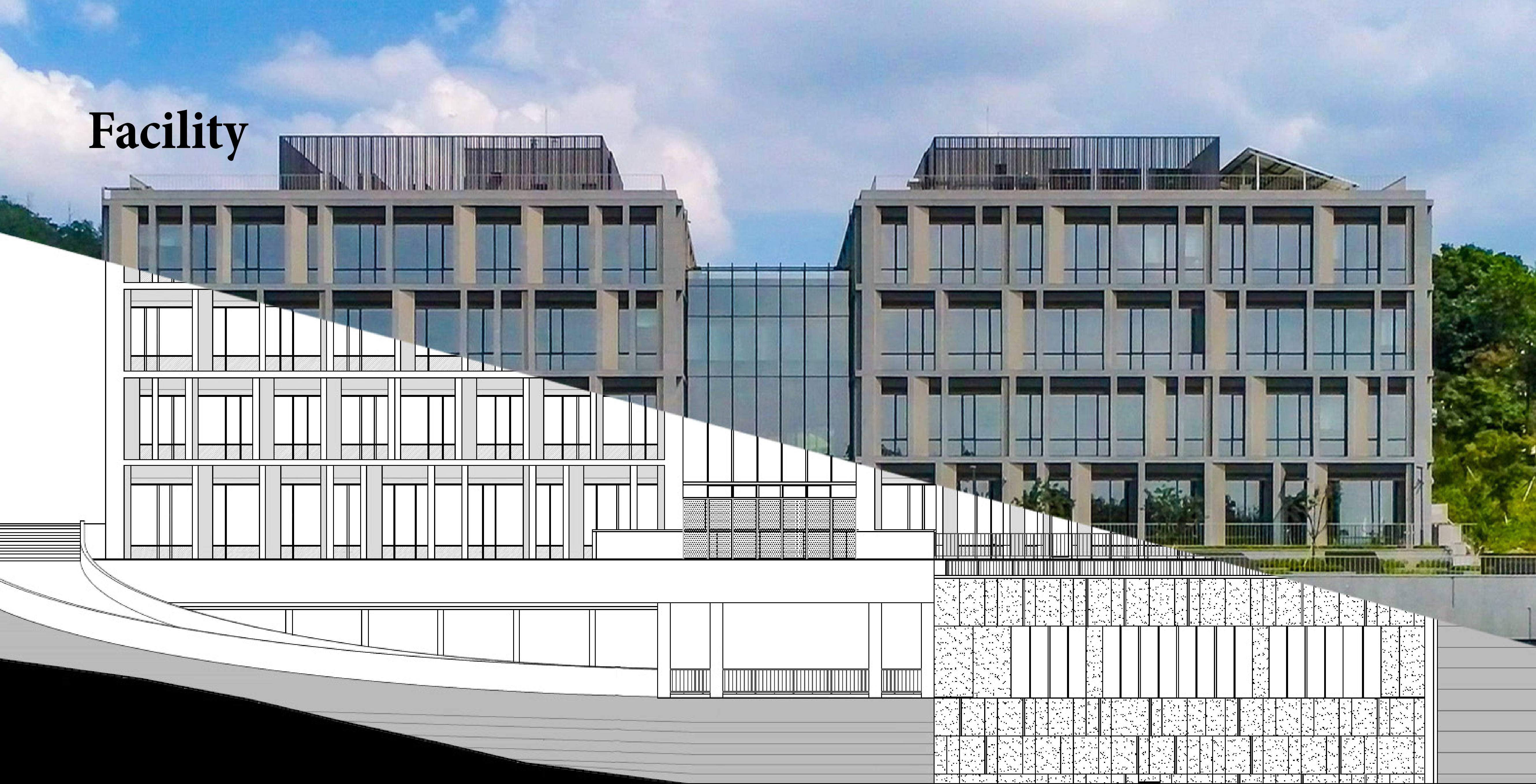
Enhanced Quantum Coherence in Exchange Coupled Spins via Singlet-Triplet Transitions

Our scientists have shown that by packing two atoms closely together they could protect their fragile quantum properties much better than for one atom alone. The spins of single titanium atoms were studied by using a STM and the atoms' spin states were detected using ESR. We found that by bringing the atoms close together, we could protect the superposition states of these two magnetically-coupled atoms 20 times longer compared to an individual atom.

The spin is a fundamental quantum mechanical object and governs magnetic properties of materials. In a classical picture, the spin can represent only up or down. However, according to the laws of quantum mechanics, the spin can also point in both directions at the same time. This superposition state is very fragile since the interaction of the spin with the local environment causes dephasing of the superposition. Understanding the dephasing mechanism and enhancing the quantum coherence are one of the key ingredients toward spin-based quantum information processing. This study allows to explore the atoms possibility to be used as quantum bits.

Y. Bae, Enhanced Quantum Coherence in Exchange Coupled Spins via Singlet-triplet Transitions, Science Advances (2018)

Facility



A Revolutionary New Facility for the Next Generation of Research

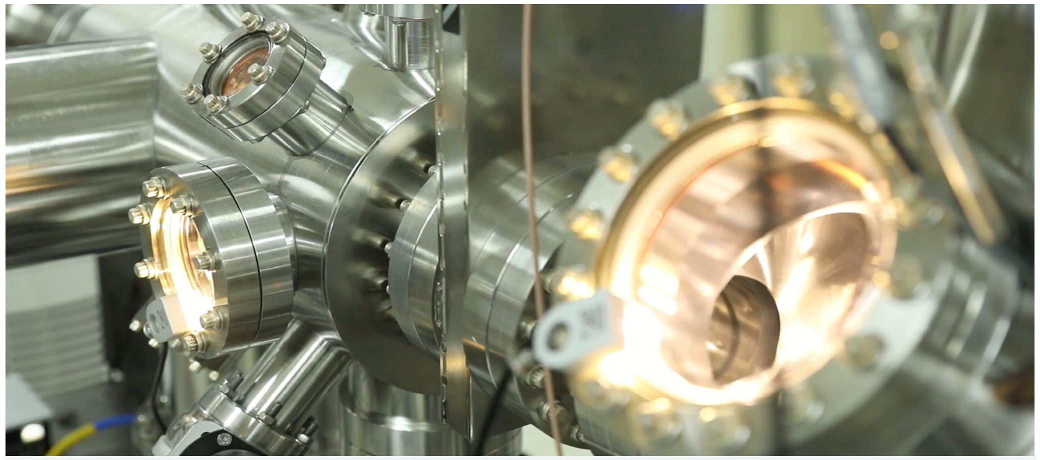
A state-of-the-art facility on the campus of Ewha Women's University in Seoul gives QNS a unique opportunity to push the limits of quantum and nanoscience. This very-low-vibration facility is comprised of:

- 8 scanning probe microscopy (SPM) labs on a separate foundation from the main building:

- Vibration-isolation facility for high-performance SPM
- Designed for 3-axis active isolation
- STM control room with interactive discussion area
- Tall ceilings for large equipment

- Four clean-rooms for optics / complimentary experiments
- Large basement laboratory dedicated for collaborative research
- Two floors of office space
- Large common-room as a meeting & gathering space
- 5500 m2 of total area for QNS

Equipment



Scanning Tunnelling Microscope (STM) at 10 millikelvin (mK)

Home-built combination of STM with a dilution refrigeration system to operate at the coldest temperatures currently available for quantum control at extremely cold temperatures. System includes two-axis magnetic field.

Surface Science Electron Spin Resonance (ESR)

Spatially-averaging ESR at temperatures from 2 to 400 Kelvin and is optimized to work on clean surfaces. Sensitivity of ESR to sub-monolayer spin density.

Low Temperature STM + Atomic Force Microscopy (AFM)

QNS operates several low-temperature STM and AFM systems. AFM systems with cold preamp are designed for spin-dependent measurements operating between 1K and 10K.

Optics STMs

QNS has focused on designing low-temperature STM systems with good optical access to detect photons from the STM and to shine laser light onto STM tip-sample junctions.

Growth Systems for Atomically-Controlled Thin Films

QNS operates several growth systems for atomically controlled sample growth, including molecular beam epitaxy for growth of thin-film materials.

Quantum Control of Atomic-Scale Defects in Solids (NV AFM)

In collaboration with researchers from Korea University QNS has built an AFM system with individual nitrogen vacancy (NV) centers in the AFM tip.

Computing Cluster

Medium-scale computing cluster to perform density-functional and quantum chemistry modelling of atoms and molecules.

Electron Spin Resonance STM

QNS is developing several STM systems with high-frequency capabilities to perform ESR on single atoms and molecules on surfaces. Operation temperature of about 0.5K and vector magnetic fields will be available. High frequency sources up to 50GHz with pulsed capabilities.

Visitors Program

Our Center welcomes long- and short-term research stays. QNS has many active collaborations worldwide and we encourage visits by researchers through out the field of quantum nanoscience.

We hold seminars at least twice monthly for our researchers and our students. Nearly **100** international visitors have already given exciting talks. Our dedicated staff for the visitors program is happy to help our guests with their stay.

If you want to visit QNS, please, write us -

stay@qns.science

Invited Talks

In only two years QNS Members have given more than **50** invited talks at international conferences. We are not only focusing on research but also doing our best to share our research results internationally with the goal of developing compelling collaborations.

Events

Workshop on Advanced Scanning Probe Microscopy (ASPM)

ASPM 2018
2018. 08.16 – 08.18
BEXCO, Busan, Korea
19 lectures
10 international speakers
21 posters
100+ participants

ASPM 2017
2017. 08.17 – 08.18
Konjiam Resort. Kyoungki-do, Korea
22 lectures
11 international speakers
13 posters
100+ participants

Workshop to Define Quantum Nanoscience

2018. 09.17 – 09.20
Ewha Womans University, Seoul
8 senior international leaders spanning the field
1 professional facilitator

This active working group grappled with the definition of this important and growing field. By the end, a definition was achieved, this was posted to Wikipedia, and the participants chose to write a paper introducing their definition to the larger scientific community.

Theory Workshop

2019. 05.27 – 05.30
Ewha Womans University, Seoul
17 lectures
13 international speakers
9 posters
40+ participants

The workshop Quantum Spins at the Nanoscale brought together international experts in the field of Quantum Nanoscience. The event was focused on recent developments in the study of open quantum spin systems at the nanoscale.

IBS Conference on Quantum Nanoscience

2019. 09.25 – 09.27
Ewha Womans University, Seoul
5 sessions, **30** lectures
16 invited speakers
30+ posters
120+ participants

There are many conferences that cover subfields of this research area but as far as the organizers know, this is the first conference that attempts to bring researchers in the broader field of quantum nanoscience together as one community.

Outreach

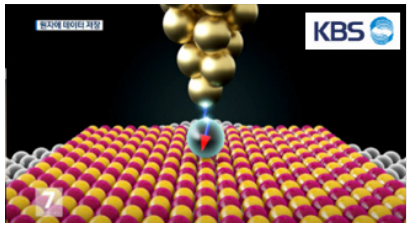
Our Center believes in paying back the investment in basic science made by Korean society by engaging the public in our exciting work.

Traditional Media

QNS held press conferences for the ***Nature*** and ***Science*** papers at Ewha Womans University. QNS researchers gave talks on the research results and were interviewed by about 25 journalists. The research was covered by various media outlets internationally and domestically including major Korean broadcasters such as ***KBS*** and ***Yonhap News TV***.

In addition, these papers have below were heavily covered by thereceived extensive media coverage:

- “Magnetic resonance imaging of single atoms on a surface” ***Nature Physics*** (2019)
- “Hyperfine interaction of individual atoms on a surface” ***Science*** (2018)
- “Probing quantum coherence in single-atom electron spin resonance” ***Science Advances*** (2018)
- “Enhanced quantum coherence in exchange coupled spins via singlet-triplet transitions” ***Science Advances*** (2018)



Projects

Art Contest “The World of Quantum“

The art contest was created to introduce the field of quantum nanoscience to a large community of creative professionals who regularly communicate with the public. Deeply engaging multiple storytellers is an exciting and cost-effective way to introduce our scientific research to the Korean public. Participating artists have learned about QNS’s research topics through talks, lab visits, and extensive Q&A and have expressed their understanding of quantum nanoscience in their own voices. These artists are giving us fresh perspectives and interpretations to interact with the public in engaging ways.

Artists attending the introductory session about quantum nanoscience: 70

30-minute lecture : 100 minutes Q&A!

Artworks submitted: 400

Pieces selected for final round: 40

Prizes: 5

Total cost: 20 million won

NanoKOMIK

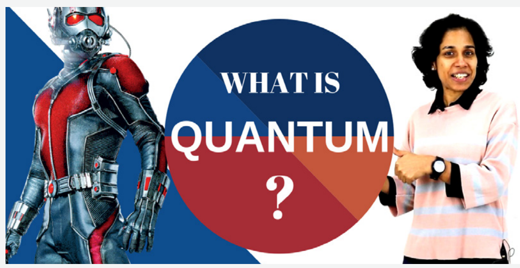
This In 2020 QNS will be bringing its own curriculum to Korean middle school classrooms. Creating this program has involved multiple layers of collaboration. The source material is a series of four comics exploring the concept of nano principles and phenomena developed by QNS’ MOU partner Donastia International Physics Center (DIPC) in San Sebastian, Spain.

DIPC happily agreed to let QNS translate the comic into Korean. From there QNS is working with education professors at Ewha Womans University and Korean middle school teachers to create a hands-on curriculum for teachers and students all over Korea. Throughout this curriculum, the students will have special experiences learning the fun of nanoscience, engaging on social media, and visiting QNS. By engaging young students, they in turn engage their parents.

Our Social Media - @QNSscience

Facebook

QNS runs an active Facebook page which is constantly updated with recent research results, educational videos, and information about our center. Our videos and posts aim to engage various audiences.



YouTube

QNS posts twice a month on our YouTube page where we upload in-depth interviews with our researchers, research results, scientific animations, and engaging and educational content. Our channel aims to interest and reach a wide audience.

Instagram

Our Instagram page shares weekly updates on our activity, including photos, definitions of key quantum nanoscience terms, and updates for followers on our research and on-going projects..

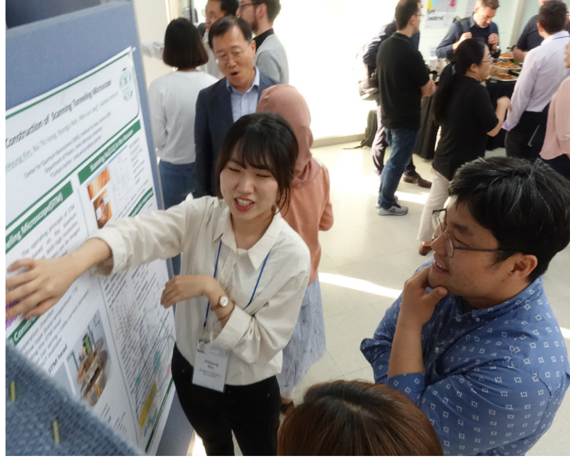
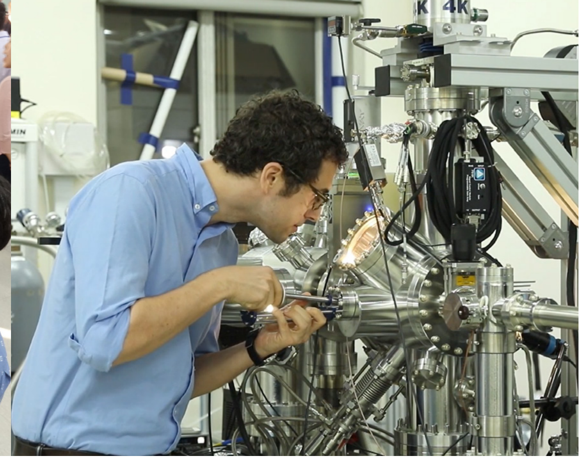
Twitter

Since many in the scientific community are active on Twitter QNS aims to use this platform to curate the field of quantum nanoscience by featuring key research developments, new breakthroughs, and future directions.

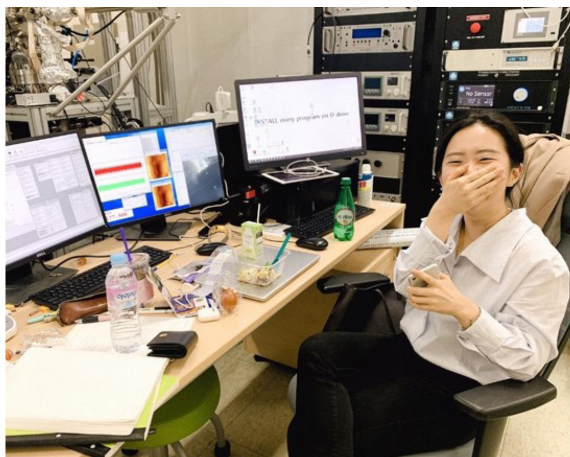
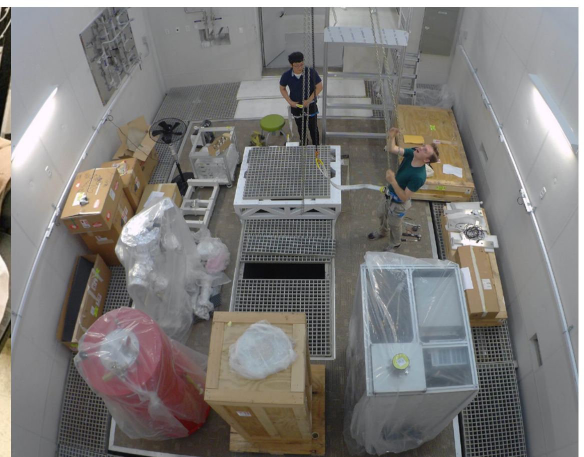
Our Team

With a team from all over the world based in Korea, culture is a critically important aspect- of QNS. We are an international research center with English as the working language. To enhance fundamental communication, we provide advanced English and beginner Korean language instruction. To ensure a smooth start at QNS we provide comprehensive onboarding for our center for all new members and Korea for new international members along with extensive resources via our intranet. Since culture is a living part of any organization, we hold annual meetings to deeply examine our culture and vision as QNS.

To maximize QNS's scientific output, our Operations (Ops) Team ensures the smooth functioning of the center while relieving researchers of every administrative burden possible. Our motto is to "let the scientist focus on the science."



Directors

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Director, Distinguished Professor

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Director of Operations & Public Information Officer

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Daniel Loss
Professor, University of Basel

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Kavli Prize Recipient,
IBM Fellow (ret)

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President, Daegu Gyeongbuk Institute of Science & Technology

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Yejin Jeong
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Future Plans

Our Research Goals:

- Achieving full control of the quantum states of atoms and molecules on clean surfaces and near interfaces.
- Exploring both theoretically and experimentally, systems and strategies for coherent manipulation of quantum nanostructures, with emphasis on understanding and mitigating decoherence.
- Demonstrating and optimizing the use of single atoms and molecules as quantum bits for quantum computation applications.
- Investigating the transition from quantum to classical behavior, including the quantum measurement problem.

Our Technology Pathway:

Phase I	Phase II	Phase III
Management and coherently control of quantum states of quantum systems	Replicate results of Phase I through chemical synthesis	Self assembly for scalable production

Patent novel tools and techniques throughout

Contacts

QNS always welcomes researchers and students. Working at QNS is a great chance to help develop your career in this growing field! If you're interested in learning more, please contact us. We are looking forward to hearing from you!

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