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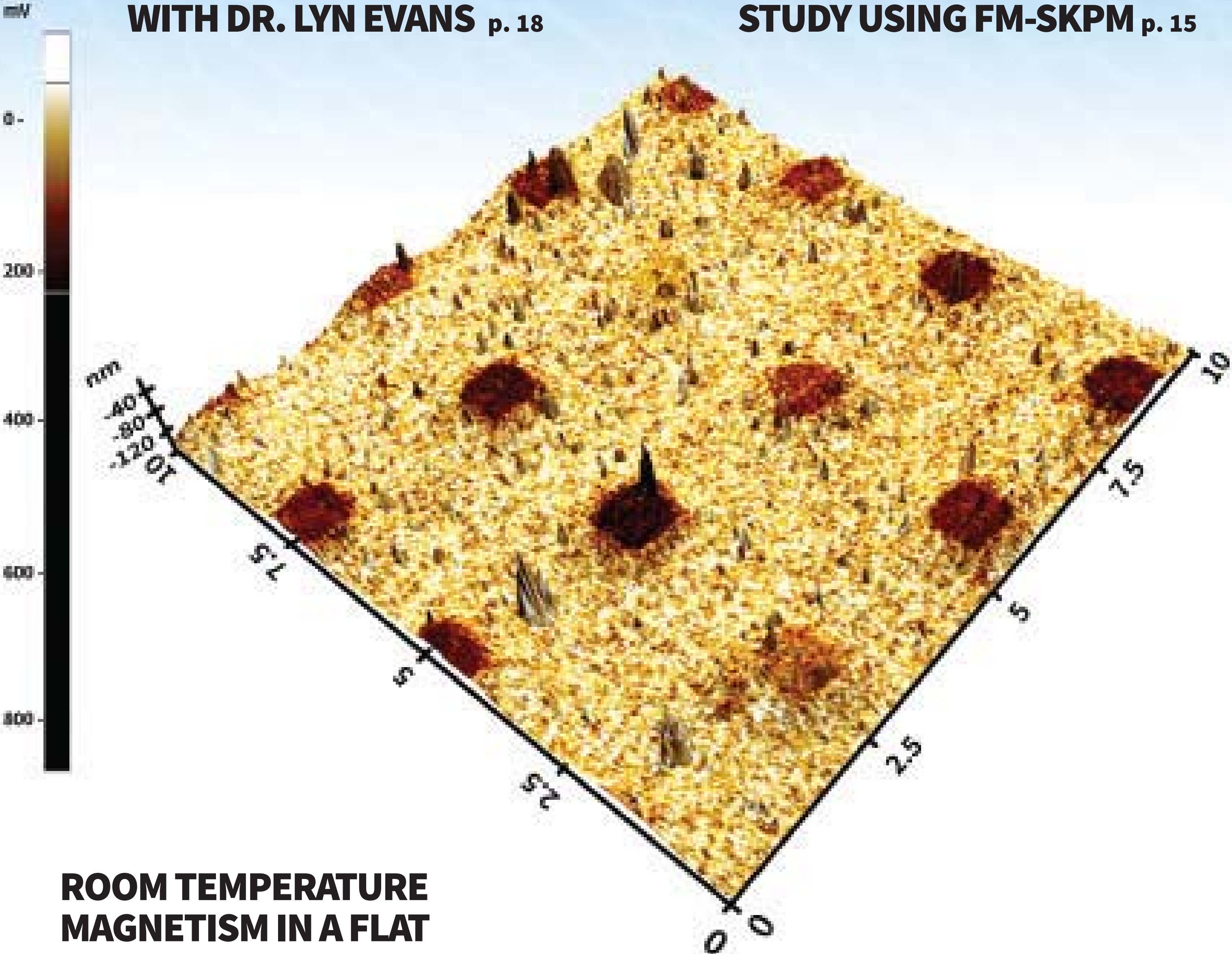

The Most Accurate Atomic Force Microscope

Park SYSTEMS

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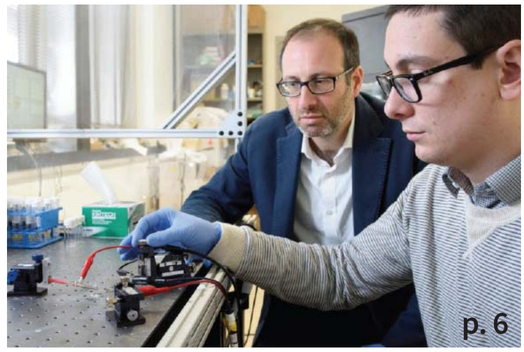
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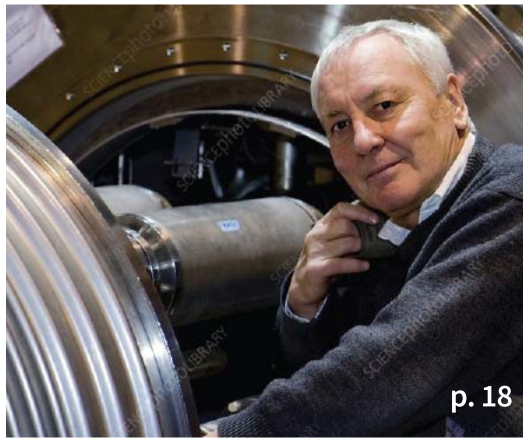
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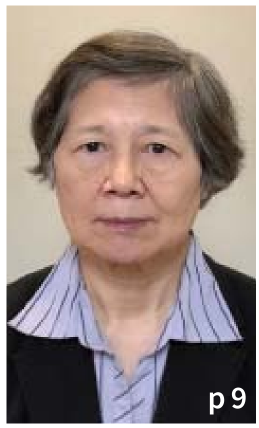
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INSET PHOTO ON COVER:

The 3D overlay of the surface potential image on topography displaying the surface charge and charge position of a polymer patterned array material deposited on silicon substrate analyzed using a Park NX10 AFM's FM-SKPM is shown.

The areas on the sample surface composing of relatively more negative charges appear darker. By taking advantage of phase input based two lock-in technique, compared to conventional SKPM techniques, the FM-SKPM (Frequency Modulation Scanning Kelvin Probe Microscope) can achieve higher signal to noise ratio and map out surface potential distribution of different materials with much improved lateral image resolution and surface potential data accuracy.

MESSAGE
FROM EDITOR

Welcome to another issue of NanoScientific.

International collaboration has played an important role in the development of nanotechnology. Scientific research knows no boundaries as we are on the brink of discoveries that change our lives.

Nanoscience is the study of the interaction, composition, properties and manufacturing methods of materials at the nanometer scale. Nanoscience facilitates the integration of many disciplinary areas of scientific research and directly impacts every sector of our economy.

Through international cooperation, nanoscience is a growing research priority in many countries, forming a massive global think tank of scientists and researchers blazing trails into our future.

In this issue, we present an article on the work of Dr. Alberto Salleo at Stanford University. His inspiring work with polymer based semiconductors has already laid a foundation for future innovative products in biomedical and neuro computing.
We also present exciting news about the International Linear Collider (ILC), which may soon become a reality if approved by host Japan and will continue the work done at CERN where, in 2012, the discovery of Higgs boson, the subatomic particle that has brought a Nobel Prize to Francois Englert and Peter Higgs was officially announced.

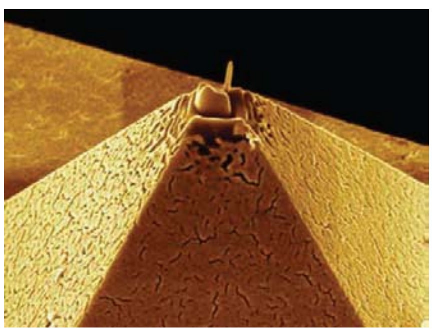
This issue showcases an in depth look into tooth whitening, a study done using PinPoint Nanomechanical Mode and an application note on enhanced surface detection techniques using FM-SKPM.

We also feature an article by RPI Applied Physics and Astronomy professor, Dr. Gwo-Ching Wang on Room Temperature Magnetism in a flat land- Transition metal dichalcogenide.

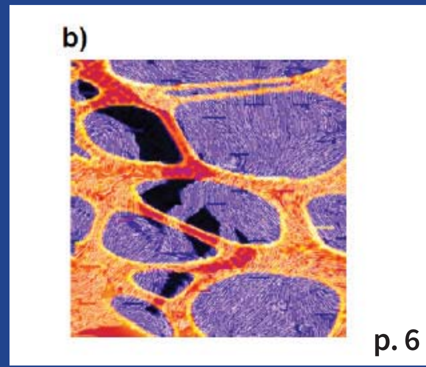
As the tools to “see” at the nanoscale continue to advance, scientific discoveries are setting an unprecedented pace for human progress.

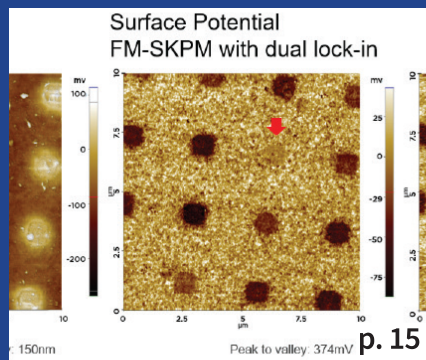
We hope you enjoy this issue of NanoScientific, please share your feedback and story ideas.

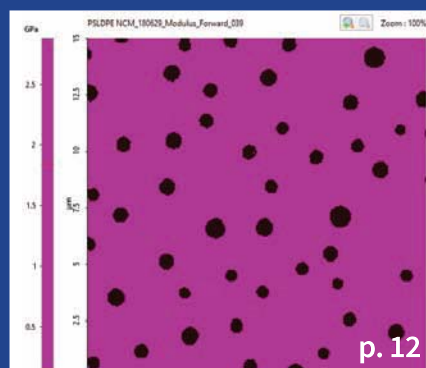
Keibock Lee
Editor-in-Chief

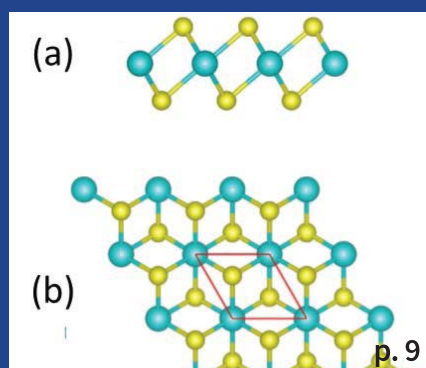


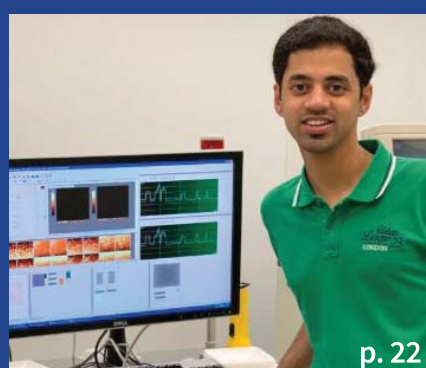
Developing new instruments to be able to "see" at the nanoscale is a research field in itself. Shown here is the tip of an atomic force microscope (AFM), one of the foremost tools for imaging, measuring and manipulating matter at the nanoscale. Here, a platinum electrode measuring one hundredth of a nanometer has been deposited on the tip of this pyramid shaped AFM tip via focused ion beam (FIB) deposition. (Image: C. Menozzi, G.C. Gazzadi, S3 (INFM-CNR), Modena. Artwork: Lucia Covi)











FEATURE ARTICLE

DR. ALBERTO SALLEO

Associate Professor Materials Science & Engineering, Stanford University

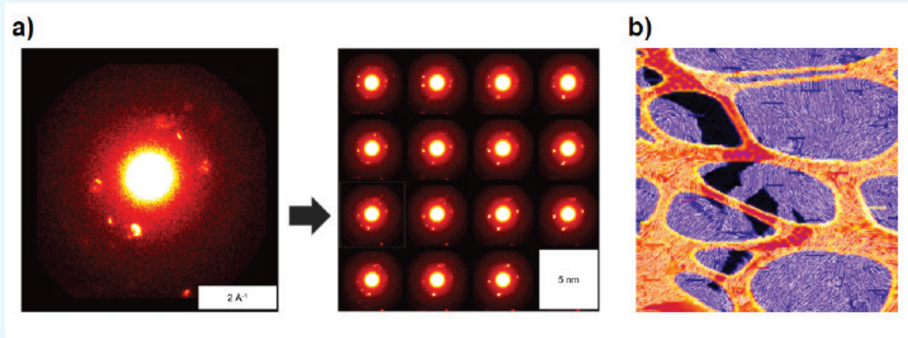
Dr. Alberto Salleo
Associate Professor Materials Science & Engineering, Stanford University

Professor Salleo received his Laurea degree in Chemistry from the University of Rome and his M.S. and Ph.D. in Materials Science from UC Berkeley investigating optical breakdown in fused silica. He spent 5 years at the Palo Alto Research Center as a postdoc and then a member of the research staff in the Electronic Materials Laboratory before joining the Department of Materials Science and Engineering at Stanford University in 2005. Dr. Salleo has been a Principal Editor of MRS Communications since 2011.

While at Stanford, Salleo won the NSF Career Award, the 3M Untenured Faculty Award, the SPIE Early Career Award and the Tau Beta Pi Excellence in Undergraduate Teaching Award and the Gores Award for Excellence in Teaching, Stanford's highest teaching honor. He has been a Thomson Reuters Highly Cited Researcher in Materials Science (top 1% cited scientists) since 2015.

The Salleo Research Group is interested in novel materials and processing techniques for large-area and flexible electronic/photonic devices. They also study defects and structure/property relations of polymeric semiconductors, as well as nano-structured and amorphous materials in thin films.

SCANNING TRANSMISSION ELECTRON MICROSCOPY



Scanning Transmission Electron Microscopy (STEM) gives spatially resolved electron diffraction images. Dr. Salleo's group uses this technique to study how crystallite quality and orientation vary across a polymer film, and what implications this has for processing and performance.

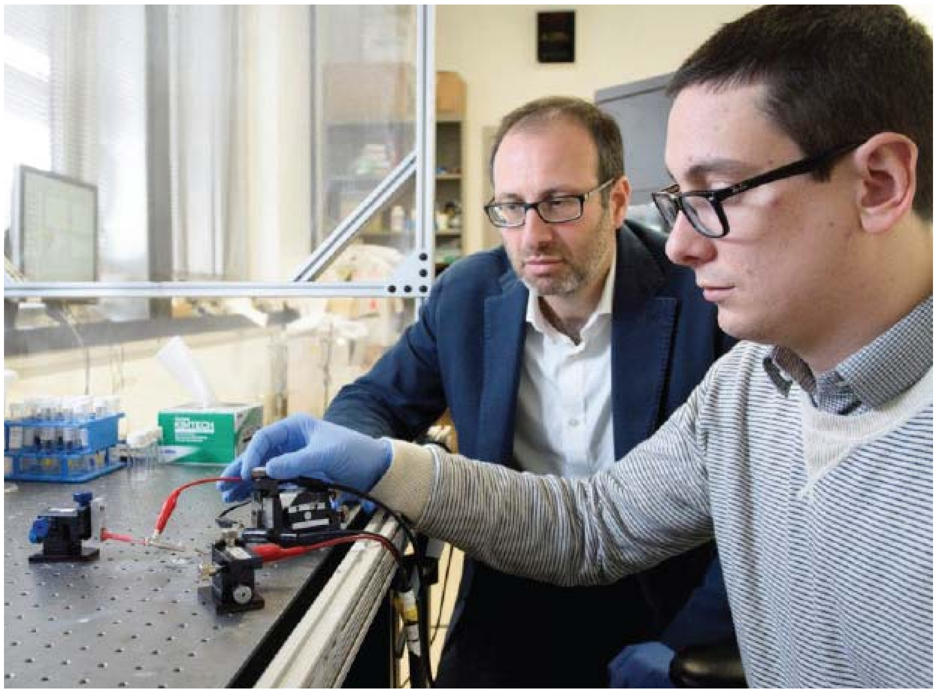
(a) Diffraction spots indicate the local direction of polymer chains (left), Comparing adjacent scans sheds light on microstructure (right). (b) Conjugated polymer (PBTTT, purple) on a lacy carbon support (orange). Lines show the orientation of polymer aggregates, calculated from STEM diffraction patterns.

Polymer-based Semiconductors and Neuromorphic Devices

Organic electronic materials offer an attractive option for polymer based semiconductor systems and could provide biocompatible and relatively inexpensive neuromorphic devices with low-energy switching and excellent tenability paving the way for neuromorphic computing to address the inherent limitations of conventional silicon technology in dedicated machine learning applications.

As Moore's scaling law reaches an end, new brain-like (neuromorphic) computing architectures that embed memory and computation into a single device are highly sought after. Traditional semiconductor memory technology has yet to satisfy the needs of the "artificial synapse" that is the core of the neuromorphic computing architecture. This group uses organic semiconductors to mimic synaptic behavior in an electrochemical organic neuromorphic device (ENODe), which couples ionic and electronic currents to emulate the strength of neuron-to-neuron connections. The high linearity and low switching energy of ENODes make them highly suitable for massively parallel neural algorithm accelerators, i.e. brain-like computer chips. Salleo's research group focuses on leveraging the ionic/electronic transport properties of polymeric semiconductors to design novel devices for neuromorphic computing.

"In the electrical field there are ions and electrons moving in a field. The motion of the ions is transduced as sensors, thereby being used as electrochemical sensors. In the case of wearable sensors such as a "sweat sensor", organic material which is able to carry both ions and electrons is used and a blend is used which carries ions. New polymers are always being tested as well as material that can carry ions, electrons or both. The advantage of organic polymers is the low cost and flexibility," explains Dr. Salleo.



Alberto Salleo, associate professor of materials science and engineering, with graduate student Scott Keene characterizing the electrochemical properties of an artificial synapse for neural network computing. They are part of a team that has created the new device. (Image credit: L.A. Cicero)

Q & A WITH DR. ALBERTO SALLEO, Associate Professor Stanford Department of Materials Science and Engineering, Geballe Laboratory for Advanced Materials; Principal Editor MRS Communications

What imaging tools such as AFM do you use to study defects and properties/structures and is accurate imaging at nanoscale crucial in your research?
We typically use standard tapping mode AFM and look at both topography and phase. Accurate imaging at the nanoscale is crucial as we often work with materials that have very small microstructural features (e.g. polymer crystallites, phase separation), which control the functional properties of the materials.

Can you give a few examples of how you use AFM in your research?
We have used conductive tip AFM to study the distribution of dopants in doped conjugated polymers. We have also used tapping mode AFM to study the terracing of crystalline organic semiconductors and the topography of grain-boundaries.

What capabilities in AFM are most significant to assist you in research?
For general use, measuring roughness is important for us. Lately we have been interested in other capabilities such as the ability to measure current, electrochemical AFM and the possibility of using AFM in water.

In the future, what advances in AFM and nanometrology can you envision that would significantly improve the functionality?
Multimodal capabilities (i.e. measuring several properties simultaneously) would improve the study of functional materials as we often look for correlations between different materials features.

What are the next significant advances you see in material science research and how will they impact society?
I think the integration of materials with living matter is poised to have an enormous impact in healthcare and possibly even computation.

STANFORD RESEARCHERS, LED BY PROFESSOR SALLEO CREATE A HIGH-PERFORMANCE, LOW-ENERGY ARTIFICIAL SYNAPSE FOR NEURAL NETWORK COMPUTING

Researchers at Stanford University and Sandia National Laboratories have made a progress that could help computers mimic one piece of the brain's efficient design – an artificial version of the space over which neurons communicate, called a synapse.

"It works like a real synapse but it's an organic electronic device that can be engineered," said Alberto Salleo, associate professor of materials science and engineering at Stanford. "It's an entirely new family of devices because this type of architecture has not been shown before. For many key metrics, it also performs better than anything that's been done before with inorganics."

The new artificial synapse mimics the way synapses in the brain learn through the signals that cross them producing a significant energy savings over traditional computing because the processing creates the memory.
This synapse may one day be part of a more brain-like computer, which could be especially beneficial for computing that works with visual and auditory signals. Examples of this are seen in voice-controlled interfaces and driverless cars. "In looking at neuromorphic computing, companies design neuro electrochemical devices designed to emulate a synapse and neurotransmitters diffuse their device. The strength of the connection can be molulated like a synapse, making a network similar to the brain. As we approach the end of Moore's Law in semiconductor like Carver Mead thought of 30 years ago, the advantage of neuromorphic computing is the very low power it requires, like a brain. Where I see this going is specialized chips instead of general purpose chips. For instance there can be a specific chip for computer vision. The silicon cmos chip is so powerful; I see neuromorphic chips as a compliment to them to augment this technology, not to replace it," explains Dr. Alberto Salleo.

ORGANIC ELECTROCHEMICAL TRANSISTORS AND WEARABLE ELECTRONICS

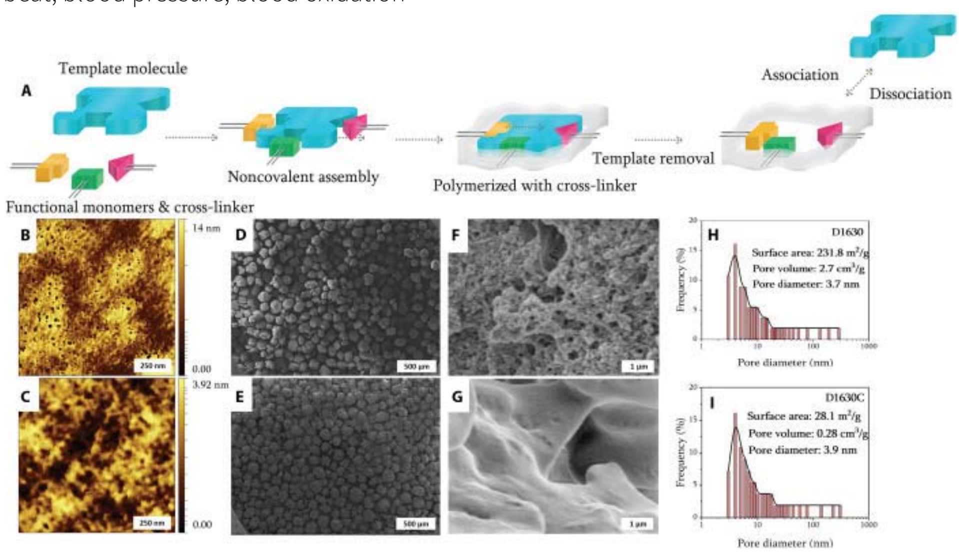
Organic electrochemical transistors (OECTs) are of high interest due to their ability to transduce ionic signals, such as those produced in biology, with relatively high gain at low operating voltages (<0.5V), making them ideal candidates for biosensing applications. Our group's research spans from elucidating fundamental structure-property relations in mixed ionic-electronic organic materials to developing novel wearable biosensors. We use characterization (i.e. synchrotron X-ray scattering, device modeling, spectroscopy, electrochemical measurements) to develop a fundamental understanding of organic materials for OECT devices. Extrapolating from fundamental principles, our group has developed various biomimetic membranes to selectively sense metabolites, ions and hormones from various bodily fluids including sweat and saliva.

In an article recently published in Science Advances (July 20, 2018), authors Onur Parlak, Scott Tom Keene, Andrew Marais, Vincenzo F. Curto and Alberto Salleo demonstrated the integration of an artificial receptor as a biomimetic polymeric membrane for stable and selective molecular recognition using OECTs to produce a wearable sweat diagnostics platform for real-time analysis of the human stress hormone cortisol. The group led by materials scientist Alberto Salleo at Stanford University has created a stretchy patch that applied directly to the skin, wicks up sweat and assesses how much cortisol a person is producing.

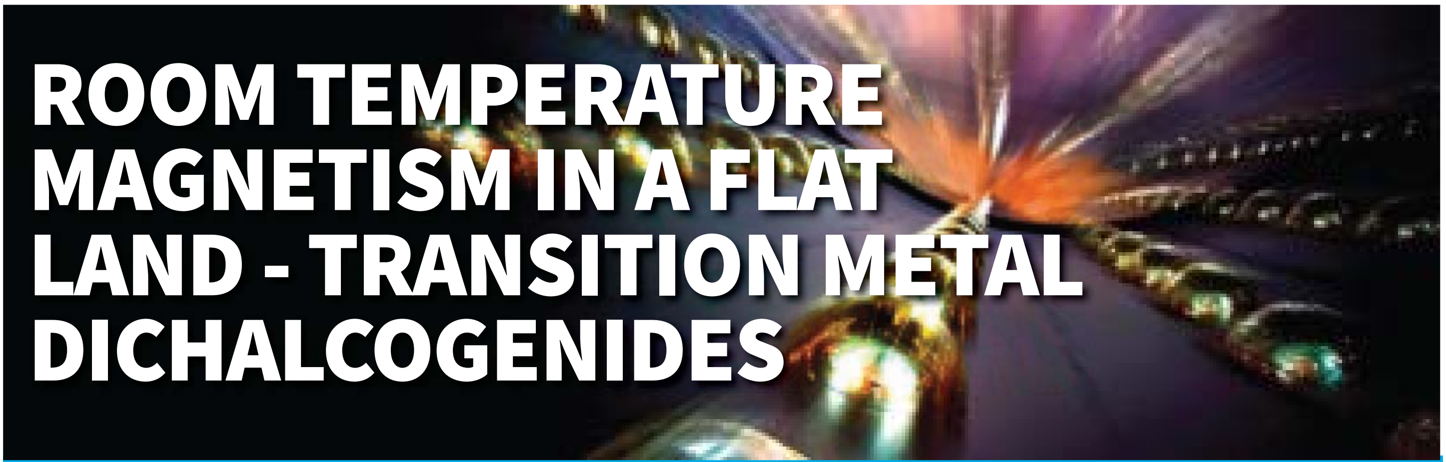
This wearable sensing device for cortisol detection was realized using a conductive polymer channel functionalized with a cortisol-selective membrane produced on a flexible and stretchable elastomeric substrate. The molecularly selective polymer-based membrane shows high chemical and physical stability at body temperature, as well as resistance to physical deformation. The presented sensor tolerates mechanical testing such as bending and stretching in conditions similar to those found in the normal range of motion of the human epidermis. Moreover, we used a simple strategy to generate a passive fluid control system consisting of a laser-patterned micro capillary channel array that provides fast and precise delivery of sweat directly to the sensor interface. The resulting wearable sensor was used for measuring cortisol concentration in a real human sweat sample collected during exercise. Considering that traditional blood analysis is often used for cortisol sensing, the wearable device provides many advantages including noninvasiveness, ease of operation, and user comfort. "We are particularly interested in sweat sensing, because it offers noninvasive and continuous monitoring of various biomarkers for a range of physiological conditions," said Onur Parlak, a post-doctoral scholar in the Salleo lab and lead author of the paper. "This offers a novel approach for the early detection of various diseases and evaluation of sports performance."

"Wearable electrochemical sensor can analyze sweat which occurs under stress. The advantage of organic material is that it is soft and pliable, making it suitable for wearing. These sensors can detect heart beat, blood pressure, blood oxidation and create bio feedback mechanisms for precision medicine. Research being done now is testing wearable electrochemical sensors worn in socks and printed on textiles so they are transparent to the user by being printed on textiles with organic integration. Evaluation of common household items such as a toilet and a toothbrush to analyze bodily secretions could be the health detection devices of the future," explains Dr. Alberto Salleo.

The Stanford team is currently working to miniaturize the device, and also hoping to develop a user interface that will assist in the evaluation of data. The team also wants to adapt the device so that it could be powered by harvested energy rather than by an internal battery. The device could be modified to detect other hormones and non-charged ions within sweat. The end goal is to have a device that is capable of monitoring several different biomarkers at the same time, which would help researchers and health professionals gain a more holistic, individualized representation of a person's health and mental state.



(A) Molecular memory is introduced on the sensor surface by copolymerizing functional monomer and cross-linker in the presence of the analyte, which acts as a molecular template. After elution of the analyte, complementary binding sites are revealed complimentary in size and shape to template by creating molecular memory on the surface that allows specific rebinding of the target molecule. The recognition sites obtained in this manner have binding affinities approaching those demonstrated by antibody-antigen systems. Tapping-mode atomic force microscopy (AFM) analysis of cortisol-selective polymer (B) and its corresponding control (C). Scanning electron microscopy (SEM) images of cortisol-selective polymer (D and F) and its control (E and G) with two different magnifications. Pore size distribution for cortisol-imprinted (H) and nonimprinted polymers (NIPs) (I). The BJH method was applied to calculate pore size distribution from experimental isotherms using the Kelvin model of pore filling. The method applies only to the mesopore and small macropore size range.



ROOM TEMPERATURE MAGNETISM IN A FLAT LAND - TRANSITION METAL DICHALCOGENIDES

Dr. Gwo-Ching Wang, Dept. of Physics, Applied Physics & Astronomy, Rensselaer Polytechnic Institute

Dr. Gwo-Ching Wang, received her PhD degree from University of Wisconsin, worked at NBS Washington, DC and Oak Ridge National Laboratory before joining Rensselaer. She is the Rensselaer Travelstead Institute Chair. She served as the head of the Physics Department at Rensselaer Polytechnic Institute (2000-2010). Her thin film and nanostructure physics lab is equipped with Park Systems AFM, high-resolution low energy electron diffraction (HR-LEED), reflection high energy electron diffraction (RHEED) and surface magneto optical Kerr effect (SMOKE) to study surface morphology, structure and magnetic properties of materials. The group members also developed RHEED reciprocal space mapping to study graphene and TMDC monolayer as well as RHEED pole figure analysis to study texture of thin films and nanostructures.

In the past decade there has been a world-wide research interest in two-dimensional materials such as graphene (one layer of graphite), transition metal dichalcogenides (TMDCs), and 2D oxides(mica, layered Cu oxides, etc.)[1]. A bulk TMDC consists of astack of MX2 monolayers. Each MX_2 consists of X–M–X where M is a transition metal atom (Mo, W, V, Nb, etc.) sandwiched between two X chalcogen atoms (S, Se, or Te). See Fig. 1(a). The out-of-plane interaction between MX_2 is weak van der Waals (vdW) interaction and the in-plane interaction is strong chemical interaction.

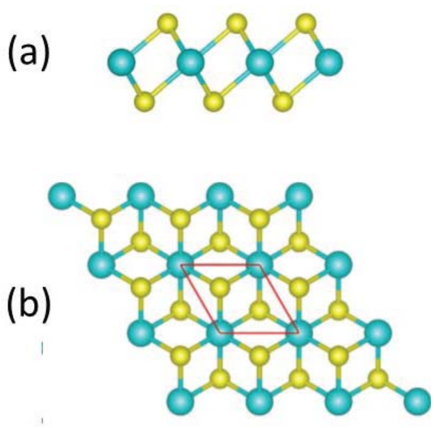


Fig. 1 (a) Side view and (b) top view of a VS2 monolayer in octahedral 1T phase. The V and S atoms are in blue and gold, respectively. The red parallelogram is a two-dimensional unit cell. [From Ref. 8]
Figure 1(b)is a top view of one monolayer of vanadium disulfide (VS_2).

Among over 40 low-dimensional TMDCs, most are semiconducting dichalcogenides. Low-dimensional vanadium disulfide (VS_2) is one of the metallicdichalcogenides.On the theoretical side, first principles spin polarized density function theory (DFT) calculations predict that a large magnetic moment exists in a free standing VS_2 monolayer form due to the quantum size effect[2-9]. DFT calculations also predict the existence of magnetic moments for a few monolayer thick VS_2[6]. These DFT predictions extended the potential of electrons in the controls and manipulations of electronic and magnetic properties of TMDCs that may enable electronic/spintronics applications.

The vdW TMDC crystals have been shown experimentally to possess many fascinating mechanical, optical and electronic properties. However, there have been fewer studies on the magnetic property of vdW TMDC crystals, because most TMDC crystals are nonmagnetic in the bulk forms. Practical methods such as defect engineering [10] have been designed to extrinsically induce magnetism within these vdW TMDC materials with the hope to observe magnetism. The challenges in the synthesis of low-dimensional TMDCs are the control of thickness, size and stoichiometry. Take VS_2 as an example. Hydrothermal [11-14],liquid exfoliation [15], and chemical vapor deposition (CVD) [16, 17] methods have produced VS_2 nanosheets, nanoplates, and nanoflowers. These nanostructures have been applied in battery anodes[17, 18], supercapacitors[13], moisture sensor[19], and electrocatalytic hydrogen evolution reaction (generating hydrogen by splitting water)[14, 16]. Despite the possibility that defects or impurities or substrates from these synthesis methods may contribute or influence the intrinsic magnetic property of nanostructure VS_2, there are signs of magnetic signals from these nanostructures measured by vibrating sample magnetometer(VSM) orsuperconducting quantum interference device SQUID 11, 12, 20.One exciting work of monolayer (ML) and nanoflowers. These nanostructures have been applied in battery anodes[17,18], supercapacitors[13], moisture sensor[19], and electrocatalytic hydrogen evolution reaction (generating hydrogen by splitting water)[14,16]. Despite the possibility that defects or impurities or substrates from these synthesis methods may contribute or influence the intrinsic magnetic property of nanostructure VS_2, there are signs of magnetic signals from these nanostructures measured by vibrating sample magnetometer(VSM) or super conducting quantum interference device SQUID [11,12,20]. One exciting work of monolayer (ML) and few ML VSe_2 (Se is in the same chalcogens column) grown by molecular beam epitaxy in ultra high vacuum was reported to show strong room temperature ferromagnetism measured by VSM and surface magneto optical Kerr effect (SMOKE) *ex situ* using a Se capping layer 21.

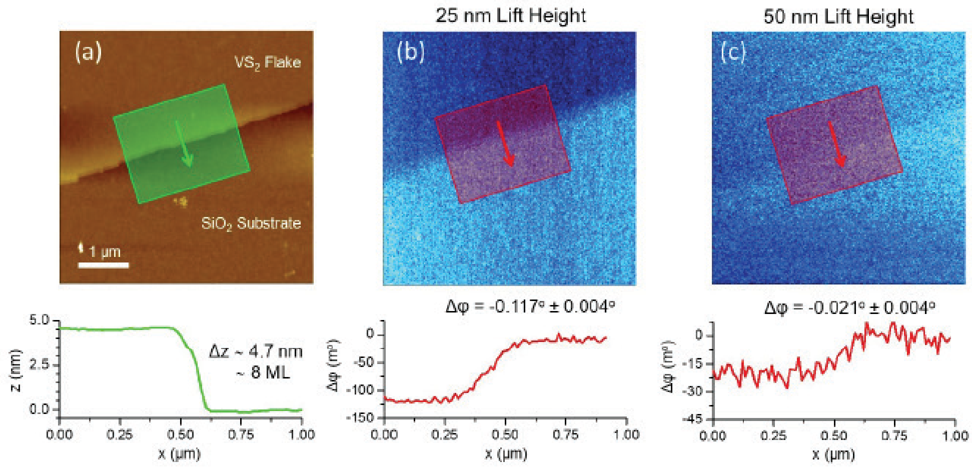


Fig. 3 An ultrathin VS2 flake on the SiO2 substrate. (a) AFM topography scan revealing the flake thickness to be ~ 4.7 nm thick, corresponding to eight S-V-S layers. MFM phase map of the area shown in (a), collected at a lift height (L) of (b) 25 nm and (c) 50 nm. Scale bars in (a) is 1 μm.

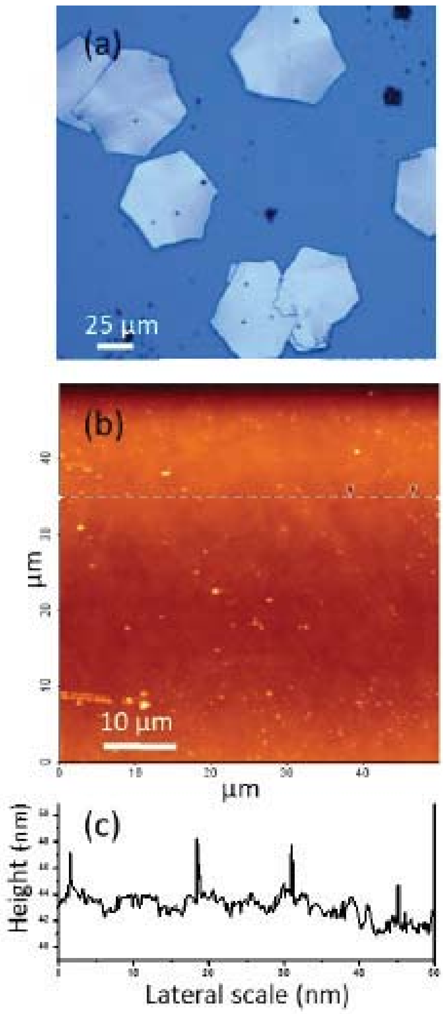


Fig. 2 (a) Optical image of VS_2 flakes grown on SiO2 substrate by chemical vapor deposition. (b) AFM image of an ultrathin flake larger than 50 μm. (c) Height scan along the surface of the flake indicated as a white dashed line in (b).

We have used CVD targeting at synthesizing monolayer and ultrathin VS_2 films and search for room temperature ferromagnetic ordering in the films. The precursor used was VCl_3 and sulfur vapor came from heated S powders. The growth parameters were systematically tested by varying the S powder amount, VCl_3 precursor amount, carrier gas type, carrier gas flow rate, heating zone temperatures and the growth duration. Under the optimum CVD growth condition various sizes and thicknesses of flakes were observed on SiO_2 substrate. Flake sizes ranged from a few microns to about 100 microns. The flake thicknesses ranged from sub-tens nm to 200 nm. Fig. 2(a) is an example of many large and thick flakes on SiO_2. Monolayer and bilayer were also observed but rare. The surface of the large flake is smooth as seen in the 50 μm × 50 μm AFM image in Fig. 2(b). Figure 2(c) shows a height scan along the white line on the surface of the flake in Fig. 2(b). The height variation is within one or two nm over 50 μm. On the surface there are 3 nm spikes occasionally observed.

The Energy Dispersive Spectroscopy of these flakes shows approximately 1 to 2 stoichiometry ratio of V to S with slightly V rich.

To study the magnetic property of ultrathin VS_2 flakes on SiO_2 substrate, we use AFM first to identify the flake and then measure the magnetic phase contrast using magnetic force microscopy(MFM) at room temperature. A Park Systems NX20 scanning probe microscope with a Park MFMR cantilever (k ~ 2.8 Nm^{-1}, selected frequency ~ 75 kHz, CoCr coated with nominal coercivity ~ 400 Oe) was used for MFM measurements.

Both the sample and tip were magnetized by a ~ 500 Oe permanent magnet prior to image collection. The MFM[22] data collection began with a traditional non-contact AFM scan to map the sample's topography by measuring the attractive van der Waals forces between the sample and the probe tip[23]. After acquiring the topography data, the tip was lifted to a pre-set distance (typically 20 – 50 nm) beyond the influence of the vdW forces. It then followed the collected topography line scan to maintain a constant sample-probe distance and detected the magnetic interactions via a shift in the cantilever's vibrational phase.

Figure 3 shows an AFM topography and MFM phase maps of a VS_2 flake on SiO_2. The optical image (not shown here) indicates an ultrathin flake with a diameter of about 20 μm that is visible due to an optical interference with the 300 nm SiO_2/Si substrate. Figure 3(a) shows a AFM topography map of the edge of a flake which gives the flake's thickness to be ~ 4.7 nm, corresponding to eight S-V-S layers. An MFM phase map collected at a lift height of 25 nm is shown in Fig. 3(b). The negative phase shift of the sample relative to the SiO_2 substrate, which is weakly diamagnetic (essentially non-magnetic), indicates an attraction between the VS_2 flake and the MFM cantilever. This phase contrast was not observed when the sample and tip were not magnetized. Furthermore, because one phase contrast was measured across the whole of each flake, one can infer that each flake is composed of just one magnetic domain. This measurable magnetic interaction implies the existence of a remanent magnetization at room temperature in the sample, a property of ferromagnetic materials.

To demonstrate the dependence of MFM phase contrast on the sample-tip distance, data were collected at the lift heights (L) of 50 nm shown in Fig. 3(c). Qualitatively, the interfacial phasecontrast decreases with an increase in L. Averaging over approximately 50 line scans in the framed box across the flake/substrate interface ensures the data's reliability and provides optimal signal-to-noise ratio. The decay of the MFM phase shift with an increase in lift height likewise indicates a decrease in the attractive force between the tip and sample, consistent with what one would expect for a magnetic interaction[24-26]. The observation of the MFM phase signal reveals the existence of ferromagnetism in the ultrathin VS_2 film consistent with density functional theory calculations[6]. This negative MFM phase shift was reproducibly measured for several flakes ranging in thickness from 5 nm to 20 nm with consistent results. In fact, slightly stronger phase signal (indicating stronger magnetization) was measured as thickness decreased, consistent with the theoretical predictions[6].

Through the use of magnetic force microscopy, room temperature ferromagnetism has been detected in ultrathin VS2 crystalline flakes grown by CVD. This property does not exist in the bulk VS_2 material, but arises due to quantum confinement effects resulting from a reduced dimensionality. This is of significance to both fundamental physics, of which the study of ultrathin layered materials (and specifically transition metal dichalcogenides such as VS_2) is a field attracting much attention. We learned that CVD growth of low-dimensional VS_2 materials, including monolayer (ML) thickness, remains challenging. A better controllable method to grow monolayer VS_2 is molecular beam epitaxy in ultra high vacuum [21, 27]. Different monolayer of magnetic TMDC can be stacked to form artificial heterostructures that have the potential application to emerging research areas including future high density storage and spintronics.

Acknowledgement
The CVD growth of ultrathin VS_2 flakes was performed by Z. Li and A.J. Littlejohn. The AFM and MFM images were collected by A.J. Littlejohn with the assistance from Dr. Wenqing Shi at Park Systems. Graduate student Yu Xiang (see photo) uses AFM extensively for morphological study of graphene and TMDC materials. He gave a talk entitled "2D Materials in Real and Reciprocal Spaces: Complimentary AFM and RHEED Studies"at the NanoScientific Symposium on SPM in Sept. 2018.This work is supported by the New York State's Empire State Development's Division of Science, Technology and Innovation (NYSTAR) through Focus Center Contract C150117.

Graduate student Yu Xiang uses Park Systems' AFM in the Rensselaer lab. Graduates from the ulta thin film physics and nanoscience lab are working at US industries or universities making contributions to the advancement of science and technology. Examples of research areas are non-equilibrium growth and etching of metal and semiconductor films, magnetism of ultrathin magnetic films and dots, transport properties of metallic and magnetic films and nanotubes, fabrication and growth mechanism of sculptured films. The lab has been equipped with state of the art commercial and homemade techniques for fabrication and characterization of novel nanostructures. Examples of real space and diffraction techniques are scanning tunneling microscopy (STM), atomic force microscopy (AFM), nanolithography, high resolution low energy electron diffraction (HRLEED), energy filtered reflection high energy electron diffraction (EFRHEED), angle resolved light scattering (ARLS), Auger electron spectroscopy (AES), x-ray photoelectron spectroscopy (XPS), four point probe, magneto optic Kerr effect (MOKE), magnetoresistance, and ferromagnetic resonance. Examples of growth/etching techniques include thermal evaporation, chemical vapor deposition, atomic layer deposition, oblique angle incidence deposition, and ion sputtering. Physical properties of these nanostructures including magnetic, mechanical, electrical, transport, and structural are characterized by these surface sensitive techniques.

References

1. Geim, A. K.; Grigorieva, I. V., Van der Waals heterostructures. Nature 2013, 499, 419-425.
2. Ataca, C.; Şahin, H.; Ciraci, S., Stable, Single-Layer MX2 Transition-Metal Oxides and Dichalcogenides in a Honeycomb-Like Structure. The Journal of Physical Chemistry C 2012, 116, 8983-8999.
3. Ma, Y.; Dai, Y.; Guo, M.; Niu, C.; Zhu, Y.; Huang, B., Evidence of the Existence of Magnetism in Pristine VX2 Monolayers (X = S, Se) and Their Strain-Induced Tunable Magnetic Properties. ACS Nano 2012, 6, 1695-1701.
4. Zhou, Y.; Yang, C.; Xiang, X.; Zu, X., Remarkable magnetism and ferromagnetic coupling in semi-sulfuretted transition-metal dichalcogenides. Physical Chemistry Chemical Physics 2013, 15, 14202-14209.
5. Zhang, Y.; Wu, X., Vanadium sulfide nanoribbons: Electronic and magnetic properties. Physics Letters A 2013, 377, 3154-3157.
6. Zhang, H.; Liu, L.-M.; Lau, W.-M., Dimension-dependent phase transition and magnetic properties of VS2. Journal of Materials Chemistry A 2013, 1, 10821-10828.
7. Kan, M.; Wang, B.; Lee, Y. H.; Sun, Q., A density functional theory study of the tunable structure, magnetism and metal–insulator phase transition in VS2 monolayers induced by in-plane biaxial strain. Nano Res. 2015, 8, 1348-1356.
8. Wasey, A. H. M. A.; Chakrabarty, S.; Das, G. P., Quantum size effects in layered VX2 (X=S, Se) materials: Manifestation of metal to semimetal or semiconductor transition. J Appl Phys 2015, 117, 064313.
9. Zhuang, H. L.; Hennig, R. G., Stability and magnetism of strongly correlated single-layer VS2. Physical Review B 2016, 93, 054429.
10. Wang, Y.; Tseng, L.-T.; Murmu, P. P.; Baoc, N.; Kennedy, J.; Ionesc, M.; Ding, J.; Suzuki, K.; Li, S.; Yi, J., Defects engineering induced room temperature ferromagnetism in transition metal doped MoS2. Materials and Design 2017, 121, 77-84.
11. Gao, D.; Xue, Q.; Mao, X.; Wang, W.; Xu, Q.; Xue, D., Ferromagnetism in ultrathin VS2 nanosheets. Journal of Materials Chemistry C 2013, 1, 5909-5916.
12. Zhong, M.; Li, Y.; Xia, Q.; Meng, X.; Wu, F.; Li, J., Ferromagnetism in VS2 nanostructures: Nanoflowers versus ultrathin nanosheets. Materials Letters 2014, 124, 282-285.
13. Feng, J.; Sun, X.; Wu, C.; Peng, L.; Lin, C.; Hu, S.; Yang, J.; Xie, Y., Metallic Few-Layered VS2 Ultrathin Nanosheets: High Two-Dimensional Conductivity for In-Plane Supercapacitors. Journal of the American Chemical Society 2011, 133, 17832-17838.
14. Liang, H.; Shi, H.; Zhang, D.; Ming, F.; Wang, R.; Zhuo, J.; Wang, Z., Solution Growth of Vertical VS2 Nanoplate Arrays for Electrocatalytic Hydrogen Evolution. Chemistry of Materials 2016, 28, 5587-5591.
15. Coleman, J. N.; Lotya, M.; O'Neill, A.; Bergin, S. D.; King, P. J.; Khan, U.; Young, K.; Gaucher, A.; De, S.; Smith, R. J.; Shvets, I. V.; Arora, S. K.; Stanton, G.; Kim, H.-Y.; Lee, K.; Kim, G. T.; Duesberg, G. S.; Hallam, T.; Boland, J. J.; Wang, J. J.; Donegan, J. F.; Grunlan, J. C.; Moriarty, G.; Shmeliov, A.; Nicholls, R. J.; Perkins, J. M.; Grieveson, E. M.; Theuwissen, K.; McComb, D. W.; Nellist, P. D.; Nicolosi, V., Two-Dimensional Nanosheets Produced by Liquid Exfoliation of Layered Materials. Science 2011, 331, 568-571.
16. Yuan, J.; Wu, J.; Hardy, W. J.; Loya, P.; Lou, M.; Yang, Y.; Najmaei, S.; Jiang, M.; Qin, F.; Keyshar, K.; Ji, H.; Gao, W.; Bao, J.; Kono, J.; Natelson, D.; Ajayan, P. M.; Lou, J., Facile Synthesis of Single Crystal Vanadium Disulfide Nanosheets by Chemical Vapor Deposition for Efficient Hydrogen Evolution Reaction. Advanced Materials 2015, 27, 5605-5609.
17. Ji, Q.; Li, C.; Wang, J.; Niu, J.; Gong, Y.; Zhang, Z.; Fang, Q.; Zhang, Y.; Shi, J.; Liao, L.; Wu, X.; Gu, L.; Liu, Z.; Zhang, Y., Metallic Vanadium Disulfide Nanosheets as a Platform Material for Multifunctional Electrode Applications. Nano Letters 2017, 17, 4908-4916.
18. Liu, J.-Z.; Guo, P.-F., VS2 Nanosheets: A Potential Anode Material for Li-ion Batteries. Journal of Inorganic Materials 2015, 30, 1339-1344
19. Feng, J.; Peng, L.; Wu, C.; Sun, X.; Hu, S.; Lin, C.; Dai, J.; Yang, J.; Xie, Y., Giant Moisture Responsiveness of VS2 Ultrathin Nanosheets for Novel Touchless Positioning Interface. Advanced Materials 2012, 24, 1969-1974.
20.Guo, Y.; Deng, H.; Sun, X.; Li, X.; Zhao, J.; Wu, J.; Chu, W.; Zhang, S.; Pan, H.; Zheng, X.; Wu, X.; Jin, C.; Wu, C.; Xie, Y., Modulation of Metal and Insulator States in 2D Ferromagnetic VS2 by van der Waals Interaction Engineering. Advanced Materials 2017, 1700715.
21. Bonilla, M.; Kolekar, S.; Ma, Y.; Diaz, H. C.; Kalappattil, V.; Das, R.; Eggers, T.; Gutierrez, H. R.; Phan, M.-H.; Batzill, M., Strong room-temperature ferromagnetism in VSe2 monolayers on van der Waals substrates. Nature Nanotechnology 2018, 13, 289-293.
22. Hartmann, U., Magnetic Force Microscopy. Annual Rviews Material Science 1999, 29, 53-87.
23. High Resolution and High Sensitivity Imaging of Magnetic Properties. https://www.parksystems.com/index.php/park-spm-modes/96-magnetic-properties/247-magnetic-force-microscopy-mfm.
24. Li, H.; Qi, X.; Wu, J.; Zeng, Z.; Wei, J.; Zhang, H., Investigation of MoS2 and Graphene Nanosheets by Magnetic Force Microscopy. ACS Nano 2013, 7, 2842-2849.
25. Neves, C., S.; Quaresma, P.; Baptista, P. V.; Carvalho, P. A.; Araújo, J. P.; Pereira, E.; Eaton, P., New insights into the use of magnetic force microscopy to discriminate between magnetic and nonmagnetic nanoparticles. Nanotechnology 2010, 21, 305706.
26. Rugar, D.; Mamin, H. J.; Guethner, P.; Lambert, S. E.; Stern, J. E.; McFadyen, I.; Yogi, T., Magnetic force microscopy: general principles and application to longitudinal recording media. J Appl Phys 1990, 68, 1169-1183.
27. Arnold, F.; Stan, R.-M.; Mahatha, S. K.; Lund, H. E.; Curcio, D.; Dendzik, M.; Bana, H.; Travaglia, E.; Bignardi, L.; Lacovig, P.; Lizzit, D.; Li, Z.; Bianchi, M.; Miwa, J. A.; Bremholm, M.; Lizzit, S.; Hofmann, P.; Sanders, C. E., Novel single-layer vanadium sulphide phases. 2D Materials 2018, 5, 045009.

APPLICATION NOTE

TOOTH WHITENING STUDY USING PINPOINT NANOMECHANICAL MODE OF PARK AFM

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Introduction

In recent years, the importance of mechanical properties measurement has become evident in various applications, ranging from understanding and screening of integrated circuit failure mechanisms of microelectronics, to diagnosis of diseases in the field of medicine, and to the development of restorative materials for human teeth [1-3]. However, during the measurement, some samples when pressed with too much force can lead to surface deformation and change in its surface characteristics that may result in inaccurate measurements. Moreover, since the sizes and features of interest in functional materials are continuously shrinking down to nanoscale level, and given that material failures start from atomic lattice structures, conventional techniques used in materials characterization are no longer adequate in identifying defects and abnormalities on material surfaces as they only allow up to millimeter range measurements. For these reasons, a next generation characterization tool that is benign and allows for nanoscale measurements is greatly needed. Recently, a new operational AFM mode developed by Park Systems called PinPoint™ Nanomechanical mode [4] offers researchers an innovative solution to these problems. This technique operates by moving the tip horizontally and moving down vertically in approach-retract manner with only few nano-Newton force. This ensures a frictionless operation that eliminates the lateral force due to continuous tip-sample contact. Furthermore, it preserves tip and sample condition. At each point of the image, force-distance curve is acquired and used to calculate the mechanical characteristics of the sample. During the data acquisition, the XY scanner stops, and the contact time is controlled to give enough time for the scanner to acquire precise and accurate data with nanoscale resolution.

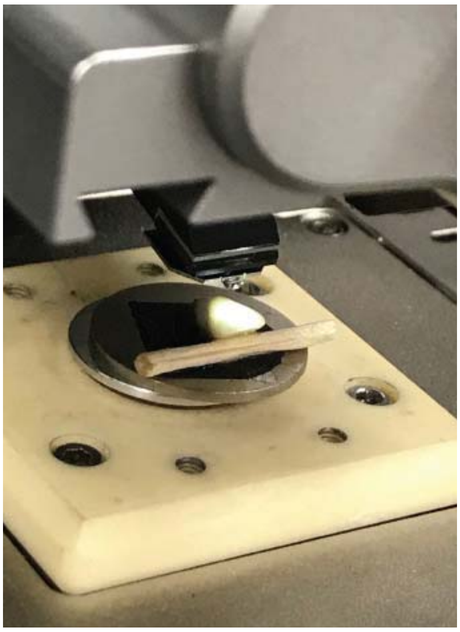
Every material structure deteriorates over time when kept in natural setting. Such changes originate from a point defect at the nanoscale level. This applies to the teeth whitening process. Everyone who whitens teeth desires for the teeth to remain whitened without redoing it often. Thus, to realize this, one must know how the topological and mechanical changes take place on the surface of teeth at the nanoscale level. In this study, PinPoint Nanomechanical mode was used to acquire topographical and mechanical data of a tooth sample to understand the effect of tooth whitening strips on the tooth's mechanical and topographical properties. The results show that tooth whitening strips lead to a decrease in tooth roughness and an increase in modulus and adhesion. This newly developed technique by Park Systems enables researchers to investigate the topographical and mechanical properties variations of different varieties of samples at nanoscale level.

Experimental

A tooth sample was analyzed using a Park NX10 AFM [5] under ambient air condition. PinPoint Nanomechanical mode with AC160TS cantilever (nominal spring constant k = 26 N/m and resonance frequency f = 300 kHz) [6] was used in the measurement to acquire topography and mechanical signals.

Before undergoing AFM scanning, the tooth was treated by placing it in deionized water and leaving it to sit for 30 minutes followed by placing it in 50% by volume isopropyl alcohol for 2 minutes, then rinsing it again in deionized water. Compressed air spray was used to dry off the tooth. This was in attempt to remove "debris" and "dirt" from the teeth that may have accumulate on to the teeth over the time. Figure 1 shows the setup of the experiment. A carbon tape and super glue were used to stabilize the sample during imaging. Tooth was placed onto a magnetic disk and stuck to double sided carbon tape. To be sure that the tooth was secured so that it would not move while taking measurements, a toothpick was placed to hold the tooth upward so that an area of the tooth would be leveled for examination. Superglue was used for extra stability.

Figure 1. Experimental set up of the tooth sample. Tooth underneath Park NX10 AFM system (labove). Tooth with AC160TS cantilever landed onto sample (below)



To validate the acquired modulus values, a reference sample was used. The sample was a PS-LDPE blend film (polystyrene and polyolefin elastomer). The scan parameters were set such that the modulus measurements were measured to be ~2.0 GPa for the PS matrix, and ~0.1 GPa for the circular features that appeared in the modulus images that are blended into the matrix—which were in agreement with the manufacturers' description of the PS-LDPE sample [7]. Figure 2 shows the 15 µm x 15 µm acquired modulus images of PS-LDPE reference sample. The images were analyzed using Park XEI software developed by Park Systems which mapped the acquired signals to a color table. The darker regions (color black in Fig. 2 left) with circular features represent the areas with lower modulus values while the lighter regions (color brown in Fig. 2 right) with flat surface known to be the PS matrix are the areas with higher modulus. All areas with purple color mean that these areas are excluded in calculating the mean modulus value. The calculated elastic modulus mean of the LDPE copolymer region is 0.116 GPa while for the PS polystyrene flat region is 2.039 GPa.

After the reference sample measurements were taken, the tooth was placed under the Park NX10 AFM with the same tip used for reference sample measurements. For statistical relevance, three measurements were taken at three different teeth surfaces of the same teeth sample that could be found using the optical microscope built in to the Park AFM. Measurements were taken in areas of the tooth no farther than 500 microns apart so that roughly the same area are imaged consistently. These measurements were performed using the same scan parameters as were used for the PS-LDPE reference sample. These parameters were utilized because under those conditions, the AFM recorded accurate modulus values.

To whiten the tooth sample, whitening strips were used [8]. One strip was applied onto the tooth surface and left to sit for the recommended 1-hour period. After this, the tooth was rinsed in deionized water and dried off with compressed air spray. A total of 3 whitening strips were used as the final whitening.

Results and Discussion

The representative topographical and mechanical images acquired in the experiment are presented on Table 1. The images are analyzed using the Park XEI software. The quantitative results of surface roughness and mechanical properties are shown in Table 2. The experimental values of the elastic modulus before and after the whitening process are compared on the previous studies [2]. The tooth is composed of three major layers, known as the enamel, dentin, and cementum. These layers are found in the respective order: enamel at the surface, dentin underneath the enamel, and cementum underneath the dentin. Based on the existing studies, the elastic modulus of the top layer of the tooth was found to be 1.3382 ± 0.3079 GPa. The measured value of the elastic modulus before the whitening process was 1.072 GPa and it increased up to 1.571 GPa after the process. Same trend is observed on the adhesion energy values wherein the measured adhesion energy prior to the process was 0.196 fJ and it increased to 1.608 fJ after the whitening process. On the other hand, the surface roughness is observed to be in decreasing trend wherein the surface roughness prior to the process was 201.0 nm while the

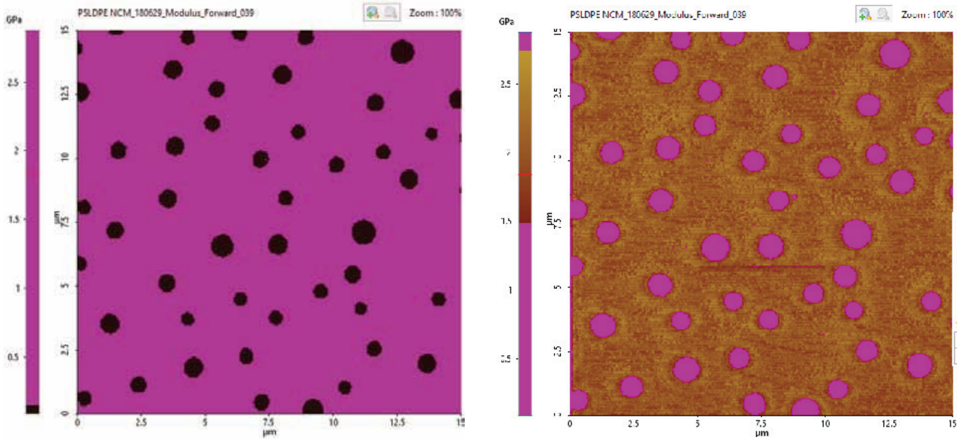


Figure 2. 15 µm x 15 µm image of PS-LDPE reference sample. Image with polystyrene flat region excluded in the elastic modulus mean calculation (left). Image with copolymer region excluded in the elastic modulus mean calculation (right).

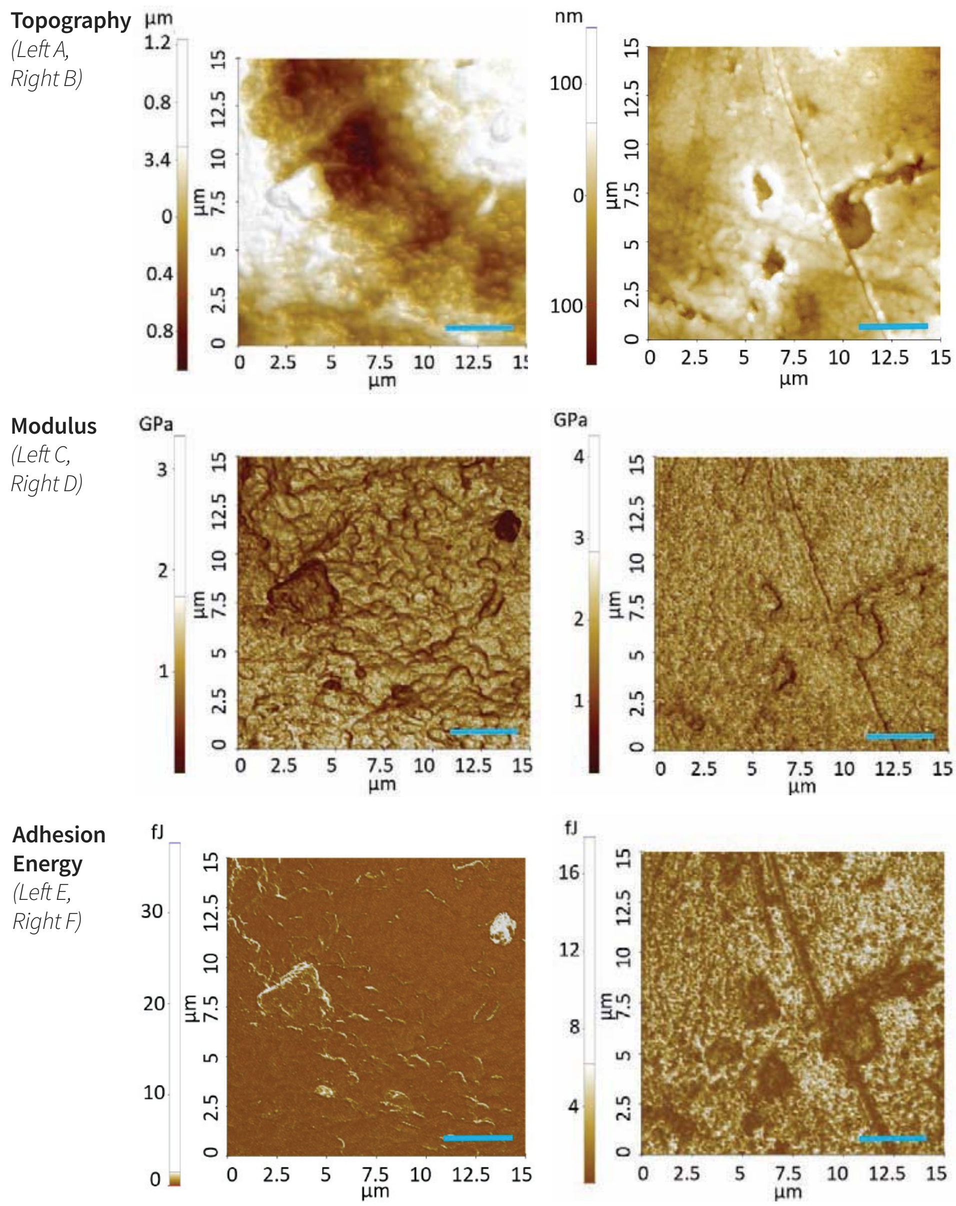


Table 1. A table of before and after whitening treatment was applied. The same 15 µm 15 µm scan region was used for the before-images, as well as the after-images. These images used were representative of the change caused by whitening treatment, as the data values coincided closely with the mean. Scale bars: 3 µm.

Data	Before	After	Difference
RMS Roughness (nm)	201.0 ± 184.2	38.33 ± 8.37	162.67
Mean Modulus (GPa)	1.072 ± 0.155	1.571 ± 0.224	0.499
Mean Adhesion Energy (fJ)	0.196 ± 0.035	1.608 ± 0.936	1.412

Table 2. Mean values of before and after the whitening process.

value for surface roughness after the process was 38.33 nm.

Tooth whitening via whitening strips is known to work by reacting the hydroxide chemicals on the strip with the staining molecules known as chromogens on the surface of the tooth. This reaction is known as oxidation. The oxidation causes the chromogen molecules to break down when gaining electrons from the hydroxide, causing it to split into molecules that do not reflect light and can be removed from the tooth later. As for whitening treatment, expectations based on previous studies were that the hardness would fall, and the roughness would increase with more whitening applied [9-10]. This experiment however found that roughness decreased and modulus increased. A possible explanation would be that the hydroxide oxidation smoothed out the surface as staining chromogen molecules would be removed from the tooth, while modulus increased since the chromogens had a lower modulus than the enamel itself.

Conclusion

The topography and mechanical data of the tooth sample was successfully acquired using PinPoint Nanomechanical mode on Park NX10. Based on the data acquired through this testing, PinPoint Nanomechanical mode found that its method of characterizing mechanical properties of the tooth matched and agreed with mechanical properties found in other methods such as macro and microindentation. It was also found that the tooth roughness decreases and the elastic modulus as well as the adhesion properties increase after it had undergone whitening process. Overall, PinPoint Nanomechanical Mode AFM technique is an ideal approach to characterize and quantify mechanical properties at nanoscale, with best precision and maximized tip life due to its frictionless and to the point operation.

References

1. J. Vella, et al., Mechanical properties and fracture toughness of organo-silicate glass (OSG) low-k dielectric thin films for microelectronic applications, International Journal of Fracture 119/120: 487–499, 2003.
2. M. Oyen, et al., A practical guide for analysis of nanoindentation data, J Mech Behav Biomed Mater. 2009 Aug;2(4):396-407. Doi: 10.1016/j.jmbbm.2008.10.002. Epub 2008 Oct 15.
3. Y. Zhang, et al., Review of research on the mechanical properties of the human tooth, Published online 2014 Apr 18. Doi: 10.1038/ijos.2014.21.
4. https://www.parksystems.com/index.php/company/news/press-release/450-nanomechanical-mode-to-characterize-nano-mechanical
5. https://www.parksystems.com/index.php/products/small-sample-afm/park-nx10/overview
6. http://probe.olympus-global.com/en/product/omcl_ac160ts_r3/
7. https://www.brukerafmprobes.com/a-3724-ps-ldpe-12m.aspx
8. https://crest.com/en-us/products/whitestrips/crest-3d-white-monthly-whitening-boost-whitestrips-teeth-whitening-kit
9. K. Chun, et al., Comparison of mechanical property and role between enamel and dentin in the human teeth, Published online 2014 Feb 6. Doi: 10.1177/1758736014520809
10. C. Pinto, et al., Peroxide bleaching agent effects on enamel surface microhardness, roughness and morphology, Braz. Oral res. Vol.18 no.4 São Paulo Oct./Dec. 2004.

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APPLICATION NOTE

ENHANCED SURFACE POTENTIAL DETECTION STUDY USING FREQUENCY MODULATION SKPM

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Introduction

Scanning Kelvin probe microscopy (SKPM) is a tool used to measure work function and local electrical potential distribution of various materials with nanoscale features. The most common application of this technique is the study of electronic properties of semiconductor nanostructures and surfaces. Potential profiling of such materials composed of negatively or positively changes are some of the measurements that can be done using this technique at nanoscale lateral resolution. Implementation of such technique to unveiling the variation of charge distribution that occurs on the nanoscale helps to better understand and improve the performance of CMOS semiconductor devices. [1-2] The SKPM has also been instrumental in characterizing and determining the quantitative physical information such as the total charge and charge position of polymer materials. [3, 4] There are other surface potential or work function measuring tools that have been introduced, such as electron beam induced current (EBIC), scanning electron microscopy (SEM), and photoelectron spectroscopy (PES). However, some of these techniques are only applicable for inorganic types of semiconductor samples, some are destructive and require high vacuum, while others don't provide high enough spatial resolution. [5] Compared to other techniques, SKPM is a nondestructive and air-ambient compatible technique, which is undoubtedly one of the easiest to use electrical failure analysis and nano metrology tool available in the market today. Conventional SKPM technique (also known as Amplitude Modulation AM-SKPM) has already made remarkable contribution in maintaining device reliability and analysis of advance materials compared to other measurement techniques. However, there is room for improvement in the signal to noise detection ability of AM-SKPM technique such that even the features having less optimal surface potential strength can be detected and mapped out with higher lateral resolution and accuracy. Toward this end, recently, Park Systems has developed a technique called Frequency Modulation FM-SKPM with Atomic Force Microscope (AFM). This technique is useful for electrical characterization allowing measurements with better sensitivity compared to AM-SKPM. In this study, a polymer material is measured to compare the performance of AM-SKPM to FM-SKPM. The results acquired in the experiment show that FM-SKPM is significantly more sensitive compared to AM-SKPM in measuring both work function and surface potential distribution of different materials.

Experimental

A polymer patterned array material deposited on Silicon substrate was analyzed using a Park NX10 AFM. Two separate scans were conducted to acquire AM-SKPM and FM-SKPM measurements. The scan parameters and the tip used in acquiring images were all the same. A conductive Mikromasch NSC36Cr-Au cantilever (nominal spring constant k = 1 N/m with resonant frequency f = 90 kHz) was used in the experiment.

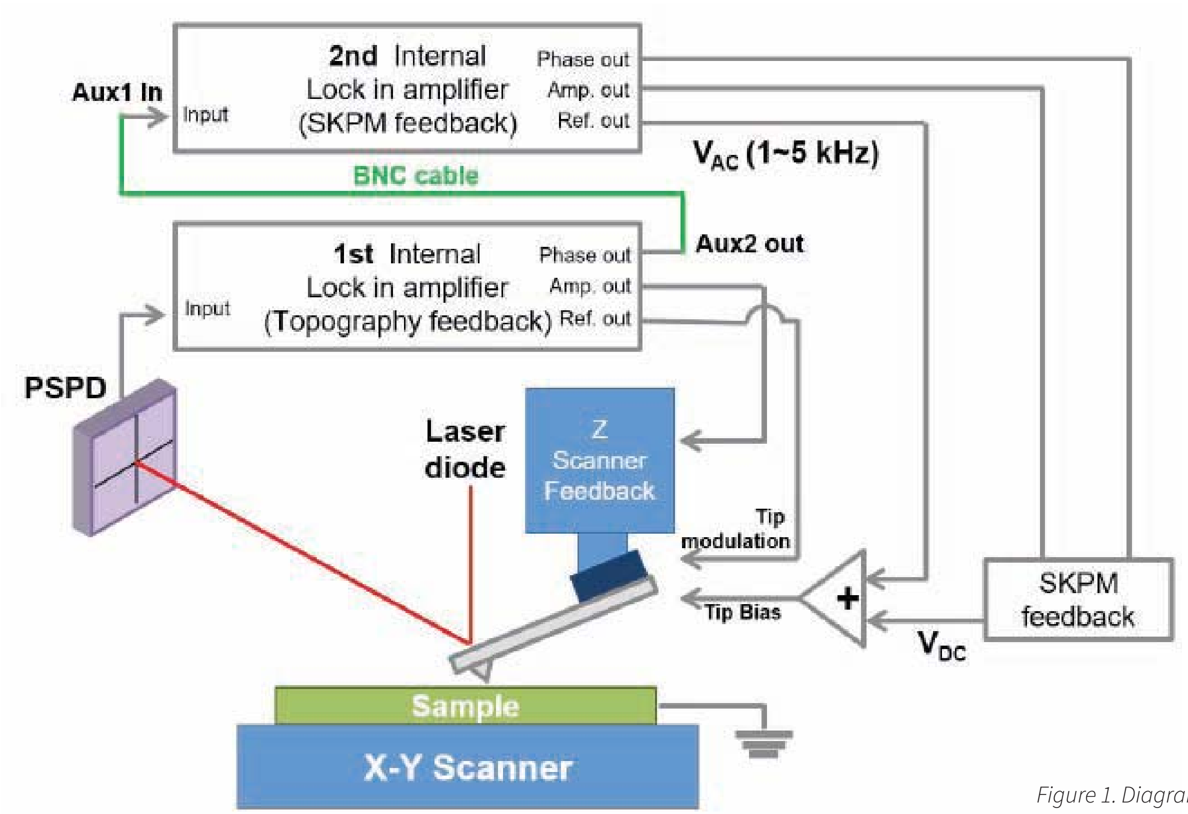


Figure 1. Diagram of FM-SKPM

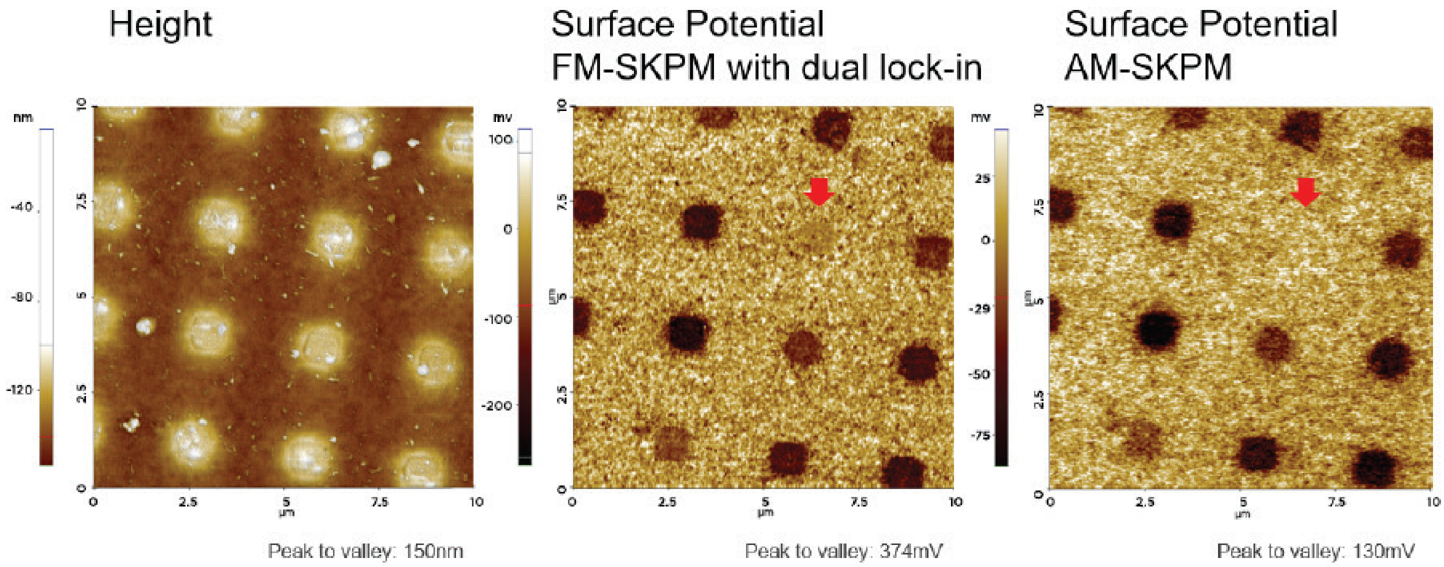


Figure 2. 10 μm x10 μm image of polymer patterned array. Topography image (left), FM-SKPM image (center), and AM-SKPM image (right).

In SKPM mode, there are two interaction forces between the AC biased tip and the sample: the electrostatic force and the Van der Waals force. The Van der Waals force is harnessed to generate the sample's surface topography while the electrostatic force between the tip and sample generates data for the sample's electrical properties. The obtained cantilever deflection signal contains both sets of information; therefore, a method that can completely separate these signals is the key to successful imaging. In Park NX10, lock-in amplifiers embedded to its electronics are used to separate the signals. This allows for the acquisition of both topography and EFM data simultaneously. Two amplifiers are used by the system, named lock-in 1 and lock-in 2. Lock-in 1 obtains the topography information by analyzing the tip motion caused by the Van der Waals interaction, while lock-in 2 obtains electrical property information by analyzing the frequency of the applied AC voltage signal to the tip which, in turn, generates an electrostatic force interaction with the sample. The frequency of the applied AC voltage signal is chosen to be smaller (5 - 20 kHz) than the cantilever oscillation frequency (70- 330 kHz), enough so that the two signals do not interfere each other. In FM-SKPM setup [6], the NCM phase signal of Lock-in 1 is transferred to Lock-in 2 to serve as a source for EFM operation by connecting BNC cable between 'Aux2 out' and 'Aux1 in' shown in Figure 1. Furthermore, a separate DC bias was applied to the cantilever and controlled to create a feedback loop that would zero out the electrical oscillation between the tip and the sample caused by the application of an AC bias to the cantilever. The value of this offset DC bias that zeroes out the AC bias-induced electrical oscillation is considered to be a measure of surface potential.

Results and Discussion

TThe topography data obtained in this experiment show that polymer patterned array with square-like features were successfully deposited on silicon substrate, but showed no significant information related to its surface potential. In contrast, the surface potential data acquired in AM-SKPM and FM-SKPM show the surface potential structure, but shows no significant information related to physical structure of the sample. The domain structure shape observed in SKPM data of the sample was similar to the physical structure observed in topography data, which was a patterned array consisting of square dots. The data acquired in this experiment were all analyzed using Park XEI software. Figure 2 shows the topography (left), FM-SKPM (center), and AM-SKPM (right) images of the polymer patterned array sample. The topography data can be acquired simultaneously with the SKPM data. In Figure 2, the topography image presented was acquired simultaneously with the AM-SKPM image. The topography shows a clear image of a well-defined lattice structure. The Park XEI software maps the acquired signals into a color table. In the topography image, the square-like features that appear to have a brighter color represent the areas with higher height while the flat surface with darker color represent the areas with lower height. The measured peak to valley in the topography image was approximately 150 nm. On the other hand, both AM-SKPM and FM-SKPM data show a patterned array with an irregularity on the surface (pointed by red arrows). In the two SKPM images, the square-like features that appear to have a darker color, represent the areas with relatively lower surface potential while the flat surface with brighter color represent the areas with higher surface potential. By comparing the surface potential results acquired from AM-SKPM and FM-SKPM, one can easily determine that FM-SKPM has better sensitivity in detecting surface potential variation compared to AM-SKPM. In this experiment, FM-SKPM technique provided a higher resolution image that shows sharper edges of the square features compared to AM-SKPM. In addition, FM-SKPM was able to detect weak potential in the irregular surface while AM-SKPM was not able to detect any potential variation.

The line profile that was generated by the XEI software in Figure 3 (bottom) provides the potential information of the polymer patterned array. The line profile for the FM-SKPM is indicated in color red while the line profile for AM-SKPM is indicated in color green. The line profile of the FM-SKPM image clearly shows that there is a slight change in potential (encircled in red) in the irregular surface compared to the areas next to it. On the other, the line profile of AM-SKPM doesn't show any changes of potential in that surface. By comparing the line profile of the two techniques, it can be concluded that FM-SKPM is at least an order of magnitude more sensitive than the conventional SKPM technique also known as AM-SKPM.

a slight decrease in potential (encircled in red) in the irregular surface compared to the areas next to it. On the other, the line profile of AM-SKPM doesn't show any changes of potential in that surface. By comparing the line profile of the two techniques, it can be concluded that FM-SKPM is at least two orders of magnitude more sensitive than conventional AM-SKPM technique.

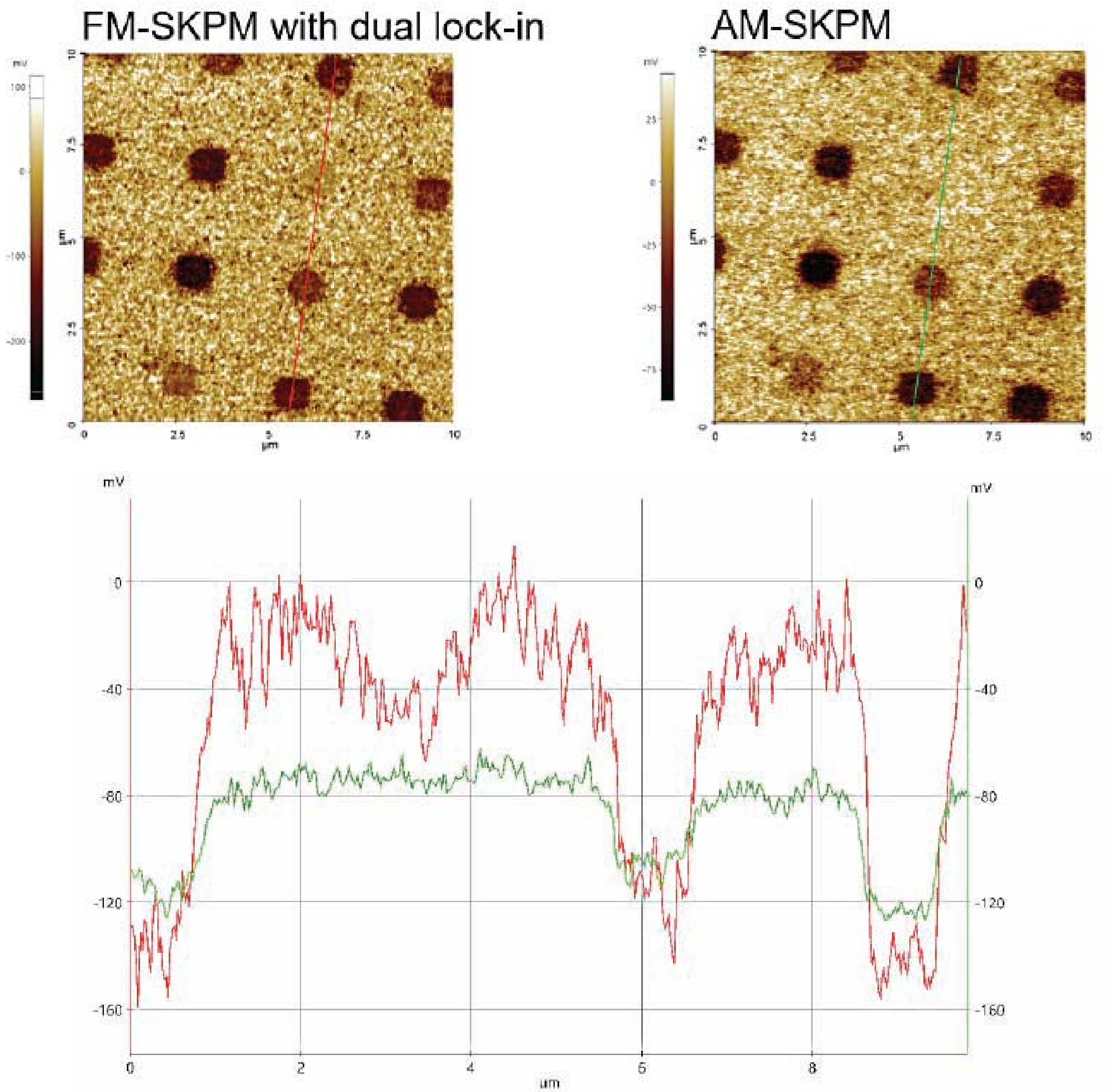


Figure 3. FM-SKPM image (top-left), AM-SKPM image (top-right) and corresponding line profile (bottom) acquired from the polymer sample. FM-SKPM line profile (red line, y-axis on left) and AM-SKPM line profile (green, y-axis on right).

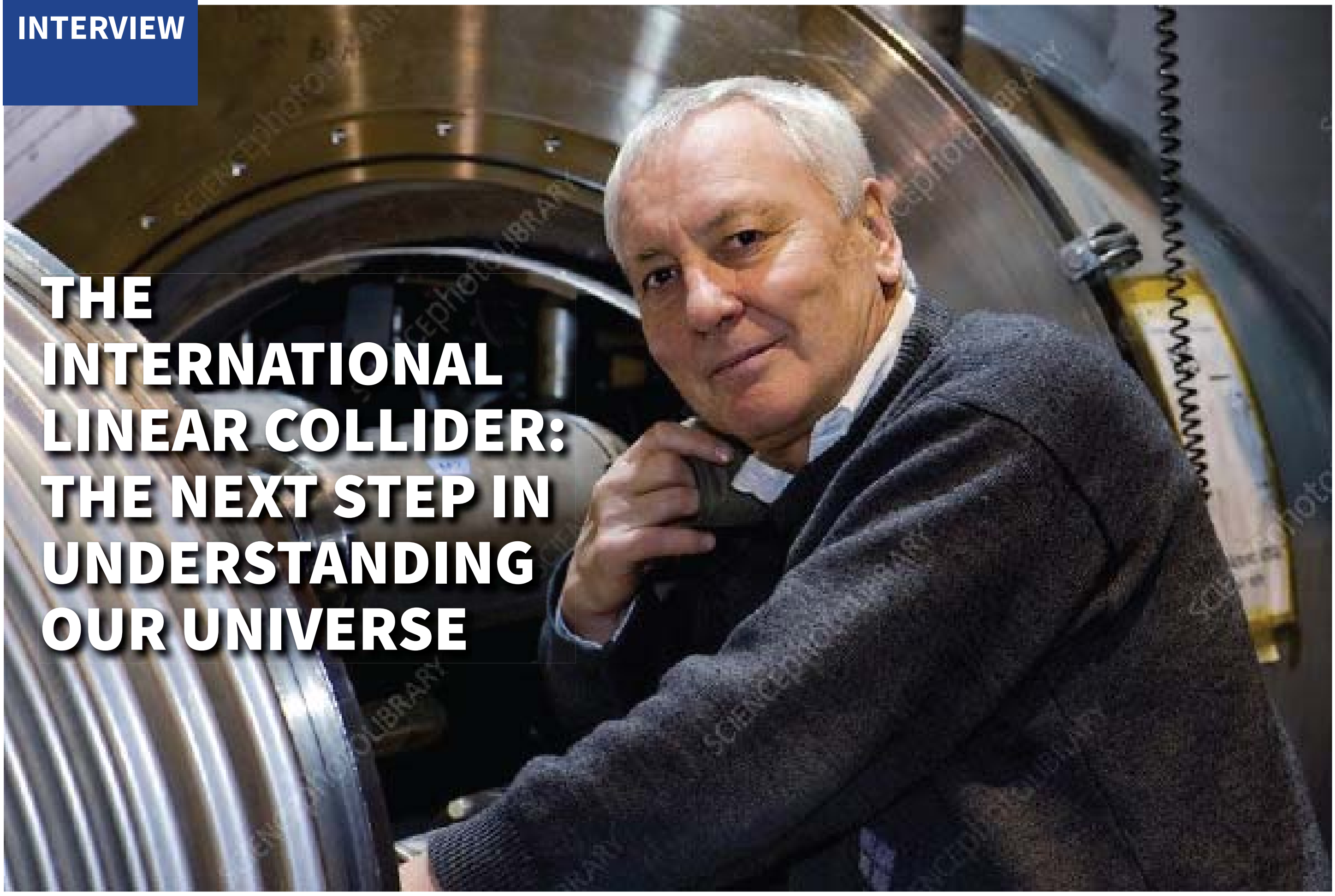
Conclusion

The polymer patterned array was successfully characterized using both the conventional method of SKPM (AM-SKPM) and FM-SKPM imaging on Park NX10. The topography data reveals that the sample surface is composed of patterned array with square-like features. Irregularity in the patterned array is observed on both AM-SKPM and FM-SKPM images. However, while FM-SKPM technique shows that the irregularity in the surface pattern is a surface with weak potential, the AM-SKPM was not sensitive enough to detect the weak potential in the same region. From the above results, it can be observed that FM-SKPM is an order of magnitude more sensitive compared to AM-SKPM and it is more useful in detecting surface potential variations. Furthermore, the increased sensitivity of FM-SKPM increases the chance of detecting defects with better resolution and accuracy in semiconductor devices and other advanced materials.

REFERENCES

1. Lan Fei (2018) FUNDAMENTALS OF KELVIN PROBE FORCE MICROSCOPY AND ITS APPLICATIONS IN THE CHARACTERIZATION OF SOLAR CELLS. Doctoral Dissertation, University of Pittsburgh.
2. J. Pineda, et al., Electrical Characterization of Semiconductor Device Using SCM and KPFM Imaging.
3. J. Gonzalez, et al., Charge distribution from SKPM images, PCCP, Issue 40, 2017.
4. M. Ortuño, et al., Conducting polymers as electron glasses: surface charge domains and slow relaxation, Scientific Reports volume 6, Article number: 21647 (2016).
5. W. Melitz, et al., Kelvin probe force microscopy and its application, Surface Science Reports 66 (2011) 1–27.
6. Charles Kim, et al., How to Measure FM-SKPM, Park Systems White Paper (2018)

THE INTERNATIONAL LINEAR COLLIDER: THE NEXT STEP IN UNDERSTANDING OUR UNIVERSE



Lyn Evans, CERN physicist. Lyn Evans (born 1945) is a Welsh physicist who became one of the leaders of the Large Hadron Collider (LHC) particle accelerator at CERN, the European particle physics laboratory. At left is part of the ring in which particles are accelerated to near the speed of light and then collided in detectors. Experiments carried out at the LHC intended to discover the Higgs boson led to the announcement of the discovery of a Higgs-like particle in 2012. Evans and other CERN physicists have received awards in recognition of this work, including the Fundamental Physics Prize in 2012. Photographed in 2008.

AN INTERVIEW WITH LYN EVANS, WHO LED THE PROJECT TO BUILD CERN AND IS NOW THE DIRECTOR OF THE INTERNATIONAL LINEAR COLLIDER COLLABORATION

A new era of discovery in particle physics opened in November 2009 with the start-up of the Large Hadron Collider at CERN in Geneva, Switzerland. Based on experiments and discoveries over the last decades, physicists believe that the Terascale will yield evidence for entirely new forms of matters, and possibly even extra dimensions of space. This new matter includes the Higgs particle, as well as the possibility of an extended family of elementary 'superparticles', the heavier cousins of the particles we already know. Lyn Evans joined CERN at 24 and after 40 years with CERN, he is now the Director of Linear Collider Collaboration and on brink of announcing the next generation Higgs Factory, the International Linear Collider Project proposed to be built in Japan as a world-wide collaboration to discover new physics.

"The idea of an International Linear Collider is not a new one," explains Lyn Evans, who has been a champion of this project for many years. In March, 2013, Lyn Evans paid a courtesy visit to Japan's Prime Minister Shinzo Abe. The Prime Minister acknowledged the significance of the linear collider project for the whole of humankind. Given that it is an international project, he said he needed to monitor the development closely and would continue to investigate the role of Japan.

While physicists agree that The International Linear Collider is essential for the next step in understanding our universe, Japan has been studying the idea for years. Recently, at the ILC technology development symposium held in Tokyo June 25, 2018, Lyn Evans stressed that, "Accelerator technology continued to develop thanks to accelerator research facilities brought online in the US, Europe, and China. This means we are in a good place to develop momentum to get [international] cooperation for the ILC." Next year, the board of directors at CERN will begin deliberations on the next 5-year strategy for particle physics in Europe, so "this is a very crucial period. The Japanese government must make their intentions clear."



"The idea of an International Linear Collider is not a new one," explains Lyn Evans, who has been a champion of this project for many years. In March, 2013, Lyn Evans paid a courtesy visit to Japan's Prime Minister Shinzo Abe. The Prime Minister acknowledged the significance of the linear collider project for the whole of humankind. Given that it is an international project, he said he needed to monitor the development closely and would continue to investigate the role of Japan. (Photo top right): Kicking things off in Tokyo, in 2013, Linear Collider Board Director Sachio Komamiya hands over the ILC Technical Design Report to Lyn Evans, Linear Collider Collaboration director.

With this deadline approaching, things are speeding up. It is very natural for this accelerator to be cited in Japan. In the 1930's Japan took an early lead in particle physics and in recent decades they have continued to be important players in experimental physics.

Based on recent exciting news from the Governors Meeting in Japan, Evan's dream may soon become a reality. "It is a great time for Japan to take a leading role in Linear Collider technology. The whole world will benefit from the data it will produce," stressed Evans.

Japan Governors Agree to Push for the Realization of the ILC

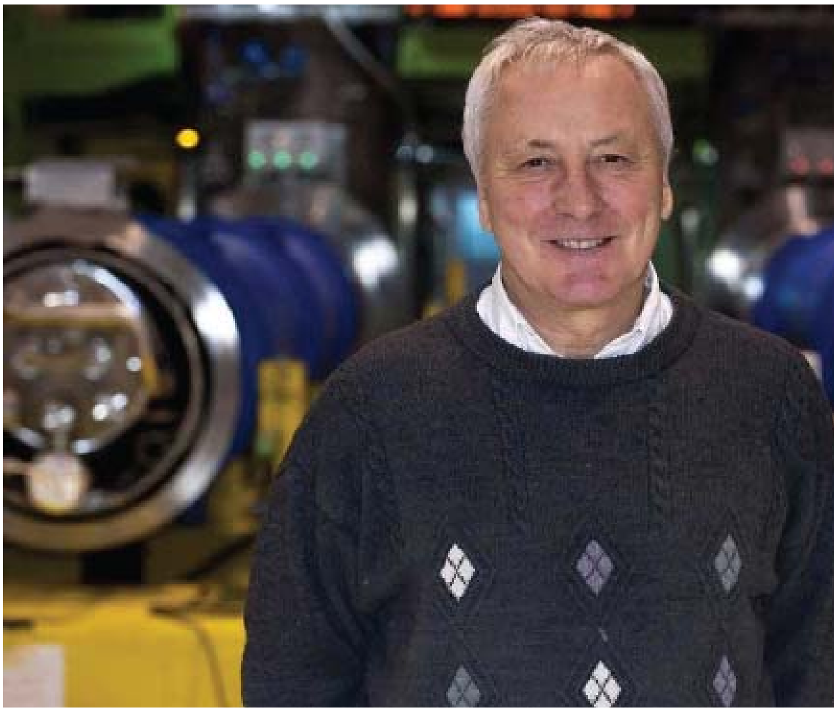
On October 31st, 2018, the meeting for the governors of Hokkaido and the Tohoku region was held in Kaminoyama City, Yamagata Prefecture where a resolution was unanimously passed to push for the realization of the ILC, which is the first time this meeting has passed a resolution solely focused on the ILC The resolution calls for the national government to make their stance clear on investment in the ILC and other international cost-sharing measures as soon as possible. Governor Tasso said, "It's a crucial time right now, as we have to get the ILC into Europe's next 5 year plan for particle physics. Those preparations begin in January 2019." Governor Tasso said, "It's extremely significant that we passed a resolution solely about the ILC. We will call upon all of the governors and related organizations in Tohoku to encourage the national government to make a decision as quickly as possible."

What is the International Linear Collider?

The International Linear Collider will give physicists a new cosmic doorway to explore energy regimes beyond the reach of today's accelerators. A proposed electron-positron collider, the ILC will complement the Large Hadron Collider, a proton-proton collider at the European Center for Nuclear Research (CERN) in Geneva, Switzerland, together unlocking some of the deepest mysteries in the universe. With LHC discoveries pointing the way, the ILC – a true precision machine – will provide the missing pieces of the puzzle.

Consisting of two linear accelerators that face each other, the ILC will hurl some 10 billion electrons and their anti-particles, positrons, toward each other at nearly the speed of light. Superconducting accelerator cavities operating at temperatures near absolute zero give the particles more and more energy until they smash in a blazing crossfire at the centre of the machine. Stretching approximately 31 kilometres in length, the beams collide 14,000 times every second at extremely high energies – 500 billion-electron-volts (GeV). Each spectacular collision creates an array of new particles that could answer some of the most fundamental questions of all time. The current baseline design allows for an upgrade to a 50-kilometres, 1 trillion-electron-volt (TeV) machine during the second stage of the project. There are also plans for a staged approach starting with a 250-GeV Higgs factory to study the properties of the particle discovered at the LHC in 2012 and then upgrading to 500 GeV.

This century, while physicists have discovered more than ever before, at the nanoscale, they can still not fully explain the origin of mass and can only account for a surprising five percent of the universe. The remaining 95 percent, the mysterious dark matter and dark energy is what the proposed International Linear Collider could explain. Not to exclude the potential of new forms of matter, new forces of nature, new dimensions of space and time and even extra dimensions.



“ THE HUGE MYSTERY NOW IS THAT WE ONLY UNDERSTAND ABOUT 5% OF OUR UNIVERSE. MY GREATEST WISH BEFORE I DIE IS TO GET A HINT OF WHAT DARK MATTER IS.”

Lyn Evans led the project to build CERN’s Large Hadron Collider (LHC) from its inception in 1994 until start-up on 10 September 2008. The LHC, which is the world’s highest energy particle accelerator, is the Organization’s latest flagship research facility. It is poised to provide new insights into the mysteries of our universe. Nations from around the globe have contributed to the construction of the accelerator and its experiments.

China Electron Positron Collider (CEPC) – Plans Well Underway

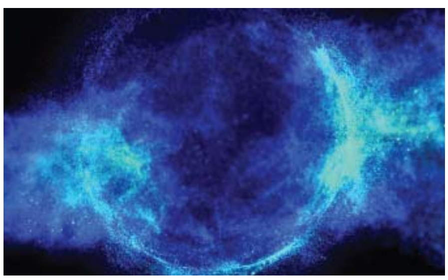
China’s plans to build a huge underground ‘Higgs factory called the China Electron Positron Collider that will be a successor to the Beijing Electron Positron Collider at the Institute of High Energy Physics in Beijing, which is expected to shut down in 2020. Plans are well underway with a conceptual design report for the China Electron Positron Collider that calls for a 100 km underground tunnel that would smash together electrons and positrons at energies of 240 GeV. If built, this will be the largest electron-positron collider with a circumference of 100 km with a precision down to 1%, allowing scientists to probe into new physics.

Does the world need two Higgs Factories?

“The world could accommodate two Higgs factories,” states Yifang Wang, director of China’s Institute of High Energy Physics in an interview with Physics World. The ILC can only host one detector at any given time. We think that the world needs at least two detectors. So, in principle, we could have two Higgs factories and a minimum of two detectors, maybe three. It very much depends on future support from the international community and the respective governments. By the end of this year the Japanese government is expected to decide about the ILC. I think it’s not too late for us to then decide afterwards to go ahead with the CEPC.”

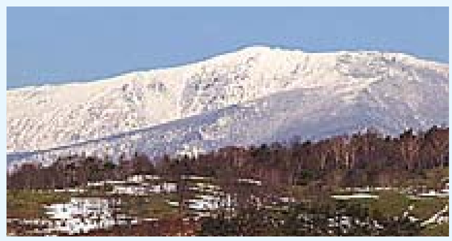
Exciting Developments at CERN

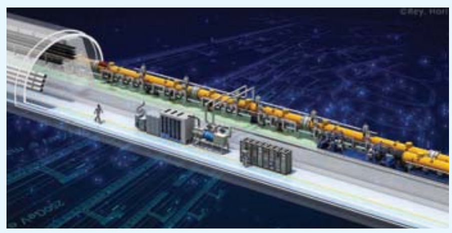
On June 4, 2018, CERN released new results from the ATLAS and CMS experiments at the LHC revealing how strongly the Higgs boson interacts with the heaviest known elementary particle, the top quark, corroborating our understanding of the Higgs and setting constraints on new physics. The Higgs boson interacts only with massive particles, yet it was discovered in its decay to two massless photons. Quantum mechanics allows the Higgs to fluctuate for a very short time into a top quark and a top anti-quark, which promptly annihilate each other into a photon pair. These results tell scientists more about the properties of the Higgs boson and give clues for where to look for new physics.



Artistic view of the Brout-Englert-Higgs Field (Image: Daniel Dominguez/CERN)

“The superb performance of the LHC and the improved experimental tools in mastering this complex analysis led to this beautiful result. It also shows that we are on the right track with our plans for the High-Luminosity LHC and the physics results it promises.” CERN Director for Research and Computing Eckhard Elsen





The International Linear Collider (ILC) is a gigantic new accelerator to study the mysteries of the universe. In 2012, one of the elementary particles known as the Higgs boson was discovered at CERN. For about 5 years, led by Dr. Lyn Evans, Japan has been encouraged to host the next large accelerator which will be a Higgs factory, where many exciting discoveries in Physics can be realized. The Japanese high-energy physics community's recommendation: If the 19-mile-long, next-generation particle collider is built in Japan, it should be located in the Kitakami mountains of the Iwate and Miyagi prefectures. The ILC will create an international hub of science, technology and innovation in the area, and an “international science city”.

The 2018 International Workshop on Future Linear Colliders (LCWS18) was hosted by the University of Texas at Arlington on Oct. 22-26, 2018, where scientists from all over the world gathered together with a firm determination to make the ILC a reality. Photo Credit: UTA College of Science

2018 INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS HELD IN TEXAS IN OCTOBER- STRONG SUPPORT FOR ILC FROM JAPAN AND INTERNATIONAL COALITION OF SCIENTISTS

Hosted by University of Texas Arlington, the International Workshop on Future Linear Colliders held Oct. 22-26, brought together enthusiastic supporters that form an international foundation for the advancing project. Scientists attending the workshop, issued a strong conviction to give unbridled support to the ILC with a written "Texas Statement", which says in part, "Together with colleagues around the world, we hereby issue this 'Texas Statement' with unshakable conviction on its scientific case and to express our strong commitment to do whatever necessary for its success. The international community represented by the participants of LCWS2018 is committed to bring the ILC to its fruition. Once the expression of intention to host the ILC is issued by the Japanese government, we will greatly expand our own efforts and work with our respective governments ever more intensively to help achieve the necessary international agreements. We eagerly await the signal to proceed and, when the ILC starts in earnest, we will be ready to carry through on its promise."

In tandem, the support offered from Japan to be the host of the ILC promised a swift outcome. In a video address at the workshop by the Honorable Shintaro Ito, Member of the House of Representatives of Japan, he declares that the "ILA is an international project that has no boundaries, and it is open to personnel from all over the world." And he further adds, "Japan will be proud to host such a project. It will produce the science and technology to create a better world."

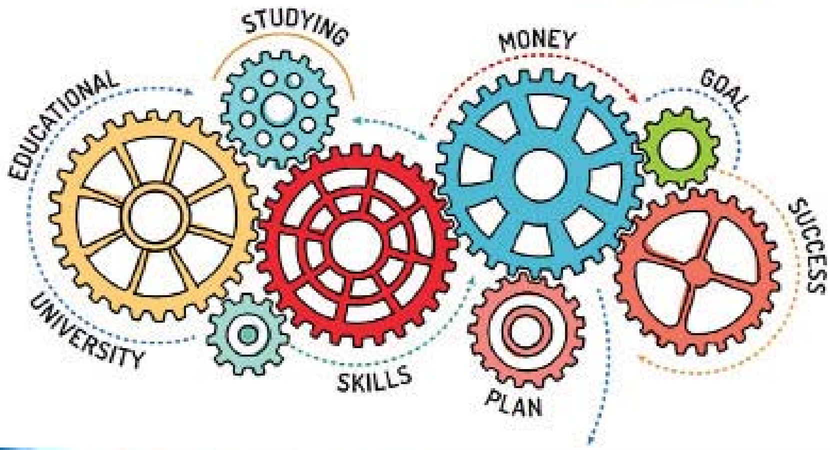
Adding that he believes it is the time for Japan to stand up and lead the ILC project, he presented the many meetings and discussions leading up to the workshop including the creation just last month by the Liberal Democratic Party of a new organization, called the Liaison Committee for Realizing the ILC which brings together various strategic groups involved in making important policies, such as science technology and innovation, regional revitalization, reconstruction from natural disasters, and national resilience. The Liaison Committee formulated their strategy to realize the ILC, by integrating the ILC project across various important policies for Japan and is working with Party members, and the Prime Minister and his Cabinet, so that the Expression of Interest can be delivered in time.

Honorable Shintaro Ito also discussed international funding and several meetings including in France and Germany and on October 10th, a very positive meeting with Under Secretary for Science of DOE in the US who said, "If the Japanese government decides to go forward with the ILC, the DOE will find it very positive, and they will participate and contribute to the project management and technology aspects. He also said, he looks forward to engaging with members of Congress, governmental figures, and others in Washington to get support for the ILC project."

Honorable Shintaro Ito closed his statement by saying," I sincerely believe we will be able to realize it together."

Lyn Evans and scientists across the globe await the opportunity to pursue new physics together when the program gets underway. The global coalition said in their Texas Statement, "Global collaboration has made enormous progress in the development of the superconducting acceleration technology, improving its performance by quantum leaps. More innovations broadly benefitting science are in store as we proceed along our path."

Attn: students & postdocs!



2019 Park AFM Scholarship

Park Systems Park AFM Scholarship Awards

Program currently open to ALL regions around the world

Park Systems, the world's leading manufacturer of atomic force microscopes (AFM) invites all researchers worldwide to apply to become Park AFM Scholars and receive a research scholarship. Park AFM Scholarship Awards are open to undergraduate or postdoctoral students working in nanotechnology research either already using Park AFM or who have research they would like to do with a Park AFM and need help getting access to equipment. Through this program, Park Systems has offered assistance to many researchers who qualify as Park AFM Scholars by matching them with one of thousands of nanoscience shared user facilities to perform their research using Park AFMs.

The Park AFM Scholarship Award is open to postdoctoral researchers and graduate students working in nanotechnology research using Park AFM. As progress for nanotechnology research and development advances at an unprecedented rate, universities worldwide offer degrees in fields working with nanotechnology. Park Systems, world-leading manufacturer of atomic force microscopes, is offering a $500 USD monetary scholarship to promote the education of future scientists and engineers in a number of nanoscience research areas that require advanced nanoscale microscopy for sample analysis and observation and to promote shared research findings and methodologies amongst their peers.

"WE NOT ONLY OFFER FINANCIAL INCENTIVE TO PARK AFM SCHOLARS WHO ARE PIONEERING NEW RESEARCH METHODOLOGIES IN NANOTECHNOLOGY AT LEADING ACADEMIC INSTITUTIONS WORLDWIDE, BUT MOST IMPORTANTLY ARE GIVING THEM ACCESS TO OUR PARK ATOMIC FORCE MICROSCOPES," STATED KEIBOCK LEE, PARK SYSTEMS PRESIDENT. "WE WILL CONTINUE TO ADVANCE NANOSCALE DISCOVERIES THRU THIS PARK AFM SCHOLARSHIP PROGRAM WORLDWIDE."

PARK AFM SCHOLARSHIP PROGRAM ACCEPTING SUBMISSIONS

Park Systems is continuing their successful Park AFM Scholarship Program. To be eligible:

1) The awardee must be a graduate student or postdoctoral researcher currently enrolled/affiliated with a research university, national laboratory, or governmental agency.

2) The research being presented must include meaningful data acquired using a Park AFM instrument. This data can either be the sole data being discussed in the presentation or be in conjunction with data acquired with other types of tools.

Park Systems will offer assistance to researchers who need a facility to perform their research using Park Atomic Force Microscope by matching them with one of their shared nano facilities.

For more information on the Park AFM Scholarship program, go to: https://www.parksystems.com/index.php/medias/programs/park-afm-scholarship

ZHEJIANG ACADEMY OF FORESTRY KEY LABORATORY OF STATE FOREST FOOD RESOURCES UTILIZATION AND QUALITY CONTROL ZHEJIANG PROVINCE, CHINA USES PARK AFM

Pictured: Liang He, Ph.D in front of the Park AFM

"OUR LAB FOCUSES ON THE MOPHOLOGY OF INDIVIDUAL BIOMOLECULES BY AFM TECHNOLOGY, ADVANCED CONFORMATION AND THEIR RELATIONSHIP BETWEEN STRUCTURE AND FUNCTION, ESPECIALLY POLYSACCHARIDE. SO THE AFM IS VERY USEFUL FOR US TO CONTINUE THIS SCIENTIFIC WORK, WHICH CAN HELP US OBSERVE AND ANALYZE SINGLE MOLECULES AT THE NANO-SCALE LEVEL."

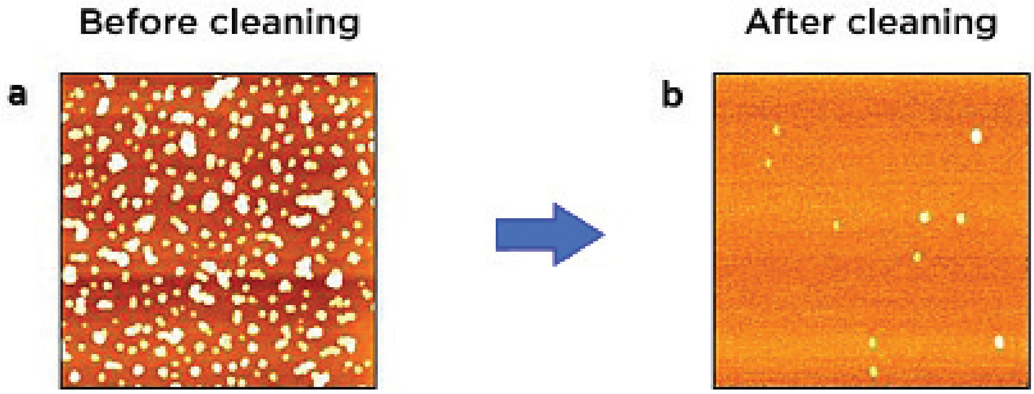
LIANG HE, PH.D, *Zhejiang Academy of Forestry Key Laboratory of State Forest Food Resources Utilization and Quality Control; Bamboo Shoots Engineering Research Center of the State Forestry Bureau, Zhejiang Provincial Key Laboratory of Biological and Chemical Utilization of Forestry Resources*

AKSHAY GOWDA, A GRADUATE STUDENT WORKING WITH DR. S.V. BABU, DISTINGUISHED UNIVERSITY PROFESSOR, CLARKSON UNIVERSITY RECEIVES THE PARK AFM SCHOLARSHIP AWARD

Title of Research Paper: Post-CMP Cleaning of Ceria Particles from Silicon Dioxide and Nitride Wafers for Advanced Technology Nodes

Abstract:
Advanced device manufacturing requires stringent process conditions to prevent defects that can lead to device failure and reliability issues. In particular, defects such as residual particles, foreign materials, scratches, etc. should be removed from the wafer surface after chemical mechanical planarization (CMP).

How do you use AFM in your research?
Chemical mechanical planarization (CMP) is one of the most crucial steps in the manufacturing of integrated circuits (ICs). In a typical CMP process, a wafer is pressed against the polishing pad fixed to a rotating platen and the chemical slurry (consisting of abrasive particles and necessary chemical additives) is supplied on to the pad. The wafer is polished by the combination of chemical and mechanical forces. CMP inevitably introduces surface defects and contaminants due to the presence of chemical additives and abrasive particles in the slurry used to planarize wafer surfaces. Surface particles are one of the major defects induced by CMP. If not removed, they can cause short or open circuits and affect the final device performance and reliability. Therefore, cleaning such particulate defects on wafer surfaces post-CMP is critical for successful manufacturing of ICs to improve productivity. Billion or so active transistors in each IC is electrically isolated using shallow trench isolation (STI) CMP. Ceria particle-based slurries are used to polish STI structures. Due to high chemical affinity of ceria particles to silicon dioxide surfaces, STI CMP leads to particle contamination making post-CMP cleaning challenging as ceria particles adhere very strongly to STI wafers during polishing. In our research, we are developing cleaning chemistries than can remove ceria particles from silicon dioxide wafers. The particles on silicon dioxide wafer surfaces before and after cleaning are imaged using atomic force microscopy (AFM) and counted. Subsequently, cleaning efficiency is calculated to evaluate the effectiveness of the developed cleaning chemistry.



Before cleaning **After cleaning**

Figure 1. AFM image of silicon dioxide wafer surface (a) contaminated with ~30 nm (mean diameter) ceria particles and (b) cleaned with a cleaning solution In this case, the number of particles before and after cleaning is 290 and 12 respectively and the corresponding cleaning efficiency is 96%.

"PARTICLES ON WAFER SURFACES CAN BE IMAGED EASILY USING AFM AS COMPARED TO OTHER MICROSCOPIC TECHNIQUES. SOME OF THE BENEFITS OF USING AFM OVER OTHER MICROSCOPIC TECHNIQUES ARE AS FOLLOWS: EVEN VERY SMALL NANOPARTICLES (<20NM) CAN BE IMAGED EASILY USING AFM; IMAGING WAFERS USING AFM DOES NOT REQUIRE ANY SAMPLE PREPARATION; AFM IS A SIMPLE, FLEXIBLE, AND COST EFFECTIVE TECHNIQUE AND THE IMAGE QUALITY IS EXCELLENT WITH GOOD REPRODUCABILTY; AFM IMAGES CAN BE FURTHER PROCESSED TO OBTAIN MORE INFORMATION LIKE SIZE, SURFACE QUALITY, ETC." AKSHAY GOWDA

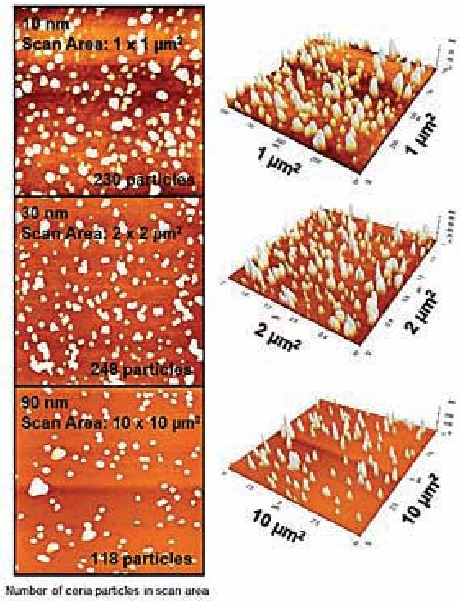


Figure 2. Topographic images of adsorbed ceria particles on silicon dioxide wafer surfaces in scan areas of 1 × 1 µm2 (for ~10 nm ceria particles), 2 × 2 µm2 (for ~30 nm ceria particles) and 10 × 10 µm2 (for ~90 nm ceria particles). Different scan areas were chosen for different sized particles to obtain adequate number of particles in AFM images.

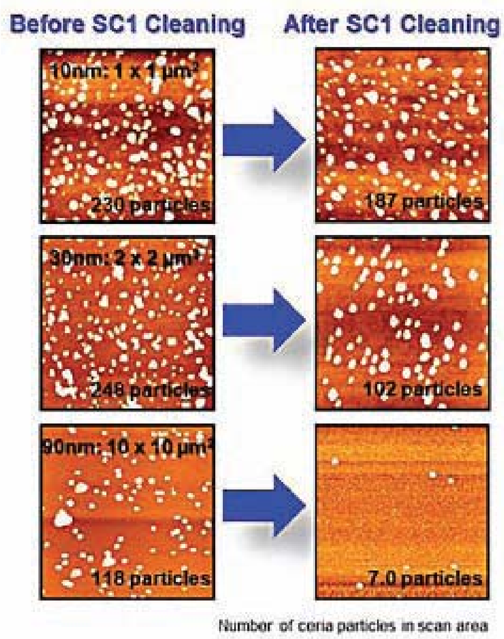


Figure 3. AFM images of adsorbed ceria particles on silicon dioxide wafer surfaces and the corresponding number of particles before and after cleaning with standard clean 1 (SC1) solution in scan areas of 1 × 1 µm2 (10 nm-ceria), 2 × 2 µm2 (30 nm-ceria), and 10 × 10 µm2 (90 nm-ceria).

PARK SYSTEMS ANNOUNCES GRAND OPENING CEREMONY FOR THEIR NEW OFFICE IN BEIJING CHINA

As the political, economic and cultural center of China, the establishment of branch office in Beijing means a milestone for the Chinese market. The Park Beijing Office will demonstrate advanced Atomic Force Microscopy (AFM) with cutting-edge applications to the customers from material science to chemistry, biology and semiconductor.

Dr. Sang-il Park, Park Systems Chairman and CEO

Park Systems, world leader in Atomic Force Microscopes (AFM) announces the opening of its Beijing Office in China. With the increasingly growing demand for AFM technology in China, Park Systems has decided to provide direct support for China's major scientific laboratories, research and industrial communities by opening an office in Beijing equipped with Park AFM.

The Grand Opening of the Park Beijing Office will be held on Nov. 22, 2018 at 9:30am with a featured talk by Park Systems' vice president, Dr. Sangjoon Cho and other notable scientists including Prof. Lei Ma from Tianjin University and Prof. Lisheng Zhang from Capital National University. A tour of the Beijing office and a cake cutting ceremony will also be included in the event.

The Park Beijing office is equipped with the latest Park AFM Systems, Park NX10 and the Park Nanoscientific laboratory in Shanghai is equipped with Park NX20. They will serve as AFM research facilities in China and will provide strong technical, application, sales and CS support for all Chinese customers.

Park Systems, a global AFM manufacturer, has regional headquarters in key cities worldwide, including Santa Clara, California; Tokyo, Japan; Singapore; Mannheim, Germany; and Suwon, Korea. As the political, economic and cultural center of China, the establishment of branch office in Beijing means a milestone for the Chinese market. The Park Beijing Office will demonstrate advanced Atomic Force Microscopy (AFM) with cutting-edge applications to the customers from material science to chemistry, biology and semiconductor.

"Increasingly, AFM is being selected for nanotechnology research over other metrology techniques due to its non-destructive measurement and sub-nanometer accuracy," states Dr. Sang-il Park, Park Systems chairman and CEO. "The Park Beijing office provides researchers with greater access to Park Systems' cutting-edge AFM nanoscopic tools, featuring reliable and repeatable high-resolution imaging of nanoscale cell structures in any environment without damage to the sample."

" Park Systems has invested significant resources to the new office in China to provide a better opportunity to Chinese scientific communities to use Park AFM. We are confident that Park AFM will demonstrate its high performance and cost efficiencies for research and production researches to Chinese customers as it has in Europe and America", commented by James Woo, Park Systems Global Sales Manager. "We invite Chinese customers to our Beijing office to use Park AFM to have a demo or do research to witness for yourself why Park has been the world leader in AFM technology since its inception."

Dr. Park further states, "SmartScan of Park Systems is an innovative, groundbreaking AFM smart software that produces high quality images with a single click. SmartScan is the best AFM operating software available with the combination of extreme versatility, easy-of-use and quality". He also added, "Park AFM has XY scanner separated from Z scanner, providing true Non-contact Mode and automatic parameter setting. The new AFM Pinpoint mode accurately measures mechanical and electrical characteristics at each measurement point with controlled contact force. Nanotube-based Ion Conductivity Microscopy (SICM) enables advanced Scanning Electrochemical Microscopy (SECM), Scanning Electrochemical Cell Microscopy (SECCM), and in situ live cell nanoscopy. These new innovations in AFM will help scientists around the world to achieve better scientific breakthroughs."

About Park Systems

Park Systems is a world-leading manufacturer of atomic force microscopy (AFM) systems with a complete range of products for researchers and industry engineers in chemistry, materials, physics, life sciences, and semiconductor and data storage industries. Park's products are used by more than a thousand institutions and corporations worldwide. Park's AFM provides the highest data accuracy at nanoscale resolution, superior productivity, and the lowest operating cost, thanks to its unique technology and innovative engineering. Park Systems, Inc. is headquartered in Santa Clara, California with its global manufacturing, and R&D headquarters in Korea. Park's products are sold and supported worldwide with regional headquarters in the US, Korea, Japan, Singapore, Germany, China, India and Mexico and distribution partners throughout Europe, Asia, and the Americas.

Visit http://www.parksystems.com or call 408-986-1110 or email at inquiry@parksystems.com for more information.

Park Systems
Improving Wafer Production Quality Assurance with Atomic Force Microscopy

Miniaturization of device geometry, new materials and increasing levels of chip integration requires the semiconductor industry to face production challenges to optimize accuracy throughout the wafer manufacturing process. Conventional techniques such as SEM (Scanning Electron Microscopy) and other optical methods have become inadequate to offer the required precision and reliability to achieve their goals. Semiconductor companies world-wide have partnered with world-leading AFM manufacturer Park Systems to fulfill their nanoscale microscopy needs, with their comprehensive line of Atomic Force Microscopes (AFM) rendering unparalleled accuracy and versatility, including Park NX-Wafer, a revolutionary AFM solution designed for bare wafer manufacturing that fully automates the automatic defect review process and increases production throughput by an astounding 1,000 percent. At the same time, the operating costs are low thanks to Park's unique technology and innovative engineering.


Keibock Lee

"Ever increasing advances in nanoscale science demand accurate and reliable 3D characterization in real-time at the highest nanoscale resolutions. Customers can choose from our diverse range of products as AFMs are used in virtually every area of nano scientific research today," states Keibock Lee, President and General Manager of Park Systems.

To bring out the solutions and performances based on client requirements, Santa Clara, California-based Park Systems works diligently on the initial conditions before placing the purchase orders in bulk. "We work along the same line of thought with some of the major semiconductor companies; Imec is one the largest consortium of semiconductor companies and they have been our partners for the last three years and helped us produce many good results."

In partnership with semiconductor manufacturers, Park Systems developed the Park NX-3DM series, designed exclusively for high-resolution sidewall imaging and critical angle measurements of semiconductor wafers. Park's wide range of AFM solutions includes proprietary software SmartScan, exclusively tailored for the automation of data acquisition and analysis, allowing even novice users to get accurate AFM results.

Park PinPoint AFM technique was designed to obtain higher spatial resolution and sensitivity over a variety of wafer samples, by developing a well defined electric contact between the tip and the surface. Furthermore, PinPoint allows imaging of samples with extremely narrow trenches of very high aspect ratio.

Park Systems developed the True Non-Contact AFM technology that maintains the probe sharpness, which is crucial for high resolution repeatability throughout the scans, and at the same time, preserve the sample from damage. Lee explains, "We have a superior technology and our AFMs are advanced as they are designed based on a fundamentally different architecture."

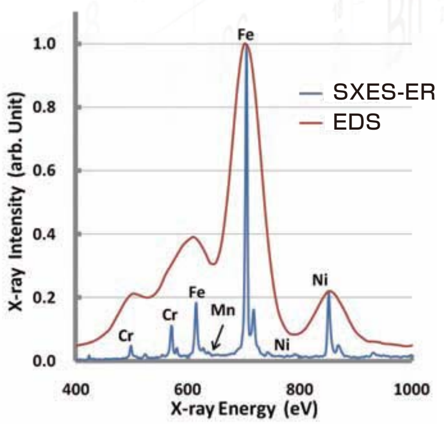
Being a technology driven company, Park Systems is set to develop new generation technologies with AFM as a part of the whole tech solution. Today, only a fraction of the tremendous amount of data generated through each layer of wafer is being utilized. "We are developing next generation software that would use the artificial intelligence to process this huge amount of data, employing the big data technology," concludes Lee.

> **"Customers can tailor our diverse range of products to their distinctive needs as AFMs are highly versatile and are widely employed in the scientific research arena to develop product and efficiency"**

Park Systems extensive product line in AFM product nanoscale metrology has resulted in continuous growth for over 25 years and significant rapid global expansion since 2015, when Park Systems issued an IPO, demonstrating their ambition to take a quantum leap forward as a premier nano-measurement company, based on their technological competitiveness and a uniquely differentiated product line. Park also offers Park AFM Scholarships, for easy access to AFM for researchers globally, hosts NanoScientific symposiums world-wide and has opened Park NanoScience Labs around the world, shared knowledge centers for nanotechnology research. In addition to Korea, there are Park NanoScience Centers at SUNY Polytech in Albany, NY, Manheim Germany at Park's new European Headquarters, Japan, China, Singapore, India, and Mexico. CR

SXES(Soft X-Ray Emission Spectrometer)
SXES-ER(Soft X-Ray Emission Spectrometer Extended Range)

Parallel Detection with High Sensitivity CCD

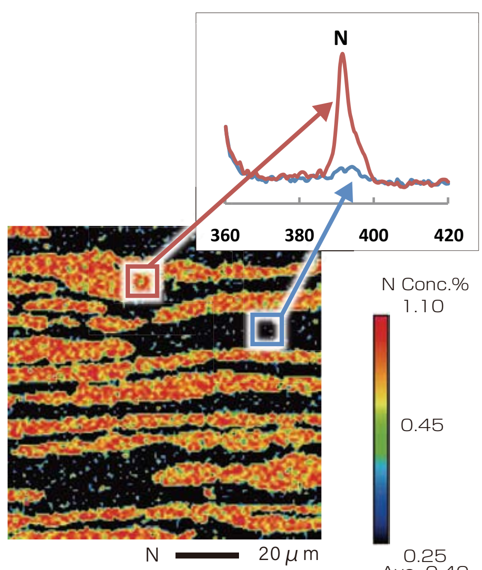


SXES-ER and EDS Spectrum comparison
Specimen：SUS304

SXES Specification

Chemical-bonding states	: Possible
Parallel detection	: Possible
Detection limit	: 20ppm (B reference value)

Detection Capability for Superior trace and light elements



Specimen : Trace of N in steel