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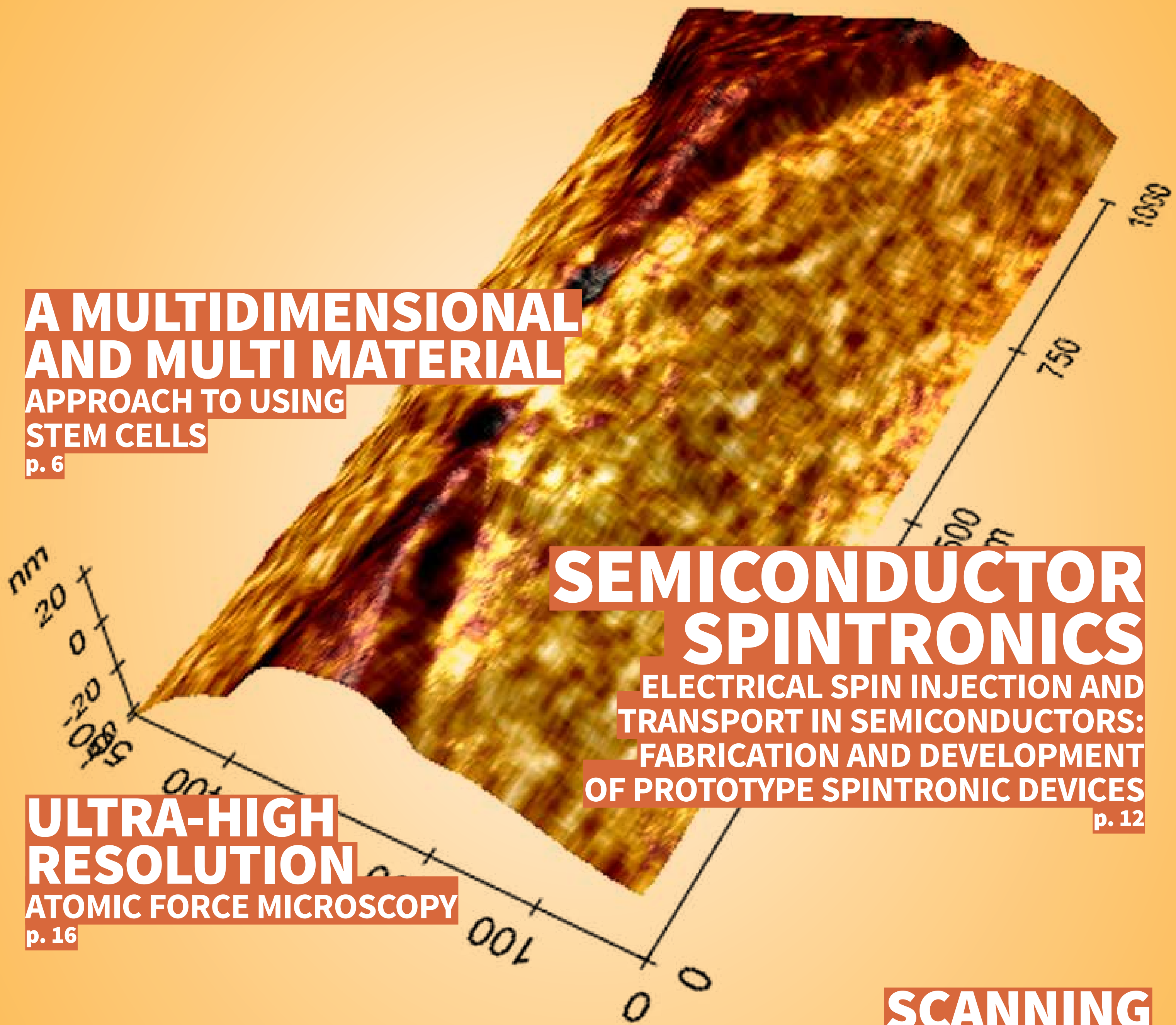
The Magazine for Nanotechnology



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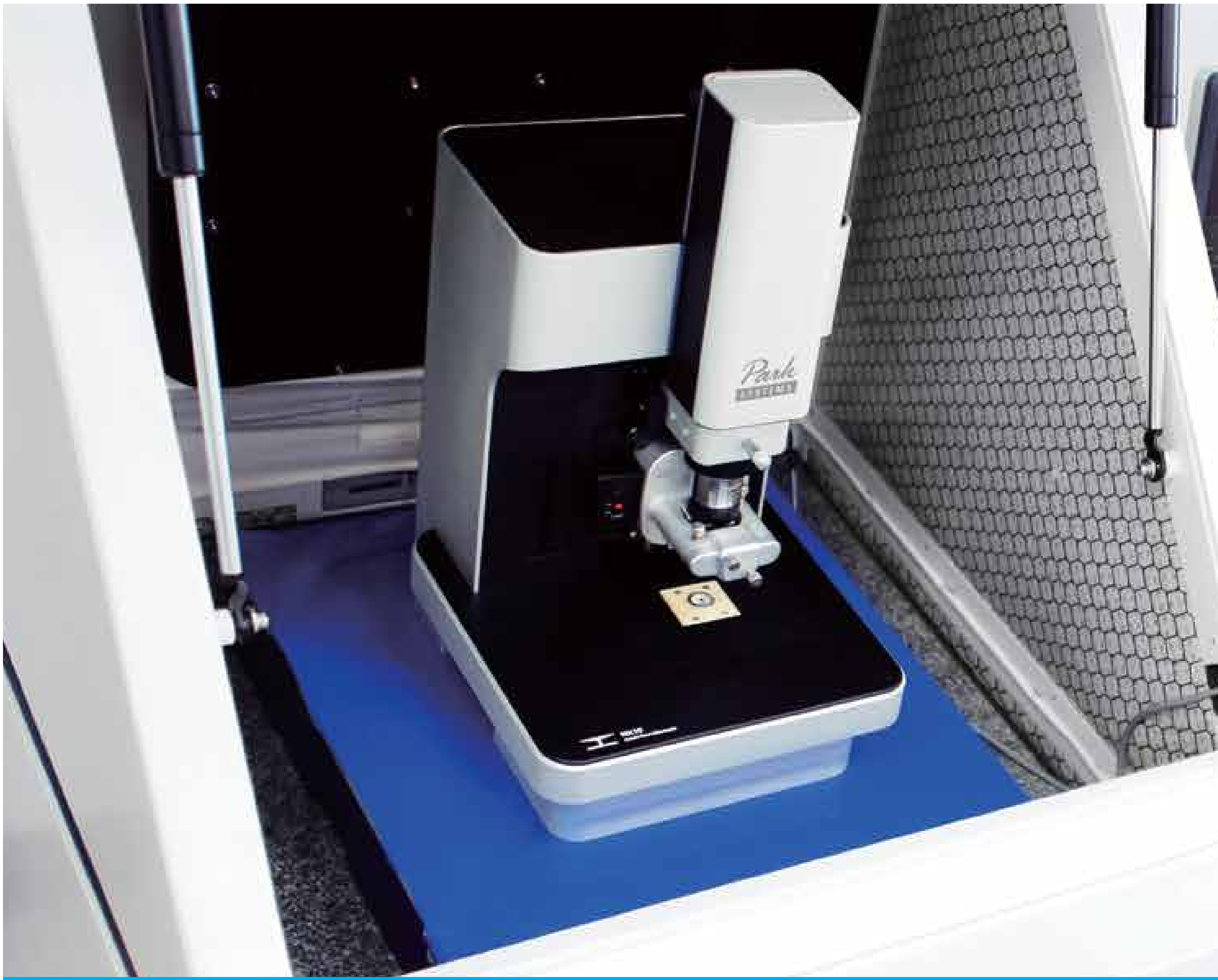

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The Most Accurate Atomic Force Microscope

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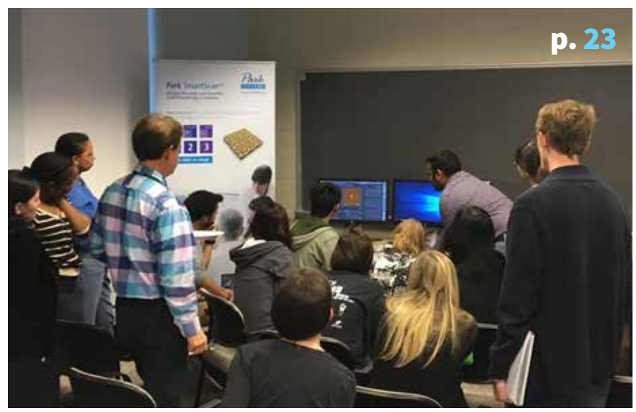

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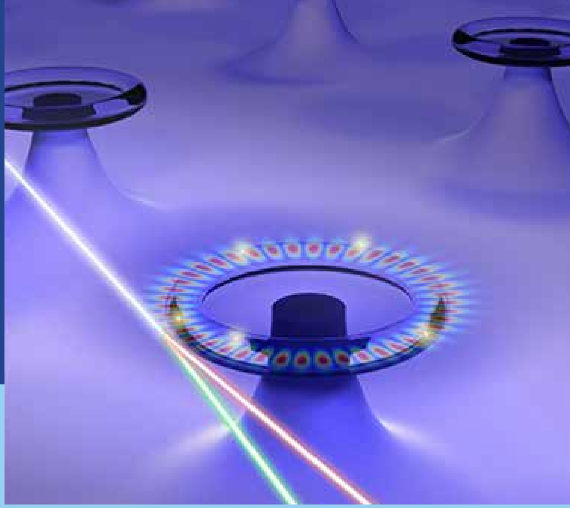
Cover Photo
This is a 3D overlay image of scanning capacitance microscopy (SCM) on topography of vacuum-channel nanoelectronic device. Such devices under development replace traditional solid-state electronics for use in space travel exploration. The SCM's ability to resolve data at nano scale enables the verification and development of this new device. Scan size is 500 nm x 1000 nm. Brighter color area means more positively charged and darker color means more negatively charged.

MESSAGE FROM EDITOR

Keibock Lee,
Editor-in-Chief



A world measured by atoms, not inches. In this picture is a micro laser, roughly the diameter of a human hair, counts individual nanoparticles as they land on a ring. J. Zhu, B. Peng, S.K. Ozdemir, L. Yang, Electrical and Systems Engineering Department, Washington University in St. Louis

HAPPY NEW YEAR!

It is with great enthusiasm that I greet everyone this New Year. Exciting times await us in 2017 as the emergence of nano science shapes our new world. As we collectively continue to press the boundaries of scientific discovery through global knowledge sharing, nanotechnology advances propel us all towards an incredible future.

In this issue, we bring you an exciting article about a far reaching idea that is quickly becoming a reality, stem cell transplants which are widely studied at Rutgers University in the KiBum Lee Group. Our interview with Hyeon-Yeol Cho gives a glimpse into the discoveries in a multi dimensional and multi material approach to using stem cells in medical applications. At Mayo Clinic in Rochester MN, stem cell transplants are already in clinical trial for multiple sclerosis at Dr. Howe's Lab where they are investigating transplant strategies. Medical and scientific collaboration across many spectrums is making stem cell science a reality in our very near future.

Another exciting article in this issue is a profile of Dr. Berend T. Jonker, Senior Scientist at the Naval Research Laboratory about the work he is doing with semiconductor spintronics and sensors. As our need for information in far reaching places continues, the Navy is advancing storage devices to new limits. The history of the Naval Research Lab goes back to Thomas Edison. The Naval Research Lab opened in 1923 at the instigation of Thomas Edison and is one of the first US Government scientific and R&D labs specializing in many scientific research areas including plasma physics, space physics, materials science and tactical electronic warfare. Dr. Jonker's astonishing career spans over 30 years and marks scientific achievements at the NRL that once seemed like science fiction.

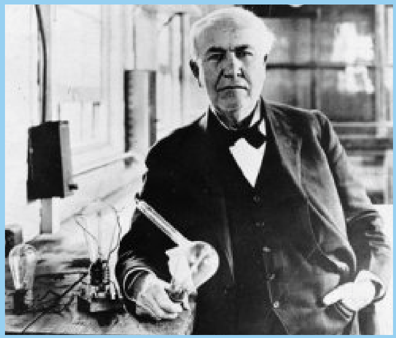
We have included three atomic force microscopy papers that focus on nanoscale measurement and characterization, an essential part of every nano scientific researcher's project. The idea is formed and once the research is conducted, then highly automated, functional tools record and measure the results. The AFM is one of many ways that scientific researchers are able to capture results and one that has wide-reaching applications. The articles presented highlight automation in AFM, high resolution of AFM, and a very significant joint research project with NASA Ames Research Center using Scanning Microscopy Characterization of Vacuum-Channel Nanoelectronic devices. The ongoing research efforts at NASA to harden electronic components and systems using solid-state devices against the effects of radiation and heat for use in space travel lead us happily and safely out into space exploration, our next frontier in scientific discovery. One final note, Park Systems is seeking to assist nano scientific researchers by offering a Park Scholarship and use of its AFM equipment to graduate and post doc students with great ideas. Submit your abstract by going to www.parkafm.com/prize to apply for the research scholarship, and a chance to be published in Nano-Scientific Magazine.

As I said in the intro, these are exciting times and we look forward to your ideas and input. Please forward your ideas for stories or content about nano-scientific applications and how they are changing our world. We will be happy to receive your articles or ideas for submission.

With Best Wishes for a
Prosperous New Year,

Keibock Lee,
Editor-in-Chief

"MY MAIN PURPOSE IN LIFE IS TO MAKE ENOUGH MONEY TO CREATE EVER MORE INVENTIONS.... THE DOVE IS MY EMBLEM.... I WANT TO SAVE AND ADVANCE HUMAN LIFE, NOT DESTROY IT.... I AM PROUD OF THE FACT THAT I HAVE NEVER INVENTED WEAPONS TO KILL." THOMAS EDISON



Sometimes called the Father of Modern Invention, Thomas Edison conceived the idea of "a great research laboratory" which led to the creation of NRL in the early 1920s. Rich in its history, the Laboratory may be one his greatest legacies.

FEATURE
INTERVIEW

Hyeon-Yeol Cho, Post Doc student at Rutgers University where is currently studying stem cell engineering. He is pictured here in front of the Park Systems NX 10 Atomic Force Microscope used in the lab. The KiBum Lee group where he works is focused on unlocking the secrets to stem cell research.

A MULTIDIMENSIONAL AND MULTI MATERIAL APPROACH TO USING STEM CELLS

An Interview with Hyeon-Yeol Cho, post doc student at Rutgers University, KiBum Lee group

Can you explain more about your research studying stem cells to regenerate cells and grow new tissue?

Stem cells, as understood, have the ability to become any specialized cells capable of replacing damaged ones which from either injuries or degenerative diseases. However, the major drawback in stem cell therapy is the low efficiency in giving rise to these specialized cells. The KBLEE group focuses on tackling this issue from multidimensional and multimaterial approaches. Our approaches include: 1) soluble microenvironmental factors, 2) insoluble physical facts, and 3) Nano-topographical features. We believe that innovative approaches are the key to untangling the complexity associated with stem cells.

Can you describe how nanochemistry is currently being used in stem cell research?

The research area of nanochemistry includes small molecule assembles or nanoparticle synthesis. In order to use the nanoparticle's versatility, it is widely used to deliver various drug and oligomers which can initiate stem cell differentiation; plasmid, short RNAs, differentiation factors. Especially, gold nanoparticle is the representative material for stem cell research with its stability and easy surface modification.

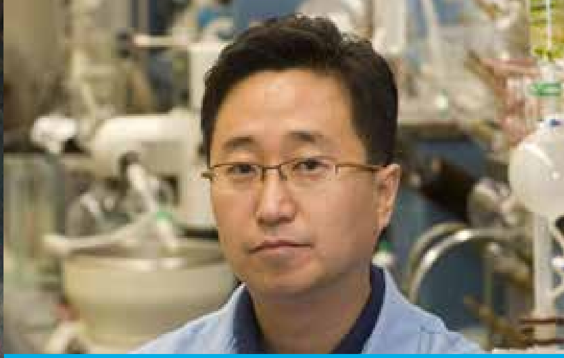
What is gene expression and how is it used to advance stem cell research?How does your research integrate nanotechnology with chemical biology to modulate signaling pathways in cancer and stem cells?

Gene expression is where genotype gives rise to the phenotype, the realization of an end product from the instruction of a blueprint. Every cell in our body has genetic blueprint encoded inside our DNAs; hence, cells can decide on the time and duration of which they turn on/off those specific genes to make specific proteins. Therefore, through innovative integration of nanotechnology (nanomaterial and genetic material) our research can modulate cancer and stem cells at the DNA level upstream of varies biological cascades.

What is NanoScript and how does it interact with DNA for stem cell research?

Transcription factors are the master regulator of gene expression, and scientists have tried to deliver these factors in hope to alter gene expression for therapeutic reasons. However, to overcome the challenges associated with vial-vector based genetic material delivery, the KBLEE group has developed an innovative, tunable nanoparticle-based artificial transcription factor protein platform, NanoScript, to effectively and selectively regulating genes in a non-viral manner. The nanoparticle-based synthetic transcription factor (STF) platform emulates the fundamental functions of transcription factors, thereby allowing for regulating transcriptional activity (e.g. activation or repression) and targeting gene expression in both an effective and selective manner. Owing to the its modular design, NanoScript is an invaluable tool in stem cell research.

How do you increase the efficacy in substrates for transplanting stem



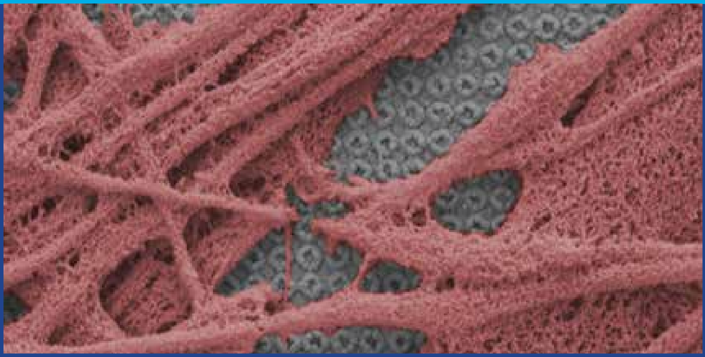
Above: Dr. KiBum Lee

Left: Dr. KiBum Lee (center) and his group at Rugers University aimed at unlocking the full therapeutic potential for stem cells. http://kblee.rutgers.edu/

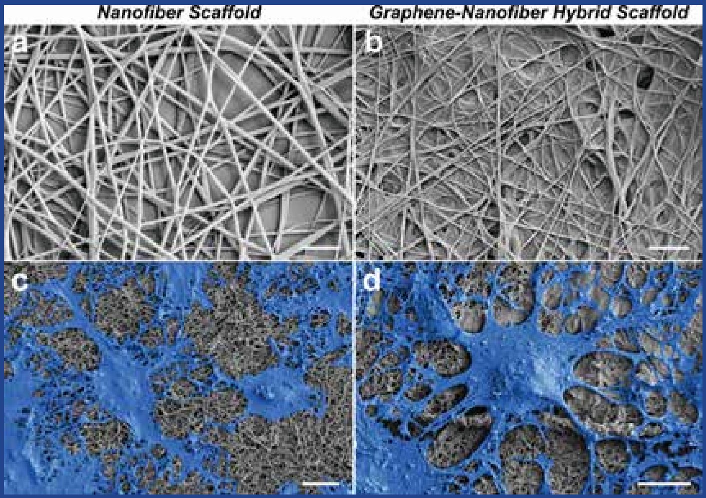
KiBum Lee is a professor of Chemistry and Chemical Biology at Rutgers University. The primary research interest of Dr. Lee's group is to develop and integrate nanotechnologies and chemical functional genomics to modulate signaling pathways in stem cells towards specific cell lineages or behaviors. In particular, his group is exploring critical problems in cancer research and stem cell biology pertaining to the cell-microenvironmental interactions, and how to control these interactions at the subcellular and single cell level using chemical biology and nanotechnology.

From this research effort, he has developed innovative technology platforms that may overcome the critical barriers to harnessing the full therapeutic potential of stem cells. technology platforms that may overcome the critical barriers to harnessing the full therapeutic potential of stem cells.

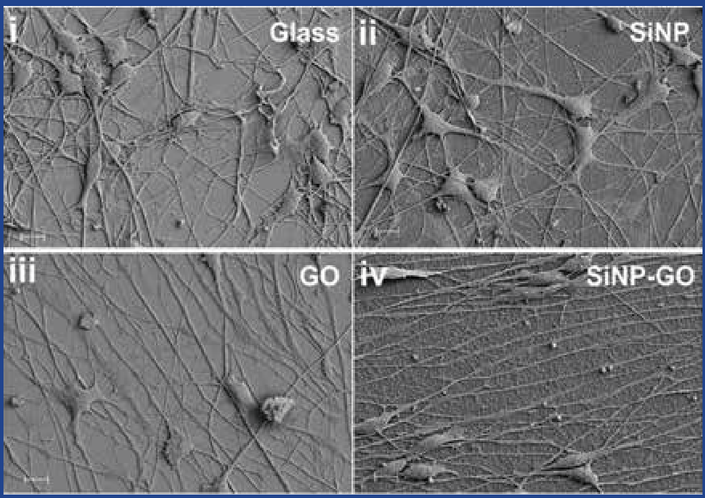
Examples of AFM images from the Rutger research lab



Pseudocolored image of dopaminergic neurons derived from hNSCs



Morphology of nanofibrous scaffolds and cultured NSCs on the scaffolds



behavior of hNSCs on silica nanoparticle-graphene oxide

“THE AFM EQUIPMENT HAS UNIQUE FEATURES TO ANALYZE THE MECHANICAL PROPERTIES IN NANOSCALE. WE UTILIZE AFM TO CONFIRM THE UNIQUE NANO-TOPOGRAPHICAL FEATURES FOR BIOAPPLICATIONS; LARGE-SCALE HOMOGENEOUS NANOARRAY, NANOFIBER SHEET, HYDROGEL.”
HYEON-YEOL CHO

cells into muscle tissue to counteract conditions such as Parkinson’s disease?

The musculoskeletal abnormality symptoms suffered by Parkinson’s disease patients is related to the unspecific dying of dopamine generating nerve cells, dopaminergic neurons, which has extremely limited regenerating ability. As mentioned before, stem cells hold the key to give rise to specific cells. In order to check with high sensitivity and selectivity, we have developed the LHONA substrate to detect the maturation of dopaminergic neuron from stem cell differentiation. This substrate platform is unique in the sense that it allows for live-cell detection contrary to conventional methods of DNA/RNA/protein harvesting and immunochemistry. Upon confirmation of mature dopaminergicneuron differentiation using the LHONA substrate, dopaminergic neurons can then be transplanted into a Parkinson’s patient to cure the disease.

How do you use AFM in your research?

The AFM equipment has unique features to analyze the mechanical properties in nanoscale. We utilize AFM to confirm the unique nano-topographical features for bioapplications; large-scale homogeneous nanoarray, nanofiber sheet, hydrogel.

Hyeon-Yeol Cho, post doc student at Rutgers University, KiBum Lee group

Hyeon-Yeol Cho is a post doc student at Rutgers University where he works in the KiBum Lee group. He has been involved in research at the interface between nanotechnology and cell biology, since 2010 when he started doctoral and post-doctoral work at Sogang University and Rutgers (with Dr. Jeong-Woo Choi and Dr. KiBum Lee). His primary research interest is to develop and integrate nanotechnologies and cell biology to modulate signaling pathways in cells (e.g. stem cells and cancer cells) towards specific cell lineages or controlling their behavior and to monitor it non-invasively. His work is focused on two primary areas where he has published a number of papers as shown below.

Inorganic/organic nanoparticle for in vivo/vitro diagnosis and therapy

My main research interest is bio-inspired nanoparticle based approaches for cancer diagnosis/therapy and stem cell manipulation. By taking advantage of the nanoparticle’s unique physical properties and appropriate size for labeling and probing biological systems,I have developed bio-inspired nanoparticle-based novel method for detecting and isolating target cells.Towards the goal of probing the fundamental mechanism of cellular response with delivered nanoparticle in cancer and stem cells, I keep focusing on the development of functional bio-inspired nanoparticles.

a. H. J. Lee, H. -Y. Cho*, J. H. Oh, K. Namkoong, J. G. Lee, J. -M. Park, S. S. Lee, N. Huh, & J. -W. Choi, “Simultaneous capture and in situ analysis of circulating tumor cells using multiple hybrid nanoparticles”, Biosensors and Bioelectronics, 2013, 47, 508–514. *Equal Contribution*

b. T. -H. Kim, H. -Y Cho, K. B. Lee, S. U. Kim, & J. -W. Choi, “Electrically controlled delivery of cargo into single human neural stem cell”, ACS Applied Materials and Interfaces, 2014, 6 (23), 20709-20716.

c. W. A. El-Said, H. -Y. Cho, C. -H. Yea, & J. -W. Choi, “Synthesis of metal nanoparticles inside living human cells based on the intracellular formation process” Advanced Materials, 2014, 26(6), 910-918.

d. Md. K. Hossain, H. -Y. Cho*, K. -J. Kim & J. -W. Choi, "In situ monitoring of doxorubicin release from biohybrid nanoparticles modified with antibody and cell-penetrating peptides in breast cancer cells using surface-enhanced Raman spectroscopy", Biosensors and Bioelectronics, 2015,71, 300-305. *Equal Contribution*

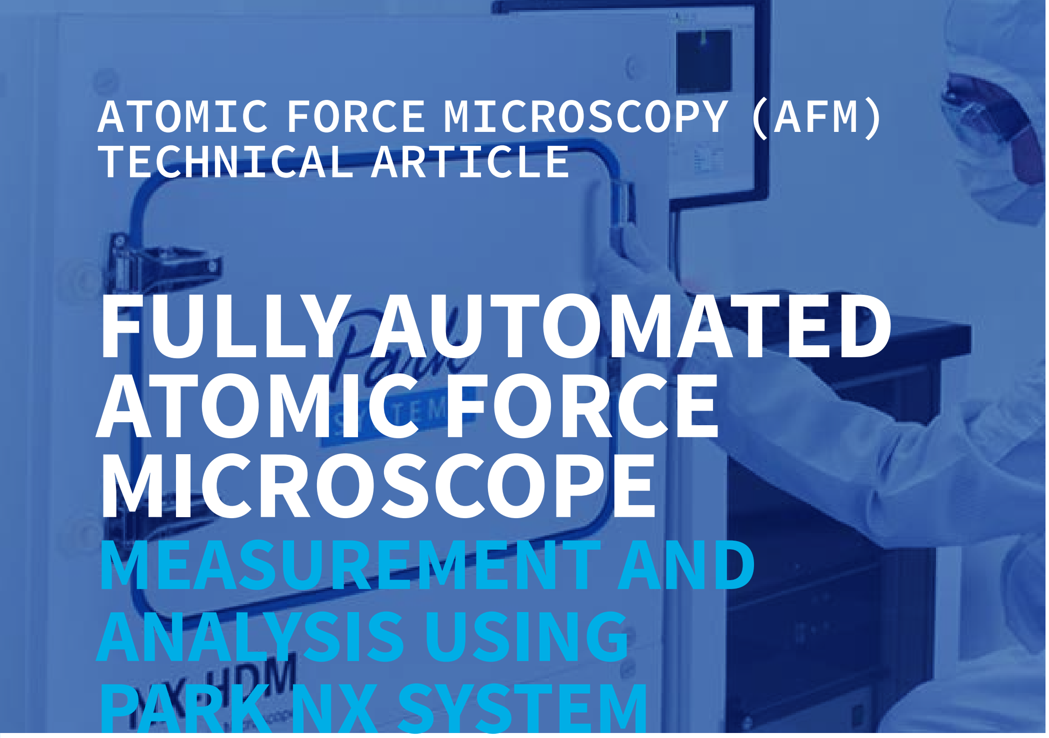
Modifications of cell-on-a-chip platform

This experience and knowledge supported to understand cellular response in drug treatment and stem cell differentiation using various functionalized substrate with nanopattern.Biomaterials (synthetic peptide and ECM molecules), organic materials (polymer, lipid, etc) and inorganic materials (metal nanostructures) can be applied to surface for improvement of biocompatibility and sensitivity of cell-on-a-chip platform.

a. H. -Y. Cho, T. -H. Kim, E. -B Ko& J. -W. Choi, "Fabrication of carbon nanotubes/RGD peptide composites to enhance electrochemical performance of cell chip", Journal of Biomedical Nanotechnology, 2013, 9(8), 1398-1402.

b. E. -B. Ko, H. -Y. Cho, T. -H. Kim, C. -H. Yea & J. -W Choi, “Cell chip with a thiolated chitosan self-assembled monolayer to detect the effects of anticancer drugs on breast normal and cancer cells”, Colloids and Surface B: Biointerfaces, 2013, 112, 387-392.

c. H. -Y. Cho, T. -H. Kim, S. U. Kim, & J. -W. Choi, “Fabrication of stem cell chip with peptide nanopatterned layer to detect cytotoxicity of environmental toxicants”, Journal of Nanoscience and Nanotechnology, 2012, 12, 834-839.



ATOMIC FORCE MICROSCOPY (AFM)
TECHNICAL ARTICLE

FULLY AUTOMATED ATOMIC FORCE MICROSCOPE

MEASUREMENT AND ANALYSIS USING PARK NX SYSTEM

By Phani Kondapani, Gerald Pascual, Byong Kim,and Keibock Lee
Applications & Technical Marketing, Park Systems, Inc., Santa Clara, USA

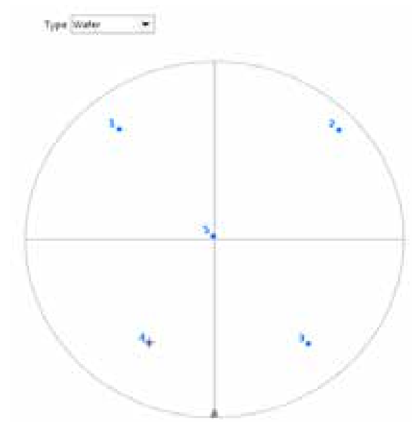


Figure 1a.
The five measurement sites selected for imaging from the sample patterned silicon wafer.

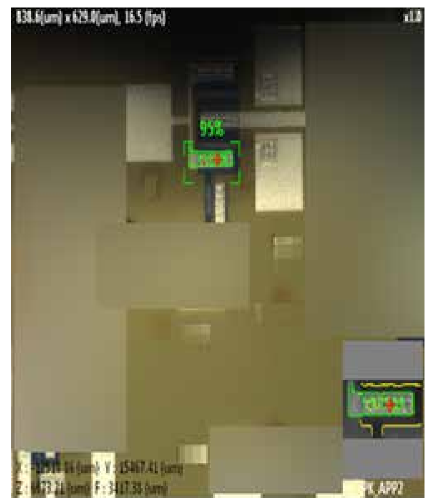


Figure 1b.
Optical camera feed from the XEA software interface displaying a 95% confidence level in the software's ability to recognize the sample pattern.

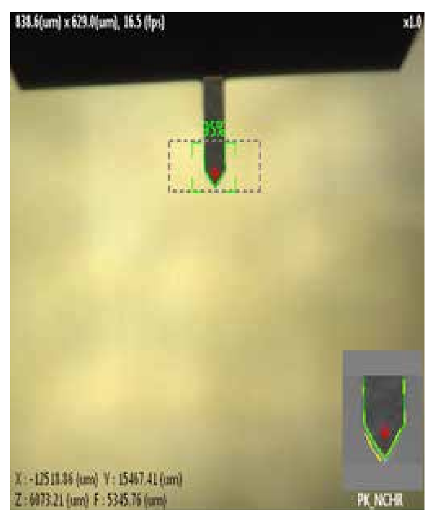


Figure 1c.
Optical camera feed from the XEA software interface displaying a 95% confidence level in the software's ability to recognize the cantilever. The red crosshair is a user-defined estimate of the cantilever tip's location.

INTRODUCTION

Semiconductor device dimensions have been moving to 1X-nm node and below for years now in order to continually meet market demand for faster and more efficient designs year-to-year. Device fabrication methods have improved all the way from 65 nm in 2006 to reaching the 1X node at 14 nm in 2014. Current projections by the International Technology Roadmap for Semiconductors have the first sub-1X node devices at 7 nm debuting as soon as perhaps 2017 [1]. To continue at this pace, manufacturers must have the capability to meet metrology requirements that simultaneously call for enhancements in resolution, precision, and accuracy.
Tools to meet these needs must provide nanoscale imaging for critical dimension measurement and results that can be repeatable and accurate enough to enhance productivity in a mass production environment [2].

A compelling nanometrology solution for these challenges has been developed at Park Systems in the form of atomic force microscopy (AFM) tools with software specifically tailored for the automation of data acquisition and analysis. Dubbed XEA [3], this software is designed to enable a process control engineer to use AFM systems to acquire accurate and repeatable nanoscale images of target devices according to user-defined procedures in custom recipe files. The corresponding increase in productivity makes this combined software and hardware solution attractive for wafer-level device fabrication plants everywhere.

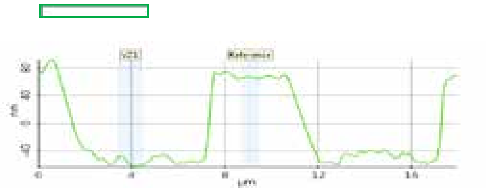
EXPERIMENTAL

A three-inch patterned silicon wafer sample was used in this experiment. The target pattern on the wafer consists of rectangular pits which have pitches of 10 μm and step heights of 120 nm.Topography and roughness analysis at the target pattern was performed on two of pits.

The sample was then mounted onto the stage of a Park NX-HDM AFM system [4] for imaging using the XEA software. AFM imaging in air was performed in non-contact mode using asilicon-based cantilever.

Five measurement locations were selected inside the wafer as shown in Figure 1a.
The reference measurement location (site #5 on Figure 1a) for creating the automated recipe was located at a NOR Gatedeviceonthe wafer. Four additional measurement sites of the same patterned device were selected at different XY coordinates inside the wafer to execute automated measurements of sample feature topography as well as roughness.

To begin creating the measurement and analysis recipe, the XEA software was put through a pair of teaching routines to allow it to optically recognize the location of the cantilever tip and sample pattern. These teaching routines (see Figures 1b and 1c) consist ofoptical image and XY stage adjustments and user-taught data fed into



Vertical Zone			
No	Name	H (nm)	R (nm)
1	VZ1	-120.762	10.919
2	Reference	0.0	6.635

Figure 2a. AFM topography image of measurement site #1 with green inset rectangle denoting specific area of interest. This area's line profile is also provided along with recorded step height (H) and roughness (R) values gathered by measuring sites VZ1 (in the first device pit) and Reference (in the raised area between the first and second device pits).

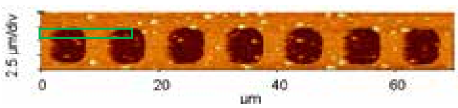
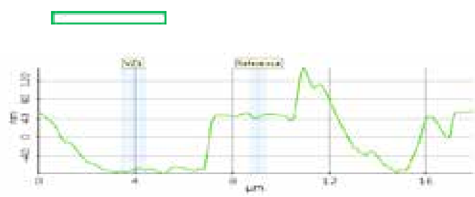


Figure 2b. AFM topography image of measurement site #2, area of interest line profile, and collected step height (H) and roughness (R) values.



Vertical Zone			
No	Name	H (nm)	R (nm)
1	VZ1	-114.303	7.813
2	Reference	-0.0	6.018

Figure 2c. AFM topography image of measurement site #3, area of interest line profile, and collected step height (H) and roughness (R) values.

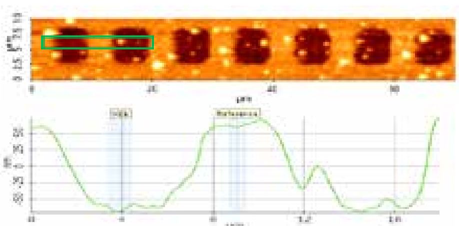
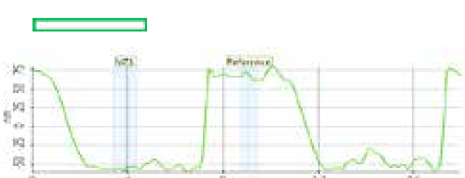


Figure 2d. AFM topography image of measurement site #4, area of interest line profile, and collected step height (H) and roughness (R) values.



Vertical Zone			
No	Name	H (nm)	R (nm)
1	VZ1	-124.678	11.278
2	Reference	-0.0	9.161

Figure 2e. AFM topography image of measurement site #5, area of interest line profile, and collected step height (H) and roughness (R) values.

the software in order to guide the hardware to bring the target pattern measurement sites to the tip landing position.

Furthermore, the initial reference scan image of the sample patternis used to adjust XY offsets in positioning when needed. For example, if a target pattern for study is not consistently optically recognizable by the software, a user can define the pattern's location relative from a nearby landmark that is. Then the recipe would be designed to automatically move the sample to the cantilever tip accordingly using the landmark for orientation. This is done with nanometer-level precision in order to accurately image the user-defined region. With the teaching routines completed and XY offsets determined, scan parameters to acquire sample topography and roughness data are then defined by the user.

This entire set of calibrations and instructions is compiled into a recipe file that can now be used to run automated measurements on the sample. Immediately after each site is measured, the XEA recipe scripted to immediately conduct an automatic analysis of the collected datathat completes.. An aggregated report for the data acquired at each measurement site is then available after all measurement sites have been investigated and the recipe exhausted.

RESULTS AND DISCUSSIONS

After the scanning was completed, we found the five user-defined measurement siteswereaccurately imaged with AFM.Their topography and roughness were measured simultaneouslywithin the user defined locations as seen in green rectanglesin the provided AFM images and the shaded blue columns in the line profiles included in Figures 2a – 2e. To determine the step height and roughness of the device within the user-defined area of interest, two locations were measured in each area: VZ1, located at the bottom of the first pit from the device's left edge, and Reference, a site on the raised area between the first pit and the second pit to its right.

Step height was obtained by taking the difference between the average height calculated at a Reference location and the same calculated at the VZ1 location. This difference in height is also reflected in the color map used for the AFM images in Figures 2a – 2e as deeper, recessed features such as the pits have a darker color whereas the raised areas between them have a much lighter shade. Roughness values for the device were again calculated by scanning the specific locations VZ1 and Reference, with the pit floor roughness (at VZ1) being of more interest to us.

The collected data shows that the five sites have pits that are approximately 120 nm in height and pitches of 10 µm in length. Note the pitch length can also be repeatedly visually confirmed simply by looking at each AFM topography image in Figures 2a – 2e. Each topography image can also be used to visually confirm while the AFM did not scan the same exact area of interest at each measurement site, the degree to which each inset green rectangle was offset can be measured within a single micron—a remarkably small amount of variance given the automation employed in the study.The final step height and roughness values collected are made available in tabular form by the software after the user-defined recipe finishes running (see Table 1).

It is noted that the sample was exposed to ambient air for a significant amount of time prior to being scanned with the AFM. This caused sample contamination on several locations on the wafer including all measurement sites, but especially at sites 3 and 4. This correlates to the discrepancies depicted in the line profiles collected in Figures 2c and 2d and the roughness values shown at each of these two sites. The standard deviation in roughness is apparently larger than what would be expected for a pristine sample. This deviationmay be attributable to the contaminants that collected on the sample's surfaceover an extended amount of time exposed to ambient air. This contamination had the unintended effect of further demonstrating the sensitivity of the AFM measurements and its ability to discern differences in features at nanoscale.

SUMMARY

Five identical NOR Gate devices on a three-inch patterned silicon wafer consisting of rectangular pits with 10um pitch and 120 nm step height weresuccessfully imaged using a Park NX-HDM AFM system with XEA, an automation software from Park Systems. Through a user-defined recipe created by combining optical pattern recognition and the precision of AFM, accurate and repeatable nanoscale metrologywith quantifiable data via automated data acquisition and analysis wasdemonstrated on all five patterns. Given

Sample ID	Site No	1_Name	1_H(nm	1_R (nm)
Data1	1	VZ1	-120.762	10.919
Data1	2	VZ1	-121.597	9.018
Data1	3	VZ1	-114.303	7.813
Data1	4	VZ1	-124.375	4.76
Data1	5	VZ1	-124.678	11.278
Average			-121.143	8.7576
Std. deviation			3.743766	2.3649503

Table 1. Step height (H) and roughness (R) values measured at each of the five selected sites with corresponding averages and standard deviations.

this ability to automate data acquisition and analysis, this process has a viable application in similar fields. Fields such as bare silicon wafer manufacturing (surface roughness) and wafer design research (critical dimension measurement) are two areas of industry and research that routinely conduct studies that could dramatically increase their throughput and efficacy by incorporating a tool capable of fully automated AFM.

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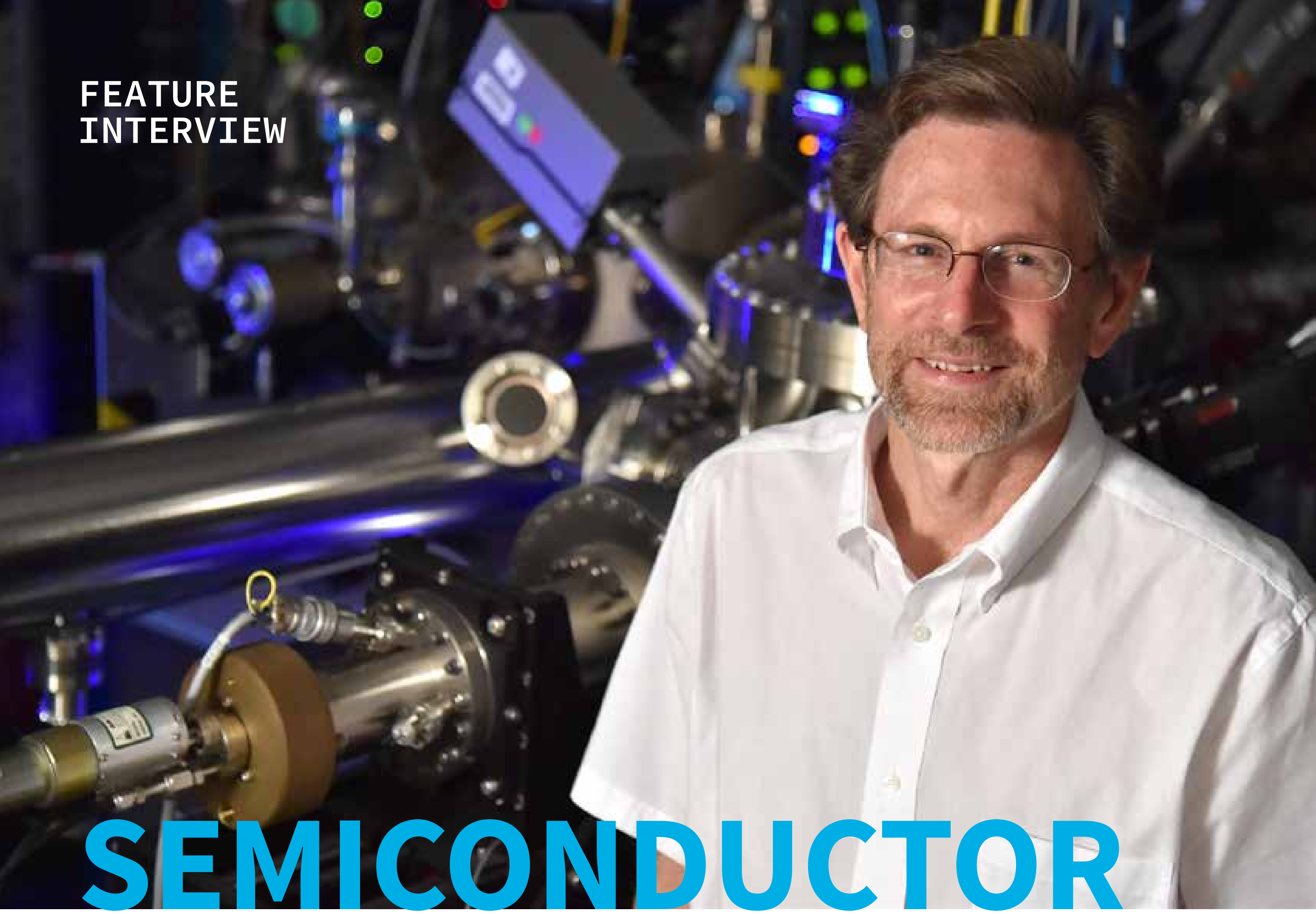
Sample mounted onto the stage of a Park NX-HDM AFM system



SEMICONDUCTOR SPINTRONICS

ELECTRICAL SPIN INJECTION AND TRANSPORT IN SEMICONDUCTORS: FABRICATION AND DEVELOPMENT OF PROTOTYPE SPINTRONIC DEVICES

An interview with Dr. Berend T. Jonker, Senior Scientist and Head of the Magnetoelectronic Materials & Devices section in the Materials Science & Technology Divison at the Naval Research Laboratory, Washington, DC

Dr. Berend T. Jonker is the Senior Scientist and Head of the Magnetoelectronic Materials & Devices section in the Materials Science & Technology Division at the Naval Research Laboratory, Washington, DC. His current research focuses on semiconductor spintronics, including electrical spin injection and transport in semiconductors, and the fabrication and development of prototype spintronic devices.

What are Magnetoelectronic devices and how are you using them?

My current work involves looking at materials properties and how they interface including magnetic metals. Select materials promise to be thero magnetic meaning they have a non zero phenomenon or a magnetic moment. This is used universally in motors, tools, etc.

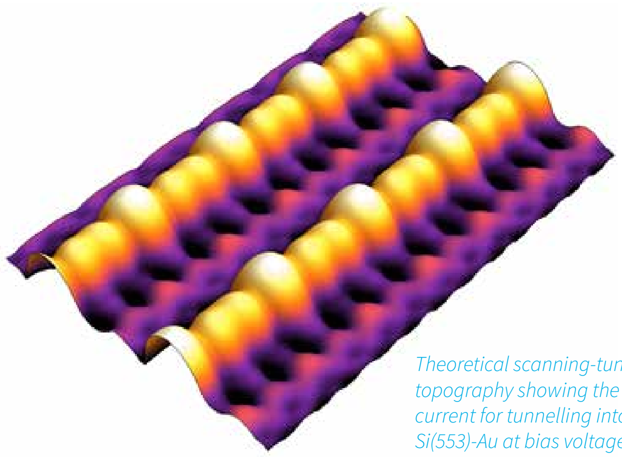
We are currently looking at developing material for IT non volitale memory for reprogramming logic, ultra low power consumption for devices and circuits and sensors for drones. These will allow us to leave a device underwater or for it to be taken out into field without carrying batteries. We are focusing on ultra low power consumption devices we can leave anywhere or have delivered by drones.

How do you use microscopy in your research?

Sensors cover a broad area for sonar optical and magnetic sensors. We routinely use SEM, AFM, MFM, and a variety of optical spectroscopy to

"WE SELECTED THE PARK NX 10 AFM INSTRUMENT ON A COST/ PERFORMANCE RATIO BASED ON OUR BID SPECIFICATIONS. THE SPECIALIZED SCIENTIFIC INSTRUMENT EQUIPMENT MARKET IS AN INTERNATIONAL MARKET, WE EVALUATED A NUMBER OF COMPANIES WORLD-WIDE BEFORE SELECTING PARK SYSTEMS AFM. PARK SYSTEMS AFM WAS IDENTIFIED AS THE ONE THAT WOULD GET THE HIGHEST RETURN FOR THE COST OF PURCHASE."

**DR. BEREND JONKER,
SR. SCIENTIST NAVAL RESEARCH LABORATORY**



Theoretical scanning-tunneling microscopy topography showing the tip height at constant current for tunnelling into empty surface states of Si(553)-Au at bias voltage +0.5 V. Coexisting tripled and doubled periodicities are visible along the Si step edge and Au chain, respectively.

evaluate materials we grow. We do a lot of material synthesis and have a broad suite of characterization tools.

The Park NX 10 AFM is one of our tools. It was selected in our government procurement program largely due to the cost performance ratio based on our bid specifications and was used in recent research published in ACS Omega on the first demonstration of metallic spin. This offers exciting opportunities for the advancement of sensors and data storage.

Specialized scientific equipment market is an international global market.

Our laboratory has a wide array of equipment for measurement including spin-polarized scanning tunneling microscopy (STM) and many others pieces of the most modern equipment available world-wide.

**Dr. Berend T. Jonker,
Senior Scientist and Head of the Magnetoelectronic Materials & Devices section in the Materials Science & Technology Divison at the Naval Research Laboratory, Washington, DC**

Dr. Jonker's is recognized industry-wide for his exemplary career achievements including his work in electron spin. He has been integral in developing solutions for key problems and demonstrating essential enabling steps in utilization of electron spin as an alternate state variable for information storage and processing in semiconductors, including electrical spin injection, detection and generation of pure spin currents. His research has also provided significant advances in the fundamental science of magnetoelectronics, particularly in interfacing the two dominant materials technologies of information storage and processing: that of ferromagnetic metals (magnetic storage) and semiconductors (logic, processing). This has led to results that enable the development of future spin-based electronics that are faster, instant-on, non-volatile with higher functionality and lower power consumption than existing charge-based electronics, that will advance capabilities of Navy / Marine Corps platforms of the "Navy after next." He is at the center of multidisciplinary research efforts, providing scientific leadership and vision to develop magnetoelectronic materials and technologies for information sensing, processing and storage including the initiation and coordination of several large research programs from 2007 to 2010 totaling ~ $15 million. He is a key advisor on science/technology problems of extraordinary scope and a panel member and contributing author for International Technology Roadmap for Semiconductors, as well as an advisor on strategic research planning for the Office of Naval Research, the Defense Advanced Research Projects Agency, the National Science Foundation and the Army Research Office.

FEATURE
INTERVIEW

NRL PRODUCES SPIN FILTERING AT ROOM TEMPERATURE WITH GRAPHENE

An interdisciplinary team of scientists at the U.S. Naval Research Laboratory (NRL) have reported the first demonstration of metallic spin filtering at room temperature using ferromagnet-graphene-ferromagnet thin film junction devices — spin is a fundamental property of electrons, in addition to charge, that can be used to transmit, process and store data.

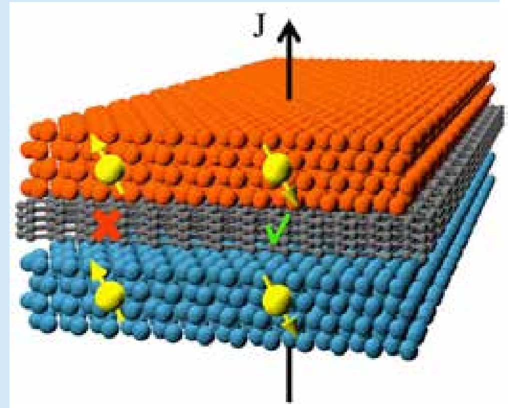
"The spin filtering had been theoretically predicted and previously seen only for high-resistance structures at cryogenic temperatures," said Dr. Enrique Cobas, principal investigator, NRL Materials Science and Technology Division. "The new results confirm the effect works at room temperature with very low resistance in arrays of multiple devices."

The thin film junctions demonstrated low resistance, and the magnetoresistance characteristic of a spin filter interface from cryogenic temperatures to room temperature. The research team also developed a device model to incorporate the predicted spin filtering by explicitly treating a metallic minority spin channel with spin current conversion, and determined that the spin polarization was at least 80 percent in the graphene layer.

"Graphene is famous for its extraordinary in-plane properties, but we wanted to look at conductivity between stacked graphene sheets and how they interact with other materials," said Cobas. To do so, NRL researchers developed a recipe to grow large multi-layer graphene films directly on a smooth, crystalline nickel alloy film while retaining that film's magnetic properties, then patterned the film into arrays of cross-bar junctions. "We also wanted to show we could produce these devices with standard industry tools, not just make one device," Cobas added.

The spin filtering phenomenon is due to an interaction of the quantum mechanical properties of graphene with those of a crystalline nickel film. When the nickel and graphene structures align, only electrons with one spin can pass easily from one material to the other, an effect termed spin filtering, that results in spin polarization of an electric current.

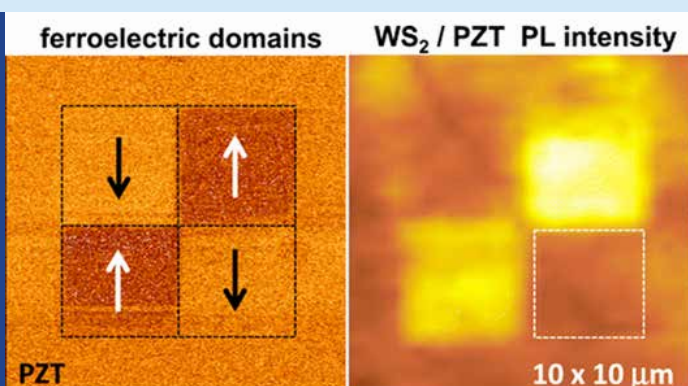
"There is room for improvement as theory suggests the effect can be increased by an order of magnitude by fine-tuning the number of graphene layers," said Dr. Olaf van 't Erve, research scientist, NRL Materials Science and Technology Division. "However, current models do not include the spin-conversion that happens inside the ferromagnetic contacts. Once we account for those effects, we're already close to the ideal case of 100 percent spin polarization in the graphene layer, enabling us to revise our device geometry and materials to maximize the effect."



Conceptual rendering of a spin-filtering graphene junction: Films of nickel (shown in blue) and iron (shown in red) contain a mixture of electrons with up and down spins. A few layers of graphene (shown in grey) lie between the metal layers to create a conductive path for electrons of one spin only, while blocking the other spin. A current driven though the metallic junction (labeled as 'J') becomes spin polarized. (U.S. Naval Research Laboratory)

The result is relevant to next-generation non-volatile magnetic random access memory (MRAM), which uses spin-polarized pulses to flip a magnetic bit from 0 to 1 and vice-versa. It may also find use in future spin logic technologies or as magnetic sensors.

The research results are reported in the November 2, 2016, issue of ACS Nano (DOI 10.1021/acsnano.6b06092). The full research team included Drs. Enrique Cobas, Olaf van 't Erve, Shu-Fan Cheng, Konrad Bussman and Berry Jonker from the Materials Science and Technology Division and Drs. James Culbertson and Glenn Jernigan from the Electronics Science and Technology Division at NRL.



Spatial Control of Photoluminescence at Room Temperature by Ferroelectric Domains in Monolayer WS2/PZT Hybrid Structures
Connie H. Li, Kathleen M. McCreary, and Berend T. Jonker
Materials Science and Technology Division, Naval Research Laboratory Supporting Information

ABSTRACT: Single-monolayer transition metal dichalcogenides exhibit exceptionally strong photoluminescence (PL), dominated by a combination of distinct neutral and charged exciton contributions. We show here that the surface charge associated with ferroelectric domains patterned into a lead zirconium titanate film with an atomic force microscope laterally controls the spatial distribution of neutral and charged exciton populations in an adjacent WS2 monolayer. This is manifested by the intensity and spectral composition of the PL measured in air at room temperature from the areas of WS2 over a ferroelectric domain with a polarization dipole pointed either out of the surface plane or into the surface plane. This approach enables spatial modulation of PL intensity and trion/ neutral exciton populations and fabrication of lateral quantum dot arrays in any geometry, with potential applications in nonvolatile optically addressable memory or optical quantum computation.

See complete article at:
http://pubs.acs.org/journal/acsodf

"THE POTENTIAL APPLICATIONS WOULD CERTAINLY BE LONG-TERM, BECAUSE SO LITTLE IS KNOWN AT THIS POINT, EXPLAINS NRL'S DR. BERRY JONKER. THE EXISTENCE OF THIS NEW QUANTUM PHASE OF MATTER WAS JUST CONFIRMED IN 2008 AND ITS PROPERTIES YET TO BE FULLY UNDERSTOOD, SO IT IS A BIT DIFFICULT TO SPECULATE ON APPLICATIONS. BUT POTENTIAL APPLICATION AREAS INCLUDE RECONFIGURABLE ELECTRONICS, SPINTRONICS AND QUANTUM INFORMATION PROCESSING." DR. BEREND T. JONKER

The Honorable Robert Work, Under Secretary of the Navy, presents the Presidential Rank Award to NRL's Dr. Berend Jonker. (Photo: U.S.Naval Research Laboratory, Jamie Hartman)

In 2011, Dr. Berend Jonker, Senior Scientist for Magnetoelectronics at the Naval Research Laboratory, was the recipient of the Presidential Rank Award for Meritorious Senior Professional, recognizing Dr. Jonker for leading long-term basic research in developing magnetoelectronic materials and technologies, and demonstrating prototype device concepts that offer increased performance for information sensing, processing and storage for supporting the Navy/Marine Corps of tomorrow and the global war on terrorism.

The NRL research team, left to right: Dr. Berend Jonker, Dr. Jeremy Robinson, Dr. Connie Li, and Dr. Olaf van't Erve. (Photo: U.S. Naval Research Laboratory

In 2014, the NRL research team above demonstrated for the first time that one can electrically access the remarkable properties predicted for a topological insulator (TI). This accomplishment identifies a successful electrical approach that provides direct access to the TI surface state spin system, significantly advances our fundamental understanding of this new quantum state, and enables utilization of the remarkable properties these materials offer for future technological applications.

IN DEC, 2016, NAVY RESEARCH LAB COMPLETED THE FIRST FLIGHT OF UAV WITH CUSTOM HYDROGEN FUEL CELL

(Dec, 2016)
Members of the chemistry and tactical electronic warfare divisions from the U.S. Naval Research Laboratory with the Ion Tiger unmanned air vehicle, which recently flew with a new, custom hydrogen fuel cell designed and built at NRL. The fuel cell system is capable of 5,000 watts and is made of formed and laser-welded metal foil bipolar plates, which saves space and weight. "NRL having the know how to build their own fuel cells in house gives the U.S. Navy the understanding and tools needed for transitioning fuel cells to the fleet," said Michele Anderson, program manager at the Office of Naval Research.

ATOMIC FORCE MICROSCOPY (AFM) TECHNICAL ARTICLE

ULTRA-HIGH RESOLUTION ATOMIC FORCE MICROSCOPY

Gerald Pascual, Byong Kim, and Keibock Lee
Technical Marketing, Park Systems Inc., Santa Clara, CA

The goal of all forms of microscopy is to enable the observation of increasingly smaller objects and their details and characteristics which cannot be seen without aid. Naturally, the course of scientific investigation demands that we eventually test the absolute limits of available metrology techniques and Atomic Force Microscopy (AFM) is no exception. AFM has been demonstrated to be capable of generating images with resolutions high enough to visualize sample features measured in fractions of nanometers—such images are often referred to as having achieved a so-called "atomic resolution." However despite this moniker, the resolution of these images is not at a level detailed enough to reveal individual atoms, but rather only the resonance of the spaces between atoms that make up materials with atomically flat surfaces [1, 2, 3], such as graphite or mica. The surfaces of these materials are arranged in uniform lattices with constants that are only several tenths of a nanometer wide and are being scanned with probes which feature tip radius curvatures that are greater in size by an order of magnitude (2-5 nm). A fresh tip detecting the resonance of features smaller than its radius curvature can be compared to an open palm running over the keys on a keyboard. By using tactile feedback one can render a mental image of the approximate layout of the keyboard, but would have great difficulty in making out single keys. Modern AFM systems, including those produced by Park Systems, are capable of producing "atomic resolution" images with features as small as few tenths of an angstrom, but the distinction of imaging by resonance versus imaging solely from the cantilever feedback response must be made. Until probe manufacturing has advanced to a point where tip radius curvatures can be on the order of widths of single atoms, innovations in ultra-high resolution AFM must come from other avenues.

Since the true resolution limit of AFM imaging is dependent on the geometry of the probe tip, logic dictates that to maintain the highest image quality for the longest amount of time consideration must be taken to preserve tips during and across multiple scans. Contact mode, the most basic AFM operation technique, requires the probe to be dragged across the surface of the sample in order to obtain topography data. The nature of this tip-sample engagement makes probe blunting a concern as higher tip radius curvatures result in decreased spatial resolution and therefore less accurate imaging. Increased long-term supply expenses to maintain stocks of contact mode probes are an additional concern for many laboratories. To maintain the highest ultra-high resolution for the longest duration and in the most cost-effective manner, AFM images should be taken in non-contact mode instead. In this operation technique, an oscillating probe's tip's distance from the sample surface during a scan is maintained by a precise, high-speed feedback loop. These state-of-the art electronics, such as those found in NX-series system architecture from Park Systems [4] keep the probe in the non-contact regime of the van der Waals forces between the atoms of its tip and those of the sample. Deviations in the amplitude of the probe's oscillation are recorded as the probe traces over the sample and are then used to create topography images. As the tip and probe do not make direct contact during scanning, tip longevity is dramatically increased with no observable loss in resolution over dozens of scans [5].

Demonstrating the efficacy of non-contact mode for ultra-high resolution AFM imaging requires a challenging sample with features that rival the smallest tip radius curvatures of commercially available AFM probes. To further strengthen the argument for non-contact mode's increased tip longevity across multiple scans, the sample must also be regarded by the research community for its difficulty as a subject for consistent, reproducible nanoscale imaging. Nanomaterials that meet both of these criteria are those that feature moiré patterns. These are secondary and visually evident patterns that are a result of periodic patterns (such as atomic lattices) being placed on top of one another and are then rotated to create a new distinct and offset design. Repeatable high resolution imaging of moiré patterns and the super lattice constants which comprise them present significant challenges if not done with non-contact mode AFM because the resolution that has to be achieved is about the size of the tip radius curvature. Any loss in tip sharpness such as the blunting effect prevalent in contact mode AFM, would introduce an unacceptable handicap to the repeatability of data acquisition. Combating this obstacle to produce any kind of serviceable AFM image and data, let alone one at an ultra-high resolution for the technique, is a tall order even for experienced AFM operators as hardware limitations and constant scan parameter optimization through trial-and-error further complicate the task. Removing any kind of additional disadvantage that increased tip deterioration would pose is a welcome reprieve for this application.

The ultra-high resolution of AFM, together with the advantages of modern system architecture and robust automation software, was demonstrated in a graphene/hexagonal boron nitride (hBN) sample evaluation conducted by Park Systems using a Park NX10 AFM system powered by Park SmartScan operation software. The sample consisted of an hBN substrate overlaid with a graphene layer and was scanned under ambient air. The purpose of the evaluation was to assess the Park NX10's ability to characterize the topography of the moiré pattern that wascreated when one layer was set on top of the other and offset by rotation. Using non-contact AFM mode and a standard AFM probe tip [6], the Park NX10 was able to successfully image the moiré pattern super lattice constant of the sample [7] in scans as large as 500 x 500 nm (see Figure 1a). A second scan (see Figure 1b), this time at 250 x 250 nm, was collected referencing a single isolated sample defect in the upper-left quadrant of the initial 500 x 500 nm scan as a landmark. The super lattice pattern around the defect in the center is now even more visually evident than before.

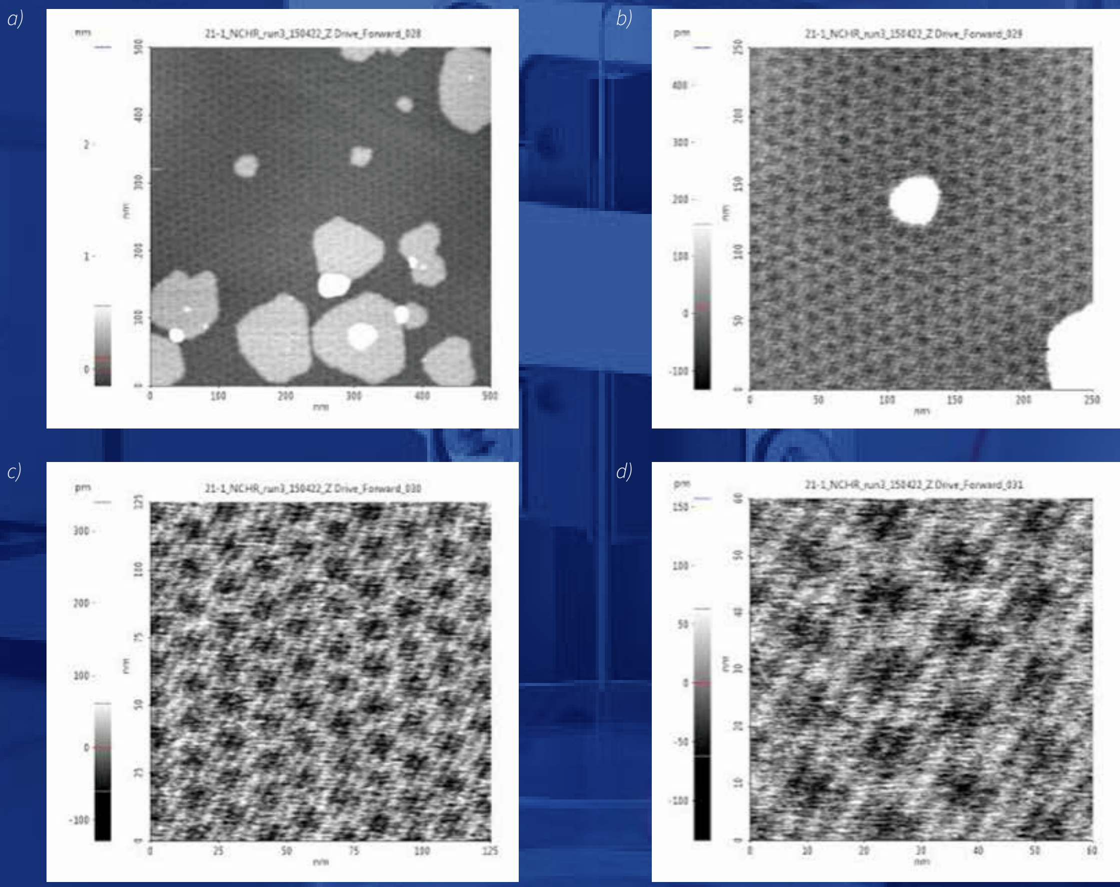


Figure 1.
A series of four non-contact AFM topographical images of a graphene sample exhibiting moiré patterns: (a) at 500 x 500 nm, (b) at 250 x 250 nm, (c) at 125 x 125 nm, and (d) at 60 x 60 nm. All images were taken with a Park NX10 AFM system using the Park SmartScan operating software's Auto mode.

The final two scans in the series serve as the most compelling evidence in demonstrating the Park NX10's ability to maintain its ultra-high resolution even after multiple scans with the same AFM tip. In Figure 1c, the diagonal striations superimposed onto the moiré pattern become evident as they repeat across the surface of the sample. The final image in the series, Figure 1d, was taken at a scan size of 60 x 60 nm and provides the clearest evidence that not only are the super lattice constants of the moiré pattern about 15 nm [7] in width, but that the spacing between each striation on the moiré pattern is roughly 4-5 nm in length.Observations of such striations in graphene/hBN systems have been previously reported [8]. This latter distance is in line with the expected tip radius curvature values for the AFM tip used to acquire all four sets of data. Given the consistency and clarity of the data as the acquired images increase in magnification and the generally accepted difficulty of the sample to characterize with AFM, this achievement is truly remarkable. This accomplishment of resolving five nanometer periodic features is compounded even further when one considers that this data can now be collected by inexperienced researchers guided by the automation software. These demonstrated advantages of non-contact mode for ultra-high resolution AFM imaging can only become more valuable as tip radius curvatures decrease and the effect of tip blunting becomes more pronounced as we characterize smaller and smaller features on our samples.

ACKNOWLEDGEMENT
We are thankful to Patrick Gallagher of Stanford University for providing the graphene/hBN sample used to acquire the images presented in this report.

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ATOMIC FORCE MICROSCOPY (AFM)
TECHNICAL ARTICLE

SCANNING CAPACITANCE MICROSCOPY CHARACTERIZATION

OF VACUUM-CHANNEL NANOELECTRONIC DEVICES

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ABSTRACT

Efforts to harden electronic components and systems using solid-state devices against the effects of radiation and heat for use in space travel have become a major engineering operation for space exploration agencies around the world. Such work has not only been time-consuming, but expensive as well with the majority of deliverable solutions being costlier and technologically older than what is typically available to consumers for other types of application. To address the drawbacks of using solid-state devices in space, research has begun focusing on reviving vacuum tube technology using silicon-based fabrication models as an alternative solution. In this investigation, a newly developed vacuum-channel nanoelectronic device was characterized via scanning capacitance microscopy (SCM) using a Park NX20 atomic force microscopy (AFM) system to assess its viability as a transistor. The representative sample had its source-drain interface examined using a scan area of 450 x 800 nm. The capacitance data acquired reveals the device may be electrically viable as a functional transistor. Its source and drain were each observed to have an average capacitance (represented in units of voltage) of -1.4 μV while the circular dots next to the end of each terminal exhibited an average capacitance of -1.8 μV. The region of the vacuum-channel between the aforementioned dots was observed to have the most positive relative capacitance amongst all features in the scan area with an average recorded value of 2.3 μV.

INTRODUCTION

From their invention at the beginning of the 20th century, vacuum tubes were used as basic electronics components that enabled the proliferation of devices which have had an incalculable impact on human society: television and radio, telephone networks, industrial process controls, and more. However, vacuum tube-based electronics were eventually rendered outmoded by the advent of solid-state devices powered by semiconductor devices. By mid-century, semiconductor devices, with their smaller footprint, greater efficiency, longer longevity, and lower cost, became the de facto wellspring for mass-produced electronics and would eventually grow into the multi-billion dollar industry it is today. However, with humanity now more than a decade into the 21st century, the challenge of expanding our space exploration efforts has revealed that semiconductor devices are vulnerable to the types of radiation that bombard spaceborne equipment. Efforts to harden components and systems have become a major engineering operation for space exploration agencies [1] and other organizations that seek to safeguard their electronic components and systems. Unfortunately, such processes are not only time-consuming but expensive; hardening electronics against radiation and heat lead to solutions that are both costlier and older than what is available to other types of consumers [2].

In order to address these drawbacks and produce a transistor technology that can achieve higher speeds and frequencies than any semiconductor device, research has begun focusing on reviving vacuum tube technology and applying its principles at nanoscale whilst still leveraging a silicon-based fabrication method. The result is a vacuum-channel transistor device which could potentially be manufactured at an industrial scale using already existing silicon fabs for solid-state transistor devices [2]. This investigation uses Scanning Capacitance Microscopy (SCM) to investigate the nanoscale electrical properties of a newly developed vacuum-channel device to both ascertain its viability as a transistor as well as to observe if the method used to fabricate its gate insulators can be controlled.

METHODOLOGY

To acquire data regarding the vacuum-channel device's nanoscale electrical properties, a Park NX20 Atomic Force Microscopy (AFM) system was used to run SCM scans of the device area containing the source-drain interface, vacuum channel, and insulated gates. Supplemental topographical data at the scan area was collected simultaneously through contact mode AFM using the same probe.

SCM with AFM

SCM with AFM is a powerful combination for investigating transistor devices—together, the two methods provide the user with a non-destructive process of characterizing both charge distribution and surface topography with high spatial resolution and sensitivity [3]. In SCM, a metal probe tip and a highly sensitive capacitance sensor augment standard AFM

A Park NX20 system was used to acquire data

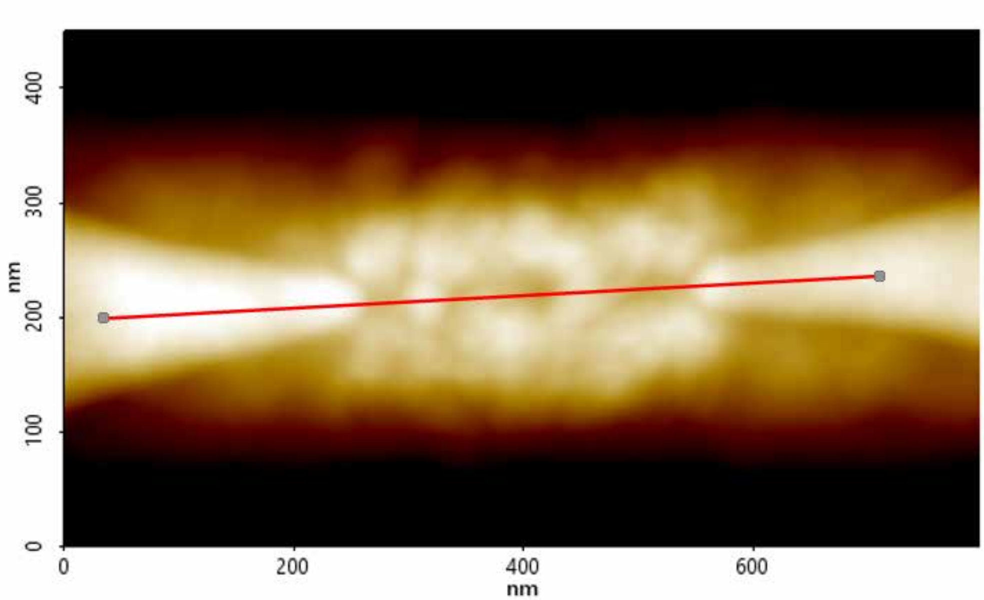

Figure 1.
Contact mode AFM topography image of the vacuum-channel device's source-drain interface. The overlaid red line corresponds to the topography line profile displayed in Figure 2. Scan size: 450 x 800 nm.

hardware. A voltage then is applied between the probe tip and the sample surface creating a pair of capacitors in series (in Metal-Oxide-Semiconductor devices) from (1) the insulating oxide layer on the device surface and (2) the active depletion layer at the interfacial area between the oxide layer and doped silicon. Total capacitance is then determined by the thicknesses of the oxide layer as well as the depletion layer which is influenced by the both how doped the silicon substrate is well as the amount of DC voltage being applied between the tip and device surface.

The principle of how capacitance is measured in vacuum-channel devices via SCM is similar. Again, a thin layer of oxide is used as insulation on the device [4], this time insulating the gate from the source-drain interface on the device surface. A DC voltage is applied between the probe tip and the sample surface as the tip scans across various device features. The data of the detected changes in capacitance are also supplemented by AFM data generated by recording the deflections of the probe's cantilever as the tip engages the device surface [5]. As the sample scan is being completed, a laser beam is reflected off the probe cantilever and onto a position-sensitive photodiode. The deviations of the laser's position are then processed with software to create a rendering of the device's surface topography.

RESULTS AND DISCUSSION

Device Topography

The vacuum-channel device (Device 4) was scanned at an area measuring 450 x 800 nm capturing its source-drain interface. Contact mode AFM reveals that the source and drain terminals are shaped into sharp tips. This design was implemented in order to intensify the electrical field generated at this location [4]. The topography data at this location also reveals the distance between the source and drain tips, a span which includes Device 4's the ends of the source-drain terminals and enclosed vacuum-channel, is approximately 250 nm (Figure 1). For reference, the mean free path of electrons and gas molecules under normal atmospheric pressure is about 200 nm [2]. If the voltages running through the device were kept low enough, the electrons traversing from source to drain would not have energy to ionize any lingering gas molecules left in the channel [4]. Therefore, Device 4 could technically operate without incident under normal air pressure—the presence of a vacuum in the channel serves as an extra precaution to guard against ionized molecules from damaging the terminals of the source-drain interface. Inspection of the topography line profile (Figure 2) for this image reveals the distance from the tallest peaks to the lowest valleys in this vacuum-channel are in excess of 5 nm. Of further interest are two bumps, speculated to be the device's quantum dots, which represent the peak heights in the vacuum-channel and stand on either end of the span in close proximity to the end of each terminal.

Device Capacitance with Topography

SCM data from was also gathered from the same 450 x 800 nm scan discussed above. This image (Figure 3) shows each of Device 4's source-drain terminals being darker in color, or more negatively charged, than other portions of the device. Note the difference in color of the terminals and nearby suspected quantum dots—these features are both more negatively charged than the rest of the imaged area. This is corroborated by the capacitance line profile (Figure 2) which shows an average capacitance (represented in units of voltage) of about -1.4μV in areas corresponding to the device's source and drain terminals. Of further significant note is the even slightly more negative -1.8 μVvalues recorded in areas corresponding to the quantum dots adjacent to the ends of each terminal.

Another important feature clearly seen in the capacitance image is the portion of Device 4's vacuum-channel between each of the quantum dots. This area shows a brighter, more positively charged region with capacitance values as high as 2 μV being detected. This particular region, approximately 175 nm in length, cannot be easily identified in the topography image but is easily spotted with the greater contrast provided in the SCM image. The capacitance change from the suspected quantum dots standing adjacent to each source-drain terminal to the middle of the vacuum-channel is observed to be 3.8μV, the greatest change observed along the selected line profile.

CONCLUSION

SCM together with AFM successfully characterized both the spatial variations in capacitance as well as the topography of a newly developedvacuum-channel nanodevice. By examining the line profiles of the topography and capacitance data acquired down an identical path on the device's source-drain interface, additional insight was gained into the relationship ofkey physical structures with changes in capacitance. The device's topography at its source-drain interface was imaged and revealed a vacuum-channel spanning 250 nm in length with peaks and valleys separated by a distance of approximately 5 nm. The electrical functionality of the device was assessed through the acquisition of a capacitance map. This map revealed a relatively negatively charged (-1.4 to -1.8μV) source-drain terminal and adjacent quantum dot followed by a relatively positively charged vacuum-channel (2μV) and another dot-terminalstructure (-1.4 to -1.8μV) on the other end of the source-drain interface. This alternating series of capacitance changes at these key structures suggest the device is capable of effective functionality as a transistor.

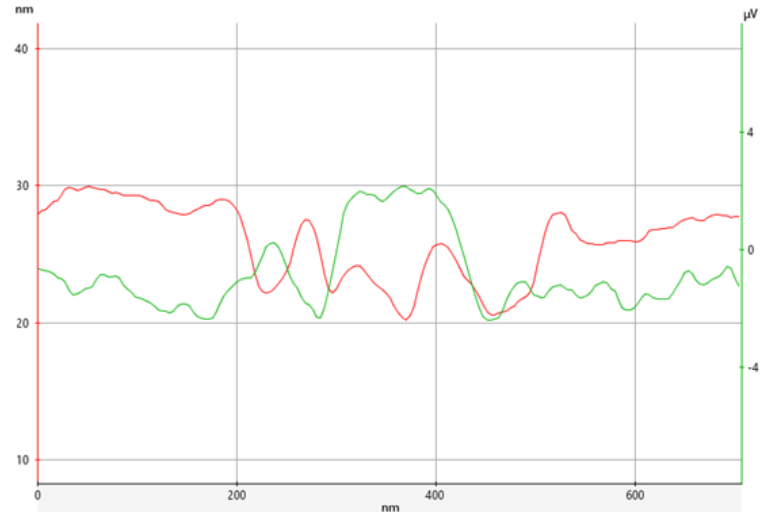

Figure 2.
Line profiles of the AFM topography (red, left y-axis in nm) and the capacitance data (green, right y-axis in μV) of the device area scanned in Figures 1 and 3.

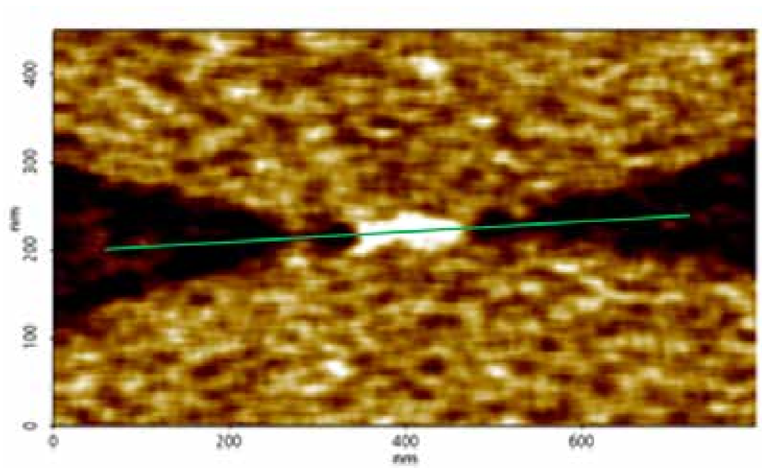

Figure 3.
An SCM capacitance image of the region containing the device's source-drain interface. Brighter colors correspond to relatively more positively charged areas on the device whereas darker colors correspond to relatively more negatively charged areas. The overlaid green line corresponds to the capacitance line profile displayed in Figure 2. Scan size: 450 x 800 nm.

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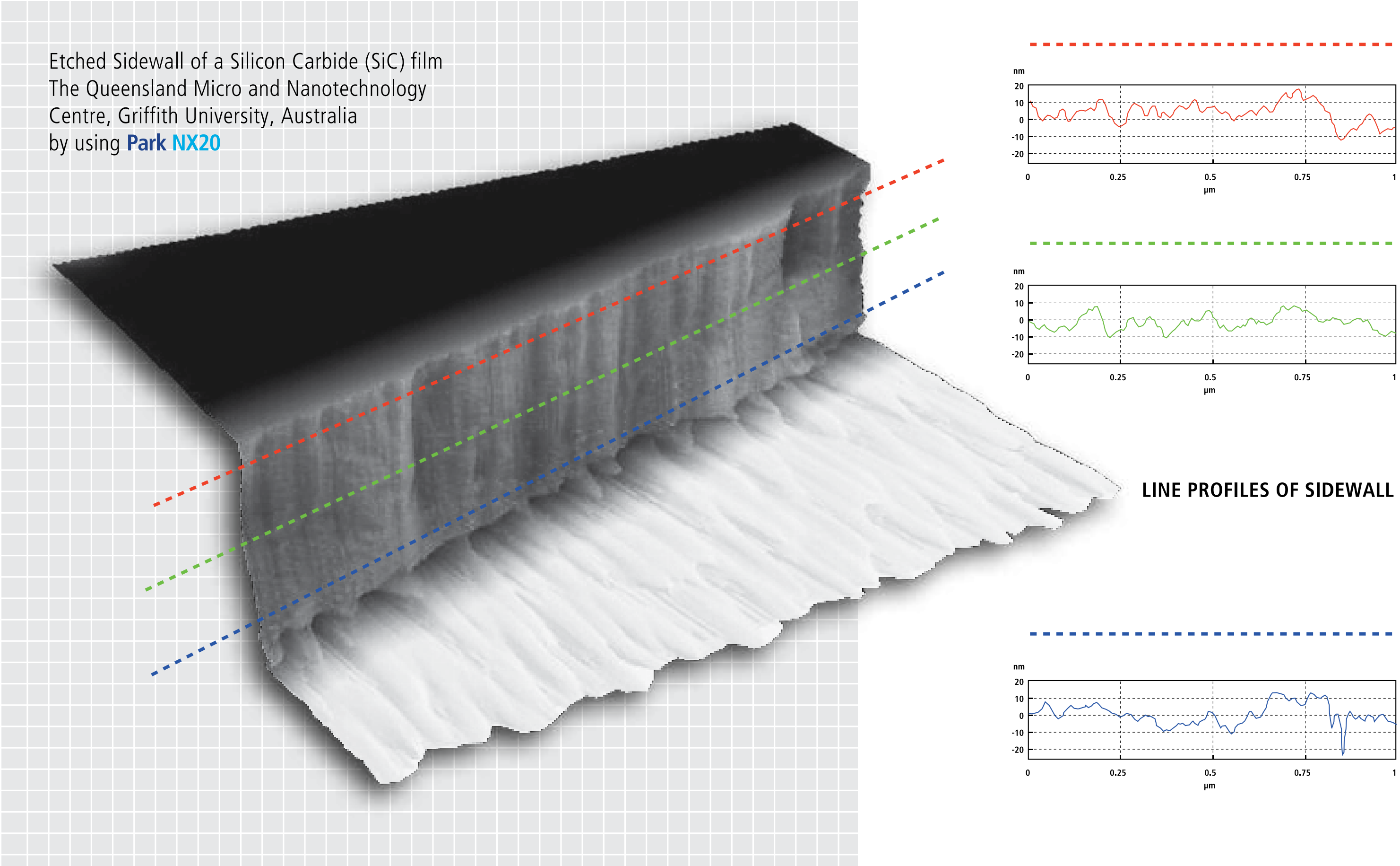
KEYWORDS
AFM, atomic force microscopy, capacitance, characterization, scanning capacitance microscopy, SCM, semiconductor, silicon, topography, transistor, vacuum, vacuum-channel



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Park Systems demonstrates SmartScan, Park NX10 SICM System—a tool designed to enable innovative studies in electrochemistry, Scanning Ion Conductance Microscopy (SICM) technology and other unique features of Park Atomic Force Microscopes to students at a Park AFM Demo at Tiernan Hall and the Otto H. York Center for Environmental Engineering and Science at the New Jersey Institute of Technology. The patented SmartScan™ operating system has revolutionized the transfer of data to a simple point-and-click system, not dependent on user experience. With new SmartScan™ on Park AFM, researchers can rely on the accuracy of the data and focus on their research

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