NEURO MORPHIC COMPUTING - HOW MATERIALS AND DEVICES WITH “BRAIN LIKE” ARCHITECTURE ARE REVOLUTIONIZING COMPUTING - AN INTERVIEW WITH DR. ALAIN DIEBOLD

CALL FOR PAPERS: 2018 NANOSCIENTIFIC SYMPOSIUM ON SPM AT SUNY POLYTECH

USING PINPOINT™ PIEZOELECTRIC FORCE MICROSCOPY

ELECTRICAL CONDUCTIVITY MEASUREMENT OF CARBON NANOTUBES FILM USING CONDUCTIVE PROBE ATOMIC FORCE MICROSCOPY (CP-AFM)

TRANSFORMING TECHNOLOGY AND MANUFACTURING IN THE AGE OF 3-D PRINTING

60 GRAMS FROM ASTEROID BENNU MAY REVEAL THE HISTORY OF OUR SOLAR SYSTEM - AN INTERVIEW WITH DR. MICHAEL DALY
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Feature Article: 60 Grams from Asteroid Bennu May Reveal the History of our Solar System – an interview with Dr. Alain Diebold, Associate Professor of Planetary Science, and Dr. Gerald Pascual, Associate Professor of Nanoscience and Nanotechnology. The publication is offered free to anyone who works in the field of nanotechnology, nanoscience, microscience, and related fields of study and manufacturing.

We would enjoy hearing from you, the reader! Send comments or story ideas to debbie@nanoscientific.org.

Inquiries about advertising in NanoScientific, please contact Gerald Pascual, gerald@nanoscientific.org.

First Test of Graphene in Space-like Applications

Working with Graphene Flagship and European Space Agency, researchers from the Cambridge Graphene Center tested graphene in microgravity conditions for the first time. Using graphene in loop heat pipes, pumps that move fluid without the need for mechanical parts, a metallic wax was coated in graphene improving efficiency of the heat pipe. Graphene’s excellent thermal properties improve the heat transfer from the hot systems into the wick and the porous structure of the graphene coating increases the interaction of the wick with the fluid, and improves the capillary pressure, meaning the liquid can flow through the wick faster. Other experiments researchers looked at use of the material for the improvement of space propulsion or solar sails for fuel-free spacecraft (pictured above) and thermal management systems. The Graphene Flagship, launched by the European Union in 2018 as its largest research initiative ever. With a budget of €1 billion, their overall goal is to take graphene from the realm of academic laboratories into European society. www.graphene-flagship.eu

Greetings!

We are excited to bring you our Spring 2018 edition of NanoScientific with a tremendous display of how Nanotechnology is quickly advancing science into new realms. Dr. Ennio Capria, Deputy Head of Business Development, RT Nanoelectronics states in his welcome message for the 21st International Conference on Advanced Nanoscience and Nanotechnology to be held in London in June. “Nanoscience is a new discipline: although it advances more than a century, it is still very much uncharted.”

In this issue we unveil one of the most exciting developments in semiconductors, the age of neuromorphic chips that mimic human neuro-biological architectures present in the human nervous system. With the ability to learn on the fly and process the extreme amounts of data needed to create the “implanted memory” for human-like machine brains, these chips revolutionize what we know as computer technology. Major companies like IBM have defined cognitive computing as their main business for the future and Intel Labs has developed a neuromorphic research chip, code-named “Loihi”, that mimics the functioning of neurons and synapses in the brain.

Neuromorphic technology can be used in a wide range of consumer and business products, from driverless cars to domestic robots. In this issue, Dr. Alan Diebold from SUNY Polytechnic Institute gives us an overview of the latest semiconductor revolution and how SUNY is conducting cutting edge research on the material design architecture.

We also present an article on NASA’s project OSIRIS-REx – the first-ever sampling mission by NASA to the distant asteroid Bennu. This mission will give us a glimpse into the formation of our solar system and important discoveries about asteroids, one of the hottest topics in space. NASA is also moving forward with a plan to develop a refrigerator-sized spacecraft capable of deflecting asteroids and preventing them from colliding with Earth and companies like Atın Engineering aim to be first with ideas that could shape the future of asteroid mining.

This issue also talks about another revolution poised to explode in the near term, 3D printing, already transforming industries and becoming 50 percent cheaper and up to 40 percent faster, it could reach $49 billion as soon as 2025 and already well underway. For example, 3D printed food is already a reality on Earth and in space. Beehex, an American startup, has received a grant from NASA to develop a food 3D printer to allow astronauts to produce their own food during long-term space missions in order to go to Mars.

As always, we feature technical application notes in this issue that highlight new technologies in Nanotechnology, the nanoscale imaging that enables scientists to visualize at the atomic scale. In this issue, we showcase Electrical Conductivity Measurements of Carbon Nanotubes and PinPoint Piezoelectric Force Microscopy. To continue collaboration on the new nanotech innovations worldwide, NanoScientific is hosting NanoScientific Symposiums which will feature leading academic and industry presentations and an opportunity to present your research and network with industry leaders. The first NanoScientific Symposium on SPM is Sept 19-20 at SUNY Polytechnic Institute and the second will be hosted by Technical University Freiberg October 10-12. We encourage you to submit an abstract to present at the NanoScientific Symposiums and share your amazing Nanoscience discoveries!

For details on these two events go to www.parksystems.com/2018spm for the US and www.parksystems.com/nsfe2018 for Europe.

We would enjoy hearing from you, our readers. Send your research or story ideas to Debbie at Debbie@nanoscientific.org and let us know if you are interested in sponsoring or attending our NanoScientific Symposiums. You can also visit our new website at www.nanoscientific.org. We hope you enjoy this issue.

Keibock Lee
Editor-in-Chief

INSET PHOTO ON COVER:
This image shows a 3D overlay of a piezoelectric response map, topographical data acquired using PinPoint piezoelectric Force Microscopy (PFM) from an annealed graphene thin film on top of an ITO surface. This material has been a challenging sample to get quality topographical and piezoelectric response data from using conventional SPM methods. The main difficulty is due to the rod shaped nanostructures on the sample surface being very susceptible to distortion by a scanning probe’s tip. The invention of Park’s latest PinPoint PFM technique gives researchers both a friction-less imaging technology that overcomes this difficulty and the means to achieve publication-ready image quality in much less time than previously possible with older methods. In this example, not only can we see well-resolved, individual rod-shaped graphene nanostructures, but also differences in electrical polarization expressed as differences in contrast (bright areas showing a positive polarization and darker areas a negative polarization).

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2018 NanoScientific Symposium
Scanning Probe Microscopy

September 19-20, 2018 • SUNY Polytechnic Institute, Albany, NY

CALL FOR PAPERS

THE NANOSCIENTIFIC JOURNAL ANNOUNCES ITS CALL FOR PAPERS FOR THE 2018 NANOSCIENTIFIC SYMPOSIUM ON SCANNING PROBE MICROSCOPY AT SUNY POLYTECHNIC INSTITUTE

Abstract Submission Deadline — June 15, 2018

Park Systems and NanoScientific Publications are proud to announce the 2018 NANOSCIENTIFIC SYMPOSIUM ON SCANNING PROBE MICROSCOPY (SPM)

A new venue for nanoscience researchers, scientists, and engineers to learn about the latest studies being formed using SPM. Keynote speakers from both academia and industry will be on hand to talk about the current cutting-edge work being performed in their laboratories and discuss the headway they have made with SPM in some of the hottest fields and topics in nanoscience today.

Do not miss your chance to join this great opportunity to learn and network with some of the best and brightest in materials characterization!

The first day, Wednesday, September 19, will be composed of keynote speakers and presenters on a variety of topics including the following:

- 2D and other nanomaterials
- Polymers and composites
- Electronics, magnetics, and photonics
- Sustainable energy applications
- Semiconductor and MEMS process and fabrication
- Analytical chemistry
- Biology, biomedicine, and other life sciences

The evening networking event will include cocktails and hors d’oeuvres.

The second day, Thursday, September 20, will focus on hands-on programming: A theory and practical class on AFM with access to live systems at the Park Nanoscience Center at SUNY Polytechnic Institute.

“As SUNY Polytechnic Institute provides cutting-edge educational and research and development opportunities, it is exciting that Park Systems established operations at our Albany campus,” said Dr. Alain Diebold, SUNY Poly Interim Dean of the College of Nanoscale Sciences; Empire Innovation Professor of Nanoscale Science; and Executive Director, Center for Nanoscale Metrology. “Our scientists and engineers look forward to working closely with Park Systems to enhance improved metrology capabilities for researchers and members of industry around the world.”


2018 NanoScientific Forum Europe
Scanning Probe Microscopy (SPM)

TU Bergakademie Freiberg (TU Freiberg), Institute of Mechanical Process Engineering and Mineral Processing host of the 1st NanoScientific Forum Europe 2018 (NSFE 2018) will give a special session during the scientific program on nanobubbles, which is a part of the flagship project of TU Freiberg and Helmholtz Institute Freiberg for Resource Technology. The special session on nanobubbles will cover the influence of nanobubbles in engineering processes like melt filtration (CRC 920, a flagship project of TU Freiberg) and flotation (SPP2045, TU Freiberg and Helmholtz Institute Freiberg for Resource Technology).

This 2 Day Event will include lectures by renowned AFM researchers, Instrument workshops on Park Systems AFMs, including basic and advanced measuring techniques as well as tips and tricks, how to obtain stunning AFM data.

Wednesday Evening: Fusing Science & People - Conference Gala Dinner
Thursday Evening: Discovering Natural Treasures - Terra Mineralia Tour & Party


NANOScientific Publications announces the 2018 NANOSCIENTIFIC SYMPOSIUMS ON SCANNING PROBE MICROSCOPY (SPM) new venues for nanoscience researchers, scientists, and engineers to learn about the latest studies being formed using SPM. Keynote speakers from both academia and industry will talk about cutting-edge work being performed in their laboratories and the hottest topics in nanoscience today - sponsored by NanoScientific and Park Systems. Poster and Oral Presentation Opportunities, submit your abstract today.

NanoScientific Symposium on SPM in Europe – Oct. 10-12, 2018 at Freiberg University
www.parksystems.com/nsfe2018

NanoScientific Symposium on SPM in US – Sept 19-20 at SUNY Polytechnic Institute
www.parksystems.com/2018spm
NEURO MORPHIC COMPUTING – HOW MATERIALS AND DEVICES WITH “BRAIN LIKE” ARCHITECTURE ARE REVOLUTIONIZING COMPUTING-

AN INTERVIEW WITH DR. ALAIN DIEBOLD INTERIM DEAN AT THE COLLEGE OF NANOSCALE SCIENCE AT SUNY POLYTECHNIC INSTITUTE AND NATHANIEL CADY, PHD, ASSOCIATE PROFESSOR OF NANOBIOSCIENCE SUNY POLYTECHNIC INSTITUTE

Dr. Alain Diebold is Interim Dean at the College of Nanoscale Science at SUNY Polytechnic Institute, Empire Innovation Professor of Nanoscale Sciences, and Executive Director, Center for Nanoscale Metrology. Dr. Diebold earned his BS in Chemistry from Indiana University-Purdue University, and holds the PhD in Statistical Mechanics of Gas-Solid Surface Scattering earned at Purdue University. He is Associate Editor of the IEEE Transactions on Semiconductor Manufacturing as well as the Metrology Section of Future Fab International. A frequent presenter at international conferences, Dr. Diebold has been named a Fellow of both the American Vacuum Society (AVS) and the American Physical Society (APS). He is recognized industry-wide as a leader in nanotechnology and Characterization for Nanoelectronics. He is recognized industry-wide as a leader in cutting edge research on advanced metrology methods to improve nanoelectronics. Dr. Diebold has published close to a hundred research papers and made over 40 presentations world wide. He has established a long career in nanometrology and nanoscale semiconductors and has done continuous work for decades with industry to collaborate on the development of new methods and technology. His books include Handbook of Silicon Semiconductormetry. He is co-editor of Frontiers of Metrology and Characterization for Nanoelectronics, Characterization and Metrology for ULSI Technology, Semiconductor Characterization: Present Status and Future Needs, Analytical and Diagnostic Techniques for Semiconductor Materials, Devices, and Processes.

Neuro Morphic Computing – How Materials and Devices with “brain like” Architecture are Revolutionizing Computing

Nanometrology Advances and Challenges

When asked what the latest in new designs for more complex device structures and advanced new materials is, Dr. Diebold explains that Nanowire type transistors fabricated from multi-layer thins are emerging as the new technology. In the past, FinFETs, which have attracted enormous attention due to their superior electronic properties, can also be used in photonic systems to achieve desired linear and nonlinear optical functionalities.

But more recently multi-layer Silicon Nanowire and Silicon Nanosheets with gates all around the transistors and a lot of 3D structure at being researched. “It is very difficult to do the metrology,” explains Dr. Diebold. “And it is hard to predict when or if this will be commercialized.” There are metrology challenges with Nanowires that are the Dielectric gate, spaces, and wires. There are advances in all of the typical nanometrology tools especially TEM. One of the key factors in today’s nanometrology research is automated TEM analysis dual column; it is becoming more prevalent as a critical new advancement due to much higher throughput characterization. One of the most significant future trends in the semiconductor industry as Dr. Diebold looks into the future are automated TEM analysis that feed into hybrid metrology. “The goal of Hybrid Metrology is to use the measurement information from multiple methods to improve 3D determination of feature shape and dimensions,” explains Dr. Alain Diebold. AFM enables the determination of surface and sidewall roughness and feature line shape and is often used in conjunction with TEM, CD-SEM, and Scatterometry in Hybrid Metrology.

The von Neumann architecture is replaced with neuro morphic architecture

The semiconductor industry is definitely going in a new direction explains Dr. Diebold. He does not see the future of silicon chips continuing to scale the way they have for the last twenty years. “Silicon chips for the future are going to be more functional, computing like the brain,” he explains. “Neuro Morphic computing is a new way of computing with different architecture to act neuromorphic.”

At SUNY, research on neuro morphic computing is well underway. In Jan of 2016, Dr. Nathaniel Cady at Associate Professor of Nanobioscience at SUNY Polytechnic Institute was awarded $1.2 million from the Air Force Research Lab as part of a $4.4 million grant in collaboration with the University of Tennessee, Knoxville enabling the fabrication and testing of a dynamic, adaptive neural network based on memristors, cutting edge technology which could one day lead to faster, more energy efficient and powerful computer capabilities.

The extra computing power of neuromorphic computing comes at a time when industry has hit a limit and won’t be able to continue to make the leaps in speed and density they did over the past decades. “Neuro computing augments the chip by building unique hardware that adds functionality,” explains Cady.

The neuromorphic computing market is poised to grow rapidly over the next decade to reach approximately $1.78 billion by 2025. For the Air Force grant, they are creating unique, non-standard materials for neuromorphic systems. Professor Cady said that he does not characterize what they are doing as AI (artificial intelligence). “The end game is to create a whole brain, by starting with a small set of neurons,” said Cady.

“WE ARE DEVELOPING A NEW FORMAT OF NEUROMORPHIC HARDWARE, LEVERAGING UNIQUE PIECES OF HARDWARE TO BUILD A HYBRID SYSTEM,” SAID DR. CADY. “THEY ARE LIKE ELECTRONIC DEVICES THAT MIMIC SYNAPSES IN THE BRAIN.”

Dr. Diebold’s group has continuously been at the cutting-edge of nanometrology since its inception. Other research interests include materials characterization, metrology and materials science at the nanoscale, and semiconductor metrology. The group is also investigating the impact of substrate interactions on the complex refractive index of graphene. Another research area is the imaging and characterization of nano-scale structures using electron microscopy. Simulation of transmission electron microscopy (TEM) and scanning TEM (STEM) imaging is more important than ever as aberration corrected microscopes are introduced.
Abstract
Electrical conductivity measurement is an effective approach to describe how a material behaves for certain applications, ranging from energy storage and energy conversion devices, to interconnections in molecular electronics and nanometer-sized semiconductor devices. A technique known as Conductive Probe Atomic Force Microscopy (CP-AFM) is a powerful technique that provides accurate nanoscale measurement and mapping of relative difference in electrical conductivity of advanced materials such as CNTs film. Several characterization techniques were introduced in the past decade to study these materials, however, the majority of these can only measure a limited electrical properties range. In this study, PARK NX20 equipped with CP-AFM was used to investigate 3 different materials with a wide range of electrical conductivity. The data acquired in this experiment clearly demonstrates the ability of this technique in measuring a wide range of electrical conductivity and differentiating surfaces of materials covered with various types of conductive materials, with the use of a logarithmic current amplifier integrated in the system.

Introduction
Carbon Nanotubes (CNTs) have attracted a great deal of scientific attention and industrial interest worldwide due to its unique electrical behavior [1, 2]. A number of different applications ranging from energy storage and energy conversion devices, to interconnections in molecular electronics and nanometer-sized semiconductor devices were demonstrated over the past decade [3, 4]. CNTs can behave as metallic or semi-conducting materials depending on the arrangement of their atoms, their chirality (degree of twist), as well as their sizes (diameter and length) [1, 2]. The electrical conductivity of CNTs plays a major role in describing its behavior and its implication to science and electronics. Therefore, it’s critically important to utilize a technique that can effectively measure the electrical conductive properties of these new materials. However, due to their fragile characteristics and nano-scale dimensions, measuring their local properties have become a great challenge to many researchers and device engineers [5, 6]. There are several methods that were introduced to characterize these materials, and the most common are scanning tunneling microscopy (STM), transmission electron microscopy (TEM) and focused ion beams (FIBs). [5, 7, 8] However, some of these techniques are destructive, some have a limited measurement and property characterization modes, others require high vacuum environment. One of the most powerful tools that was designed to overcome these problems is Conductive Probe Atomic Force Microscopy (CP-AFM). This technique provides both electrical properties and topography at the same time, first by monitoring the current flowing between the conductive tip and sample, and the latter by monitoring the cantilever deflection as the tip scans over the sample surface.

In this study, Park NX20 equipped with CP-AFM was used to investigate 3 different materials namely: 1) glass, 2) silver and 3) CNTs film. The results acquired in this experiment clearly demonstrate the ability of this technique to accurately measure a wide range of electrical conductivity of advanced materials such as CNTs film. In addition, this technique can be used effectively to differentiate regions covered with various types of conductive materials.

Experimental
Sample and Probe
The sample that was investigated in this experiment is a CNTs film made of soot of carbon nanotubes that were deposited on a glass substrate to form a thin film layer. Subsequently, an Ag electrode is patterned into the surface to make an electrical contact. A conductive diamond coated probe (NANSENSORS® CDT-CX159) with a nominal force constant of k = 0.5 N/m and resonance frequency of f = 20 kHz was utilized in the entire experiment.

CP-AFM Experimental Conditions
The CNT film sample was investigated using Park NX20-AFM instrument under ambient air conditions to perform a 45 x 45 µm scan outputting to an image size of 256 x 256 pixels. Figure 1 shows the principles of CP-AFM. The topography and electrical properties of the sample can be acquired simultaneously during operation. The topography data is acquired by monitoring the deflection signal of the cantilever as the conductive tip scans the sample surface in contact. On the other hand, electric conductivity is measured by monitoring the electrical current passing through the conductive probe and sample, produced by applying a bias voltage in between the two. The electrical conductivity is calculated through an electric current amplifier. In this experiment, the bias voltage that was used is positive 0.3V, since the optimum current distribution was observed using this value. Generally, the current flow is acquired by a current amplifier and then processed into an image. The Park NX20-AFM is equipped with internal current amplifier with variable gain of 106~1012 V/A though the current range of experimental data distribution was observed using this value. Generally, the current flow is acquired by a current amplifier and then processed into an image. The Park NX20-AFM is equipped with internal current amplifier with variable gain of 106~1012 V/A. However, the current range of experimental data distribution was observed using this value. Generally, the current flow is acquired by a current amplifier and then processed into an image. The Park NX20-AFM is equipped with internal current amplifier with variable gain of 106~1012 V/A, however, since the sample consists of different materials with wide range of electrical conductivity from nearly non-conducting 0 μA to relatively well conducting 23.18 μA, a logarithmic amplifier adaptable to this range was utilized in the experiment.

Result and Discussion
The acquired images were analyzed using XEI software developed by Park Systems, which mapped the acquired signals to a color table. For topography image, the intensity of the shading correlates to the surface height variation with extremely bright and dark areas having the highest and lowest height regions. Figure 2 shows the topography and current image of the CNTs film sample. The topography data clearly shows that the 45 um by 45um scanned surface of the sample is composed of areas with various heights which can be divided into 3 regions. It can be observed that the region with the lowest height has a relatively smooth surface, suggesting that this region is glass substrate. On the other hand, the other two regions have relatively rough surface, suggesting that these regions are the CNTs and Ag materials. To confirm this, the surface roughness of each regions were calculated using XEI software. The measured surface roughness of the glass substrate was approximately 1.46 nm, while the other two regions have around 14.25 and 14.71 nm. Since the CNTs and Ag has almost the same features, differentiating these two materials will be difficult by simply looking at the topography data.

The current image clearly differentiates the material composition of the sample and it also shows that the surfaces of the sample is divided into 3 regions. The areas with highest conductivity are represented by the red color map, while areas with lower conductivity are represented by the green color map, and for the areas that are non-conductive are represented by brown color map. Among the 3 materials composition of the CNTs film, Ag has the highest conductivity, while CNT has 2nd to the highest, and the glass has the lowest conductivity. [9]

If one were to analyze the corresponding line profile of topography and current image, the region with the highest height in the topography image is the region with the highest conductivity in the current image which is known to be the Ag materials, while the region with 2nd to the highest height and conductivity is the CNTs film, and the lowest is the glass substrate. The quantitative results of conductivity in terms of measured current values are shown in Table 2. The average measured conductivity of Ag is approximately 23.56 μA, while for CNT it is 0.98 μA, and for glass is 0.0 μA. The results were plotted in Figure 3 to better analyze the data. The standard deviations of the electrical conductivity results were also calculated. The glass sample has the lowest standard deviation with Std = 0.9, while Ag sample has the highest standard deviation with Std = 8.
Table 2. Measured mean and standard deviation (Std) of current.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Current (µA)</th>
<th>Std (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CNT</td>
<td>0.98</td>
<td>0.94</td>
</tr>
<tr>
<td>Ag</td>
<td>23.56</td>
<td>8</td>
</tr>
</tbody>
</table>

Summary

The topography and electrical conductivity of a CNTs film have been characterized using CP-4FM with a Park N200 AFM system. The data collected in this experiment reveals that this technique can provide qualitative and quantitative information for electrical characterization of advanced materials. Moreover, the results demonstrate that this technique is an effective mean in measuring wide range of electrical conductivity and differentiating surfaces of materials covered with various types of conductive materials, with the use of a logarithmic current amplifier integrated in the system. Overall, the technique described in this study will successfully help researchers and device engineers with key electrical parameters information to better understand the behavior of certain material with unique properties such as CNTs.

Reference

1. J. Xu, Experimental Study of Electrical Conductivity of Carbon Nanotube, Nonfiber Buckypapers and Their Composites.
4. J. Maklin, ELECTRICAL AND THERMAL APPLICATIONS OF CARBON NANOTUBE FILMS
7. T. K. Lee, Failure analysis and the innovative PinPoint™ conductive AFM
9. A. Helmanstine, Table of Electrical Resistivity and Conductivity.

## 60 Grams from Asteroid Bennu May Reveal the History of our Solar System

As of this week, OSIRIS-REx has travelled over 1.5 billion km since its launch in Sept. 2016. It is currently 47.7 million km from Earth and has a little over .5 billion km left to travel until it reaches the asteroid Bennu.

**"The 60 Grams of Primitive Material We Collect from Bennu Can Give Us Chemical Indicators of Life on Other Worlds"**

Dr. Daly, who leads the science contribution of Canada’s OSIRIS-REx Laser Altimeter (OLA) to the NASA New Frontiers mission that was launched in September 2016 toward asteroid 101955 Bennu - the first B type asteroid to be visited by a spacecraft.

Professor Michael Daly is the York University Research Chair in Planetary Science. He recently received the honor from the International Astronautical Union of having the asteroid 1999 UV36 renamed as (129978) Michaelidaly. He was also the Canadian Aeronautics and Space Institute’s 2016 William R. P. Collins Memorial Award winner. Dr. Daly was also the Canadian Aeronautics and Space Institute’s 2016 W. Rupert Turnbull lecturer who is selected for his/her association with some significant achievement in the scientific or engineering fields of aeronautics, space-associated technologies or their application. This honor recognized Dr. Daly’s contribution to Canadian planetary science mission contributions.

Dr. Daly is currently leading the science contribution of Canada’s OSIRIS-REx Laser Altimeter (OLA) to the NASA New Frontiers mission that was launched in September 2016 toward asteroid 101955 Bennu — the first B type asteroid to be visited by a spacecraft. A scanning laser altimeter, the OLA instrument will measure the range between the OSIRIS-REx spacecraft and the surface of Bennu, to produce digital terrain maps of unprecedented spatial scales for a planetary mission. He also works in the area of deep-UV Raman spectroscopy as well as time-resolved laser-induced fluorescence. He is the PI for a new $3.5M Canadian planetary science laboratory focused on the simulation and understanding of planetary surface processes as well as developing instrumentation and improving analysis techniques for planetary science in-situ investigations. Initial investigations will focus on Mars, asteroids, and comets.

He is also the Undergraduate Program Director for York’s unique Space Engineering and Space Science Programs and has been the acting director for the Centre for Research in Earth and Space Science. Prior to joining York University, he initiated and led the engineering of Canada’s first instruments to operate on Mars. These were a two-wavelength atmospheric lidar that observed snowfall on Mars, as well as a temperature and pressure measurement instrument. Dr. Daly has also been the engineering lead for a variety of space-flight cameras including the design of the cameras in the DEXTER robot’s end-effectors aboard the International Space Station. He was awarded a Tier 2 York Research Chair in Planetary Science which enabled his participation in NASA’s OSIRIS-REx mission to the near-Earth asteroid Bennu and the return of Canada’s first sample of material from another solar system.

60 Grams from Asteroid Bennu May Reveal the History of our Solar System

The asteroid Bennu, OSIRIS-REx — the first-ever sampling mission by NASA to the distant asteroid E — was successfully launched into space on Sept. 8, 2016 from Cape Canaveral Air Force Station in Florida. The mission will revolutionize our understanding of asteroids.

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**Figure 2.** Topography (top-left) and current image (top-right) acquired from CNTs film sample. Scan size: 45 x 45 µm, image size: 256 x 256 pixels, and line a) and b.) Current image acquired from the CNTs film sample. Topography line profile (red line, y-axis on left) and current line profile (green, y-axis on right).

**Figure 3.** Potted view of measured mean standard deviation of current.

**Figure 2.** Topography (top-left) and current image (top-right) acquired from CNTs film sample. Scan size: 45 x 45 µm, image size: 256 x 256 pixels, and line a) and b.) Current image acquired from the CNTs film sample. Topography line profile (red line, y-axis on left) and current line profile (green, y-axis on right).
Lidar works very similarly to radars, but uses light instead of radio waves. A lidar system is comprised of sending short laser pulses that reflect from a target and are subsequently detected by an internal detector. Very precisely measuring the return transit time of the laser pulse, it can calculate the distance to the target. Repeating these measurements over numerous locations on the asteroid’s surface allows the user to build up a 3D model.

To do so, OLA will rely on its two separate transmitters. The High Energy Laser Transmitter (HELIT) will be used to scan from distances 1.5 km from the asteroid’s surface, and the Low Energy Laser Transmitter (LELT) will provide rapid measurements at shorter ranges (225m to 1 km).

What kind of topographical data will it be able to provide?

OLA data will be used to create a global shape model at a resolution of approximately one point every 7 cm. Given that Bennu is approximately 500m in diameter, this translates to over 150 million individual topography measurements covering the asteroid’s surface.

The global shape model will be used to understand the current state and evolution of the asteroid as well as to provide contextual information for the mission’s scientists to interpret geological data collected by other instruments on board the spacecraft, and also to help select candidate locations to retrieve the sample. As the spacecraft gets closer to Bennu to further investigate these candidate sampling sites, OLA will be used to produce even higher resolution maps with topography measurements spaced less than 5 cm apart.

Is the OLA used on any other space or earth based missions?

OLA, itself, is a unique instrument. However, its concept has been drawn from previous terrestrial and space examples. Among others, airborne lidar systems are widely used on Earth for geological, archeological, agricultural, and ecological applications. Moreover, they can be adapted for use in vision systems for purposes such as robotic mining vehicles.

The OLA system is based on MDX’s heritage design of a scanning lidar system flown on the US Air Force Research Laboratory’s XSS-11 mission. The system was augmented utilizing heritage derived from NASA’s Phoenix Mars Lander mission, where a version of the HELIT was flown as part of the NRT instrument, also built by MDX.

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Is the OLA used on any other space or earth based missions?

OLA, itself, is a unique instrument. However, its concept has been drawn from previous terrestrial and space examples. Among others, airborne lidar systems are widely used on Earth for geological, archeological, agricultural, and ecological applications. Moreover, they can be adapted for use in vision systems for purposes such as robotic mining vehicles.

The OLA system is based on MDX’s heritage design of a scanning lidar system flown on the US Air Force Research Laboratory’s XSS-11 mission. The system was augmented utilizing heritage derived from NASA’s Phoenix Mars Lander mission, where a version of the HELIT was flown as part of the NRT instrument, also built by MDX.

“THE PROBABILITY THAT THE ORBITS OF BENNU AND EARTH COULD COINCIDE IN A COLLISION IS CURRENTLY 1 IN 2,700 SOME TIME BETWEEN THE YEARS 2175 AND 2193. ONCE WE_GAIN A BETTER UNDERSTANDING OF THE YARKOVSKY EFFECT FROM OUR CHARACTERIZATION OF BENNU, WE WILL BE ABLE TO BETTER PREDICT THE TRAJECTORY OF BENNU AND OTHER ASTEROIDS WITH THE POTENTIAL TO COME CLOSE TO EARTH.”

- Dr. Tom Zega, Professor of planetary materials science at the University of Arizona and member of the OSIRIS-REx science team

When the sample is returned to Earth, what kind of tests will be done and what primarily will the team be looking for?

We will do a list of different types of measurements. Generally, we are interested in what materials comprise the sample, their textures, their spatial relationships to one another, their crystal chemistry and atomic structures. We will use light, ion, and electron microscopy in addition to mass spectrometry to image the sample, measure its elemental composition, and its isotopic composition. Those measurements will be conducted at scales ranging from meters down to the atomic level. Data types will include optical images, including reflected and transmitted light, element and isotopic maps in two dimensions, spectra of various types, and high-resolution atomic-scale images.

Some of the instruments we will use include:

- SEM - scanning electron microscopy for high-resolution imaging and chemical analysis of the sample.
- TEM - transmission electron microscopy for highly detailed atomic-resolution analysis and chemical-atomic analysis of the sample.
- SIMS - secondary ion mass spectrometry for measuring isotopic composition of the sample.
- FIB-SEM - for high-resolution imaging, chemical analysis, microstructural analysis, and in situ site-specific extraction of regions of interest in the sample.

These tests will be used to characterize the sample. This gives us quantitative information on material stoichiometry and two-dimensional chemical maps of the sample.

Is there any update on the possible collision of Bennu with Earth?

The probability that the orbits of Bennu and Earth could coincide in a collision is currently 1 in 2,700 sometime between the years 2175 and 2193. Luckily, the science we learn from OSIRIS-REx will help us better understand the hazards posed by asteroids and how to mitigate them. One of OSIRIS-REx’s goals is to study the Yarkovsky Effect, a force caused by the emission of heat from a rotating object that can slightly change its orbit. These orbit changes make it difficult to predict the path of a small, potentially hazardous asteroid over time.

Once we gain a better understanding of the Yarkovsky Effect from our characterization of Bennu, we will be able to better predict the trajectory of Bennu and other asteroids with the potential to come close to earth.
The goal of the OSIRIS-REx mission is to collect a sample from an asteroid and bring it back to Earth. By bringing a sample back to the Earth, we could on a space craft and we can analyze the sample with future instrumentation not yet discovered." said Dr. Daly. “By bringing a sample back to the Earth, we can examine much smaller portions of the sample with modern instrumentation with multiple analysis pathways such as morphology and biology and we can separate out very small components of the sample from a nanotechnology standpoint,” said Dr. Daly. “By bringing a sample back to the Earth, we can examine much smaller portions of the sample with modern instrumentation with multiple analysis pathways such as morphology and biology and we can separate out very small components of the sample from a nanotechnology standpoint.”

How was Bennu chosen?
The goal of the OSIRIS-REx mission is to collect a sample from an asteroid and bring it back to Earth. But just how did the OSIRIS-REx team choose Bennu from the over 500,000 known asteroids in the Solar System?

Proximity to Earth
The closest asteroid to Earth are called Near-Earth Objects (NEOs). As the name suggests, NEOs are objects that orbit within 1.3 AU of the Sun. (1 AU is the distance between Earth and the Sun, or ~93 million miles) For a sample return mission like OSIRIS-REx, the most accessible asteroids for a spacecraft to reach are located between 1.6 AU and 0.8 AU. The ideal asteroid has an Earth-like orbit with low eccentricity and inclination. At the time of the mission’s asteroid selection in 2008, there were over 7,000 known NEOs, but only 192 had orbits that met these criteria.

Bennu Selection

Size
Asteroids with small diameters rotate more rapidly than those with large diameters. With a diameter less than 200 meters, an asteroid spins so rapidly that the loose material on its surface (regolith) can be ejected from it. The ideal asteroid has a diameter larger than 200 m so that a spacecraft can safely come into contact with it and collect a sufficient regolith sample. This size requirement reduced the number of candidate asteroids from 192 to 26.

Composition
Asteroids are divided into different types based on their chemical composition. The most primitive asteroids are carbon-rich and have not significantly changed since they formed nearly 4 billion years ago. These asteroids contain organic molecules, volatiles, and amino acids that may have been the precursors to life on Earth. Of the 26 asteroids left on the list, only 12 had a known composition, and only 2 were primitive and carbon-rich.

From these 5 asteroids, Bennu was selected. Bennu is a B-type asteroid with a ~500 meter diameter. It completes an orbit around the Sun every 436 604 days (1.2 years) and every 6 years comes very close to Earth, within 0.002 AU. Bennu’s size, primitive composition, and potentially hazardous orbit make it one of the most fascinating and accessible NEOs... and the ideal OSIRIS-REx target asteroid.

Bits of dust are flash heated to molten rock and solidify to become chondrules — some of the building blocks of the solar system. Chondrules clump together via electrostatic and gravitational forces to become asteroids and planets. Chondrules may make up a large part of the material in Bennu. By analyzing the sample collected from Bennu, the OSIRIS-REx team will be able to examine some of the most pristine material to be found anywhere in the solar system. Bennu may also harbor organic material from the young solar system. Organic matter is made of molecules containing primarily carbon and hydrogen atoms and is fundamental to terrestrial life. The analysis of organic material found on Bennu will give scientists an inventory of the materials present at the beginning of the solar system that may have had a role in the origin of life. “The biggest advantage we have now is we can examine much smaller portions of the sample with modern instrumentation with multiple analysis pathways such as morphology and biology and we can separate out very small components of the sample from a nanotechnology standpoint,” said Dr. Daly. “By bringing a sample back to the Earth, we can access more information than we could on a space craft and we can analyze the sample with future instrumentation not yet discovered.”

In this application note, piezoelectric force microscopy is performed utilizing the newly-developed PinPoint™ PFM and conventional PFM was carried out on an annealed phenanthrene film, and improved resolution was observed in both topography and piezoelectric force response signal with PinPoint™ PFM.

In the introduction, piezoelectric effect is defined as the intrinsic material property, in which the application of an electric field leads to thickness changes and/or shearing of the material. This unique electromechanical coupling property has been employed in a wide range of applications ranging from medical imaging and energy harvesting, to actuators and sensors. Example of piezoelectric materials include crystals (e.g., quartz), biological materials (i.e., DNA, bones and proteins) and man-made materials such as synthetic ceramics (barium titanate and zinc oxide) and some organic thin films.

Driven by the developing nanotechnology and the increasing demands for miniaturization of electronic devices, characterization of piezoelectric effect at micro- and nanoscale has attracted significant interest. Piezoelectric force microscopy (PFM), also termed as dynamic-contact electrostatic force microscopy (DIC-SCFM) by Park, is an atomic force microscopy (AFM) based method that allows for high-resolution imaging, quantification and manipulation of piezoelectric materials at micro- and nanoscale length scale. Conventional PFM is usually performed in contact mode, and concurrent topographic imaging and piezoelectric response measurements is obtained.

In conventional PFM operation, an electrically-biased conductive tip is brought in contact with the surface of a piezoelectric material. Through application of an AC modulation to the conductive tip, the piezoelectric response of the material can then be measured by tracking the deflection of the cantilever as a result of sample's local expansion or contraction based on the applied AC field. As these surface displacement are often very small with a low signal-to-noise ratio, they are amplified in both topography and PFM (quadrature) signals by a feedback controller.

PinPoint™ PFM mode, the AFM probe monitors its feedback signal, approach and retract toward the sample surface until a predefined force threshold point is reached, measures the Z scanner’s height, then the AFM probe is rapidly retracted away from the surface to a user-defined height. The XY scanner stops during the piezoelectric response acquisition, and the probe substrate contact time is controlled to allow sufficient time for quality data acquisition. In vertical piezoelectric force microscopy, in the presence of piezoelectric domains, the tip point of contact is perpendicular to the sample surface. In pinpoint mode, the cantilever deflection is measured with respect to the feedback signal, and the probe substrate contact time is controlled to allow sufficient time for quality data acquisition. In this application note, piezoelectric force microscopy is performed utilizing the newly-developed PinPoint™ PFM and conventional PFM was carried out on an annealed phenanthrene film, and improved resolution was observed in both topography and piezoelectric force response signal with PinPoint™ PFM.

In vertical piezoelectric force microscopy, the presence of piezoelectric domains point out-of-plane or perpendicular to the sample surface (Figure 1a-b). The PinPoint™ PFM technology has proven to solve all of the shortcomings of conventional PFM including quick tip wear, degradation of resolution, low signal to noise ratio, and poor reproducibility of data.
In PinPointTM PFM imaging, a conductive 6.84 nN.
4.5 V and a frequency of 17 kHz. No external
biased with AC potential with an amplitude of
curvature is ~25 nm. Scan size was 20 µm ×
was applied to the tip, and no DC potential was
was 20 µm/s. The contact time between the
was 0.3 µm. The retract/approach speed
was compared to that taken with conventional
PFM imaging, a NSC36-C (nominal spring
radius of the tip curvature is ~25 nm. Scan size
was 20 µm × 20 µm. Same as the conventional
Experimental
A Park NX10 AFM was used to image the
material and observed to be rod-shaped features
in the PinPoint PFM measurements. However, the
scraping on the surface repeatedly. Of note,
the probe was constantly scratching on the
height was 0.3 µm. The retract/approach speed
was 20 µm × 20 µm. NSC36-C has a smaller force constant compared
alleviate the scraping on the surface. Albeit the
phenanthrene polymer film. These hysteresis curves
were obtained by measuring the piezoelectric response at a specific location of the sample
while applying the sample bias from ~1.5 V to
The hysteresis curves provide localized information with respect to the switching properties of piezoelectric material. In
a) a characteristic “butterfly” shape that is similar to the ideal strain versus bias curve was
observed in the amplitude signal. In addition, the coercive voltage, which is a measure of ability to withstand an
external electric field without depolarization, is ~0.3 V. In Figure 4b, the phase hysteresis loop is shown, which is
the typical response of a ferroelectric material.

Conclusions
Here we make use of both imaging and response mapping of the sample to extract additional information with respect to the switching
behaviors of interest. These results may be used as a basis for the design of novel ferroelectric materials.

References
2. Vijaya MS. Piezoelectric Materials and Devices: Applications in Engineering and Medical Sciences. CRC Press; 2012.
3-D printing of electronics

Innovation has paved the way for 3-D printing technologies to aid in manufacturing. With the advancements in various fields, including medicine and construction, it’s now possible to fabricate customized products on demand. However, this technology is still in its infancy, and its applications continue to expand. For example, the 3-D printing industry is poised to transform many industries, including healthcare, automotive, and aerospace, among others. The flexibility and versatility of 3-D printing make it an attractive option for companies looking to stay ahead of the curve.

But how fast are manufacturers adapting to the next industrial revolution, poised to transform many industries? Experts predict that 93 percent of manufacturers will be using 3-D printing technologies within two years. Can 3-D printing potentially become the most viable method for mass producing electronics? For now, incorporating the traditional pick-and-place method of building electronics with 3-D printing technologies could be a workable strategy. In this case, the printed electronics could be reconfigured to suit the needs of the end product. But how do we ensure that the-space occupied and materials used to build it also be reduced? In the future, it becomes more and more practical to accurately embed electronic components with conductive interconnects within a three-dimensional substrate as an approach for a more robust and space-saving model.

According to the 2016 Markets and Markets analysis report, printed electronics, in general, was considered to have a market value of 3.3 billion US dollars at the end of 2018, with a potential to reach 12.1 billion US dollars in the coming decade. But for 3-D printed electronics alone, it was valued at 20 million US dollars in 2013. According to Hargreaves, the director of ITN’s research, A Group of 3-D printed interconnects could be used to replace traditional, expensive, and often unreliable printed interconnects in electronic circuits. This would enable more flexibility in the design and manufacturing process.

Optomec, the company that pioneered Aerosol Jet printing, has envisioned the idea of mass production of electronics using integrated 3-D printing technology. While most of the aforementioned companies are outsourcing some of their machine parts (e.g., print heads), Optomec manufactures their own, using open systems design for flexibility. The print heads are made compatible with most CNC machines, making it adaptable to any 3-D printing systems for any given production settings.

3-D printing of silicone

Printing of paste mixtures or viscous solutions will become a trend in the future along with the need for building freedom for complex shapes and geometries in manufacturing flexible materials. A broad array of functionalities has been demonstrated for flexible electronics. This unique category of electronics has already been playing an important role in manufacturing solar cells, displays and LEDs, sensors, and thin-film transistors. Flexible electronics has been a trend due to its application in flexible displays and wearable electronics.

Conductive polydimethylsiloxane (PDMS) has been successfully 3-D printed by using a unique embedded 3-D printing (e-3DP) method, as shown. a) A photograph of a glove with embedded strain sensors produced by e-3DP. b) Electrical resistance change at different hand gestures. c) A three-layer strain and pressure sensor in the unstrained state (left) and stretched state (right).

Park Atomic force microscopy (AFM) plays an important role in our 3-D printing projects in the laboratory. This powerful tool is capable of looking at the surface profile of 3-D printed objects.

A three-faced 3-D printed sensing circuit that consists of a plastic tank with circuitry on it was printed using Pure PA12. PA12 with reduced GO while the base was printed using pure PA12. The photo shows a spinning 3-D printed electrostatic motor. The rotor blades and the electrodes were made of processed conductive PA12 with reduced GO while the base was printed using pure PA12.

Conductive polydimethylsiloxane (PDMS) has been successfully 3-D printed by using a unique embedded 3-D printing (e-3DP) method, as shown. a) A photograph of a glove with embedded strain sensors produced by e-3DP. b) Electrical resistance change at different hand gestures. c) A three-layer strain and pressure sensor in the unstrained state (left) and stretched state (right).
A rising technology in food fabrication called extrusion-based food printing uses the same mechanism as paste extrusion printing but is specifically intended for building food products using edible materials in a layer by layer manner. Researches have been conducted using edible materials in a layer by layer specifically intended for building food products mechanism as paste extrusion printing but is currently only being done in a few and largely experimental manner. Food fabrication is seen to grow 500% in the next 5 years, reaching around $16.2 billion by 2025.

IN 2014, THE 3-D PRINTING INDUSTRY WAS ESTIMATED TO BE AT $4 BILLION. WITH NEW PREDICTIONS THAT 3-D PRINTING WILL BE 50 PERCENT CHEAPER AND UP TO 400 PERCENT FASTER, THE INDUSTRY COULD REACH $49 BILLION BY 2025.

References
Jingshan Du pictured above with Park AFM at Northwestern University where he uses the unique nanolithography module in Park AFM to rapidly generate nanoreactor arrays on an electron microscopy-compatible substrate.

of high performance and multifunctional nanomaterials such as catalysts, sensors, and medicines.

How might your research be used?
From a basic science perspective, my study provides insights into how multiple elements, phases, and materials interact and evolve in nanoparticles in different environments. This allows us to look at complex multicomponent nanoparticles in a new way, as complex systems, and start to understand their behaviors that stem from fundamental chemical physics. We also invest significant efforts into studying their properties such as plasmonics and catalysis. These multicomponent nanoparticles, with the desired composition and structure, may be able to enable some exciting new applications such as cascade catalysis.

Why is the Park AFM important for your research?
My research focuses on interfacing nanopatterning techniques and electron microscopy into a platform for investigating complex nanoparticle systems. These systems, including multicomponent, multiscale nanoparticles, and their interfaces with fluids and gases, are generally difficult to prepare in a systematic and combinatorial way. I use the Park AFM to generate nano reactors on electron-transparent substrates. This precise control of scanning probe position in three dimensions allowed me to deposit nanoscale features of fluids, such as polymer solutions, onto films that are only few nanometers thick.

What features of Park AFM are the most beneficial and why?
The unique nanolithography module in Park AFM allows us to rapidly generate nanoreactor arrays on an electron microscopy-compatible substrate. Compared to other sample preparation methods that result in randomly located nanoparticles, the regular arrays generated on Park AFM enables us to index and trace back to each particle individually. This makes correlation characterization, ex situ, and in situ studies using electron microscopy possible on the individual nanoparticle level.

Please summarize the research you do and explain why it is significant?
My current research mainly focuses on developing novel micro/nanoscale measurement techniques combined with multiscale modeling at the atomic and continuum levels to advance our fundamental understanding of mechanical and electrical behavior of atomically thin layered materials and newly emerged vdW heterostructures. Such powerful characterization techniques are then to be leveraged to improve synthesis, transfer, manipulation, integration, and performance of opto-, bio- and nanoelectronic devices incorporating such materials.

Why is the Park AFM important for your research?
The novel design of the Park XE-70 AFM coupled with highly user-friendly interface software KEP has made it possible to simultaneously image sample surfaces with atomic-scale resolution, precisely manipulate nano-objects down to single molecules and accurately measure the physical properties of interest through a comprehensive range of innovative modes supported by the Park AFM (e.g., imaging mode, electrical mode, nanomechanical mode, etc.).

Hossein Rokni Damavandi Taher is currently a Postdoctoral Fellow in Prof. Wei Lu’s group at the University of Michigan. He earned his Ph.D. from University of Michigan in 2018, M.S. from University of British Columbia in 2011 and B.S. from Iran University of Science and Technology in 2005, all in Mechanical Engineering. He is the recipient of the 2015 I.K. Meier Award for excellence in research and scholarship in Applied Mechanics and the 2016 Rackham Predoctoral Fellowship Award for unusually creative, ambitious and impactful dissertation research and the nominee for the 2018 ProQuest Distinguished Dissertation Award. He has also co-authored over 50 publications with more than 1100 citations. His research focuses on micro/nanomechanics, micro/nanomaterials, and atomistic-to-continuum modeling of atomically thin layered materials, vdW heterostructures, biomaterials and smart materials as well as on the development of MEMS/NEMS devices incorporating such materials.
USING AFM PINPOINT™ NAMOMECHANICAL MODE FOR QUANTIFICATION OF ELASTIC MODULUS IN MATERIALS
TWO ORDERS OF MAGNITUDE FASTER THAN FORCE VOLUME SPECTROSCOPY

JOHN PAUL PINEDA, GERALD PASCUAL, BYONG KIM, AND KEIBO LEE
PARK SYSTEMS INC., SANTA CLARA, CA USA

Introduction
Since the invention of atomic force microscopy, AFM has had a revolutionary impact in material sciences and device engineering by providing accurate, reliable, non-destructive imaging at the nanoscale. AFM is used across a wide range of nanotechnology applications such as biomedical implantable actuators to ultrathin cathode material for batteries to photo detectors and sensors in many strategic storage and logic circuits. [1-3] As the dimensions of devices continuously shrink, measurement methods of local properties of materials have become more effective over bulk property in providing accurate nanoscale measurement. Local mechanical properties such as adhesion and elastic modulus are critical parameters in determining the reliability and performances of these devices. [4-6] There were existing AFM-based nanomechanical methods introduced to measure the local properties, examples include force-volume spectroscopy, and nanoindentation. However, some of these techniques are extremely time consuming and others are destructive which doesn’t allow in situ and high-throughput monitoring in certain applications.

Figure 1 demonstrates the principles of AFM PinPoint™ nanomechanical mode developed by Park Systems. The patented PinPoint™ technique is at least two orders of magnitude faster than the conventional force-volume technique which allow users to acquire quantitative mechanical properties and high-resolution topography images simultaneously in a short period of time. During operation, the tip moves in an approach retrace manner, ensuring a frictionless operation which eliminates the lateral force due to continuous tip-sample contact and preserves tip and sample condition, ideal in measuring both hard and soft samples such as hard disks and biological samples. At each point of the image, force-distance curve is acquired and used to calculate the mechanical characteristics of the sample being measured. During 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.

In this experiment, 4 different materials with various ranges of modulus were successfully quantified. The results acquired for each test are close to the nominal modulus value of each material, proving the superior ability of the Park™ mode in quantification of mechanical properties. In addition, high-resolution images were acquired simultaneously which revealed the surface features of the samples. The samples were investigated using Park N5000 AFM system under ambient air condition. Each force curve scan, the scanned parameters used in measuring the samples were all the same.

Results and Discussion
Hertzian model
The quantification of mechanical properties of Pinpoint mode such as elastic modulus is based on the well-established Hertzian model. In this technique, it is assumed that no other interaction other than elastic deformation can be observed between tip and sample. The calculation is based on the equation (1). [7]

\[ E = \frac{3}{4} \frac{F d^3}{R} \]

where \( E \) is the elastic modulus, \( F \) is the force measured, \( d \) is the displacement created in the sample surface by the tip, and \( R \) is the radius of the spherical tip.

Feedback control
Pinpoint Imaging Conditions
The samples were investigated using Park N5000 AFM system under ambient air condition. Using standard protocol and scan range, the scanned parameters used in measuring the samples were all the same.

Table 1: Topography images and correlated maps of elastic modulus acquired for each material.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Modulus (GPa)</th>
<th>Std (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PS</td>
<td>1.955</td>
<td>0.187</td>
</tr>
<tr>
<td>LDPE</td>
<td>1.32</td>
<td>0.085</td>
</tr>
<tr>
<td>HOPE</td>
<td>22.093</td>
<td>2.224</td>
</tr>
</tbody>
</table>

Note: The quantitative and qualitative data of the four materials were successfully acquired by Park N5000 AFM using PinPoint™ nanomechanical mode in the form of topography images of the samples such as the atomic terraces surface of the PDMS, the rough surface of the PS, and the circular dots matrix of the LDPE. The PDMS and PS-LDPE were all observed using XEI software developed by Park Systems which allows high-speed data acquisition and analysis. The topography images acquired in this experiment were all the same.

These terraces demonstrate a homogeneous diagonal path and they were measured to have approximately 1.5 nm step height. On the other hand, the elastic modulus map shows few variations on the mechanical properties of the sample surfaces. The diagonal dark lines visible on the elastic modulus image represent the high modulus regions. The topography image of the PDMS revealed the rough surface of the sample. It can be observed on both topography and modulus image that there are only few variations on height and modulus of the surfaces. However, the PDMS sample is composed of two different materials. The dark circular dots features are the LDPE (low density polyethylene) materials, while the brighter regions in this image are the PS (polystyrene) materials. As expected, the elastic modulus map of this sample has two domains, wherein LDPE materials represented by the dark circular dots are the domains with lower modulus, while PS represented by the areas with bright color are the domains with higher modulus.

Conclusion
The quantitative and qualitative data of the four materials were successfully acquired by Park N5000 AFM using PinPoint™ nanomechanical mode in the form of topography images of the samples such as the atomic terraces surface of the PDMS, the rough surface of the PS-LDPE, and the circular dots matrix of the LDPE. The PDMS and PS-LDPE were all observed using XEI software developed by Park Systems which allows high-speed data acquisition and analysis. The topography images acquired in this experiment were all the same.

The quantitative results of elastic modulus are shown in Table 1 and corresponding graph shown in Figure 3. The results were plotted to better analyze the data. To evaluate the performance of Pinpoint mode, the results acquired in this experiment were compared to the nominal values of each sample. And it was found that the measured modulus values of all the samples are close to their nominal values. For PDMS, the measured modulus is 22.09 GPa, close to its nominal value of 18 GPa. For the PS-LDPE, the measured modulus is 1.03 GPa, close to its nominal value of 0.93 GPa. For the PS, the measured modulus is 1.32 GPa, which is also comparable to their nominal values of 2 GPa and 0.1 GPa respectively. The standard deviation of the modulus results were also calculated and based on the results, PDMS sample has the lowest standard deviation with Std = 4.03E-04 GPa, while PDMS sample has the highest standard deviation with Std = 2.224 GPa.

REFERENCES
Park NX12
The most versatile atomic force microscope for analytical and electrochemistry

- Built on proven Park AFM performance
- Equipped with inverted optical microscope

Proven Performance
The Park NX12 is based on the Park NX10, one of the most trusted and widely used AFMs for research. Users can rest assured that they are taking measurements with a cutting-edge tool.

Built for Versatility
Multi-user labs need a versatile microscope to meet a wide range of needs. The Park NX12 was built from the ground up to be a flexible modular platform to allow shared facilities to invest in a single AFM to perform any task.

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To learn more about Park NX12 please call: +1 408-986-1110 or email: inquiry@parkafm.com

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