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The Magazine for Nanotechnology

USING SICM TO UNDERSTAND THE MOVEMENT OF IONS IN COMPLEX SYSTEMS

AN INTERVIEW WITH DR. LANE BAKER, ASSOCIATE PROFESSOR INDIANA UNIVERSITY

p. 10

NANOFIBER RESEARCH CREATES SMART NANO PARTICLES

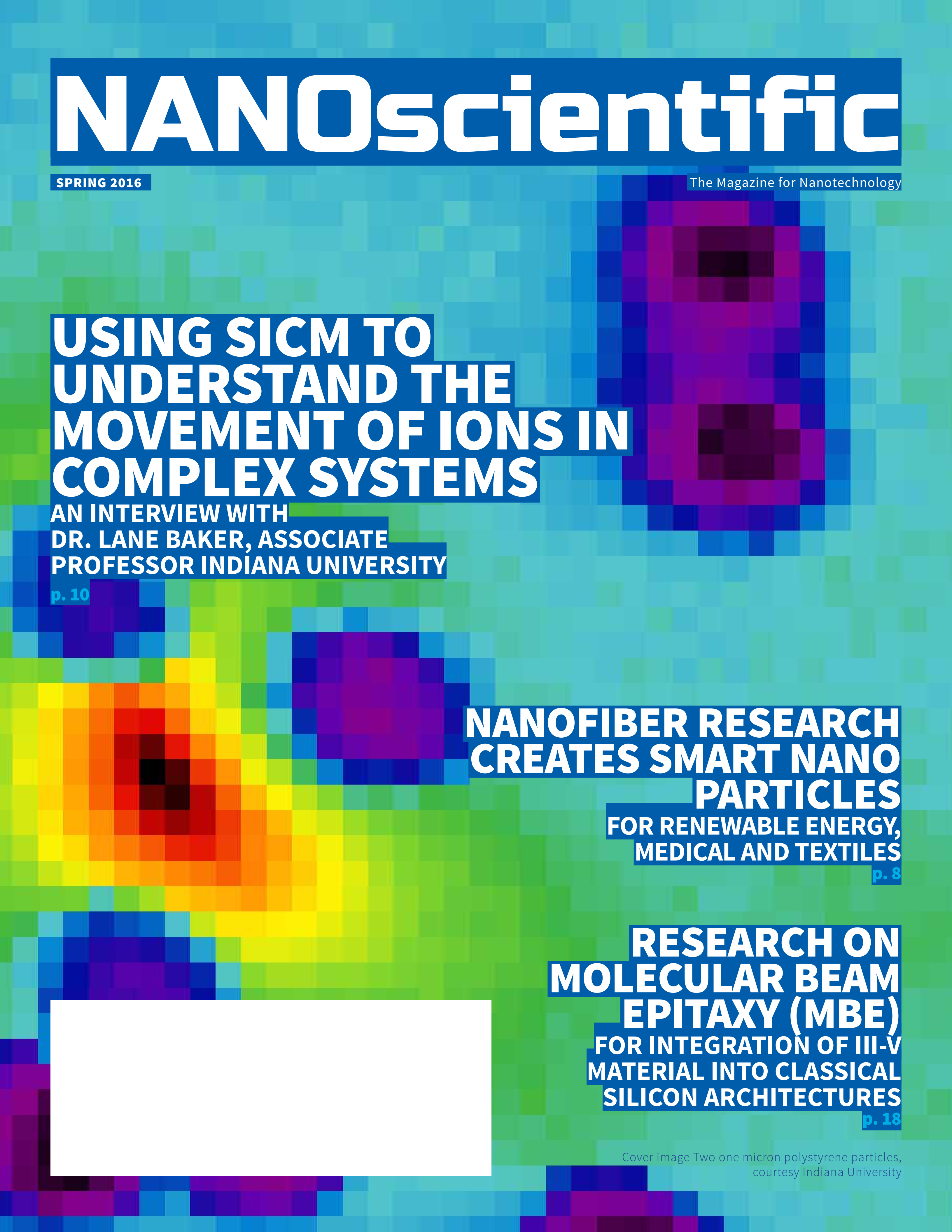
FOR RENEWABLE ENERGY, MEDICAL AND TEXTILES

p. 8

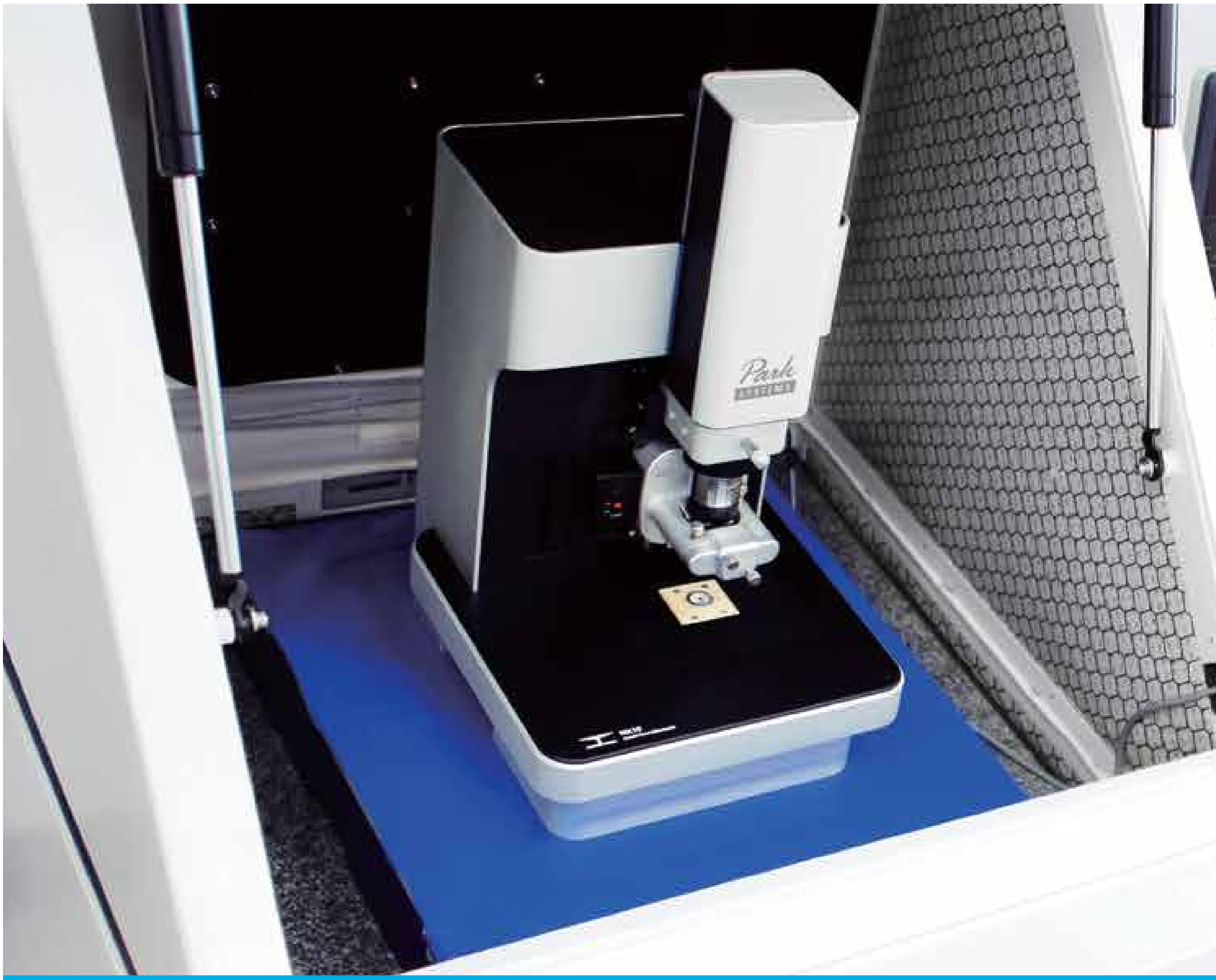
RESEARCH ON MOLECULAR BEAM EPITAXY (MBE)

FOR INTEGRATION OF III-V MATERIAL INTO CLASSICAL SILICON ARCHITECTURES

p. 18



Cover image Two one micron polystyrene particles, courtesy Indiana University



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The Most Accurate Atomic Force Microscope

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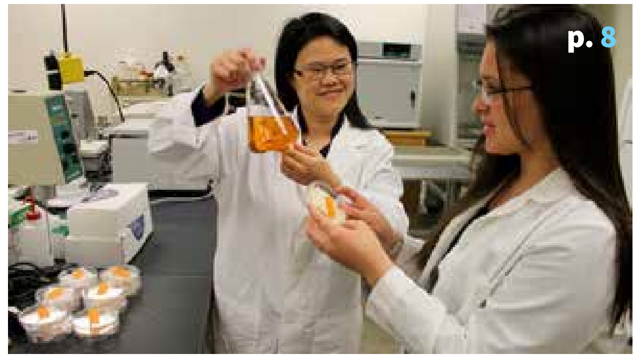
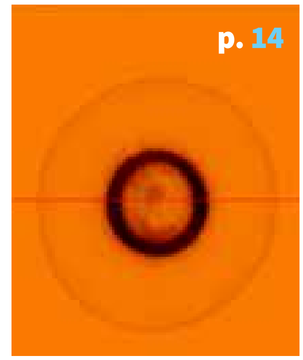
TABLE
OF CONTENTS





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Keibock Lee,
Editor-in-Chief

MESSAGE
FROM EDITOR

The convergence of many interdisciplinary sciences witnessed in Nanotechnology brings great scientific minds together to broaden the horizon of possibilities. By 2020, the global nanotechnology industry could reach US75.8 Billion and with this economic growth which spans the entire globe, we are poised to witness the most miraculous discoveries humanity never dreamed possible.

We are seeing unparalleled stages of commercialization with new products emerging across numerous market segments ranging from energy to textiles to medicine, but the historical impact of the "Nano Revolution" is yet to come. Imagine the unbelievable and it may just be possible. Google has and is focused on solving the "difficult problem of dying" by pouring money into their Calico Life Sciences division investigating the aging process thru gene therapies and DNA research at the cellular level. Scientists are in search for what was formerly thought impossible; to further extend human life to perhaps hundreds of years or more by halting the damage to the body and repairing cells using nanomedicine. When futurist Ray Kurzweil announced that he has joined Google in 2012 he stated "I'm thrilled to be teaming up with Google to work on some of the hardest problems in computer science so we can turn the next decade's 'unrealistic' visions into reality." This is just what we are now seeing. Medical and bio scientists are finding new discoveries everyday that make this dream a reality, to rid our species of disease and extend humanity's life and purpose.

In this issue, we present the Park Systems AFM story of success in reaching their goal of an IPO in 2015. With a clear vision to enable Nano Scientific advancements thru quality AFM equipment and continuous product innovation, Park's landmark accomplishment symbolizes the importance of industry collaboration and heralds in a new year for them. It is with gratitude for all those in the NanoScientific community that support Park AFM that I recognize this milestone year and acknowledge all those who work so hard to make them the world's leading AFM company.

We also showcase the work being done at Colorado State University on textiles and in lithium batteries. The impact of Nanotechnology can be witnessed by wearable products that are flourishing as textile materials become Smart and

Smart Textiles that interface with our portable devices hit the commercial market, revolutionizing human wearables. Performance enhancing smart textiles for extreme sports and military and aerospace industries are fabrics that help regulate body temperature, reduce wind resistance and control muscle vibration.

Interactive, sensing electrical, thermal, chemical, magnetic or other stimuli. End-user products include medical vital vests that read vital signs and T-shirts and shorts made of more breathable polyester that can be used for weeks overcoming concerns of sweat, bacteria, odor and infection, first developed for the crew on the ISS, but now in commercial use. The textile industry has many exciting products they are working on and our story highlights the work being done by Prof. Vivian Li at Colorado State.

We also have an incredible story from South America that showcases the work of LNNano and the Brazilian Nanotechnology National Laboratory. This article features Dr. Christoph Feiedrich Deneke work at LNNano tech lab and the in-house research focused on molecular beam epitaxy (MBE). Another interview in this issue is with Dr. Lane Baker and his research group at Indiana University which consists of analytical and materials chemists who are creating new ways to examine SICM (scanning ion conductace microscopy) and developing new innovations in measurement science. We also examine automatic defect review using enhanced vision for the hard disk market, a closer look at the essential tools for failure analysis.

It's clear that discoveries in nanotechnology bring improvements to human existence never dreamed possible and that microscopy methods allow us to visually detect, dissect and apply this new science to our lives. But nature shows us many intricately woven designs at Nanoscale that evolved without human intervention and scientists are witness to and often employ the intricately woven designs created from nature. One such example is the silks in spider webs, which are stronger than steel and made from thin crystal proteins only nanometers wide joined together at the atomic level by hydrogen bonds. But the silk is smart, using an ingenious design of loosely attached bonds lets the web stretch to withstand strong winds. Breakthroughs in NanoScience are equally as amazing as those found in nature that evolved naturally and continue to this day to astound researchers. As we humans extend our lives and examine the world around us at a sub atomic level, what discoveries are yet to be realized?

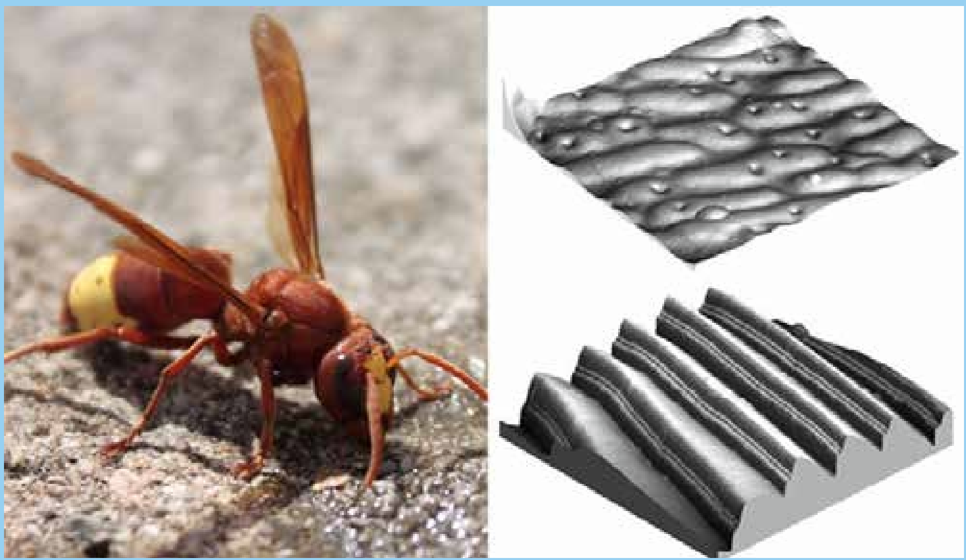
NanoScientific will continue to bring you the latest news and information, please send us your story ideas and may you all prosper in the New Year.

So please share your story ideas by submitting them to me at kei@parkafm.com. Enjoy the issue!

EXAMPLES OF NANOTECHNOLOGY IN NATURE

Nature’s Nano Textile

Spider Silk is Made from crystal proteins nanometers wide held together by hydrogen bonds Spider silks are some of the toughest materials known to man--pound for pound, they're stronger than steel, and their webs can stand up to gusts of wind and catch hurtling insects without falling to pieces. The silks get their strength from thin crystal proteins only nanometers wide, which are stacked together like pancakes. On the atomic level, the layers are joined together by hydrogen bonds. Those bonds actually aren't particularly strong, but that turns out to be an advantage, because they can easily pull apart and reform, allowing the silk to stretch and flex under pressure instead of snapping like a twig.



Nature’s Sustainable energy design with SOLAR-POWERED Bees

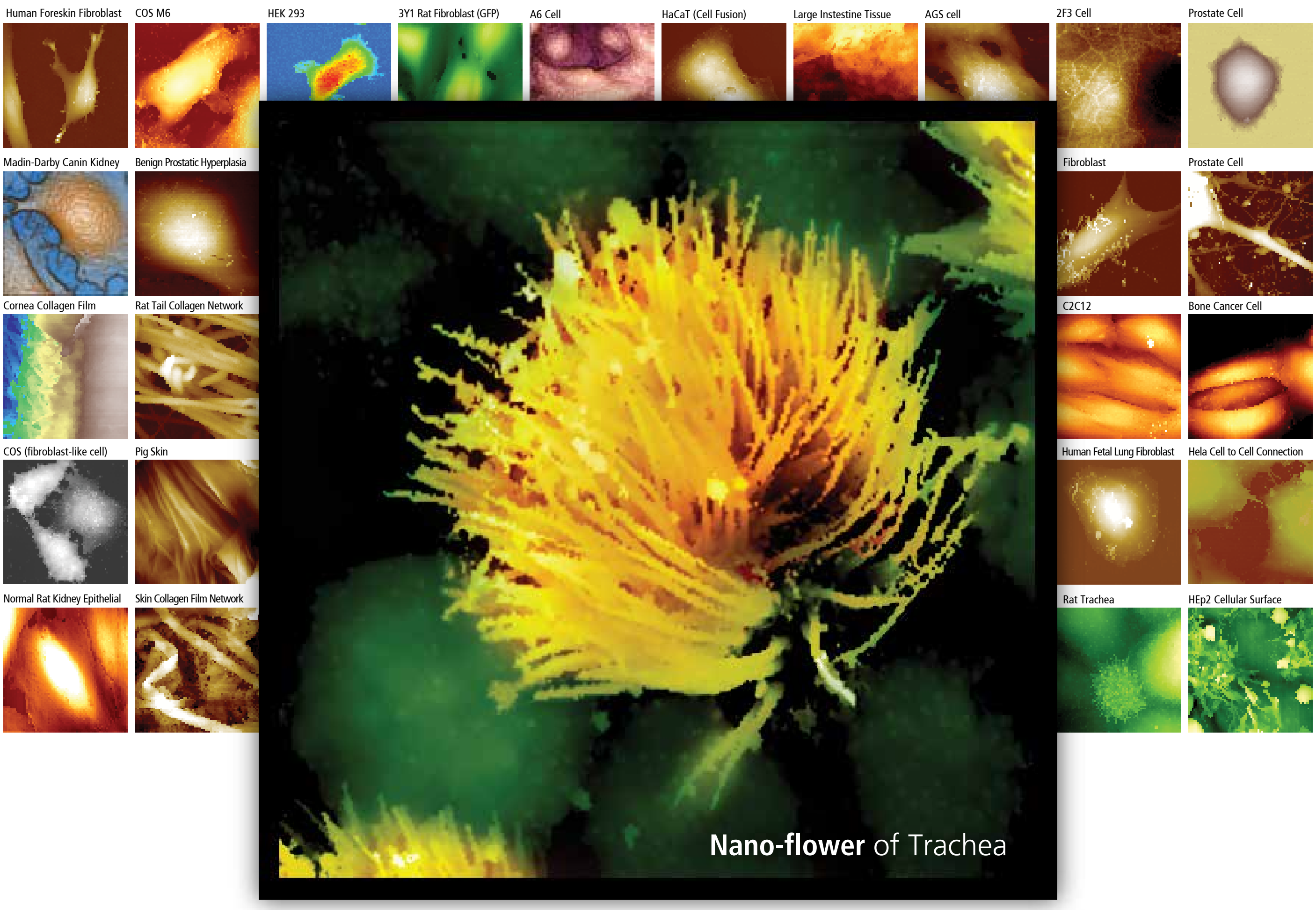
Nanostructures in this hornet’s exoskeleton form a kind of solar cell, harvesting light energy that could power the hornet's work. In the brown section of the hornet's abdomen, the layers of cuticle that make up the exoskeleton are embossed with grooves about 160 nanometers high. The grooves are arranged into a sort of grating, which helps trap the light that hits the hornet and bounce it around within the cuticle. The yellow section, which has small, interlocking protrusions about 50 nanometers high, also absorbs light and xanthoperin, the pigment that gives it its yellow color, can be used to convert light into electricity.

Nature’s design to overcome gravity with Gecko powered toes

This gecko uses nanotechnology to stick itself to trees, walls, windows, and even ceilings. His feet are covered in microscopic hairs, called setae, which branch into thousands of smaller hairs with paddle-shaped ends. Those branches, or spatulae, are a mere 200 nanometers wide at the tip. The extra surface area of the spatulae maximizes the effect of van der Waals forces, the weak electrical pull between every molecule in the gecko and every molecule in whatever it's sticking to. The combined force is so strong that a gecko can hang its whole weight from a single toe, even on a sheer piece of glass. Engineers have used carbon nanotubes mimicking gecko setae to create super-sticky tapes, and glues.

Cell Discovery like Never Before

In-Liquid Biological Imaging with **Park SICM**



The main image above shows the world's first observation of tracheal tissue in aqueous condition. Scanning ion conductance microscopy (SICM) by Park Systems successfully imaged the trachael tissue's luminal surface. Both the ciliated and non-ciliated cells of tracheal tissue are pictured with a particular focus on the hair-like appearance of ciliated cells. A small piece of the tissue was obtained from Wistar rats, then mounted on a glass slide and imaged using Park NX-Bio, a three-in-one microscopy system that combines SICM, an AFM (atomic force microscope) and an inverted optical microscope.

By using the SICM of Park NX-Bio, Professor Ushiki and his team from the Microscopic Anatomy division of Niigata University Medical School captured the ciliated cells of rat trachea in liquid. "We can directly acquire cell and tissue images in liquid condition and the resolution is comparable with SEM," said Prof. Ushiki. "With SICM imaging technique, we don't need to take [the] risk of sample damage that is often caused during SEM sample preparation, causing image artifacts."

Prof. Ushiki has been active in histology and anatomy research using SEM and SICM. Park's SICM has made live cell imaging in liquid not only possible but also practical for his research and routine imaging needs.

The SICM works like this: A glass nanopipette filled with an electrolyte acts as an ion sensor. It provides feedback on its location relative to a sample completely immersed in liquid. The nanopipette tip maintains its distance from the sample by keeping the ionic current constant, applying no force on the sample surface. This way, unlike SEM or AFM, samples are not damaged at all or even disturbed by the nanopipette tip, and physiological morphology can be measured in liquid condition.

Park NX-Bio by Park Systems is a powerful 3-in-1 scientific research tool at nanoscale that uniquely combines the industry's only True Non-Contact AFM with SICM and an inverted optical microscope on the same platform. Park Systems provides its customers with a complete range of SICM solutions including the system, options and software, along with global service and support.

To learn more about Park NX-Bio or to schedule a demo, please call: +1 (408) 986-1110 or email inquiry@parkafm.com

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NANOFIBER RESEARCH

AT COLORADO STATE UNIVERSITY: NANOTECH FIBER INDUSTRY ADVANCEMENTS IMPROVING MEDICAL APPLICATIONS AND MOVING TOWARDS CLEAN ENERGY

Prof.William Sanford, an associate professor of Geosciences at CSU and Vivian Li collaborated to understand what goes on in the sub-surface during oil recovery and the fracking process. Hydraulic fracturing of wells has caused a political firestorm in recent years, as Colorado residents have questioned the health and safety risks of injecting chemicals into the ground to free oil and natural gas. There is still debate about whether these chemicals are harming the environment and some question where the chemicals go after injection, fearing they may be contaminating groundwater supplies. They are developing modified "smart" nano particles known as smart tracers that could sense high pH levels or the presence of hydraulic fracking chemicals.

There is a constant need to upgrade the functions and performance of textiles and apparel for the improvement of protection and living conditions. Dr. Li is aimed at addressing this need by focusing on the development of multifunctional textiles and apparel through the application of nanotechnology. Her research seeks to fundamentally understand, assess and control the functionality and performance of fibers and fabrics at the nanoscale. Main focus areas are: Nanostructured materials for high-tech textiles, smart/intelligent medical textiles, textile materials for renewable energy and sustainability.

An interview with Prof. Yan Vivian Li, PhD

What are smart/intelligent medical textiles?

Smart textiles are the first generation wearable technology that can predict biological signals such as heart rate or temperature using a integrated electrical sensor device. The Vital Vest is one of the first such textile garments used for medical applications. The challenge for these wearable textiles is that the bio sensors are integrated into the clothing, making it difficult for wearability and can be easily damaged during laundering.

To solve this challenge, we are doing new research using nanotechnology for textiles that shrinks the size of the device, enhancing the wearability. The next stage of research into wearables is being done on the raw material by manipulating smart polymers to respond to biological responses.

Using this method, we are adapting smart polymers, for instance, that can respond to bacteria by changing color. This can be used for medical bandages for early detection of infection in wound care and is a new direction for polymer and fiber chemists in the future.

So our goal is to manipulate materials at the nanoscale level; this emerging research eliminates the washing issue for wearables because it is built into the raw material of the fabric within the fibers.

What is the research you are doing with Nano spheres?

The particle is designed to change color as it experiences different reactions based on chemicals that it encounters. We use fluorescent colors to trace various chemicals that stick to the nano spheres such as oil. When hydraulic fracturing is done, half of the oil remains hidden, and using this method, the nano-sphere can detect the hidden oil for more efficiency and cost effectiveness. This method also works well in harsh environments.

The Nano spheres can also be used to engineer a particle to find contaminants in ground water and surface water. The nano sphere is trained to respond to certain chemicals and will change color when they are detected, allowing scientists to measure the amounts. This method applies surface chemistry on small nano particles and is in early stage research for several potential applications.

How might your research be applied to renewable energy and sustainability?

We are researching methods to create nano particles that selectively absorb lithium ions on surface water where it is commonly found especially in South American lakes or in sea

Professor Yan Vivian Li (left) and her graduate student (right), Daniela Jankovska working with a carbon nanoparticle solution in their lab.

Park XE 70 Atomic Force Microscope (AFM) used at the Colorado State University Research Center

" THERE IS A CONSTANT NEED TO UPGRADE THE FUNCTIONS AND PERFORMANCE OF TEXTILES AND APPAREL FOR THE IMPROVEMENT OF PROTECTION AND LIVING CONDITIONS. NOVEL FIBERS WILL BE CONTINUOUSLY BENEFITED FROM NANOTECHNOLOGY FOR ADVANCED APPLICATIONS IN MEDICAL TEXTILES, MILITARY TEXTILES, AND TECHNICAL AND INDUSTRIAL TEXTILES."

"WE USE THE PARK SYSTEMS ATOMIC FORCE MICROSCOPE (AFM) TO DETECT DIFFERENT CHARACTERIZATION AND MORPHOLOGY OF THE FIBERS. THE AFM FEATURE THAT ENHANCES OUR RESEARCH IS THE ABILITY TO DETECT MECHANICAL PROPERTIES SUCH AS HARDNESS WHICH CANNOT BE DONE USING OTHER MICROSCOPY."

PROF. YAN VIVIAN LI, PHD.

water. We are developing nano particles that can reproduce the lithium over a large surface area that gives a very high absorption of lithium and reproducing it economically for use in batteries.

How do you use Atomic Force Microscopes in your work?

We use the Park Systems AFM to detect different characterization and morphology of the fibers. The AFM feature that enhances our research is the ability to detect mechanical properties such as hardness which cannot be done using other microscopy. With AFM, we can quantify other properties as well as take nanoscale measurements, which is important in our examination of fibers and polymers.

Can you explain how you are using the Funding from the National Institute of Food and Agriculture and USDA to create smart hygiene wipes?

Smart hygiene wipes are made by non-woven fabrics created by electrospinning a mixture of polydiacetylene (PDA) and polyethylene oxide (PDA/PEO). The electrospun PDA/PEO nanofibers will be examined in AFM for fiber morphology and mechanical properties.

What advances do you see in the future for Scientific Fiber Research using Nano Technology?

Nanotechnology is able to significantly enhance fiber properties including mechanical properties, flame-resistant properties, and breathability. Novel fibers will be continuously benefited from nanotechnology for advanced applications in medical textiles, military textiles, and technical and industrial textiles.

Dr. Yan Vivian Li, Assistant Professor in Fiber Science, Department of Design and Merchandising, College of Health and Human Sciences, Associate Faculty, School of Biomedical Engineering, Colorado State University

Dr. Yan Vivian Li joined the department of Design and Merchandising at Colorado State University in 2013. Dr. Li obtained a Ph.D. from the department of Fiber Science and Apparel Design at Cornell University and a B.Sc. and a M.Sc. in Materials Science and Engineering from Donghua University (Shanghai, China). Prior to joining CSU, Dr. Li had her postdoctoral training in the Kaust-Cornell Center for Energy and Sustainability (2009-2013) where she developed nanostructured material technology for enhancing oil and gas exploration and production.

For more information go to: https://sites.google.com/site/smartextilesnanotech/

Baker (right) discusses research results with graduate students Yuhan Zeng (left) and Wenqing Shi (center)

USING SICM (SCANNING ION CONDUCTACE MICROSCOPY) TO UNDERSTAND THE MOVEMENT OF IONS IN COMPLEX SYSTEMS

An interview with Dr. Lane Baker, Associate Professor Indiana University

Dr. Baker's research group at Indiana University consists of analytical and materials chemists broadly interested in electrochemistry, bioanalytical chemistry, new mass spectrometry methods, materials for electrode fabrication and instrumentation development. He has a great group of student coworkers - right now around 10 - from around the world. At Indiana University, the Analytical Division provides the students with pretty rigorous training in measurement science.

Why is your work important and how is it applied in today's society?

I think what we do is important to society on primarily two fronts. First, we develop new instruments and materials to help us understand the movement of ions in complex systems. This includes biological samples, like cells and tissues, and synthetic samples, like membranes and polymers. Ions are essentially currency for energy in both of these kinds of systems (living and synthetic), and measurement, control and manipulation of ions at really small scales helps us to better understand how things work. The second, possibly more important part of what we do is to train the next generation of scientists. We try hard to develop students who like to be both "thinkers and tinkerers". Meaning they have to understand the fundamentals of what they are doing (be a thinker) and they have to have the skills to build new tools and reconfigure or repurpose existing technology (be a tinkerer). These are really the two most important traits we can develop, and I would like to think my student coworkers leave well trained in these areas.

How do you collaborate with other research teams involved in Nanotechnogy research and are they world-wide across a wide range of disciplines?

We work with physicists, cell biologists, other chemists and materials scientists. That is one of the great things about nanotechnology, you can apply it almost anywhere to any field. A lot of our collaborations consist of my lab developing a new tool or method and then working with colleague with a really interesting sample.

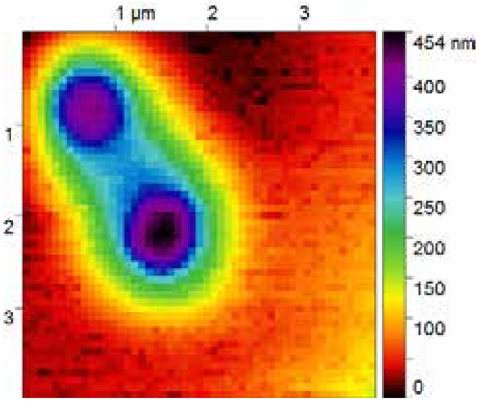
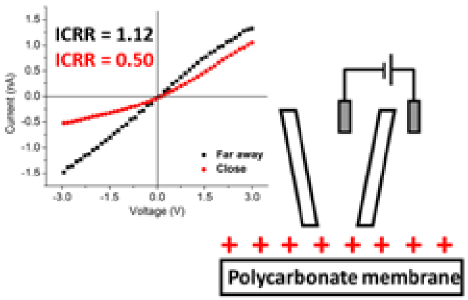


Image collected by Scanning Electrospray Microscopy (SESM) module develop with the Park XE-Bio. Two one micron polystyrene particles can be observed, where electrospray from a nanopipette provided feedback and position control.



Ion current rectification measurements of surfaces with Park XE-Bio. By measuring the current-voltage rectification response (ICRR) far away from a surface and close to a surface, the net surface charge can be deduced. In plots shown a positive surface charge is measured for a solution of lithium ions in propylene carbonate.

"WHAT I LIKE BEST IS SEEING STUDENTS WHO MIGHT BE INITIALLY AFRAID TO TAKE ANYTHING APART, END UP BUILDING THEIR OWN INSTRUMENTS OR MODIFYING INSTRUMENTS TO MAKE COOL NEW MEASUREMENTS. I START OUT POINTING THEM IN A DIRECTION AND GIVING THEM ACCESS TO SOME TOOLS (EG THE PARK XE-BIO), BUT BEFORE LONG THEY ARE DESIGNING AND RUNNING THEIR OWN EXPERIMENTS. IT IS A REALLY REWARDING PROCESS TO WATCH, MAYBE AS FUN TO WATCH THE STUDENTS DEVELOP AS TO GET TO MAKE NEW SCIENTIFIC DISCOVERIES, JUST A REALLY REWARDING JOB."

LANE BAKER,
ASSOCIATE PROFESSOR INDIANA UNIVERSITY

Dr. Lane Baker,
Associate Professor Indiana University

Lane Baker was educated at Missouri State University, Springfield, MO (BS Chem 1996) and Texas A&M University (Ph.D. 2001) working with Richard M. Crooks. He joined the group of Lloyd J. Whitman (2001) in the Surface Nanoscience and Sensor Technology Section of the Naval Research Laboratory as a National Research Council Postdoctoral Associate, conducting research on atomically resolved scanned probe microscopies. He then joined the group of Charles R. Martin (2004) at the University of Florida as a Postdoctoral Associate investigating polymeric nanopores for sensing and separations. He started as an Assistant Professor at Indiana University in the Analytical Chemistry Division (2006) and was promoted to Associate Professor with tenure in 2012. His research group is interested in four areas. (i) Transient and spatial measurement of ion concentrations with scanned probe microscopies. (ii) Electrospray from nanoscale pipettes. (iii) Electrochemistry in small domains.

http://www.indiana.edu/~bakergrp/wordpress/

How does studying electro chemical transports help with battery life and chemical degradation.

Electrochemical transport we have studied, in this case across a Nafion® membrane is one of the key steps in balancing charge between two halves of a significant number of really important next generation energy technologies (eg fuel cells). When the membrane loses the ability to selectively transport protons (H+), the overall operation can be compromised. With the Park XE-Bio and SECM-SICM probes we developed, we were able to observe the heterogeneity in membrane degradation. This could be a useful tool to help develop next generation membranes that have improved chemical durability.

Why is it important to understand how lithium affects surface charge?

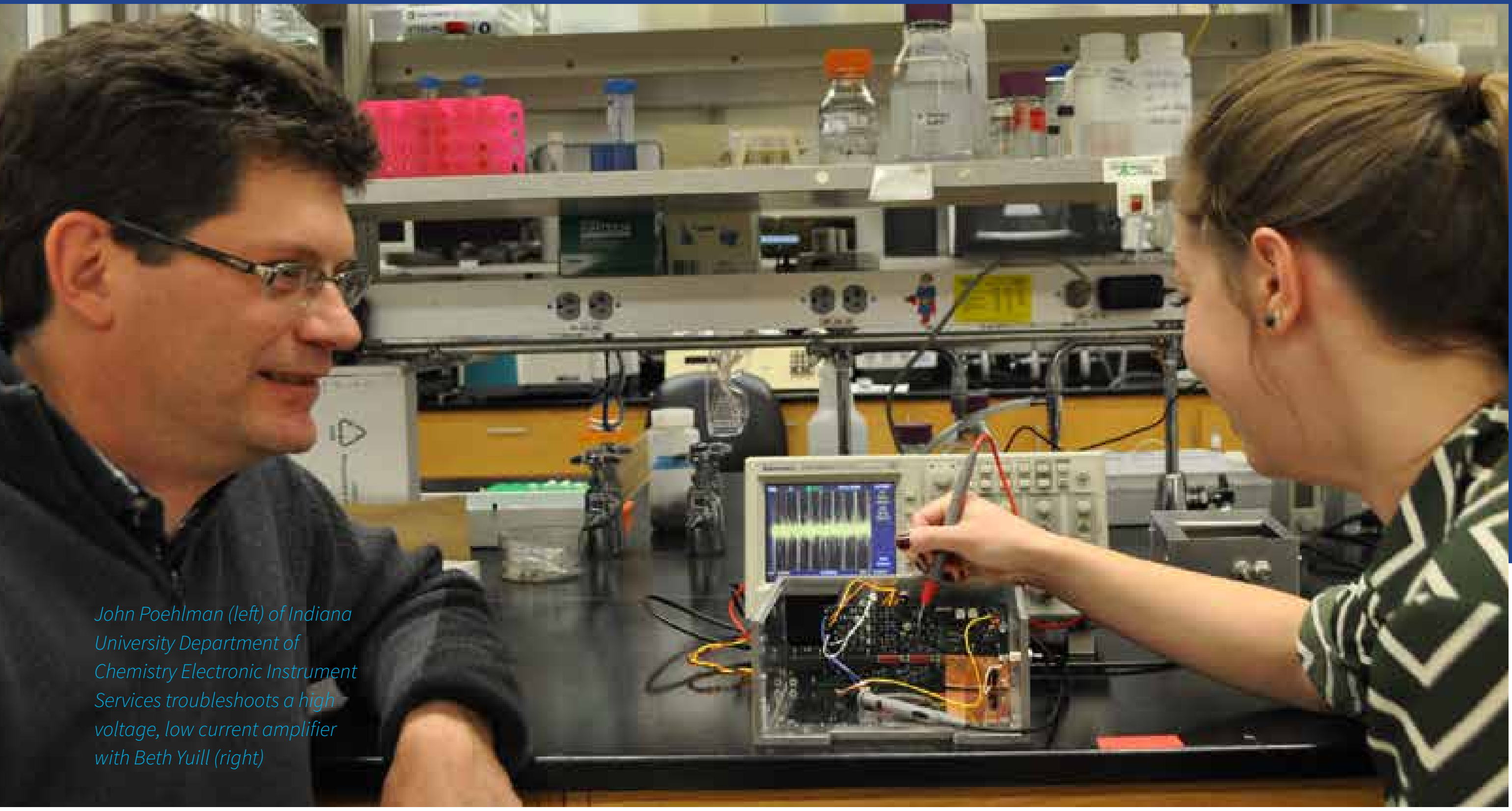
Lithium is the key player in lithium ion batteries, which can be found everywhere. But lithium ions, especially in non-aqueous solvents, which are commonly used in energy applications, can behave in unexpected ways. With our collaborators at the University of California-Irvine (Zuzanna Siwy and students) and Oak Ridge National Laboratory (Ivan Vlassiouk) we were able to make some really neat measurements that showed lithium ions adsorb polycarbonate films and form a surface with a net positive charge. This could be really important for nanostructuring battery materials, where the surface area increases will make surface charge an important consideration.

Why did you develop a new SICM using electro spray and how does it perform vs the traditional method?

We developed an electrospray imaging system (we call is Scanning Electrospray Microscopy, or SESM) to open new routes for surface patterning, and possibly for new routes to surface-desorption mass spectrometry techniques. SESM also gives us the chance to understand the electrospray process at really small scales, which is hard to do.

How is SICM helping to measure Ions and how is that different than how it was done in the past?

The big difference SICM makes is the ability to probe small scales, to make local



John Poehlman (left) of Indiana University Department of Chemistry Electronic Instrument Services troubleshoots a high voltage, low current amplifier with Beth Yuill (right)

measurements of ion transport. SICM is great because you can take high resolution images in operationally relevant (biological or electrochemical) solutions, and – even more importantly – there are a lot of chemical processes you can measure with SICM or hybrid versions of SICM (like SECM-SICM). In the past ten years the SICM community has really added a lot of exciting measurement ability to SICM.

How do you use Park SICM for your research and what are the key benefits of Park SICM?

We use the Park for several projects in my research group, especially for our energy related research and for development of scanning electrospray microscopy (SESM). The Park XE-Bio is really easy to use, so most students start out training on it. The Park also has a good physical design and the electronics give us good signal-to-noise. The ability to swap out the SICM head with the AFM head has also proven really useful in several experiments where AFM gives us nice complementary data.

How might we use AFM-based bioanalysis for the study of desease?

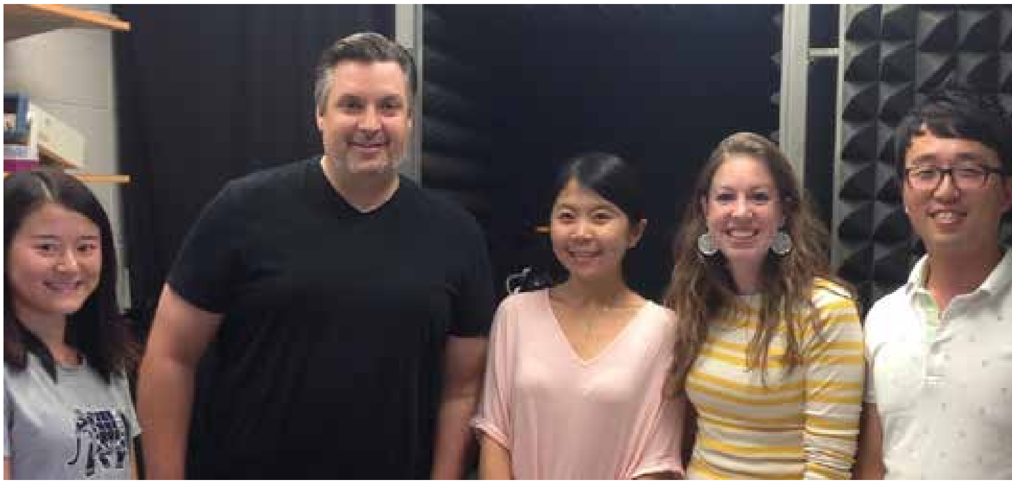
AFM is great for measuring a number of cellular properties, especially properties like cell stiffness, which can be very useful for understanding the physiology of disease. One of the more exciting applications of AFM are pull-off based mapping for cell surface receptors, this represents a really exciting, unique application of AFM in helping us understand biology.

Can you describe advances we might see in DNA research using SICM in the future?

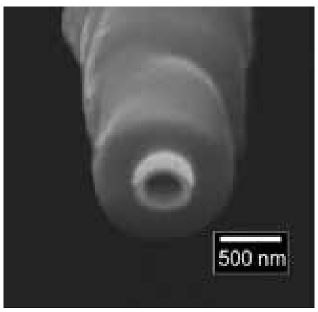
SICM has been used recently as a tool to sample DNA from subcellular regions in single cells, DNA which was then used to explore the genomics of the cell. I expect in the future this will prove especially powerful.

You worked with Lloyd Whitman who is now the Asst Director for NanoTechnology at the White House Office of Science and Technology Policty and he has done alot of work on bio sensors. Can you tell us about some of the projects you worked together on and their significance?

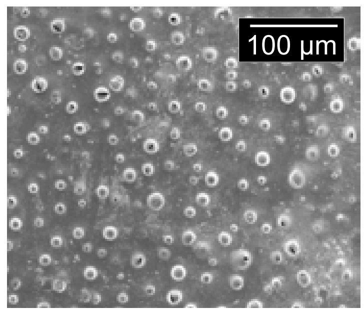
I was a NRC postdoctoral associate at the Naval Research Laboratory in Washington DC, and Lloyd was my mentor. In Lloyd's lab I got to work with a lot of really smart staff scientists (Arnaldo Laracuente, Tom Clark, Paul Sheehan) and other postdocs on biosensors and interfacial chemistry/physics. With Lloyd I got some good training on scanned probe microscopy, specifically scanning tunneling microscopy (STM). I was able to put that training to good use when I started my own research group doing SICM.



Dr. Lane Baker and his team pictured above with Brian Choi of Park Systems (far right) in front of the Park AFM

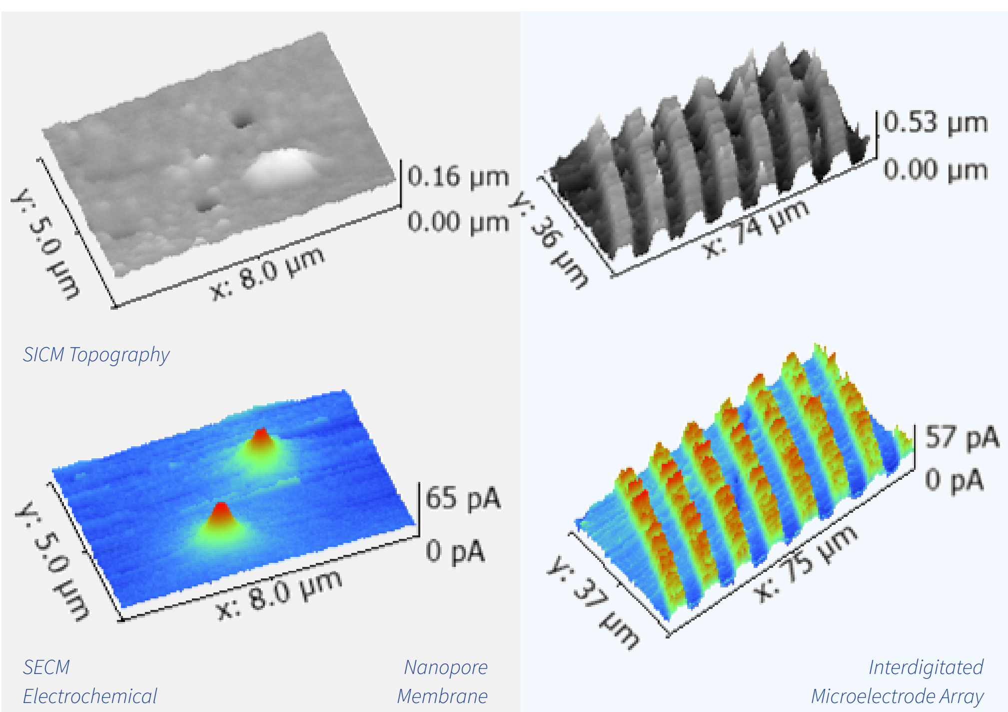


A hybrid scanning electrochemical microscopy – scanning ion conductance microscopy (SECM-SICM) probe. The central barrel is used for SICM and provides distance control, the crescent-shaped gold electrode is used to measure faradaic electron transfer. The entire pipette is insulated in a layer of vapor-deposited parylene.

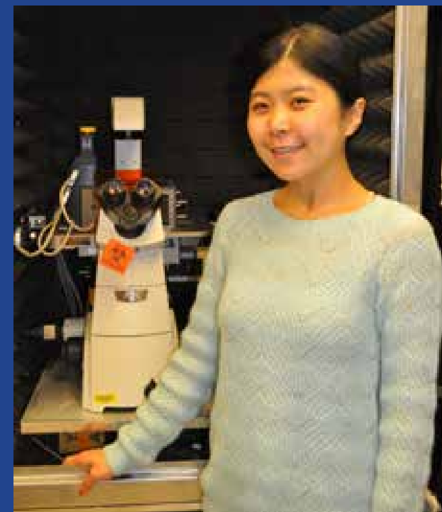


This image shows a Nafion© membrane that has been chemically degraded. With SICM-SECM, changes in ion transport through the degraded membrane were observed.

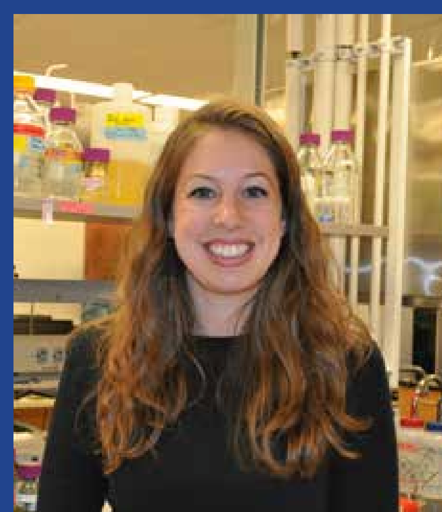
(Top) Scanning ion conductance microscopy (SICM) images of nanopores in a polymer membrane and of an interdigitated microelectrode array.



(Bottom) Scanning electrochemical microscopy (SECM) is used to meaure diffusion of redox active molecules through the nanopores of the membrane or to measure redox cycling at the microelectrode array.



Wenqing Shi studied chemistry at Wuhan University and received her BS in 2011. She is currently conducting her PhD research at Indiana University under the mentorship of Prof. Lane Baker. Her research interests includes fabrication of multi-functional nanoelectrodes, understanding fundamentals ion transport properties at nanoscale, and applications of multifunctional nanoelectrodes as probes for scanning ion conductance microscopy-scanning electrochemical microscopy (SICM-SECM).



Beth Yuill is a PhD candidate in the Department of Chemistry at Indiana University. Her research focuses on development of scanning electrospray microscopy (SESM), which utilizes nanopipettes as probes and electrospray current as a mechanism for topographical imaging feedback. Her present motivations include advancement of SESM to a mass spectrometry imaging platform. She obtained her B.S. in Chemistry from the University of Michigan in 2012.

ATOMIC FORCE MICROSCOPE (AFM) TECHNICAL ARTICLE

AUTOMATIC DEFECT REVIEW AFM WITH ENHANCED VISION

ESSENTIAL TOOL FOR HARD DISK MEDIA FAILURE ANALYSIS

By Dr. Ardavan Zandiatashbar, Ph.D., Research Scientist Park Systems Inc., Santa Clara, California.

Failure analysis engineers in data storage rely on atomic force microscope (AFM) as one of the key techniques for obtaining three-dimensional information about the topological defects on hard disk media samples. This information is critical for proper identification of defects and eliminating defect sources. Although optical microscopy can provide a quick image of sample surface, the technique has limited resolution due to light wavelength. On the other hand, electron microscopy can provide higher resolution but it is essentially a destructive technique and provides only a two-dimensional image. AFM provides the highest vertical and lateral resolution and provides a three-dimensional topography of the sample surface [1]. The conventional AFMs were known to have limited throughput and tip life since imaging was performed in destructive mode. To address these limitations of AFM, Park Automatic Defect Review (ADR) AFM has been developed and introduced in mid 2000s for a non-destructive high throughput 3D imaging of defects. This solution was widely accepted and welcomed in failure analysis (FA) labs globally. In this article we introduce the latest generation of ADR-AFM. The new ADR-AFM utilizes enhanced vision technique to facilitate locating defect of interest (DOI). This solution carries the commercial name of Park NX-HDM.

The main objective of the FA lab for hard disk media is studying the defects and investigating the possible defect sources to improve yield management. For this purpose, defect study consists of two main steps: defect inspection, and defect review. In defect inspection, an inspection tool searches the media surface using optical, electron beam, or magnetic probe to find the location of the defects. The output is a map of defects which indicates their distribution over the sample surface. The defect map can also be used for locating the DOI for further investigation. Although the inspection tools have high throughput and are able to test several samples per hour, they are limited in resolution and are not suitable for characterizing each defect effectively. Therefore some of defects are selected for defect review and detailed characterization. In defect review, defects of interest are characterized to obtain a high resolution image and classified accurately. The defect review process relies on techniques that can provide high resolution topographical information about each defect. The examples for defect review techniques are AFM and S/TEM. Unlike inspection tools, the review techniques are relatively slower and need to accurately locate DOI for imaging.

Locating DOI is the major challenge for defect review tools. There is a difference between the coordinates of DOI on the stage of inspection tool versus its coordinates on the stage of review tool. This difference is referred to as stage error. The stage error is generally larger for in-house inspection tools (e.g. AOI, Tester) comparing to commercial inspection tools (e.g. KLA-Tencor Candela). The process of defect inspection and review is depicted schematically in Figure 1a. In the past and before introducing ADR-AFM, manual AFM was used for imaging DOI. To facilitate locating DOI in manual AFM, FA engineers initially marked every single defect. As shown in Figure 1a hard disk media is inspected with an automated optical inspection (AOI) tool which is the most commonly used equipment in mass production and the map of defects is generated. Then the disk is investigated by an optical microscope for locating and marking each DOI. Marking defects was done by making observable scratches around each defect to facilitate finding it through the optics of AFM (Figure 1b). This process path is shown by green arrows in Figure 1a. This included performing multiple survey scans to find DOI. This method had a low throughput of 10 defects per day in best scenario. In addition, conventional AFMs were using destructive scanning method (tapping mode), therefore, tip life was limited due to performing multiple large survey scans that was required for finding each defect and the whole process resulted in high cost of ownership.

The first generation of Park ADR-AFM had been introduced in order to address the limitations of conventional AFMs in the defect study process. This solution provided two major advancements comparing to conventional AFMs. First, it has a significantly improved throughput up to 10 defects per hour as a result of automated process. Since the system was operated by automated software, the user

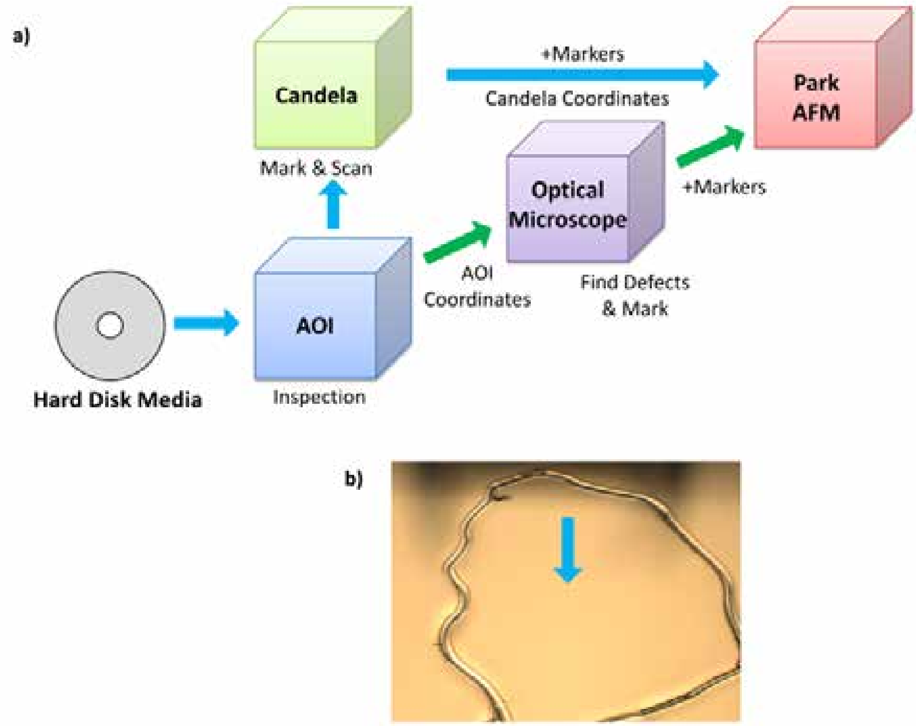


Figure 1.
a) Current process of defect inspection and review for hard disk media. The green path shows the process path for conventional AFMs. The blue path shows the process with the first generation of Park ADR-AFM. b) A defect on hard disk media sample which is marked by a surrounding scratch. The defect is hardly visible in optical vision of AFM.

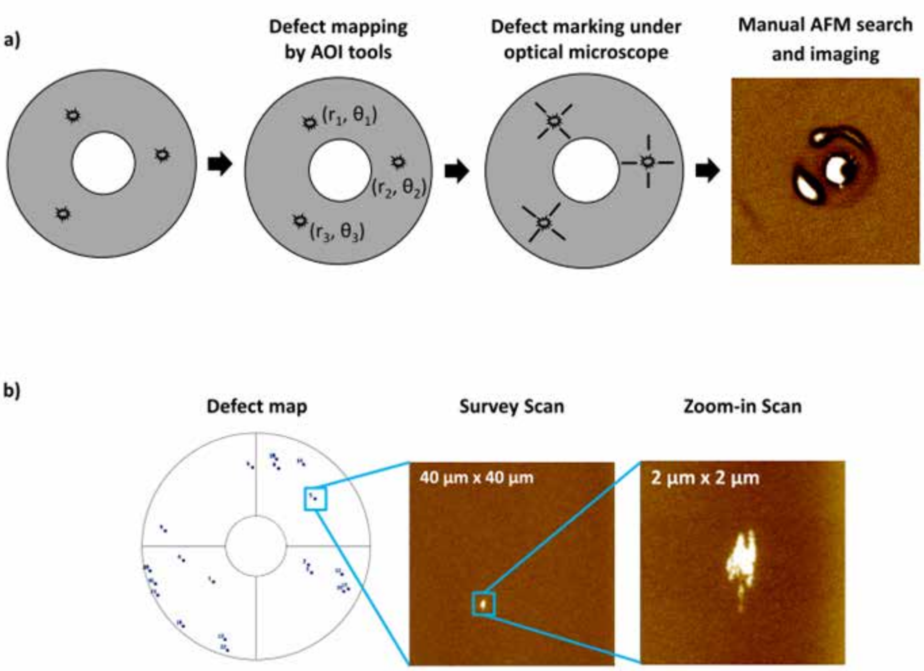


Figure 2.
The AFM based defect study process is schematically shown for a) manual AFM, b) ADR-AFM. In ADR-AFM, locating the defect from defect map, survey scan, final zoom-in scan are performed automatically by the system.

did not need to be present during the scan. Hence the system could continue locating and imaging a large number of defects on its own (even overnight). This improved the throughput of an AFM system significantly. Second, the imaging was performed in non-contact mode. Using non-contact mode imaging extended the tip life, which is critical for automated defect review process and getting consistent data. Therefore a single tip could be used for a significant number of images without user being present.

The ADR-AFM process is depicted in Figure 2 and compared to conventional process using manual AFM. In conventional AFM imaging (Figure 2a), the sample surface was first searched with an inspection tool. This was followed by marking the DOI on the surface using optical microscope. After laborious efforts of marking each DOI, the sample was brought to AFM for imaging. Finding the defect in AFM required visual search in vision and followed by multiple low and high magnification scans (green path in Figure 1a). In ADR-AFM, DOI coordinates from inspection tool are initially imported which is followed by coordinate alignment. After this step, automated software moves the tip to each defect, performs a survey scan, images the defect, and classifies the defect automatically. With ADR AFM throughput of defect review increases up to 100 defects per day. In addition, since this process is fully automated, engineer do not need to stand by and operate the system during the runs which frees up their time and boosts productivity.

The survey scan size of old Park ADR-AFM was selected based on the stage error of the inspection tool used to generate defect maps. A 40 µm × 40 µm survey scan was typical to cover for a stage error up to 20 µm between AFM and Candela. Since the stage error of AOI tools are very large (≥ 50 µm), using a linkage tool (e.g. Candela) with smaller stager error was necessary in order to have the process of defect study complete as shown by blue path in Figure 1a. A set of 16 markers were added to each wafer before the inspection run by Candela to be used for sample alignment in Park ADR-AFM.

The new generation of Park ADR-AFM is introduced recently for both hard disk media and 300 mm wafers [2]. Bright field enhanced vision is introduced in the new generation of Park ADR-AFM. It provides the ability to observe defects in ADR-AFM optical field of view (FOV). Bright field enhanced vision utilizes differential frame averaging technique and precise movement of sample by decoupled XY scanner to observe small defects that are hardly visible through regular

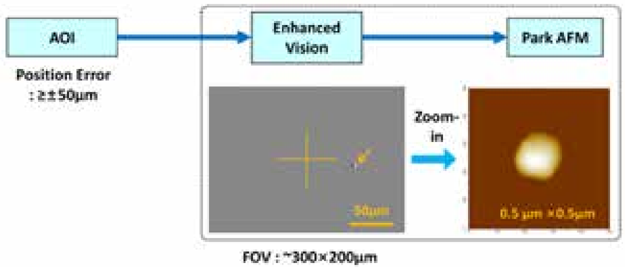


Figure 3.
An example of enhanced vision image and how it facilitates linkage between the AOI tool which has larger stage errors and Park ADR-AFM.

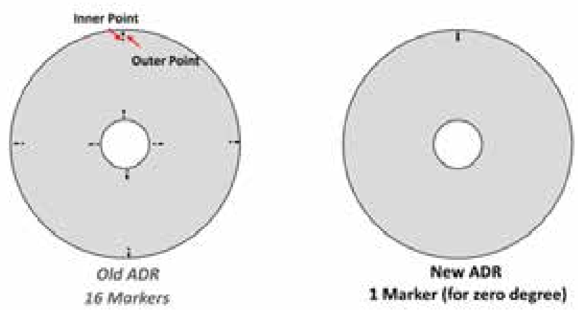


Figure 4.
The schematic shows the sample alignment process in the first (left) versus the new (right) generation of Park ADR-AFM. In the latest Park ADR-AFM only one marker is needed to indicate zero-degree location of hard disk media samples.

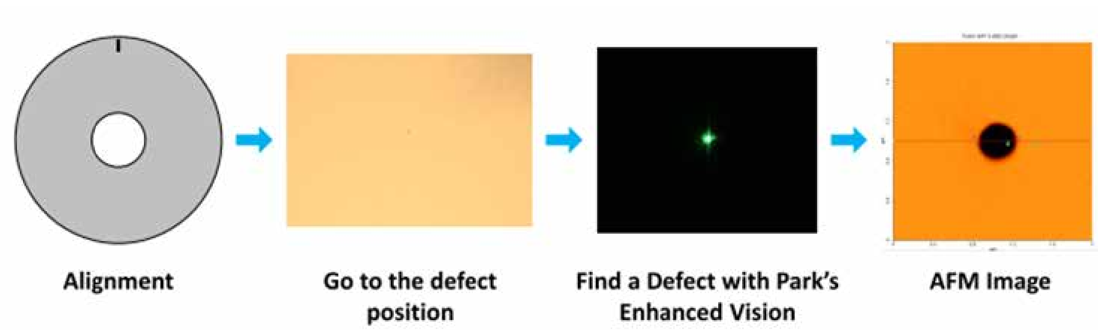


Figure 5.
The new ADR-AFM process with newly introduced dark field enhanced vision for hard disk media with reflective surface.

optics of the system. Decoupled XY and Z scanner structure of Park ADR-AFM enables using differential frame averaging by collecting optical images of the sample surface at two precisely separated positions of XY scanner. The differential image of the frames of sample surface collected at two different positions enhances the contrast of small defects and makes them visible in optics of ADR-AFM. Since the FOV of ADR-AFM is larger than the maximum survey scan size, enhanced vision enables the ADR-AFM to accommodate even larger stage errors of inspection tools (Figure 3). Collecting a typical bright field enhanced vision image takes between 1 – 30 sec for each defect.

In addition to bright field enhanced vision, a new sample alignment algorithm is developed to facilitate the linkage between the ADR-AFM and inspection tools. In the first generation of ADR-AFM, a sample alignment by using 16 markers was needed to align the sample on the ADR-AFM stage. The coordinates of 16 markers were generated by Candela, and were matched with the coordinates of ADR-AFM stage. In the next generation of ADR-AFM, only one marker is needed for sample alignment. The new alignment process consists of one coarse and one fine alignment step. In the coarse alignment, three points at the circular perimeter of the hard disk media sample is used for finding the sample center, and a zero-degree marker is used for finding the rotation of the sample. In the fine alignment step, ADR-AFM uses few larger defects for minimizing the remaining positioning errors by utilizing enhanced vision. The new alignment process is faster and more convenient for sample alignment comparing to the first generation of ADR-AFM. In addition, it can also be used as a tool for evaluating the stage error of AOI or other inspection tools (Figure 4).

Dark field enhanced vision is introduced in the latest generation of Park ADR-AFM. The new dark field enhanced vision enables AFM to observe defects in a short time on reflective surfaces by collecting the light scattered due to surface defects. For this purpose, a new hardware module is developed and implemented in the AFM system. In this module a laser beam is emitted to the location of interest on the sample. The beam angle of incidence is larger than zero degrees such that the direct beam reflection is not collected by the on-axis optics of ADR-AFM. For a reflective sample, majority of laser beam is following the expected reflection path with similar angle of incidence. In case the surface a topological defect is present on the sample surface, part of the laser beam will be scattered in different directions other than the regular reflection path and are collected by on-axis ADR-AFM optics. The collected frame is an image of the surface with collected scattered light from the defects. Examples of standard optical and dark field enhanced vision images are shown in Figure 5.
The upgraded ADR-AFM process with dark field enhanced vision is presented schematically in Figure 5. In the new process, after the sample alignment, ADR-AFM goes to defect location, recognizes the defect using dark field enhanced vision (without AFM scanning), and performs the imaging, analysis, and classification. The new process enables ADR-AFM to minimize the positioning error. As a result the required survey scan is also minimized and the throughput is increased. As a result, it enables ADR-AFM to accommodate defect maps from AOI systems that have large stage errors. The ability to see the defects by enhanced vision enables ADR-AFM to be used as the reference tool for evaluating the stage errors of different inspection tools.

The results of a defect review by ADR-AFM on a 95 mm hard disk media sample are shown in Figure 6. The defect coordinates were provided by an in-house inspection tool with large stage error (> 50 μm). Dark field enhanced vision has been used for locating the defects. As the result, ADR-AFM was able to find 33 out of 37 defects successfully using the addition of enhanced vision. The defects are classified to two groups of pit and bump by ADR-AFM. An example of each group is depicted in Figure 7. In this figure dark field enhanced vision images and AFM images of defects are shown. ADR-AFM was able to find defects with vertical dimension as low as < 3nm.

In summary, the latest generation of Park ADR-AFM is equipped with new bright field and dark field enhanced vision modules. The bright field enhanced vision utilizes frame averaging technique

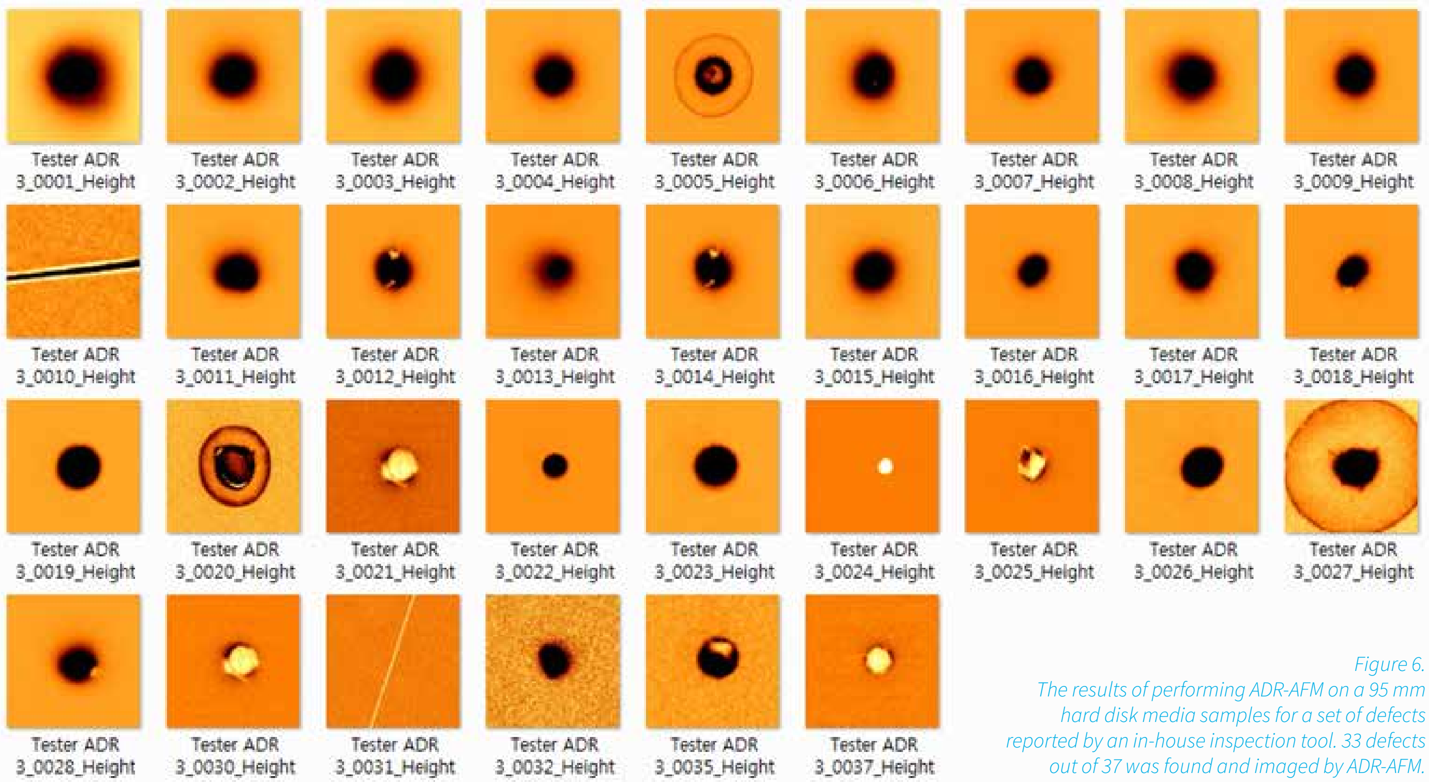


Figure 6.
The results of performing ADR-AFM on a 95 mm hard disk media samples for a set of defects reported by an in-house inspection tool. 33 defects out of 37 was found and imaged by ADR-AFM.

and ADR-AFM's decoupled XY scanner to obtain a high resolution optical image of the sample surface to help locating the DOI. Dark field enhanced vision is enabled by collecting the scattered laser signal by the on-axis vision of ADR-AFM and enables detecting defects on the surface of reflective surfaces. Park ADR-AFM uses non-contact mode imaging and therefore is imaging the samples in a non-destructive method. Park ADR-AFM with enhanced vision modules and updated alignment algorithms is used for high throughput AFM based defect review. Additionally, ADR-AFM with enhanced vision is a potential reference tool for evaluating the stage error for in-house inspection systems that are being developed or maintained.

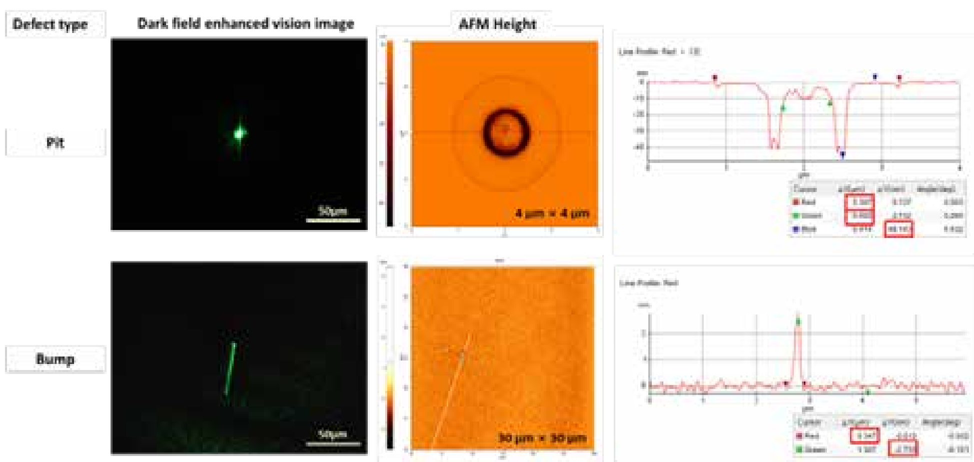


Figure 7.
Representative pit and bump type defects on a hard disk media samples which were found and imaged by ADR-AFM. The dark field enhanced vision images are shown side by side the AFM images and selected profiles of the defects.

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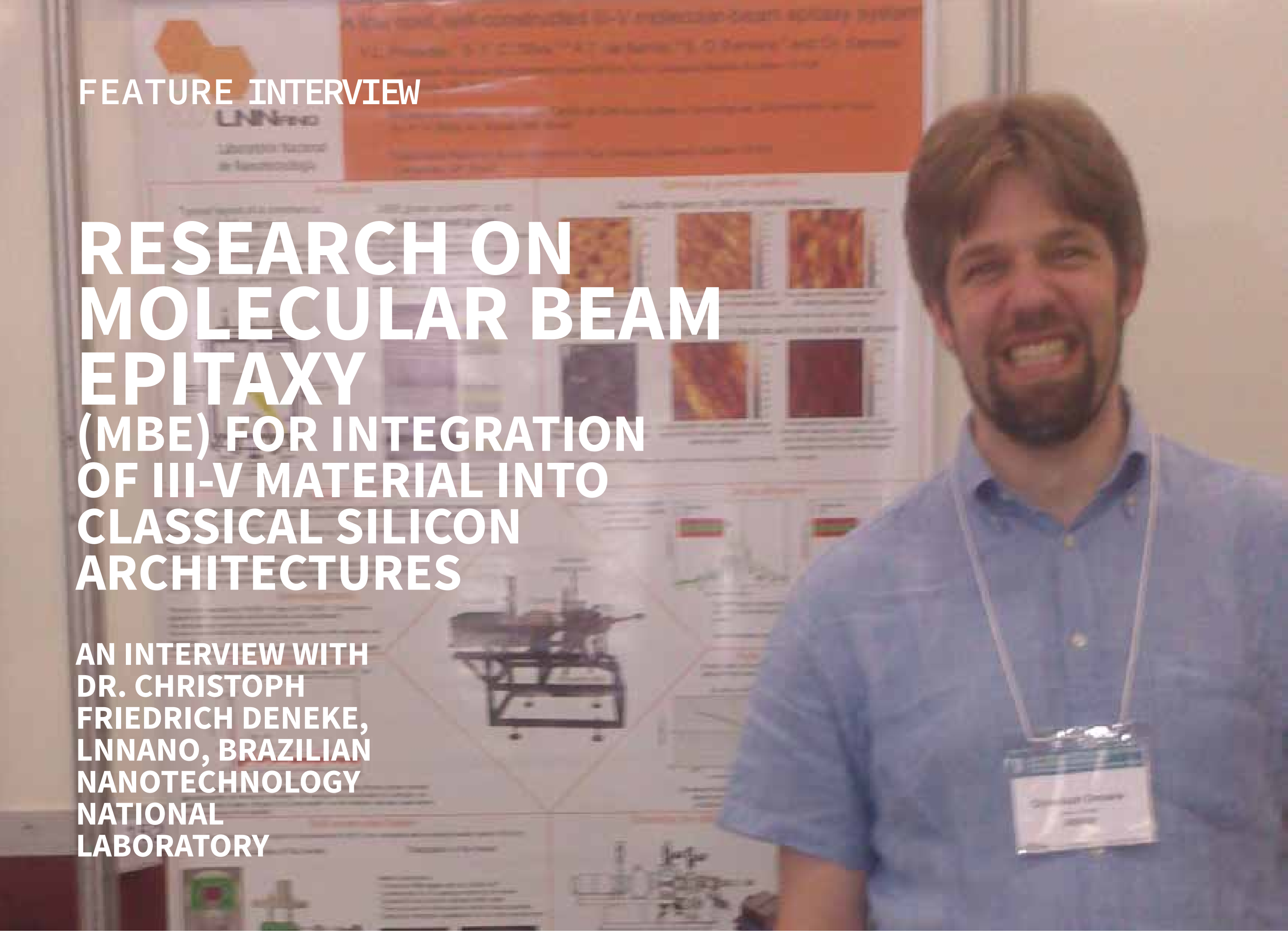
[1] Smith, G. T., Industrial Metrology: Surfaces and Roundness, Springer, London, 103-105 (2002).

[2] Ardavan Zandiatashbar et al., "High-throughput automatic defect review for 300mm blank wafers with atomic force microscope," in Proc. SPIE 9424, Metrology, Inspection, and Process Control for Microlithography XXIX, 2015, p. 94241X.

Dr. Ardavan Zandiatashbar is an application scientist at Park Systems. Prior to Park he worked as an adjunct faculty at School of Engineering, Rensselaer Polytechnic Institute, Troy, NY. Ardavan received his PhD in Mechanical Engineering for his work on studying multi-scale mechanical properties of graphene-filled epoxy nanocomposites in 2012. During his doctoral studies, he worked with Park Systems and Veeco AFM machines. His main research was performed using a Park XE-100 atomic force microscopy system to study the mechanical properties of defective graphene sheets in a collaborative effort with Columbia University. He has been also active in leadership and service and has been selected as a member of Phalanx Honor Society at Rensselaer.



RESEARCH ON MOLECULAR BEAM EPITAXY

(MBE) FOR INTEGRATION OF III-V MATERIAL INTO CLASSICAL SILICON ARCHITECTURES

AN INTERVIEW WITH DR. CHRISTOPH FRIEDRICH DENEKE, LNNANO, BRAZILIAN NANOTECHNOLOGY NATIONAL LABORATORY

What area of scientific discipline do you focus on and what type of research are you doing?

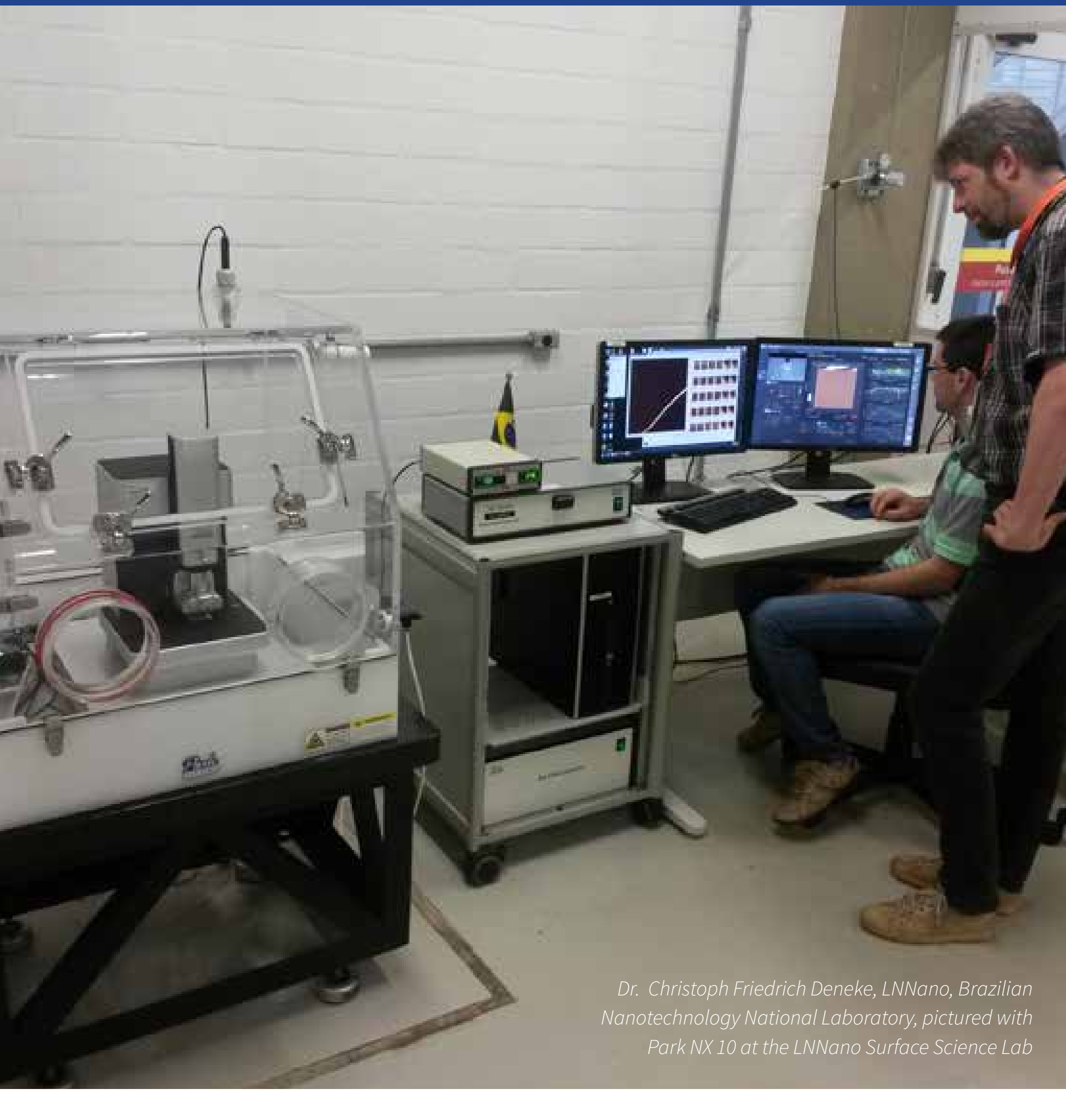
Our group inside the Brazilian Nanotechnology National Laboratory (LNNano) runs the scanning probe microscopy facilities. We are an open user facility doing also in-house research. Therefore, our area of science and interested is quite board and ranges from condensed matter physics with a focus on semiconductor epitaxy to general material science and surface characterization of samples from our users. In more detail, we are studying the formation of self-assembled nanostructures in the InGaAs system on complained membranes, but are also involved in general scanning probe microscopy techniques applied from magnetic characterizationof steel to electrical characterization of diverse systems like graphene oxide or polymers derived from celluloses.

Can you describe your research and what the benefits are?

Our in-house research is focused on molecular beam epitaxy (MBE). As pointed out some years ago in a Nature Nanotechnology article, MBE is one of the funding techniques of nanotechnology. It allows the perfect crystal growth of different semiconductor materials on each other, so called heterostructures. Such structures are used in our days to provide high quality electrical, optical and electro-optical devices such as lasers and heterojunction bipolar transistors.

We investigate the growth of semiconductor heterostructures in the III-V system. In classical epitaxy, bulk semiconductor wafers are used for material deposition – we want to use compliant, extremely thin semiconductor membranes as substrates. Our investigation started with basic growth studies to understand, how the material behaves on these novel substrates and aims for the

> **"WE LIKE THE NEW PARK SYSTEMS SMARTSCAN SOFTWARE, WHICH MAKES THE ACQUISITION OF THE STANDARD ATOMIC FORCE MICROSCOPE (AFM) IMAGES IN HIGH QUALITY VERY EASY. FURTHERMORE, THE LARGE FLEXIBILITY OF THE PARK NX10 (ONE OF OUR THREE AFMS) IS IMPORTANT FOR US. THE AVAILABILITY OF VARIOUS TECHNIQUES AS WELL AS A THIRD INTEGRATED LOCKIN MAKES THE INSTRUMENT THE MICROSCOPY OF OUR CHOICE FOR EFM MEASUREMENTS AS WELL AS THE CAPACITIVE COUPLING TECHNIQUES."**
>
> **DR. CHRISTOPH FRIEDRICH DENEKE, LNNANO, BRAZILIAN NANOTECHNOLOGY NATIONAL LABORATORY**



Dr. Christoph Friedrich Deneke, LNNano, Brazilian Nanotechnology National Laboratory, pictured with Park NX 10 at the LNNano Surface Science Lab

creation of well know device structures in the III-V system.

We hope that with these compliant substrates allow a new class of semiconductor device. We think that we can grow heterostructures that cannot be grown on classical bulk wafer substrates.

Why is your work important in today's society?

The trend in modern computer and semiconductor technology request stronger integration. Furthermore, we have to reduce the energy footprint for environment, but also for customer application – everyone complains, the smartphone drains the battery too fast, right? We hope to address these demands with our research making computers less energy hungry, help to improve integration and the production less resource demanding.

Our work as an open user facility benefits directly the Brazilian society by educating a new generation of Brazilian researchers and helping the research community to gather their results.

How do you use Atomic Force Microscopes in your work?

For our in-house research, we use AFM mainly for topographic images of the samples after material deposition. It is our standard tool to judge the sample quality, characterize the diffusion behavior of the deposited material and understand how to change the parameters of the epitaxial growth.
For our users, we offer a large variety of AFM based techniques, with electric force microscopy or Kelvin force microscopy being the important ones. In the last year, we started to rediscover the know technique to do capacitance coupling providing new insides in the samples.

Dr. Christoph Friedrich Deneke, LNNano, Brazilian Nanotechnology National Laboratory

Christoph Friedrich Deneke (CD) got his final degree (Dipl.-Ing.) from the TechnischeUniversität Darmstadt (Germany) in 2000. Afterwards, he moved to the Max-Planck-Institute for Solid State Research in Stuttgart (MPI-FKF) to work with the MBE group of the von Klitzing department. He received his PhD in Physics (Dr. rer. nat.) for his work on rolled-up nanotubes at the MPI-FKF from the Universität Stuttgart (2005). He stayed as a PostDoc with the MBE group at the MPI-FKF (2005-2007) still working with free-standing semiconductor nanoobjects. In 2007, he was invited to join the IFW Dresden at the new founded Institute for Integrative Nanotechnology. During the time in Dresden (2007-2011), he established the semiconductor growth facilities as well as broadened his research interest.

Since 2011 CD is at the Laboratório Nacional de Nanotecnologia (LNNano) as head of the surface science group (Laboratório de Ciência de Superfícies - LCS). His research focus on nanostructures evolving from nanomembranes and 2D materials. He specialized in the structural characterization of strain driven nanostructures (transmission electron microscopy, X-Ray diffraction) and is interested synthesis (thin film growth, MBE, lithography) and characterization (TEM, SEM, FIB, XRD) of semiconductor nanomembranes and self-assembled structures based thereon. Recently, he developed an interest in scattering scanning optical near field microscopy applied to study 2D materials like graphene and graphene based heterostuctures.

http://lnnano.cnpem.br/laboratories/mta/

"WE INVESTIGATE THE GROWTH OF SEMICONDUCTOR HETEROSTRUCTURES IN THE III-V SYSTEM. THE PAST HAS SHOWN THAT MBE AND SEMICONDUCTOR EPITAXY ARE ONE OF THE BACKBONES OF NANOTECHNOLOGY AND INFORMATION PROCESSING AND WE WILL HAVE TO EDUCATE MANY GENERATIONS OF SEMICONDUCTOR GROWERS, NOT ONLY FOR BASIC RESEARCH BUT ALSO FOR INDUSTRY."

DR. CHRISTOPH FRIEDRICH DENEKE, LNNANO, BRAZILIAN NANOTECHNOLOGY NATIONAL LABORATORY

What features of Park AFM do you feel are most vital for success and how is it important in your process?

We like the new Smartscan software, which makes the acquisition of the standard AFM images in high quality very easy. Furthermore, the large flexibility of the Park NX10 (one of our three AFMs) is important for us. The availability of various techniques as well as a third integrated lock-in makes the instrument the microscopy of our choice for EFM measurements as well as the capacitive coupling techniques.

What advancements do you see in the future using AFM that can enhance or improve current methods?

The development of user-friendly interfaces and software is very important. We have a lot of users from – let's call it – non-classical AFM fields like Dentists, organic chemistry or Archology. Whereas the new Smartscan software provides a very easy interface and therefore easy access to AFM, we miss the same functionality for techniques like MFM or EFM. Currently, we help those researchers with data acquisition and evaluation, but easier software and interfaces will open these methods to a completely new group of users.

What areas of scientific knowledge will benefit from your research?

We contribute mainly to the broad are of classical nanoscience or nanotechnology as well as to semiconductor science. We add to the understanding, how to integrate self-assembled nanostructures into functioning semiconductor devices.

Describe how your research can be applied in industry?

Semiconductor industry is struggling with the integration of III-V material into classical silicon architectures. Whereas we will not solve this problem – simply because of the tremendous complexity of making computer chips and memory devices – we hope, we can contribute and show a possibility, how one could achieve this in the future.

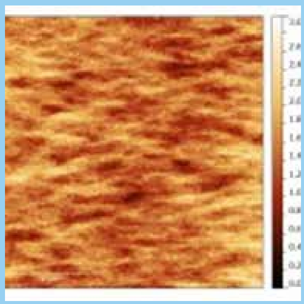
What do you see in future developments in your area of research?

The past has shown that MBE and semiconductor epitaxy are one of the backbones of nanotechnology and information processing. I assume, it will keep its roll there and we will have to educate many generation of semiconductor growers, not only for basic research but also for industry. It seems that in the research environment there is a shift away from basic studies to device oriented research showing how the field becomes more device and application oriented.

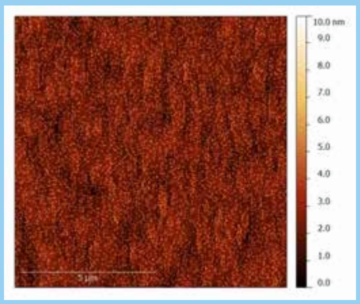
"MBE IS ONE OF THE FUNDING TECHNIQUES OF NANOTECHNOLOGY. IT ALLOWS THE PERFECT CRYSTAL GROWTH OF DIFFERENT SEMICONDUCTOR MATERIALS ON EACH OTHER, SO CALLED HETEROSTRUCTURES."

DR. CHRISTOPH FRIEDRICH DENEKE, LNNANO, BRAZILIAN NANOTECHNOLOGY NATIONAL LABORATORY

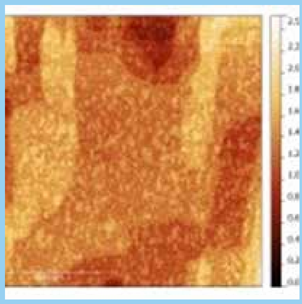
Dr. Christoph Friedrich Deneke shown above with students studying at LNNano



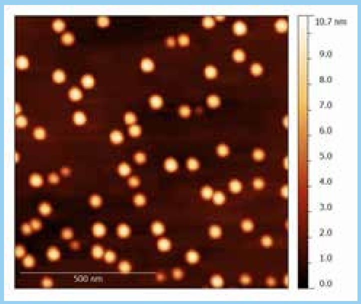
10×10 micron AFM image of a hydrogen cleaned substrate surface with 10 ML of GaAs redeposited after cleaning.



10×10 micron AFM image of InAs self-assembled islands grown at ca. 500°C.



AFM Image of the surface of a AlGaAs/GaAs heterostructure.



AFM image demonstrating the 1×1 1×1 micron area used for the dot statistic. - See more at: http://lnnano.cnpem.br/laboratories/mta/thin-film-growth-facilities/#sthash.cPDISisF.dpuf

GREETINGS:

At the close of a very meaningful year, I send warm greetings to all of you and some great news. Despite the deep recession and challenging economic environment affecting the stock markets, our company achieved solid performance in 2015, culminating in the announcement on December 17th, that we went public on the KOSDAQ stock market.

As we examine the industry closely, we see a steadily growing world-wide acceptance that our atomic force microscopes are far superior to any of the competition. This has resulted in a surge of orders from major new clients including Apple, JPL, TSMC and others. The joint technology development contract we signed earlier this year with imec, the world's top semiconductor consortium, has produced significant orders for production process equipment from major semiconductor giants including Micron, ST Microelectronics and others. In addition, NX-Hivac, our high-vacuum equipment is being sold to IBM Fishkill, attracting a great deal of attention. We also signed a sales agent agreement with JEOL, a specialized electron microscope company in Japan which is expected to improve our profile and provide major assistance in overall performance improvement within that country.

Much like previous years, I gave lectures on technology at various institutions including Stanford Univ., Lawrence Berkeley National Lab., Texas Instruments, Applied Materials, Toray Research Center, JEOL and others throughout the year. In addition, I gave lectures on company startup and entrepreneurship at Hanyang University, Yonsei University, Seoul National University, and Chung-Ang University. I also participated in the Presidential Advisory Council for Science and Technology, Future Preparation Committee, and writing of the national future strategy at KAIST, where I emphasized the importance of scientific technology and technology commercialization.

Looking back over this past year and remembering some of these precious moments, I humbly express my appreciation to everyone who has helped us to achieve these milestones. Our sincere pledge to you for the coming year is to meet your every expectation with focus and determination. I send best wishes for you and your family and hope you have a very happy new year!

"PARK SYSTEMS IS A KNOWLEDGE-INTENSIVE BUSINESS WITH A STRONG FOCUS ON R & D," COMMENTS DR. SANG-IL PARK, "THIS IPO DEMONSTRATES OUR AMBITION TO TAKE A QUANTUM LEAP FORWARD AS A PREMIER NANO-MEASUREMENT COMPANY, BASED ON OUR TECHNOLOGICAL COMPETITIVENESS AND A UNIQUELY DIFFERENTIATED PRODUCT LINE. WE HAVE A LONG HISTORY OF PROVIDING ACCURACY AND UNMATCHED SUPERIORITY IN AFM TECHNOLOGY, WHICH HAS BEEN THE HALLMARK FOR OUR SUSTAINED GROWTH."

SANG-IL PARK, PH.D.
CHAIRMAN AND CEO,
PARK SYSTEMS CORPORATION

Dr. Sang-il Park Stanford alumnus and founder of Park Systems presents at the AFM live demo and workshop at Stanford Nano Shared Facility (SNSF) in Nov 2015, part of continuing education offered by Park Systems Nano Academy which also includes Webinars. For a list of events go to http://www.parkafm.com/index.php/medias/nano-academy/webinars

PARK SYSTEMS

WORLD LEADING MANUFACTURER OF ATOMIC FORCE MICROSCOPES WITH AA RATING ANNOUNCES ONE MILLION SHARES IN IPO LISTING ON KOSDAQ

Dec. 17, Seoul, Korea

Park Systems, world-leader in atomic force microscopy (AFM) officially announced 1 million shares for its initial public offering on December 17th at KOSDAQ, which is a Korean version of NASDAQ, established in 1996 to be a capital supplier of venture and small and medium-sized businesses. The underwriter of the company is KB Investment & Securities Co. Ltd.

Park Systems received “AA” from two separate rating agencies on advanced technologies, becoming the first company that will be listed on the KOSDAQ in 2015 through the special technologies IPO program. Dr. Sang-il Park CEO and founder of Park Systems worked as an integral part of the group at Stanford University that first developed AFM technology and created the first commercial AFM in 1988.

“Park Systems is a knowledge-intensive business with a strong focus on R & D,” comments Dr. Sang-il Park, “This IPO demonstrates our ambition to take a quantum leap forward as a premier nano-measurement company, based on our technological competitiveness and a uniquely differentiated product line.”
“We have a long history of providing accuracy and unmatched superiority in AFM technology, which has been the hallmark for our sustained growth,” adds Dr. Park.

Park Systems, founded in 1997, is a global market leader in the AFM industry. Park Systemsholds 32 patents related to AFM technology, including True Non-Contact Mode™ using decoupled XY and Z scanners, PTR measurements of HDD application, NX-Bio technology using Scanning ion conductance microscopy (SICM) on live cell, 3D AFM, Full automation AFM operation software (SmartScan™). Park System’s major customers include thousands of prestigious universities and international research agencies world-wide and they are the premier supplier of AFM to all of the leading semiconductor and HDD manufacturers including Seagate and IBM. Park’s exclusive product line has evolved from a research tool to an industrial system for cutting edge technology companies where unmatched performance has resulted in user-customized product lines at leading manufacturers world-wide.

Additional accelerated revenue growth is projected thru a partnership announced earlier this year with IMEC, a worldwide nano-electronics research center, for the next generation of nano-instrumentation for inline atomic force microscopy technology development. This partnership extends to a wide-ranging customer base from the global semiconductor consortium members and major institutions in the future.

Investments in Korean companies are on the rise with strong growth prospects expected, demonstrated by the significant increase in market capitalization from KRW 32 trillion at the end of 2004 to 203 trillion at the end of the first half of 2015, and the average daily trading value which has grown from KRW 0.6 trillion to 3.5 trillion in the same periods.

Dr. Sang-il Park, Founder and CEO of Park Systems presents at a free workshop and live demo as part of Park Nano University on November 9, 2015 at The Molecular Foundry at Berkeley. The Molecular Foundry is a Department of Energy-funded nanoscience research facility located at the Lawrence Berkeley National Laboratory in Berkeley, CA that provides users from around the world with access to cutting-edge expertise and instrumentation in a collaborative, multidisciplinary environment.

Park Systems booth at Materials Research Society's (MRS) Fall Meeting & Exhibit in Boston,MA where Park demonstrated the latest AFM technology including SmartScan™, revolutionary point and click imaging software that lets even inexperienced, untrained users produce high quality nanoscale imaging through a single click of a mouse in auto mode to achieve reliable images in five times the normal speed of a traditional AFM.

Dr. Luc Van den hove (President & CEO, Imec) and Dr. Sang-il Park (Chairman & CEO, Park Systems)

Park Systems and JEOL sign a distribution agreement for Japan Market. JEOL is a leader in bringing high performance electron optics and analytical technology products to the global market for world-class scientific and metrology instruments, industrial equipment, and medical applications. Mr. Shin-ichi Watanabe (Center), Director and Executive Vice President, and Chairman of JEOL Asia PTE Ltd and JEOL (Beijing) Co., Ltd and Dr. Sang-il Park (Center), CEO and Chairman of Park Systems Corporation