NANOscientific

FALL 2014

The Magazine for Nanotechnology

SEMICONDUCTOR
SPECIAL EDITION

HIGH RATE NANOSCALE PRINTING

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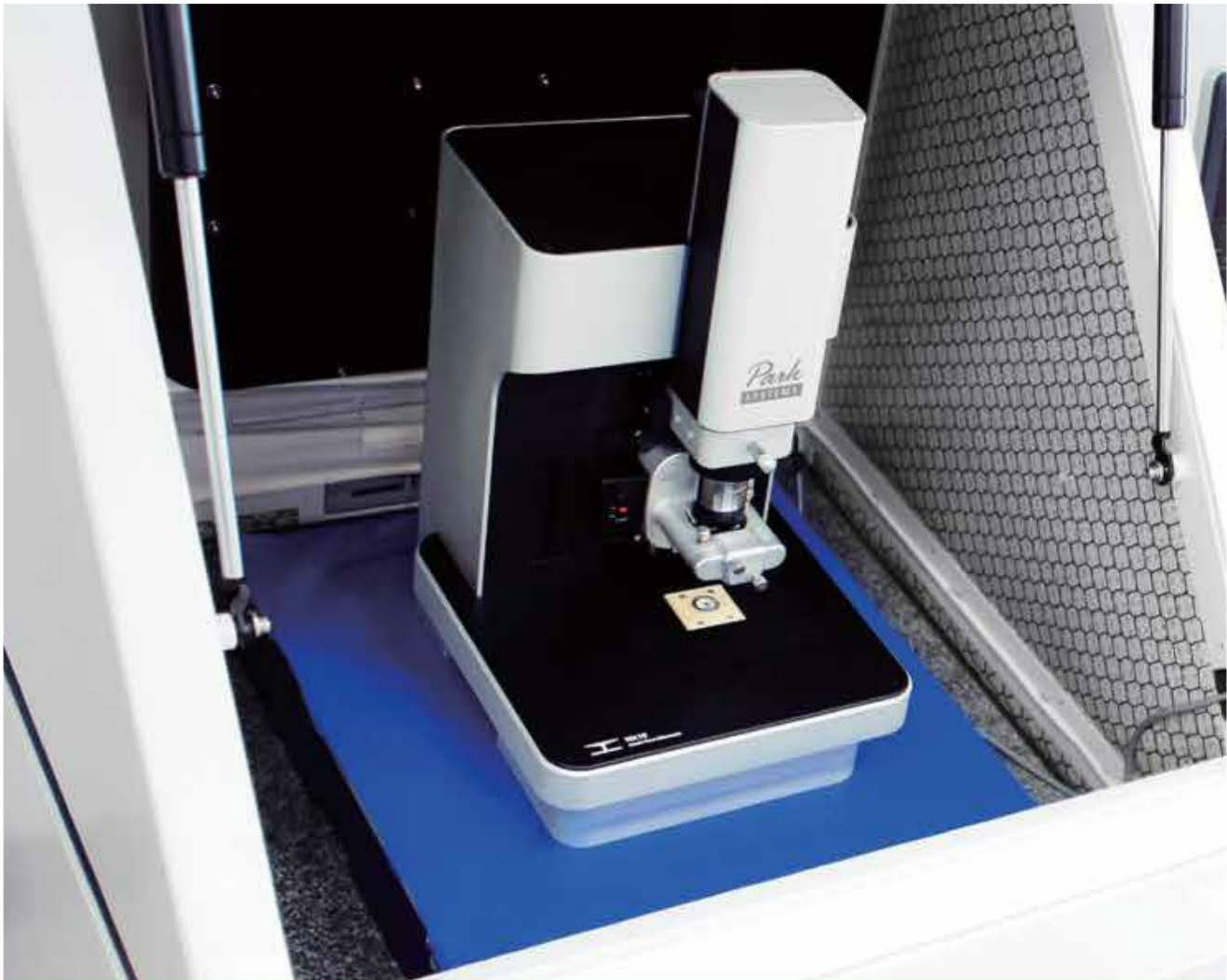

The Most Accurate Atomic Force Microscope

Park
SYSTEMS

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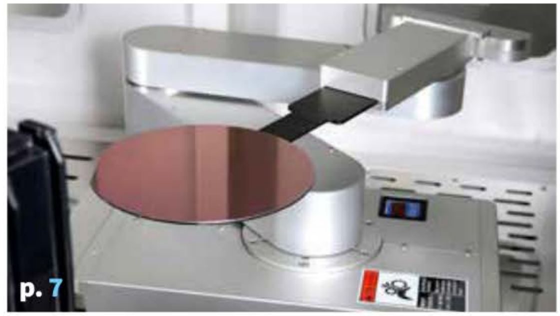
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NANOscientific
The Magazine for Nanotechnology

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NANOscientific is published quarterly to showcase advancements in the field of nano science and technology across a wide range of multidisciplinary areas of research.

The publication is offered free to anyone who works in the field of Nanotechnology, Nano Science, Microscopy and other related fields of study and manufacturing.

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Park SYSTEMS

MESSAGE
FROM EDITOR

Keibock Lee, Editor-in-Chief

Science and engineering at nanoscale is indeed one of the fastest growing segments in the new world economy, one with a powerful impact on our society and our lives. In this pioneering magazine, **NanoScientific**, we will bring you the latest advances on nano-related tools for imaging and metrology, and their applications that are unveiled at unprecedented speed, as nano science and technology becomes the future of scientific exploration.

Nanoscale technology spans across all areas of scientific research and development, from cancer research to semiconductor engineering, from novel materials to drug delivery. Increasingly all facets of science and technology advancements relate to evershrinking precision and geometry down to nanoscale. We plan to share the latest research from many areas of nanotechnology in each issue of **NanoScientific**, including exciting aspects of atomic force microscopy (AFM) that enables the further advancement in nano science and engineering with the expanded ability to image, view and analyze things at the atomic and molecular level.

I hope you enjoy this first issue that focuses on the semiconductor application, where explosive advances in semiconductor technology are pushing the boundaries of electrical engineering to unrivaled levels of advancement. I welcome your comments and your feedback, and since this is an interactive forum, I would love to hear about your latest applications for feature stories in upcoming issues of **NanoScientific**.

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

NANOTECHNOLOGY:
MANY EXCITING CAREER OPPORTUNIES FOR THE FASTEST GROWING MARKET THE WORLD HAS EVER SEEN

In their latest research study, "Nanotechnology Market Outlook 2017", RNCOS analysts identified that the global nanotechnology industry has been growing at a rapid pace with rising applications in sectors like drug delivery, diagnostic devices etc. In addition, market trends like nanotechnology based thin film solar cells with high efficiency, nanomaterials with higher strength, robust growth in nanofibers and nanomedicine market etc are booming growth in this industry. Considering the above factors, the global nanotechnology market is anticipated to grow at a CAGR of around 19% during 2013-2017.

According to a recent study by market researcher Global Information Inc., the annual worldwide market for products incorporating nanotechnology is expected to reach US $3.3 trillion by 2018. According to the National Nanotechnology Infrastructure Network, the need for technology professionals working in nanotechnology will increase to 1 million employees by 2015.

One place where such qualities are important is in semiconductors, which currently make up the biggest commercial application of nanotechnology. The technology has enabled advances in computer memory, storage capacity, reduced power consumption, and increased speed. "It's a great term for creating public interest and for collaborative research," says Robert D. "Skip" Rung, president and executive officer of the Oregon Nanoscience and Microtechnologies Institute, in Corvallis. "But 'nanotechnology' is the new word for chemistry," he says. Rung is one of the professionals in nanotechnology profiled on TryNano.org. "Semiconductors applications dwarf everything else combined, by a factor of 10," according to Rung.

Donald R. Baer, another expert profiled on TryNano.org, notes that experience with handling the equipment used in nanotechnology is invaluable. "You need to know the same clean-room technology that's used in the semiconductor industry," says Baer, lead scientist for interfacial chemistry and interim chief science officer at the Environmental Molecular Sciences Laboratory at the U.S. Department of Energy's Pacific Northwest National Laboratory in Richland, Wash. "Contamination and safe handling issues are the same in nano as they are in semiconductors.

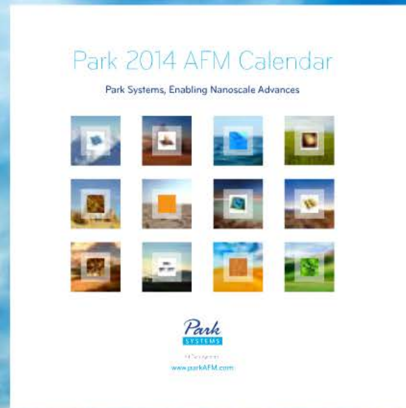
"The number of labs working with nanomaterials is growing dramatically," Baer adds. "They're looking at all kinds of new nano properties, for applications ranging from catalysts to energy conversion." He says that will require an increasingly sophisticated workforce prepared to deal with issues such as cleanliness and nanofabrication quality control.
But the understanding of how to use nano devices is in short supply, too. Rung recommends that students get as much experience with fabrication and measuring equipment as they can, whether it's from working on research projects, helping out in their professors' labs, or through internships.

NanoTechnoloogy will offer many high growth employment and education opportunities. Education in all levels of NanoTechnolgy is now available at all levels at several universities. To find out more about a NanoTechnology career and educational opportunities, visit:

www.trynano.org/nanotechnology_degrees.html

PARK SYSTEMS 2015 ATOMIC FORCE MICROSCOPY IMAGE CONTEST

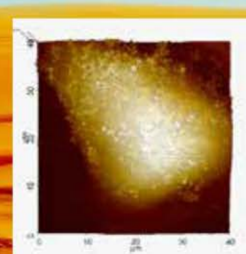
SUBMIT YOUR AFM IMAGE BY OCT. 15 TO WIN PRIZES AND APPEAR IN 2015 PARK AFM CALENDAR



Park Systems 2014 Atomic Force Microscopy Calendar

Namuna Panday Florida International University, Park Systems 2014 AFM Photo Contest Winner

2014 Park AFM Photo Winning Image HeLa cell treated with 10 µM water



The 2nd annual Park AFM Image contest is now open for submissions, go to parkafm.com for details. The contest was widely received by AFM users in the first year resulting in a spectacular 2014 AFM Calendar showcasing the industry's most spectacular AFM imaging. Winning images will be displayed in the 2015 Park AFM calendar and prizes will be awarded based on judges evaluation of the images submitted. The Park Systems AFM image contest is open to scientists, engineers, researchers and others who work with AFM who are invited to submit their favorite AFM images with a chance to be selected to appear in the Park Systems 2015 calendar.

PARK SYSTEMS 2014 ATOMIC FORCE MICROSCOPY CALENDAR

Last year's AFM image contest winner was Namuna Panday, a Graduate Student at Florida International University. Her winning AFM image was of a HeLa Cell used in her research studying drug delivery methods for cancer research

Panday's winning AFM image, which appeared in the Park Systems 2014 Calendar is a fascinating image of a HeLa cell created using Park XE-Bio, scanning ion conductance microscopy (SICM) mode with a glass nanopipette tip. It is a topography image the HeLa cell treated with 10 µM water soluble conjugated polymer nanoparticles for 1 hour at 37 °C. This image helps us understand how conjugated polymer nanoparticles (CPNs) interact with and enter cells and the research will help determine which bio materials are most effective to use during drug delivery for cancer treatment.

Runners up from the 2014 AFM contest also appearing in the calendar were Ronaniel A. Almeda, Research Associate, University of the Philippines Los Baños, Dr. Gwan-Hyong Lee, Postdoctoral Research Scientist, Columbia University and Dr. Richard Piner, Research Scientist, University of Texas, Austin.

"Park Systems XE Bio dramatically extends our research technology by allowing us to review the cells in their native environment, thus enabling us to study how the cell reacts to each bio polymer in a controlled setting," explains Namuna Panday. "We rely on Park XE Bio's proven advanced nanotechnology design for our scientific research into how cells interact for cancer treatment, gene delivery and in other research in our labs because it is a very reliable and accurate AFM."

"The AFM image contest is a great way for us to interact with our users gaining more insight into their applications and sharing some holiday fun," commented Keibock Lee, Park Systems President. "We are excited to invite AFM users to select their best images again for next year's contest which we will showcase in our 2015 calendar. We are looking for images with outstanding quality and visual appeal showcasing nanotechnology's most interesting applications."

To participate, please go to www.parkafm.com/contest or email us at contest@parkafm.com.

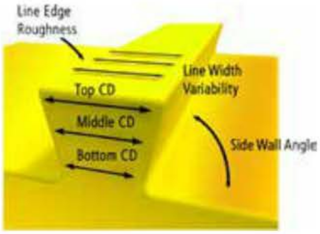


Figure 1.
LER, LWR and SWR are the limiting factors of resolution in optical lithography.

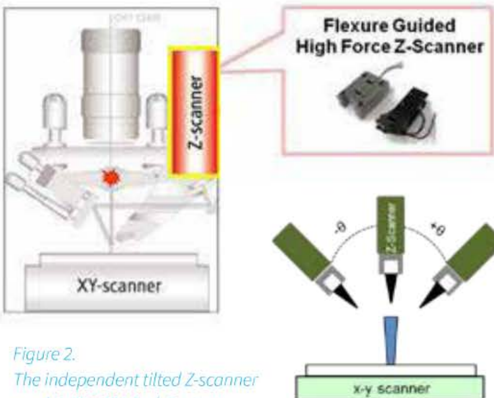


Figure 2.
The independent tilted Z-scanner used in 3D-AFM Park Systems

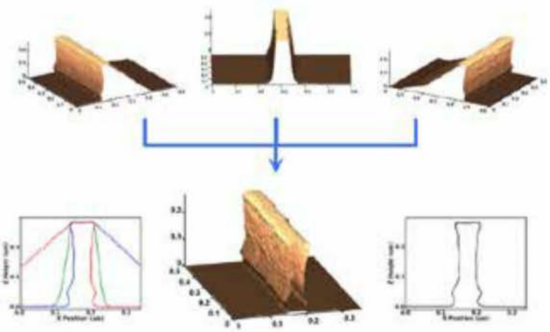


Figure 3.
Combination of the three acquired images for 3D AFM pattern reconstruction.

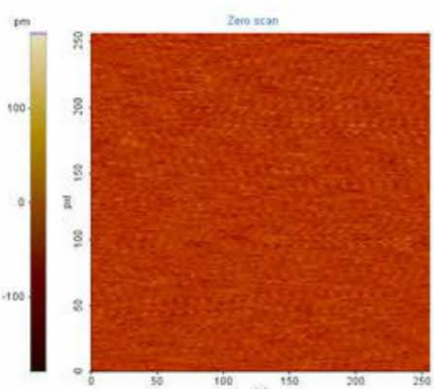


Figure 4.

depicted in figure 2, the Z-scanner, which moves the tip, is decoupled from the XY scanner, which solely moves the sample, thus, offering incredibly flat scanning and an additional benefit by improving its Z-scan bandwidth. Furthermore, by tilting the Z-scanner we can access the sidewall of the nanostructures and perform roughness measurements along the sidewall of photoresist lines while at the same time measure the critical dimensions of top, middle, and bottom lines (see figure 2).

More specifically, data acquisition is performed by a conical tip in predefined tilted angles typically 0º, a, and -aº. Consequently, and by combining these three scans (a method called image stitching),we can reconstruct the 3D pattern as shown in figure 3.

This provides an excellent and extremely accurate method that takes advantage of the interference pattern of the standing waves in order to measure features such as the total height, the top, middle, and bottom width. This system is capable of advanced three-dimensional imaging of both isolated, and dense line profiles. AFM is less costly than the alternative techniques (CD-SEM and focused ion beam (FIB)) for imaging and measuring parameters of line profiles since the preparation of the sample is by far simpler.

NOISE LEVELS IN 3D-AFM

A critical requirement when dealing with metrology tools is associated with constraining the level of noise in the manufacturing environment, which Park has studied and researched extensively, providing evidence that correlates noise levels with productivity. The study of noise levels on a 300 mm wafer proved that Park 3D-AFM is not only a powerful nano-characterization automated tool with excellent resolution but also a system that keeps the overall system noise at levels lower than 0.05 nm (0.5 angstrom) as depicted in figure 4.

ROUGHNESS MEASUREMENTS

Roughness can be transferred into the final etched profile, thus, roughness measurements can describe and determine the quality of the patterns. The unique tilted Z scanner in combination with the low noise levels that are prevalent during the AFM process can provide excellent and very accurate results in terms of sidewall roughness measurements. Figure 5 depicts the 3D AFM imaging of a photoresist semi-dense line pattern and the respective grainy structure of its sidewall. The precision with which the SWR was measured is validated by the excellent repeatability (0.08nm 1 sigma for 5 sites wafer mean) for the sidewall roughness of about 6.0 nm.

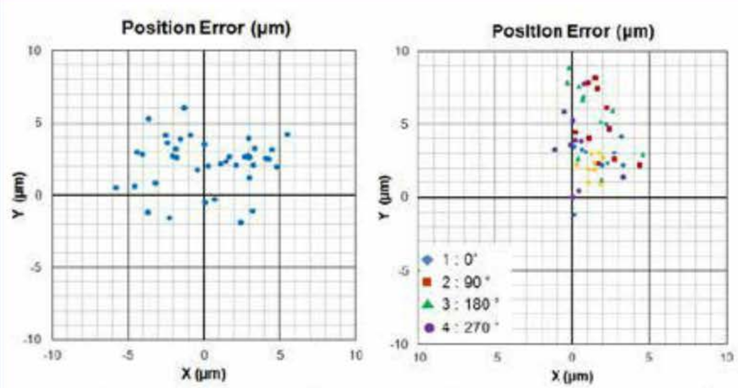
It needs to be noted that roughness depends, amongst others, on the aerial image contrast (AIC) or in other words the physics of exposure. AIC is determined as the quotient between the subtraction and the addition of the maximum and minimum image intensities.

$$AIC = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}. \text{ Eq. 1}$$

Several consequent series of images with variable exposure reveal that LER significantly increases when the AIC is decreased, a fact that underlines that AIC is a controlling factor for LER. Moreover, and as depicted in figure 6, reduced levels of AIC produced line profile images of the resist that were more blunted, and also smaller sidewall angles (SWA).

Figure 7 illustrates the capability of Park 3D AFM to image all surfaces of the pattern, in contrast to the conventional AFM or the SEM, which cannot fully characterize the surface data, and obtain information such as base, top and both sidewall roughness from sidewall characterization. We imaged a 300 nm photoresist line pattern and we obtained the respective line profiles that clearly showed a substantial difference in terms of SWR between 97% and 40% AIC. More specifically, the lower the value of AIC the more increased was the measured roughness. This intense decrease of roughness is underlying the fact that LER and the measured sidewall roughness are clearly correlated.

Finally, it needs to be emphasized the role of non-contact 3D AFM in terms of preserving



RMS Error (μm)	4.185

Loading Position	RMS Error (μm)
1 : 0°	3.779
2 : 90°	5.885
3 : 180°	6.423
4 : 270°	4.430
Average	5.129

Figure 4
(a) The positional error of actual defect sites after the automatic stage mapping is quite small; about 5μm in rms. (b) The positional error remains nearly the same regardless of wafer loading positions.

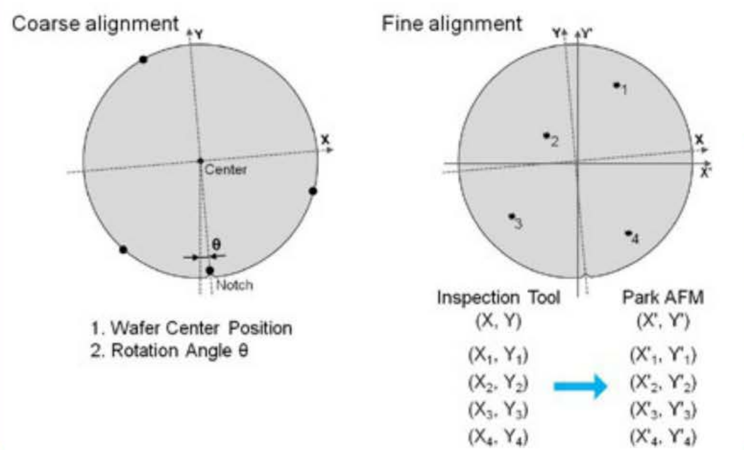


Figure 3.
Wafer edge and actual defects are used to orient the wafer and translate the coordinate between the inspection tool and Park AFM.

defects is time consuming with conventional manual AFM, hindering productivity, let alone throughput. Thus it is important to have an automated solution for both failure analysis and production engineers who need to find the cause of defect sites on bare wafers and minimize them.

To address this need, Park Systems have delivered the Automatic Defect Review (ADR) AFM which speeds up and improves the way defects are imaged and analyzed. With this solution, users are now able to obtain the additional details and the height/depth information of the defects which were not possible or too expensive to obtain with SEM based ADR.

HOW TO TRANSFER DEFECT MAP FROM INSPECTION TOOL TO REVIEW AFM

The general defect review concept is simple, yet complicated when it is done on the nanometer scale. Simple, because all it would require is the proper transferring of the defect map from an inspection tool and re-locating those same defects on a review tool. Coordinates from the inspection tool are translated to the review tool, which is used to zoom in and image the details of the defect, revealing its characteristics.

The complicated part comes into play when attempting to accurately go near the defect site, in order to image it, and to do this all in automation. This is due to the fact that there are stage mapping errors between the inspection tool and the review tool.

In case of a patterned wafer, alignment marks are used as reference points to map the two stages between the inspection tool and AFM, and the position error from both tools can be accurately estimated. Park's initial success in Automated Defect Review (ADR) AFM solution was implemented in the hard disk industry, utilizing the reference marks inscribed by the optical inspection tool such as KLA Tencor's Candela series. Utilizing these marks, the defect maps of hard disk media or substrates could be accurately and reliably transferred and the automated review AFM, Park HDM Series, was able to get near enough to the defect to conduct a survey scan, and then follow up with a zoom-in scan to provide the details the user required. As a whole, this solution proved to be effective, increasing the productivity in the HDD industry's FA labs by up to 1000%.

AUTOMATED, ACCURATE TRANSFER OF DEFECT MAP WITHOUT REFERENCE MARKS

Success in the HDD industry resulted in similar requests coming from the semiconductor industry. Since the cleanness level requirement for the semiconductor industry is much stricter than that of HDD, creating markers on the bare wafers is not possible, hence the need for ADR process WITHOUT any reference

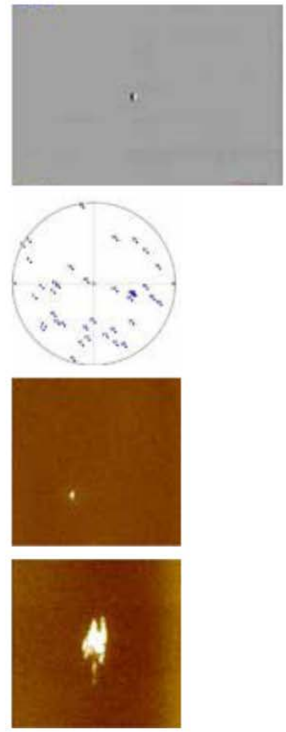


Figure 1.
The goal of defect review is to locate the defect site identified by an inspection tool and image the defect by a review tool.

AUTOMATED AFM SIGNIFICANTLY BOOSTS THROUGHPUT IN AUTOMATIC DEFECT REVIEW

REDUCES COST AND INCREASES EFFICIENCY IN PRODUCTION OF SEMICONDUCTOR WAFERS

INTRODUCTION

The scaling trend in semiconductor design requires tighter control over defects on wafers. In order to characterize the defects, both inspection and review tools are needed.

The inspection tools such as surface scanning inspection systems (SSIS) are employed first to locate and map defect sites, and the review tools such as scanning electron microscopy (SEM) are used to obtain morphological information.

Large defects, which are visible by optical microscopy, can be easily found by an inspection tool and imaged by a review tool. However, as processing requirements become more stringent, the defect size of interest gets smaller, below the diffraction limit of optical microscopy. To locate and identify small defects, a large survey scan needs to be performed by the review tool in order to find the exact location of the defects.

Defect review SEM has been used to image the defects of a bare wafer after defect sites are mapped by the laser-scattering defect inspection tools such as Surfscan from KLA-Tencor. However, the imaging by defect review SEM is limited to 2D and cannot provide the 3D information, which has become more crucial in recent days for bare wafer manufacturing control. Also, smaller defects, less than 50nm, are increasingly not detected by defect review SEM.

WHY AUTOMATIC DEFECT REVIEW (ADR) AFM?

Atomic force microscopy (AFM) is gaining more importance as the choice of a review tool in recent days because it can directly measure the defect dimensions (height and width, hence shape) and the physical properties of defects of interest. However, for engineers and researchers working with bare wafers, the process of identifying nanoscale

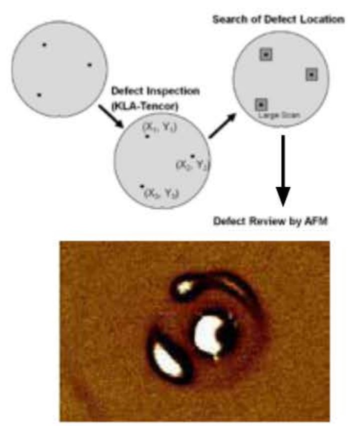


Figure 2.
Typical routine of defect review process by manual AFM has a very low throughput, 10 defects per day at best. Moreover, the tip cost can run high if one uses a destructive scan mode such as tapping.

A NEW ADVANCED MANUFACTURING BREAKTHROUGH

CENTER FOR HIGH-RATE NANOMANUFACTURING NORTHEASTERN UNIVERSITY

An Interview with Park Systems AFM Customer, Dr. Ahmed Busnaina Director, NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing at Northeastern University

What key benefits are offered by nanoops to the nanoscale manufacturing process?

Commercial nanoscale electronic device manufacturing is still largely top-down, silicon-based, and expensive. In addition, few nanoscale devices manufactured today exploit the unique properties and behaviors of nanomaterials such as nanotubes, quantum dots, and nano particles. Printing offers a novel approach to fabricating devices and products incorporating nanomaterials. Electronic printing today is used for making low-end electronics, however, these products are made using inkjet technology, which is very slow and limited to only micro scale resolution. Even with today's slow electronic printing and lower resolution, they still offer significant savings compared to silicon electronics. For example, the cost of a printed integrated sensor-plus-digital-readout device is 1/10th to 1/100th the cost of current silicon-based systems. The printed electronic market is close to $50 billion this year and is projected to reach $250 billion in 10 years. This is based on current electronic printing capability, however, if printing can be used to print high-end electronic devices at the same price but orders of magnitude faster, we think that the market will many times larger in the near future. Our new Nanoscale Offset printing System (NanoOPS); has been shown to be capable of being orders of magnitude faster and higher resolution than current inkjet based electronic printing and 3D printing. Our unique fully-automated NanoOPS that can be flexibly adapted to print a variety of micro- to nano-scale devices for many applications including electronics, energy, medical and functional materials.

What is an example of a nanoscale device that makes a difference in our daily lives?

There are applications that utilize nanomaterials such as nanoparticles, carbon nanotubes (CNTs) and Quantum Dots (QDs) but not at the nanoscale. For example, many printed electronics as well as organic photovoltaics utilizes nanomaterials using printing or roll-to-roll process. In addition, some large LCDs have already utilized QDs to display bright colors. However, all of these are low end application of nanomaterials.

Image (a)

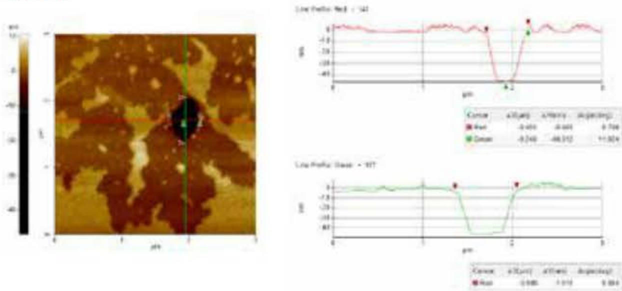


Image (b)

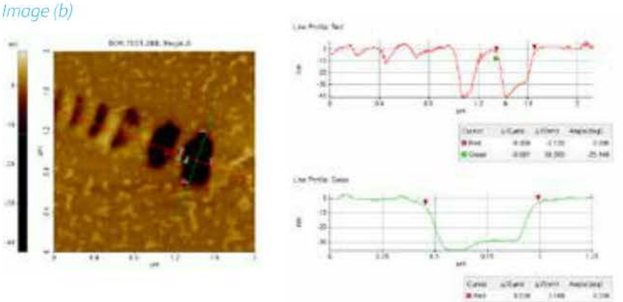
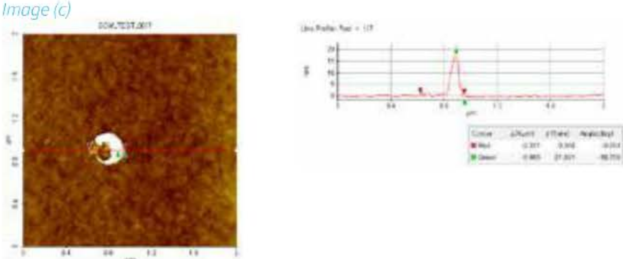


Image (c)



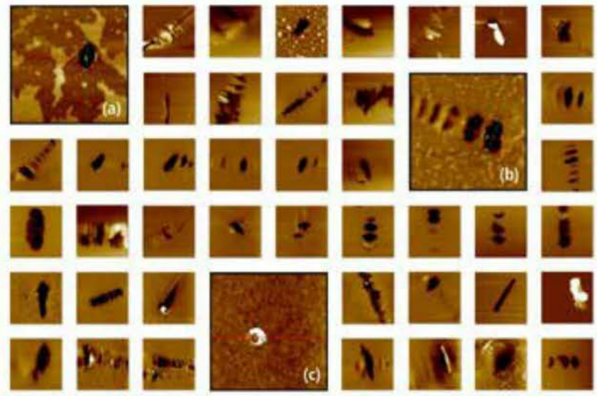


Figure 5.
The 300mm bare wafer ADR AFM correctly locates all the defect sites identified from an inspection tool and automatically zooms in for the detailed imaging.

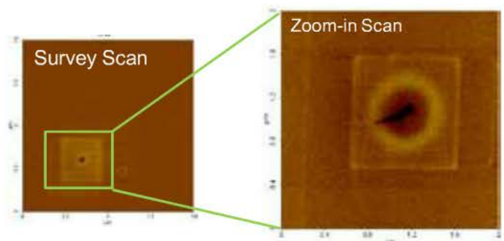


Figure 6.
LER, LWR and SWR are the limiting factors of resolution in optical lithography.

marking on a bare wafer is required.

Without alignment marks the positions of defects are roughly estimated [1, 2]. Therefore, additional alignment process is required to decrease the positional error [3] during the defect map transfer. To address this issue, a new method was developed that utilizes the wafer edge, notch, and large defects, which are visible by optical microscopy, as the reference points.

The improved remapping technique, combined with enhanced vision, does not require any reference marker on a bare wafer. Furthermore, it also does not need any separate step to calibrate the stage of the targeted inspection system.

The success rate of the 300mm bare wafer ADR depends on two factors: the accuracy of stage mapping and the size of initial survey scan. The more accurate the stage mapping, the smaller survey scan size can be used for higher success in finding the defect. The new stage mapping technique vastly improves the accuracy by adopting advanced remapping algorithm and enhanced vision technique.

The RMS position error of survey scans are less than 5 μm regardless of wafer loading positions. It means that all the defects are located within ±5 μm using the defect map provided from a defect inspection tool

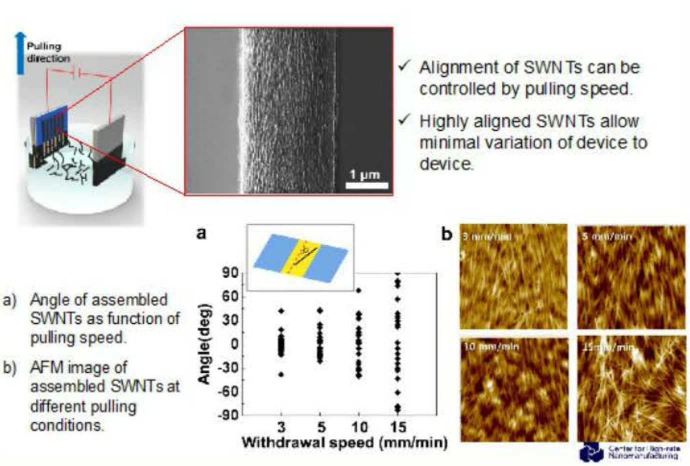
CONCLUSION: RESULTS OF 300 MM BARE WAFERS ADR BY PARK NX-WAFER

Utilizing the advanced coordinate translation technique, the defect map obtained from a laser-scattering defect inspection tool, such as Surfscan from KLA-Tencor, can be accurately transferred to a 300mm AFM system, allowing full automation for high throughput defect imaging.

With the new 300mm bare wafer ADR, a typical automated measurement run would go as follows.

- A bare wafer is run by a laser-scattering defect inspection tool (e.g. Surfscan)
- Then an operator registers the resulting defect coordinates file, known as KLARF for the Surfscan tool, to Park NX-Wafer.
- The coordinates of the defect map are automatically de-skewed and the linkage of the two stages is enabled between the inspection tool and Park NX-Wafer
- Park NX-Wafer then runs the automatic defect review (ADR) on the sample bare wafer.

The above set of data shows the results from the 300mm bare wafer ADR with Park NX-Wafer. Typical success rate is higher than 95% regardless of the orientation of a wafer. The zoomed-in scans show the detailed morphology of defects, clearly distinguishing various types such as pit, bump, and scratch.



SWTNs Alignment Control

Park Systems NE312021 in motion

attention to. Most of university research and breakthrough technologies get published and patented and then if no company licensed the technology or no spin off company is launched, the technology will not be commercialized. There is no mechanism for funding such the missing middle. Large companies like to buy a complete solution such as a start up that already built prototype and has developed the necessary technology and filed the necessary patents needed for commercialization. However, a company has to be lunched and funded for a few years before that point is reached. Venture capitals and angel investor have been very conservation during the last decade. The new Advanced manufacturing institutes were supposed to provide a solution top this problem, but so far the institutes have focusing on improving or refining existing technology and less on developing emerging technology.

Note: The US Government Accountability Office (GAO) released a 100+ page report early this year on the state of nanomanufacturing in America that addressed the concern regarding the lack of funding or middle-stage support from initial proofs-of-concept in laboratory settings to full-scale manufacturing which leads to many promising nanotechnology ideas dying on the vine before they can reach their full potential.

What advances in high-rate nanomanufacturing do you envision in the near future?

New nanomaterials based manufacturing techniques are finding more acceptance and more companies are using or considering them. Among those are electronic printing with a market close to $50 billion. Even with today's slow electronic printing and lower resolution, they still offer significant savings compared to silicon electronics. Printing, however, can be used to print or nanomanufacturehigh-end electronic devices at the same price but orders of magnitude faster. Our new Nanoscale Offset printing System (NanoOPS) has been shown to be capable of being orders of magnitude faster and higher resolution than current inkjet based electronic printing and 3D printing. This unique fully-automated NanoOPS that can be flexibly adapted to print a variety of micro- to nano-scale devices for many applications including electronics, energy, medical and functional materials. We believe that high-ratenanoscale printing of devices will transform nanomanufacturing and nano-enabled technologies and spur innovation by overcoming the high cost entry barrier to the fabrication of high-end printed devices at a fraction of today's cost.Although the flexible Damascene templates can be used in Roll-to-Roll printing system, NanoOPS utilizes a batch process to be able to apply nanoscale registration and alignment. The vision is to "democratize" nanomanufacturing, making it more broadly accessible to industry and entrepreneurs and unleashing a wave of creativity for nano-enabled product innovation - analogous to what the advent of the personal computer did for computing.

Dr. Ahmed Busnaina

Ahmed A. Busnaina, Ph.D. is the William Lincoln Smith Chair Professor and founding Director of National Science Foundation's Nanoscale Science and Engineering Center (NSEC) for High-rate Nanomanufacturing and the NSF Center for Nano and Microcontamination Control at Northeastern University, Boston, MA.

Dr. Busnaina is internationally recognized for his work on nanomanufacturing, nano and micro scale defects mitigation and removal in semiconductor fabrication and specializes in directed assembly of nanoelements and in the nanomanufacturing of micro and nanoscale devices. Author of hundreds of technical papers, he is a frequent spokesperson at industry events and associate editor of the Journal of Nanoparticle Research. He has also served on many advisory boards including Samsung Electronics; Chemical Industry Nanomaterials Roadmap, Semiconductor International, and Journal of Advanced Applications in Contamination Control.

Northeastern University's Center for High-rate Nanomanufacturing has developed a fully-automated system that uses offset-type printing technologies at the nanoscale to make products that fully take advantage of the superior properties of nanomaterials. In minutes, the system can print metals, organic and inorganic materials, polymers, and nanoscale structures and circuits (down to 25 nanometers) onto flexible or inflexible substrates. The Nanoscale Offset Printing System (NanoOPS) is a new system that has the potential to transform nanomanufacturing and spur innovation. Because of its relative simplicity, NanoOPS is expected to eliminate some of the high cost entry barriers to the fabrication of nanoscale devices for electronics, energy, medical, and functional materials applications.

Current nanofabrication facilities cost billions of dollars to build, and their operation requires massive quantities of water and power. NanoOPS could operate at a fraction of the cost, making nanomanufacturing accessible to innovators and entrepreneurs and creating the potential for a wave of creativity, perhaps similar to what the PC did for computing and what the 3D printer is doing for design. In addition to reducing manufacturing costs, NanoOPS will go beyond current fabrication capabilities by enabling the commercialization of nanoscale properties, such as nanotubes, that have been identified in laboratory settings. This will enable critical manufacturing in areas such as new and more affordable medicines; stronger, lighter building materials; or faster, cheaper electronics.

Once scalable high-rate nanoscale printing becomes available, then we will see a paradigm shift in the use of nanoscale devices produced with nanomaterials.

How does NanoOPS provide a solution for nanomanufacturing?

This spring, we are taking some of our key discoveries to date out of the lab and into the marketplace.

In collaboration with a Massachusetts-based company, the CHN has developed a unique fully-automated system: Nanoscale Offset Printing System (NanoOPS) that can be flexibly adapted to print a variety of micro- to nano-scale devices for many applications including electronics, energy, medical and functional materials. This one of a kind fully automated cluster tool printing system will be unveiled in September this year. The hexagonal machine is about seven feet across and has a central robotic arm that transfers the printing templates and the final products that will result from the precision multi scale manufacturing process.

If there's a key differentiator between past approaches and your own to high-throughput manufacturing at the nanoscale, what would it be?

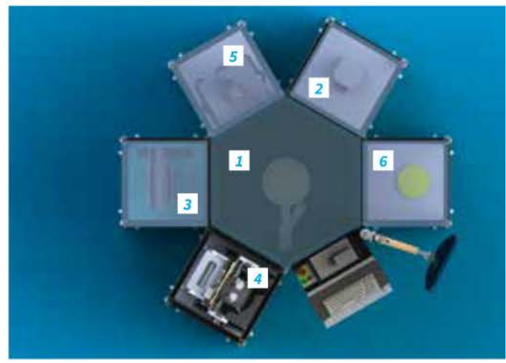
The NanoOPS system will be fast, scalable, and capable of printing multiscale structures using a wide variety of functional nanomaterials at very low facilities and operational cost. This new system will transform nanomanufacturing and nano-enabled technologies and spur innovation by overcoming the high cost entry barrier to the fabrication of high-end printed devices at a fraction of today's cost. Although the flexible Damascene templates can be used in Roll-to-Roll printing system, NanoOPS utilizes a batch process to be able to apply nanoscale registration and alignment. The vision is to "democratize" nanomanufacturing, making it more broadly accessible to industry and entrepreneurs and unleashing a wave of creativity for nano-enabled product innovation - analogous to what the advent of the personal computer did for computing.

How is AFM (Atomic Force Microscopy) used ?

One of the many examples where the AFM could provide a unique and useful information(without sample damage) is regarding the alignment of single walled or multi walled carbon nanotube (SWNTs or MWNTs) structures which affects conductivity of the assembly (very significant for electronic or sensor applications) as well as for structural or composite materials applications. Below is an example of how the alignment of SWNTs can be controlled during directed assembly (using a dip coater). The AFM measurements clearly showed that the angle of assembled SWNTs is a function of pulling speed (as shown in the AFM image of assembled SWNTs at different pulling conditions).

What sets AFM apart from other forms of microscopy for your approach's needs?

The AFM is capable of characterizing nanomaterials assembled in a 2D or 3D structure or just on a surface. SEM and other vacuum approaches can provide measurements with affecting the sample either because of the e-beam that will damage nanomaterials such as CNTs if exposed (more than few seconds at



NanoOPS includes six modules:

1. Hexagon Frame Module
2. Template Load Port Module
3. Directed Assembly Module
4. Mask Aligner Module
5. Transfer Module
6. Template Load Port Module

high magnification. Also, in the SEM, typically organics that accumulates in the chamber end up depositing on the substrate affecting and damaging the sample. Charging of samples also occurs and could cause sample damage. The AFM does not have any of these drawbacks. In addition, the quantitative measurements capabilities such as the 3D mapping of nanostructures cannot be matched by other techniques.

Nanoscale Offset printing System NanoOPS

Can you explain what is meant by the Missing Middle in the Manufacturing process?

This is an excellent question and one that the US government has to pay

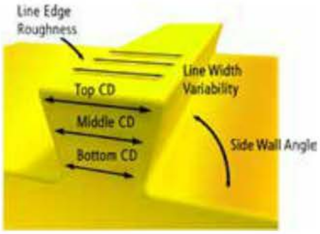


Figure 1.
LER, LWR and SWR are the limiting factors of resolution in optical lithography.

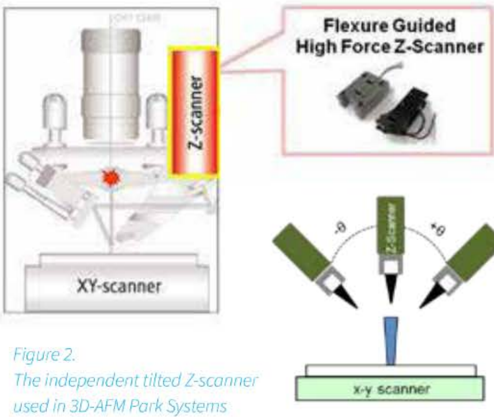


Figure 2.
The independent tilted Z-scanner used in 3D-AFM Park Systems

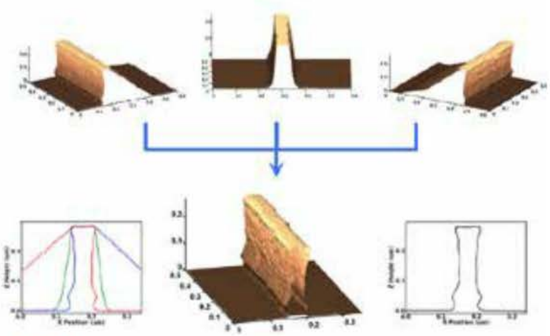


Figure 3.
Combination of the three acquired images for 3D AFM pattern reconstruction.

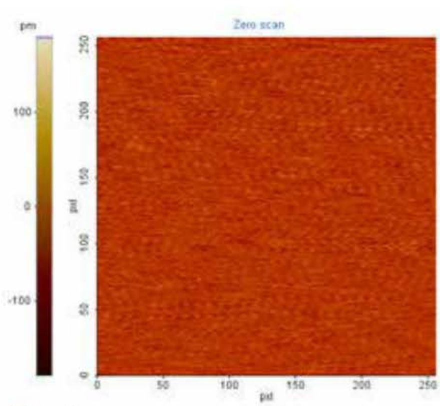


Figure 4.

depicted in figure 2, the Z-scanner, which moves the tip, is decoupled from the XY scanner, which solely moves the sample, thus, offering incredibly flat scanning and an additional benefit by improving its Z-scan bandwidth. Furthermore, by tilting the Z-scanner we can access the sidewall of the nanostructures and perform roughness measurements along the sidewall of photoresist lines while at the same time measure the critical dimensions of top, middle, and bottom lines (see figure 2).

More specifically, data acquisition is performed by a conical tip in predefined tilted angles typically 0º, a, and -aº. Consequently, and by combining these three scans (a method called image stitching),we can reconstruct the 3D pattern as shown in figure 3.

This provides an excellent and extremely accurate method that takes advantage of the interference pattern of the standing waves in order to measure features such as the total height, the top, middle, and bottom width. This system is capable of advanced three-dimensional imaging of both isolated, and dense line profiles. AFM is less costly than the alternative techniques (CD-SEM and focused ion beam (FIB)) for imaging and measuring parameters of line profiles since the preparation of the sample is by far simpler.

NOISE LEVELS IN 3D-AFM

A critical requirement when dealing with metrology tools is associated with constraining the level of noise in the manufacturing environment, which Park has studied and researched extensively, providing evidence that correlates noise levels with productivity. The study of noise levels on a 300 mm wafer proved that Park 3D-AFM is not only a powerful nano-characterization automated tool with excellent resolution but also a system that keeps the overall system noise at levels lower than 0.05 nm (0.5 angstrom) as depicted in figure 4.

ROUGHNESS MEASUREMENTS

Roughness can be transferred into the final etched profile, thus, roughness measurements can describe and determine the quality of the patterns. The unique tilted Z scanner in combination with the low noise levels that are prevalent during the AFM process can provide excellent and very accurate results in terms of sidewall roughness measurements. Figure 5 depicts the 3D AFM imaging of a photoresist semi-dense line pattern and the respective grainy structure of its sidewall. The precision with which the SWR was measured is validated by the excellent repeatability (0.08nm 1 sigma for 5 sites wafer mean) for the sidewall roughness of about 6.0 nm.

It needs to be noted that roughness depends, amongst others, on the aerial image contrast (AIC) or in other words the physics of exposure. AIC is determined as the quotient between the subtraction and the addition of the maximum and minimum image intensities.

$$AIC = \frac{I_{max} - I_{min}}{I_{max} + I_{min}}. \text{ Eq. 1}$$

Several consequent series of images with variable exposure reveal that LER significantly increases when the AIC is decreased, a fact that underlines that AIC is a controlling factor for LER. Moreover, and as depicted in figure 6, reduced levels of AIC produced line profile images of the resist that were more blunted, and also smaller sidewall angles (SWA).

Figure 7 illustrates the capability of Park 3D AFM to image all surfaces of the pattern, in contrast to the conventional AFM or the SEM, which cannot fully characterize the surface data, and obtain information such as base, top and both sidewall roughness from sidewall characterization. We imaged a 300 nm photoresist line pattern and we obtained the respective line profiles that clearly showed a substantial difference in terms of SWR between 97% and 40% AIC. More specifically, the lower the value of AIC the more increased was the measured roughness. This intense decrease of roughness is underlying the fact that LER and the measured sidewall roughness are clearly correlated.

Finally, it needs to be emphasized the role of non-contact 3D AFM in terms of preserving

THREE-DIMENSIONAL ATOMIC FORCE MICROSCOPY: CHANGING THE FUTURE OF NANOMETROLOGY FOR THE SEMICONDUCTOR INDUSTRY

By Keibock Lee, Park Systems

ABSTRACT

The Three-Dimensional Atomic Force Microscopy (3D AFM) by Park Systems is an innovative and cost effective means of accurately characterizing the roughness and the sidewall morphology of photoresist semiconductors and was created by industry's need for a nanoscale measurement tool that surpassed the limited scans available using SEM. As the device critical dimension decreased, industry demanded an advanced method for high resolution data. The 3D AFM offers a unique solution to the challenges facing semiconductor manufacturers and provides many cost effective and resolution advantages not previously available in standard systems. One of the most unique features of Park 3D AFM is the independent Z-scanner that can be tilted in order to gain access to the sidewalls of the material and, hence, measure its critical dimensions (CD), its sidewall and line edge roughness (SWR and LER respectively). This article will briefly introduce the notions behind the Park 3D AFM and will demonstrate its capability to acquire high-resolution measurements of both sidewall and line width roughness (LWR) throughout the pattern transfer process. Another feature highlighted is the unique low noise level properties that are of utmost significance when dealing with metrology tools. Finally, by varying the aerial image contrast (AIC), different degrees are derived of line edge roughness identifying trends in sidewall-roughness that clearly depend on the levels of AIC.

INTRODUCTION

One of the most challenging features in the semiconductor industry is the continuous research and the subsequent fabrication of integrated circuits with enduringly smaller critical dimensions (CD). This term not only defines the respective smallest possible feature size of the semiconductor itself but it is also interwoven with the design and implementation of a viable, refined, easy–to-use and accurate apparatus that will allow for measuring various parameters such as the line edge roughness (LER), the line width roughness (LWR) and the sidewall roughness (SWR).

The characterization of such factors that determine the shape and the roughness of the device patterns for device manufacturers is of utmost importance due to the fact that they directly affect the device performance. Optical lithography, which was initially used for the creation of patterns in the manufacturing of semiconductors, is severely limited in terms of resolution. Therefore, the existing prevalent method for measuring these factors prior to 3D AFM was primarily the scanning electron microscopy (SEM) with its image analysis software. Despite the fact that this technique offers substantial advantages such as automation and compatibility with standard critical dimension SEM tools, it cannot provide the user with high resolution LER data due to the fact that SEM resolution is reaching its limits, therefore 3D AFM offers a highly desirable solution. Leading manufacturers have implemented Park 3D AFM that can measure resist profile, LER and SWR in a way that is highly accurate, non-destructive and cost-effective. The precise and full characterization of such features is extremely essential during the pattern transfer process as it offers the possibility of imaging all surfaces of the pattern.

WHAT IS NON–CONTACT 3D AFM AND WHAT ARE ITS INNOVATIVE FEATURES?

The basic principle of non-contact 3D-AFM is that the cantilever rapidly oscillates just above the surface of the imaging sample. This offers a plethora of advantages, as compared to the traditional contact and intermittent modes. One of the most essential advantages is that there is no physical contact between the tip and the surface of the sample. Moreover, as

Park XE-3DM
A 3D Atomic Force Microscopy System by Park Systems

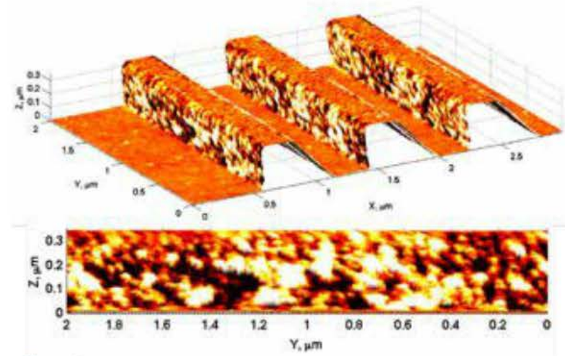


Figure 5.
Park 3D AFM image of a photoresist semi-dense line pattern imaged with Z-scanner tilt. The bottom figure clearly depicts the grainy structure of the sidewall.

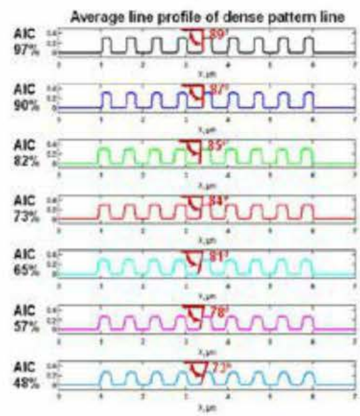


Figure 6.
Park 3D AFM line profiles at different AIC levels reveal the proportionate relationship between SWA and AIC.

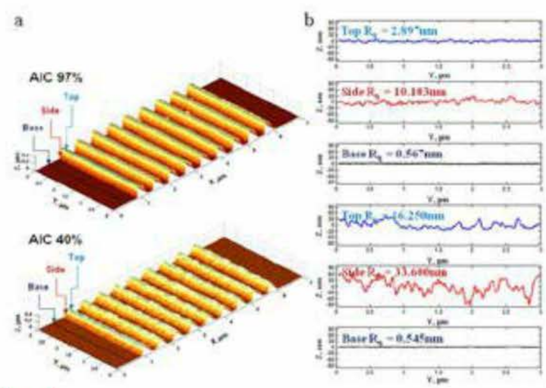


Figure 7.
a) A Park 3D AFM image of a 300 nm photoresist line pattern yields full information regarding the morphology of the sidewall. B) Side-wall Roughness is different at different AIC levels, a fact that indicates the connection between LER and SWR.

the tip sharpness of the cantilever. In an independent study, researchers performed 150 consecutive measurements using the same tip and the tip wearing proved to be minimal. This is a prominent feature of AFM that prevents the continuous costly replacement of the tip but also ensures that the sample will be viable and not damaged by the AFM cantilever. The preservation of the tip sharpness allows for continual measurements of high resolution roughness data.

CONCLUSIONS

This paper clearly demonstrates the potentialities of the innovative, non-destructive imaging technique of3D AFM compared to the existing SEM system. Clear examples of the many features of 3D AFM include the introduction of an independent and tilted Z-scanner proven to overcome the disadvantages of alternative metrology tools and measure parameters such as detailed sidewall morphology and roughness, and sidewall angle characterization that render the optimization and evaluation process easier and far more detailed. The development of 3D AFM by Park Systems proves to keep pace with the requirements and challenges from continuously shrinking semiconductor device critical dimensions by offering a solution that encompasses excellent resolution, high precision and accuracy, and easy sample preparation. 3D AFM sets a new standard for nanotechnology measurement and performance in a rapidly changing industry where new technologies and advancements pioneer future opportunities.

About Park Systems

Park Systems is a leading manufacturer of atomic force microscopy (AFM) systems with a complete range of products for researchers and industry engineers in materials science, chemistry, physics, life sciences, semiconductor and data storage industries. Park's products are used by over a thousand of institutions worldwide. Park's AFM features unique patented set of technologies that yields highest data accuracy at nanoscale resolution, superior productivity, and lowest operating cost to its customers. Park Systems, Inc. is headquartered in Santa Clara, California with its global manufacturing, and R&D headquarters in Korea. Park's products are sold and supported worldwide with regional headquarters in the US, Korea, Japan, and Singapore, and distribution partners throughout Europe, Asia, and America. Please visit www.parkafm.com or call 408-986-1110 for more information.

VIBRATION ISOLATION

AND BETTER SCAN SIZE ENABLES ATOMIC FORCE MICROSCOPY (AFMS) TO SEE MORE AT THE NANOSCALE LEVEL

The need for more precise vibration isolation with AFM, though, is becoming critical as resolutions continue to bridge from micro to nano. AFM systems are extremely susceptible to vibrations from the environment. When measuring a very few angstroms or nanometers of displacement, an absolutely stable surface must be established for the instrument. Any vibration coupled into the mechanical structure of the instrument will cause vertical and horizontal noise and bring about a reduction in the ability to measure with the highest resolution.

EXPANDING AFM CAPABILITY AND SCANNING RANGE

Since the release of the first commercial atomic force microscope about 25 years ago, technology advances have improved AFM performance. One of these advances has expanded the AFM ability to image biological samples in an aqueous buffer and provide a range of physical data for the sample. Another has increased the imaging speed of AFMs.

Within the past several years, research into AFM design, conducted In the Paul Hansma Research Group, Department of Physics, at the University of California, Santa Barbara, has demonstrated success with AFM imaging of large-scale samples at nanoscale resolutions while extending the range of the Z-axis.

To image at the extreme depths necessary in large-scale cracks and deep microcracks the AFM must have a Z-range of at least 200 microns and a cantilever tip long enough to probe the crack. As the vertical movement of the tip is increased, however, it brings into play a greater possibility for vibration. This issue was solved with the incorporation of negative-stiffness vibration isolation.

IMPROVING ON AFM VIBRATION ISOLATION

Developed and patented by Minus K Technology, negative-stiffness isolators use a completely mechanical concept in low-frequency vibration isolation while achieving a high level of isolation in multiple directions.

The isolator provides 0.5 Hz* isolation performance vertical, and 0.5 Hz horizontal, using a totally passive mechanical system —no air or electricity required, (*Note that for an isolation system with a 0.5 Hz natural frequency, isolation begins at about 0.7 Hz and improves with increase in the vibration frequency. The natural frequency is more commonly used to describe the system performance.)

“The negative-stiffness vibration isolation device has a very low vibrational frequency in the vertical direction, which is critical for atomic force microscopy.” said Hansma. Negative-stiffness isolators resonate at 0.5 Hz. At this frequency there is almost no energy present. It would be very unusual to find a significant vibration at 0.5 Hz. Vibrations with frequencies above 0.7 Hz (where negative-stiffness isolators begin isolating) are rapidly attenuated with increase in frequency.

“We like the vibration isolation to be at 0.5 Hz, which we can achieve with the negative-stiffness table,” continued Hansma. “Not so much because of the vibrations at that frequency, which are minimal, but because 0.5 Hz is 16x more resistant to transmitting vibrations at a building resonance of 10 or 20 Hz, than compared with a resonant frequency of 2 Hz which would be found with air tables.”

Air tables, as vibration isolation systems, deliver limited isolation vertically and less isolation horizontally. They will amplify rather than reduce vibrations in a typical range of 2 to 7 Hz because of the natural frequencies at which air tables resonate. All isolators will amplify at their resonant frequency, and then they will start isolating.

Transmissibility is a measure of the vibrations that are transmitted through the isolator relative to the input vibrations. The negative-stiffness isolators, when adjusted to 0.5 Hz, achieve 93% isolation efficiency at 2 Hz; 99% at 5 Hz; and 99.7% at 10 Hz.

“We did consider active isolation systems for our prototype AFM, as well,” explained Hansma. “We played around with a number of them. But, we did not want to add the complication of active feedback, which is inherent in an active vibration isolation system.”

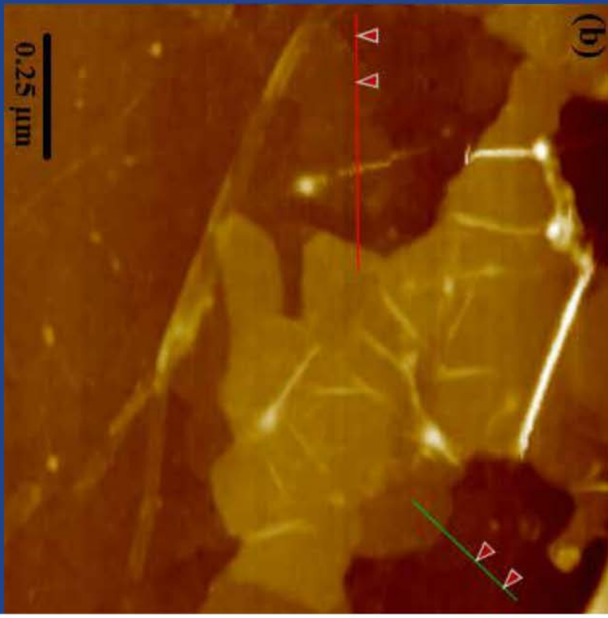
EXTENDED AFM RANGE

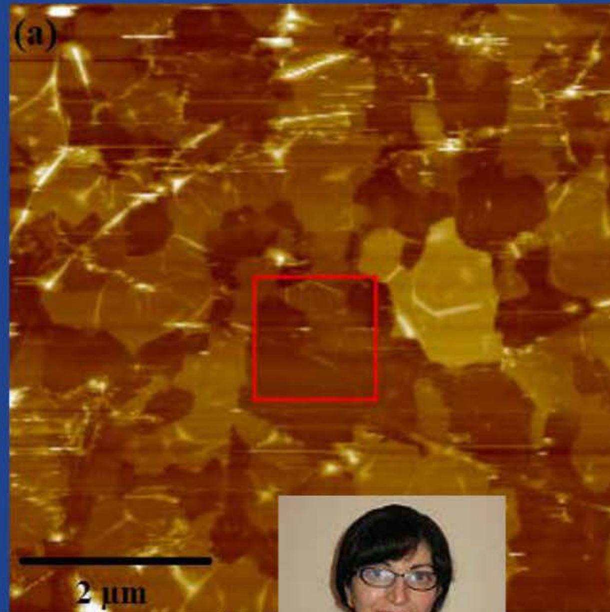
Using the lab’s prototyped combined AFM and RPI techniques, and supported by its passive negative-stiffness vibration isolation system, it has been able to achieve scan ranges exceeding one millimeter, an order of magnitude larger in the Z-axis than any commercially available AFM.

The AFM/RPI system has also proved capable of exploring the molecular origins of fracture resistance in bone tissues to more than 1 mm^2, with acceptable resolution and linearity.

Dr. David L. Platus

Dr. David L. Platus is the inventor of negative-stiffness isolators, and President and Founder of Minus K Technology, Inc. *(www.minusk.com)*. He earned a B.S. and a Ph.D. in Engineering from UCLA, and a diploma from the Oak Ridge School of (Nuclear) Reactor Technology. Prior to founding Minus K Technology he worked in the nuclear, aerospace and defense industries conducting and directing analysis and design projects in structural-mechanical systems. He became an independent consultant in 1988. Dr. Platus holds over 20 patents related to shock and vibration isolation.





NANOSCALE OBSERVATION REQUIRED TO STUDY NANOSCALE DEVICES

DR. IRMA KULJANISHVILI DESCRIBES NANOSCALE FABRICATION RESEARCH OF SEMICONDUCTOR DEVICES

An interview with Dr. Irma Kuljanishvili, Assistant Professor at Saint Louis University

Dr. Irma Kuljanishvili, is passionate about integrating nanoscience into technology. In a recent telephone interview, Dr. Kuljanishvili translated her research interests, their importance and their potential application from the language of pure physics into terms that scientists from other disciplines could more easily understand.

As an applied material physicist, she is interested in new ways to create and modify materials that are important for technological innovation. Specifically she uses her expertise in graphenes and carbon nanotubes to investigate their potential incorporation into future devices that will find applications in widespread fields, including semiconductor manufacturing and quality control as well as other sensing and testing applications.

Dr. Kuljanishvili uses a variety of standard scanning probe techniques in her laboratory, but also is pushing the technology delving into development of scanning probe techniques themselves. As these techniques to interrogate nanodevices are developed and mature in research labs such as Dr. Kuljanishvili's, they will transition to production facilities where they will be integrated into quality control of new generations of nano-scale devices rolling off of assembly lines. Dr. Kuljanishvili is an avid user of Park AFM, currently at Saint Louis University, and in the past while at Northwestern University.

Can you describe your research problem?

Our group specializes in carbon nanostructures and devices. Although we are an applied physics group, we also make our own materials. The two main materials we're interested in are carbon nanotubes and graphene. We also work with different types of thin films, but that's not our primary interest. We synthesize our own materials and we have a unique way of handling catalyst particles on substrates to grow our materials. Most techniques that we use in the lab in one way or another use scanning probe microscopy. For example, if we would like to create and grow carbon nanotubes, catalytically grown on the substrate of silicon for example, we force pattern the catalyst particles. We derive them from solution. We generate a solution from say, iron or nickel containing salts. We dissolve them in solvent and then to pattern we use a technique that is based on scanning probe microscopy, very reminiscent of DPN (dip pen nanolithography) to pattern the catalyst. We do this with an AFM, but we also have a stand alone, home built system that nevertheless uses the scanning probe microscopy technique to create clusters of catalyst on the substrate for the growth.

Why can't you use normal light based lithography techniques to pattern the catalyst?

Resolution of traditional, conventional lithography, depending on which type of lithography you use, photolithography or helium lithography, is a multistep process that requires facilities that need to be used on a daily basis to perform. Resolution wise, with helium lithography you will be able to get resolution down to the nanometer scale, or sub-nanometer scale easily. But it's mainly not about resolution, mainly it's about having one step, directly using AFM probes to write, without using any sort of mask, or any sort of process in between. You write your

"WE REALLY WOULD LIKE TO LEARN WAYS WE CAN CREATE AND MODIFY MATERIALS THAT WE MAKE. SOME MATERIALS, AS GROWN, ARE PERFECT AND CAN BE USED FOR SPECIFIC APPLICATIONS. SOME MATERIALS HAVE EXTREMELY UNIQUE PROPERTIES, LIKE GRAPHENE. ONE PROPERTY THAT GRAPHENE DOESN'T HAVE IS INHERITED BAND GAP IN ITS ELECTRONIC STRUCTURE. BUT YOU CAN CREATE BAND GAP OPENING IF YOU MODIFY GRAPHENE WITHOUT REALLY DESTROYING THE STRUCTURE, WITHOUT CREATING DEFECTS AND USE THIS AS A SENSOR"

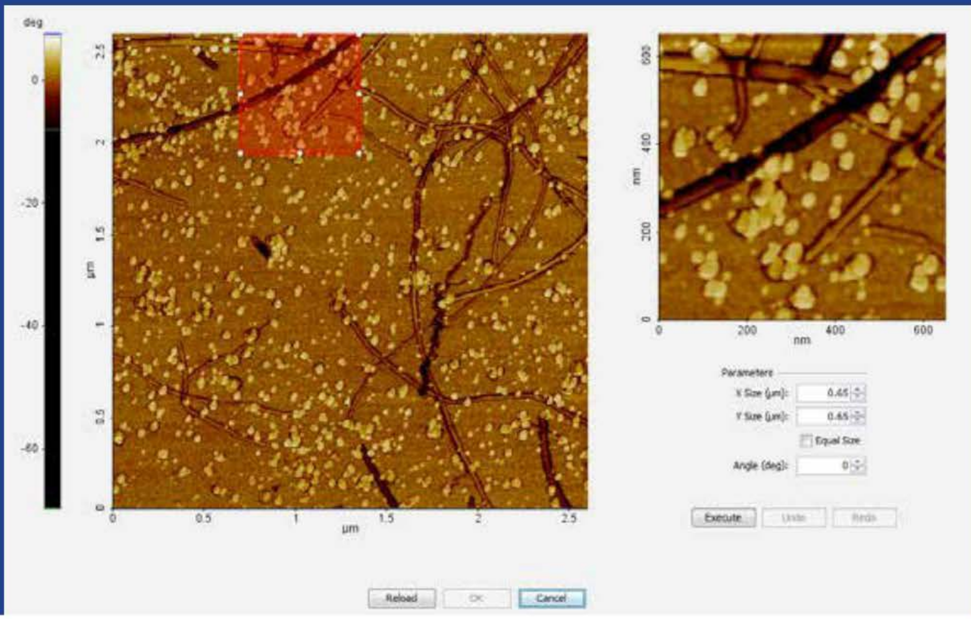
more and more involved in chemistry and become a cross-disciplinary group, so we'll see. But our goal is still to work with devices and try to understand how modified devices behave, how reliable they remain after process of testing. I think that's how ultimately anything we study or discover becomes an application. If it's really something that reliably performs after many cycles of treatments, whether it's cooling it down and measuring conductivity, or measuring other characteristics, or doing spectroscopy on the device, we would like to know how well the device survives.

How is AFM used in your research?
Well, we need nanoscale observation to study nanoscale devices. We use AFM, and of course non-contact is better, to observe the nanoscale materials we are making. Non-contact AFM allows us to "see" our materials without perturbing them. Ultimately we need to find out the behavior of our devices without destroying them, so we need techniques that are non destructive. When your materials are so small, the chance that the observation will change the device is something that we have to be careful of. Also as you shrink your sizes, quantum behavior becomes more prominent and so we utilize other scanning probe techniques to measure physical properties of our materials. We cannot avoid contact when use electrostatic force microscopy to measure the electrical responses of our devices. I've described our DPN technique to you already that we use for patterning catalyst to grow carbon nanotubes, but we can perform localized annealing or heat treatment on the nanoscale. We also use magnetic force microscopy to measure magnetic properties graphene and carbon nanotubes, which are not magnetic, but after we engineer graphene with a high density magnetic field.

What can typical consumers hope to see in the future that would be derived from something you're studying now?
We really hope, with the studies that we do, we get something interesting discovered. For example, if we can make a reliable sensor, or a reliable transistor out of graphene that has been modified – for a consumer it probably means faster components of electronic devices, or nanoscale electronic devices, smaller nano-electro mechanical devices. Testing and sensing applications can be performed on the nanoscale. Perhaps it could also mean a new type of diagnostic probes that we can also manufacture on a small scale. Imagine that you need to test or investigate a small sample or valuable specimen that you have very little of. You can test it in a traditional way, but you need big volumes of it. With AFM techniques you can deposit tiny portions (femtoliters) of something on a glass slide and study it this way. I'm thinking of specimens, especially biological, DNA based or protein based, that you could do this with. This means that a lot of tests could be performed with a much smaller amount of specimen that you would currently need to provide. This could also be applicable to devices for all other fields, for example semiconductors, but biology is a natural fit, simply because things that you can do in solution are easy. You can manipulate this and have really tiny volumes, in femtoliters.

I have a colleague in biomedical engineering department and right now we are trying to develop a project for a mutual student who will work with carbon materials and cells. Using scanning probe techniques, we won't be able to manipulate micron scale objects like cells, but we can try to get a nanoscale response from a cell that is attached to a device. We can study a cell that sits on a patch of graphene or a carbon nanotube and record its electrical response or its capacitance response. Actually, if it is already sitting on a device, we can also record conductivity while simultaneously stimulating the cells by releasing molecules from within the carbon nanotubes at specific times. My colleague is very excited at the prospect of studying responses of individual cells.

But you don't have to apply our research to biology. For example, semiconductor manufacturing is currently a bottom up approach and we hope to achieve similar thing at the nanoscale. But really, we want to integrate nanoscience techniques into technology.As we develop methods of fabrication on the nanoscale, these devices will have applications everywhere. Anything with a sensor, or integrated circuits can be miniaturized and therefore require less sample or potentially become much less costly to produce.



catalyst where you want it and you grow your materials only at that location. So we call it predefined, preferentially grown at a specific location. This is something that is still very desirable for device applications. You can create arrays of devices. You would clearly like to have your carbon nanotube grow only where you want it and not have catalyst at other places where you don't need it. Plus it eliminates the multiple step process required in convention nanofabrication. The process that is usually used, if you really want to create islands of catalysts and grow from there and the one we use is using AFM probes.

What volume of droplets can you deposit onto your substrate using scanning probe techniques?
It is usually in femtoliters (10-15 liters). Everything is femto, volumes are femtoliters, measurements are femtofarads, charge is femtocoulombs

Can you manipulate single catalyst molecules?
No Not at this point. At this point when we deposit catalyst in molecular solution, it is still in solution. It dries out and we reduce it. We still get, at the end, a sample of catalyst particles. Statistically, the smaller the cluster, the fewer individual particles that will be in the cluster. We keep them as uniform as we can. Statistically at this point we are growing individual carbon nanotubes from the cluster of catalyst containing, perhaps, tens of molecules. Then we use chemical vapor deposition technique, which is pretty high temperature thermal furnace that we grow carbon nanotubes in. We have been playing around with devices that are already pre-fabricated, like pre-fabricated transistors. We collaborate with researchers at Argonne National Lab, they provide us with devices and then we put catalyst on the device in specific pre-determined locations and then we grow our nanotubes. The downside of this is that the material and leads that are still metal degrade a little in the furnace at 900°C. You have to be clever, either using a lower temperature so your metallic components don't degrade, or use some other metal that still preserver their integrity even after high temperature processes. Most devices do not survive CVD conditions. That's another area of research. Eventually, perhaps, we will go to a different regime or schematic, or use different recipes for significantly lower growth temperatures, which could be ideal.

What types of devices do you hope to build/ construct with the materials that you are growing?
We are interested in different types of devices. Basically those are field effect transistors. We would also like to create 3 dimensional structures. Imagine that we build a device – a planar field effect transistor from individual carbon nanotubes, or individual piece of graphene, later we can, depending on the size of the device, with scanning probe lithography, or patterning, we can deposit molecules, DNA, proteins, or other particles, on top of your ready device and modify it this way. The important thing when we work with graphene or carbon materials is not to modify the structure through covalent bonding. What we would like to do to modify, to some extent, with chemisorption or physisorption so it could be reverse processed, or it could be a process that doesn't permanently destroy the crystalline structure of graphene. That's what we also do with the surface of graphene and we've demonstrated patterning of magnetic particles on the surface of graphene with our AFM based direct writing techniques.

Why is your research important?
We're still physicists. We really would like to learn ways we can create and modify materials that we make. Some materials, as grown, are perfect and can be used for specific applications. Some materials have extremely unique properties, like graphene. One property that graphene doesn't have is inherited band gap in its electronic structure. But you can create band gap opening if you modify graphene without really destroying the structure, without creating defects and use this as a sensor. We would like to use modified graphene with organized arrays of patterned structures, whether it's kinetic/magnetic/233 or else to preserve its integrity and also is modified to be able to be used as a semiconductor.

What techniques do you use in your research?
We use techniques that relate to nanoscience and nanotechnology. We are now

PARK SYSTEMS DOMINATES THE AFM DISC STORAGE MARKET

Park Systems, a leading manufacturer of atomic force microscopy (AFM) systems and nano metrology tools for research labs and industry has recently announced a 90% market share in the disc storage market for AFM. Park AFM offers superior technology and performance unmatched by the competition, specifically the highest accuracy in nanoscale due to the independent XY stage and Z scanner architecture, and flexure based design, the low operating cost by its unique True Non-Contact AFM, and many automated features for ease of use in failure analysis lab and production environments. Since 2007, Park has gained a reputation as the technology leader of nanoscale measurement and systems in both research and industry and their impressive client list that includes Harvard, Stanford, NASA, NIST, Hitachi, Seagate and Western Digital.

"Our recent successes which include capturing 90% of the hard disc industry market were accomplished by outperforming our competition," commented Keibock Lee, Park Systems President. "The old technology was riddled with problems and limitations, so Park created a new architecture and perfected the non-contact scanning technology that drastically increased accuracy and usability while bringing down the total cost of ownership of AFM tools. The manufacturers switched to Park AFM with the proof that our superior technology would meet their needs in the short and long term."

Park Systems achieved the impressive market share in the disc storage market thru a focused effort on customer needs and performance requirements, resulting in a superior AFM product. In this highly competitive market, where a transition from one vendor to another means eventually replacing all the tools, each costing a million dollars, it is a testament to Park's customer service and technology strengths that the manufacturers switched vendors.
Park is constantly developing and enhancing their products to meet the ever increasing stringent industry requirements and they continue to invest heavily in research and development to provide the most advanced AFM for failure analysis and quality assurance.

Park is the only AFM that provides the 3D scanning with rotated head and automated defect reviews which can pin point hundreds of defects in the time it would take less than ten to find in manual method. In case of its new 3D AFM tool, it allows customers to do side wall angle and roughness measurements that was not possible before. Park also developed and deployed a Programmable Density Scanning for the read/write poles. Programmable Data Density AFM scanning is done to magnify the region of interest, enabling customers to do more effective pole tip recession metrology. For the semiconductor and hard disk industry, Park AFM can measure below 0.3 angstrom of roughness, now the cutting edge in industry requirement.

PARK SYSTEMS UNVEILS NEW PARK XE15

POWERFULLY VERSATILE ATOMIC FORCE MICROSCOPE WITH UNIQUE MULTISAMPLE™ SCAN

Park Systems, a leading manufacturer of atomic force microscopy (AFM) products, announces the debut of Park XE15, a powerfully versatile atomic force microscope featuring a unique MultiSampleTM scan. This newly developed large sample AFM provides researchers and operators with the ability to automatically image and measure up to nine individual samples. Park XE15 can also easily scan larger samples of up to 200 mm x 200 mm, a vast improvement from the current AFM products on the market. Park XE15 is ideally suited for shared labs environments that handle a diverse range of samples, researchers doing multi variant experiments, and failure analysis engineers working on wafers.

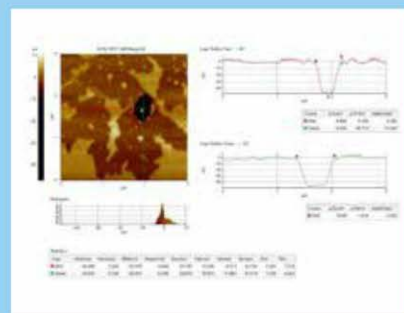
"We continue to set new standards of excellence with our new technology and high accuracy in AFM imaging and measurements," says Dr. Sang-Il Park, the founder and CEO of Park Systems. "Park XE15features our most inclusive set of scan modes and can process a range of sample sizes, designed specifically to provide ease of use for shared labs with a wide range of individual requirements."

Park XE15 is the only AFM that maximizes the efficiency of product use with MultiSampleTM scan, automated imaging of multiple samples in one pass. Specially designed multi-sample chuck holds up to nine individual samples which allows operators to scan the samples under identical environmental conditions, improving the accuracy and reliability of the data. After loading the stage with multimple samples, the scan process can be intitated. This makes it ideal for researchers wanting to scan larger samples or failure analysis engineers who need to place silicon wafers on the stage.

"Over the many years that I have worked with Park System, I have found them very responsive to customer feedback in developing new products. Park XE 15 is a problem-solver for engineers who need to process multiple samples simultaneously in a controlled environment," Comments Ahmed A. Busnaina, Professor and Director The NSF Nanoscale Science and Engineering Center for High-rate Nanomanufacturing (NSEC) and the NSF Center for Microcontamination Control, Northeastern University. "The Park engineering team is a great nanoscale partner, working in unisom with customers to create products that meet customer performance requirements."

PARK NX-WAFER

DESIGNED FOR WAFER-FAB MANUFACTURING FULLY AUTOMATES SEMICONDUCTOR INDUSTRY'S BARE WAFER AUTOMATED DEFECT REVIEW PROCESS, INCREASES THROUGHPUT BY ASTOUNDING 1,000%



Park Systems, a leading manufacturer of atomic force microscopy (AFM) products announces Park NX-Wafer, a revolutionary AFM design for bare wafer manufacturing that fully automates the automatic defect review process and increases production throughput by an astounding 1,000%. Park NX-Wafer produces sub-Angstrom roughness measurements for the flattest substrates and wafers with tip-to-tip variation of less than 2%, for the first time ever in the entire history of the semiconductor industry. This fully automated defect review and identification system enables a critical inline process to classify defect types and source their origin through high resolution 3D imaging only available at Park Systems, the world's leading AFM provider.

"Park NX-Wafer is an updated continuation from the wafer metrology product line, the Wafer Series, with new application capabilities focusing on automatic defect review (ADR), atomic force profiler, and sub-Angstrom surface roughness control. Among the three, SmartADR for 200/300mm bare wafers is a disruptive technology that improves productivity by up to 1,000% compared to traditional defect review methods by AFM," explains Sang-il Park, CEO and Chairman Park Systems."Designed specifically for the semiconductor industry, the new bare wafer ADR is the most advanced, fully automated defect review solution available, featuring advanced coordinate translation with enhanced vision that does not require any separate steps to calibrate the stage of the targeted defect inspection system nor labor intensive reference marking on the target wafer sample. Unlike SEM which leaves square-shaped destructive irradiation marks on defect sites after its run, the AFM-based defect review enables non-destructive 3D imaging of defects as small as a few nanometers."

NX-Wafer has several new features that help revolutionize the Wafer Fab Manufacturing process offering the improvements needed for full scale production of bare wafers. One is a long range sliding stage that combines with NX-Wafer to become an Atomic Force Profiler (AFP). The new low noise AFP provides very flat profiling up to 50mm with profiling speed as fast as 1mm/sec for both local and global uniformity measurements including dishing, erosion, and edge-over-erosion (EOE)after chemical mechanical polishing (CMP). It guarantees accurate height measurements with no non-linear or high noise background subtraction over a wide range of profiling lengths.

Another new featureis the fully automated defect review process from transfer and alignment of defect maps to the survey and zoom-in scan imaging of defects on 200/300mm bare wafers. By utilizing Park's proprietary coordinate translation technique using enhanced vision, the new bare wafer ADR can accurately transfer the defect maps obtained from a laser-scattering defect inspection tool to the Park NX-Wafer system. This technology does not require any separate step to calibrate the stage of the targeted defect inspection system and allows full automation for high throughput defect imaging.

"Park develops not only the most advanced atomic force microscopy system for wafer fab but also its own system software for automation. The extent of automation offered in our inline measurement and analysis are unprecedented and unparalleled. This makes Park NX-Wafer an automated AFM with true wafer-fab manufacturability. It is a genuine inline AFM system that works 24/7 for production or process engineers, not the other way around," states Ryan (YK) Yoo, Vice President of Global Sales and Marketing Park Systems. "The Atomic Force Profiler (AFP) is an essential component of CMP metrology and Park NX-Wafer comes with a dedicated user interface for the automated CMP profiling and analysis, rendering complex background subtraction or calibration after each profiling measurement unnecessary.Both chip makers and wafer suppliers are demanding more accurate roughness control of ultra-flat surface on Si or SOI wafers, and Park NX-Wafer enables fully automated surface roughness measurement with sub-Angstrom repeatability and minimum tip-to-tip variation for either micro-roughness or long-range waviness." Park NX-Wafer includes Park's patented design features well-known throughout the industry to provide accuracy and durability including True Non-ContactTM mode and industry leading ultra-low noise Z detector.

Park will be showcasing NX-Wafer and their full line of atomic force microscopy (AFM) systems and nano technology tools used by the world's leading semiconductor, academic and research facilities at Park Americas headquarters in Santa Clara, California. For private showing, please call (408) 986-1110 or email inquiry@parkafm.com.

THE JOURNAL OF PHYSICAL CHEMISTRY C

PROBING TRANSIENT ELECTRIC FIELDS IN PHOTOEXCITED ORGANIC SEMICONDUCTOR THIN FILMS AND INTERFACES BY TIME-RESOLVED SECOND HARMONIC GENERATION

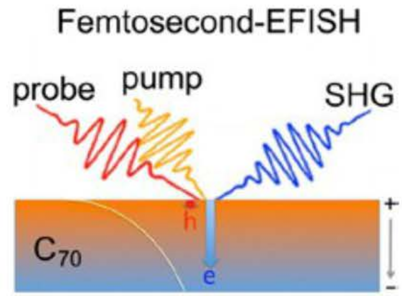


Photo-Dember-effect in organic semiconductor

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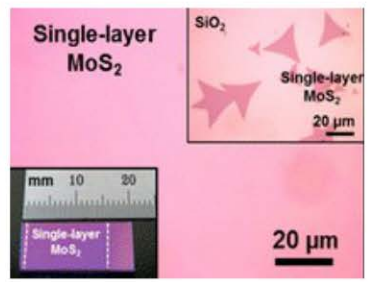
J. Phys. Chem. C, 2014, 118 (20), pp 10670–10676
Publication Date (Web): May 5, 2014

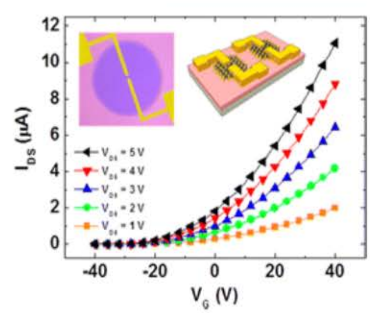
ABSTRACT
We have probed photoinduced charge separation dynamics in organic semiconductor thin films and at their interfaces by femtosecond time-resolved second harmonic generation (TR-SHG), using the model systems of fullerene (C70) thin films and copper phthalocyanine (CuPc)/C70 interfaces. In neat C70 thin films, the formation of an internal electric field on a 10-ps time scale following photoexcitation is attributed to the photo-Dember effect, namely, charge separation resulting from a gradient in excitation density and the differential electron/hole mobility. When an ultrathin film of the electron donor CuPc was deposited on top of the C70 film, an additional interfacial charge separation channel occurring on the ultrafast time scale of 0.1 ps was observed. We discuss how SHG fields from different origins can interfere to give the overall transient response.

For Full Article go to:
http://pubs.acs.org/doi/pdfplus/10.1021/jp502381j

ACS NANO

PHOTOELECTRON SPECTROSCOPIC IMAGING AND DEVICE APPLICATIONS OF LARGE-AREA PATTERNABLE SINGLE-LAYER MOS2 SYNTHESIZED BY CHEMICAL VAPOR DEPOSITION





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ACS Nano, 2014, 8 (5), pp 4961–4968
DOI: 10.1021/nn501019g
Publication Date (Web): April 14, 2014

ABSTRACT
Molybdenum disulfide (MoS2) films, which are only a single atomic layer thick, have been synthesized by chemical vapor deposition (CVD) and have gained significant attention due to their band-gap semiconducting properties. However, in order for them to be useful for the fabrication of practical devices, patterning processes that can be used to form specific MoS2structures must be integrated with the existing synthetic approaches. Here, we report a method for the synthesis of centimeter-scale, high-quality single-layer MoS2 that can be directly patterned during CVD, so that postpatterning processes can be avoided and device fabrication can be streamlined. Utilizing X-ray photoelectron spectroscopic imaging, we characterize the chemical states of these CVD-synthesized single-layer MoS2 films and demonstrate that the triangular-shaped MoS2 are single-crystalline single-domain monolayers. We also demonstrate the use of these high-quality and directly patterned MoS2 films in electronic device applications by fabricating and characterizing field effect transistors.

For Full Article go to:
http://pubs.acs.org/doi/abs/10.1021/nn501019g