

## INSIDE

1/2 \_\_\_\_\_

News

3 \_\_\_\_\_

Tips and Tricks

4/5 \_\_\_\_\_

Application Note

6 \_\_\_\_\_

Events

Training

Social Media

7 \_\_\_\_\_

Employee

Spotlight

8 \_\_\_\_\_

Customer News

# EDAXinsight

December 2016

Volume 14 Issue 4



EDAX NEWS

## EDAX Takes the Next Step with OIM Analysis™ v8 Release

Orientation Imaging Microscopy (OIM) Analysis™ has been established as the benchmark for analytical capability and performance in the Electron Backscatter Diffraction (EBSD) market. This product has helped EDAX users investigate microstructural data and improve understanding in a diverse range of applications, including the development of high-temperature materials for next-generation engines, pipeline steels with enhanced corrosion resistance, solar cells with improved operational efficiencies, and lightweight alloys used for weight reduction in automobiles. With the introduction of OIM Analysis™ v8 new features and functionality are now available to help users better characterize their materials and expand the capability of their EDAX EBSD system.

One of the main improvements in OIM Analysis™ v8 is the optimization of the code to take advantage of modern multi-core computers. Previously, OIM Analysis™ used only one core, or processor within the computer. When computers only had a single core, you bought a computer with a faster processor if you wanted OIM Analysis™ to run faster. However, computer manufacturers were running into processor speed limits due to transmission delays and heat build-up on the

chips based on the materials, size, and designs used. The solution to this limitation was multi-core processors, where two or more processors are integrated within a single component. This design allows a given function to be multithreaded or broken into smaller steps that can be sent to different cores for concurrent processing. This approach allows for faster completion of a given function.

Multithreading in OIM Analysis™ v8 brings a range of advantages and improvements for users. OIM Analysis™ v8 is a 64-bit application, which allows it to handle very large EBSD mapping datasets, which are becoming more common with the availability of the high-speed Hikari EBSD detectors. With OIM Analysis™ v8 the rendering of maps has been optimized for multithreading, which means these maps appear much quicker than with previous versions. This makes analysis of these large datasets much more convenient. Interactive highlighting, which allows users to select features of interest in a map, chart, or plot and then see this information overlaid onto another map to visualize the correlation between these different representations, has also been multithreaded.

(Continued from Page 1)

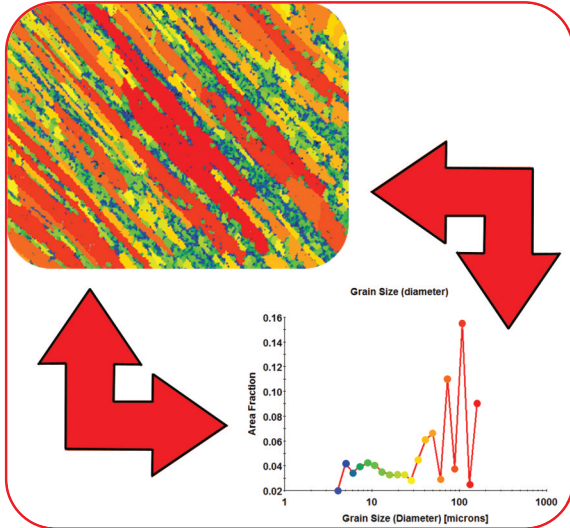


Figure 1. An example of interactive highlighting. A grain size distribution chart created for a region of a friction stir welded aluminum sample.

A grain size distribution chart was created for a region of a friction stir welded aluminum sample (Figure 1). The entire range of the distribution was then interactively highlighted, and a color code was applied to the histogram with the smallest grains colored blue and the largest grains colored red. This color code was then subsequently applied to the map image to show the spatial distribution of the grain sizes within the measured structure.

A new feature introduced into OIM Analysis™ v8, which also takes advantage of multithreading, is EBSD pattern indexing. The term indexing refers to determining a crystallographic orientation and phase from an EBSD pattern, and the term reindexing refers to repeating this process after an initial attempt. Ideally all EBSD patterns are correctly indexed when collected using the TEAM™ EBSD software. Sometimes, either intentionally or unintentionally, this is not the case. For example, there could be an unexpected phase within the region of interest, and that phase was not included in the crystallographic material file used during data acquisition. Historically, users could reindex the data within the TEAM™ or OIM Data Collection platforms. However, users would often use Confidence Index analysis within OIM Analysis™ to determine if reindexing was necessary, so the process would involve using multiple applications. With the introduction of pattern indexing, OIM Analysis™ v8 is now a more comprehensive package for total analysis that can be used away from the Scanning Electron Microscope (SEM) lab more efficiently.

With reindexing, users have the option to use either saved EBSD patterns or saved band positions detected via the Hough Transform during the initial acquisition. Saving EBSD patterns is an option in the TEAM™ software, while Hough Peak data is saved by default.

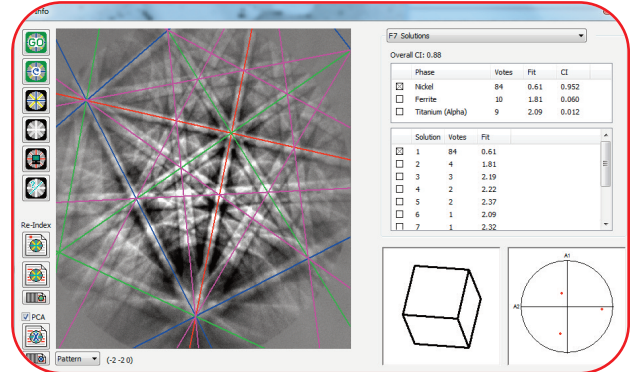


Figure 2. A saved EBSD pattern reindexed in OIM Analysis™ v8.

Figure 2 shows a saved EBSD pattern reindexed in OIM Analysis™ v8. There are several advantages to using saved EBSD patterns for reindexing. First a signal background can be created for each phase and then applied to each pattern. This is useful if the average atomic number of each phase varies significantly, as the average intensity of the EBSD pattern will vary with this metric. Optimizing the background for each phase improves band detection and eliminates artifacts from poor background fitting. Second, image processing can be optimized for each phase. Several routines are available to enhance and improve pattern quality including background subtraction and division, high and low pass filters, and median and Kalman filters for noise reduction. Third, band detection can be optimized for each phase by adjusting the Hough Transform parameters. Fourth, EDAX's patented NPAR™ routine can be used to improve indexing performance through local pattern averaging to improve image signal-to-noise ratio.

With either saved EBSD patterns or Hough Peak reindexing, OIM Analysis™ v8 offers other useful features for pattern reindexing. New phases can be loaded for pattern reindexing, and the quality for the reindexing can be evaluated via the Solutions window. All the points within a dataset can be reindexed, or now specific subsets can be reindexed using the partitioning functions within OIM Analysis™. For example, users can identify points with a low confidence index after initial indexing, and group these points together into a partition. The reindexing can then be applied only to these points. This approach makes reindexing more efficient, as only the suspect points are analyzed. Simultaneously collected EDS data can be used to differentiate crystallographically similar phases, in an approach termed ChI-Scan™. Furthermore, batch reindexing is available to analyze multiple datasets with the same settings. This function is particularly useful for in-situ or 3D EBSD datasets, where multiple scans are collected under similar acquisition conditions.

In summary, OIM Analysis™ v8 represents a significant step forward in microstructural capability and builds upon the solid foundation of the market-leading OIM Analysis™ platform.

## Understanding the EDAX Autophase Selection Routine

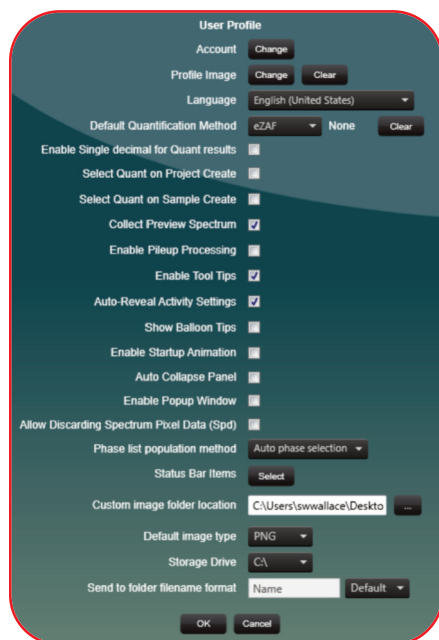


Figure 1. The Auto Phase Selection Routine is turned on by selecting it from the Phase List Population Method pulldown found in the User Profile window.

One of the most common questions received from new Electron Backscatter Diffraction (EBSD) users is “How do I know what phase file to choose from?”. This is not an easy question to answer for some materials, but for many materials, our built in Autophase Selection Routine works well. This routine can help the novice user understand their samples better, removing the need for understanding all the complexities of phase ID.

The most important step of this routine is turning it on. It can be found under the User Profile window under Phase List Population Method (Figure 1). Select “Auto phase selection” and it is now ready to use.

The next step in using this process is making sure that the Energy Dispersive Spectroscopy (EDS) system is ready for use, as it uses the EDS data to populate the phase list. The EDS detector needs to be both inserted and cooled to get optimal results. The routine is started when you image the area inside TEAM™. After the area is imaged, the routine does a full EDS scan over the entire field of view determining what element(s) are present and in what proportions. One word of caution here is that it does use the entire field of view. It is usually best to make sure at this point, that the field of view is the area you want to run. The biggest thing to avoid here is the mounting material. Make sure you do not include epoxy, aluminum stubs, or glass slides in the area as it will include their elemental makeup.

After the EDS survey is done, the found elements are searched for in

Graphite	Austenite	Ferrite	Aluminum	Copper	Nickel	Brass-Alpha
Brass-Beta	Cobalt-Alpha	Cobalt-Beta	Titanium-Alpha	Titanium-Beta	Zirconium-Alpha	Zirconium-Beta
Zinc-Beta	Tungsten	Tantalum	Molybdenum	Manganese-Alpha	Manganese-Beta	Manganese-Gamma
Cadmium Telluride	Aragonite	Calcite	Quartz	Silicon	Gold	Platinum

Table 1. A partial list of phases included in the Autophase Selection Routine.

a special subset of our database. From this search, the phases are added to the phase list and are ready for you to use in your analysis. At this point, it is best practice to confirm the phases via our Survey Mode. You should try multiple spots over the sample and look at our indexing metrics to see if the phases selected are correct for your sample.

The two main metrics to look at are Confidence Index (CI) and Fit. Fit is a relatively straight forward concept. The Fit metric compares the indexed solution versus the Hough Transform and sees how well the triangles we use for indexing overlay the solution. The deviation between the two are measured as the Fit. In general, these values should be  $<2.0^\circ$ , ideally less than  $1^\circ$ . In deformed samples or lower quality patterns, this value can be expected to be higher.

The CI is slightly more complicated to understand than the Fit metric. CI is a measure of uniqueness between the two best solutions. This metric takes the votes for the winning solutions and subtracts from it the second best solution. This value is then divided by the number of ideal solutions to give you the actual CI value. These values range from 0 to 1. Users should feel comfortable knowing that the solution

is correct with any value greater than 0.15. The attached graph (Figure 2) shows that for the value 0.15, we have the solution and orientation for the solution correct over 90% of the time. Any value greater than 0.2 quickly goes to 100%

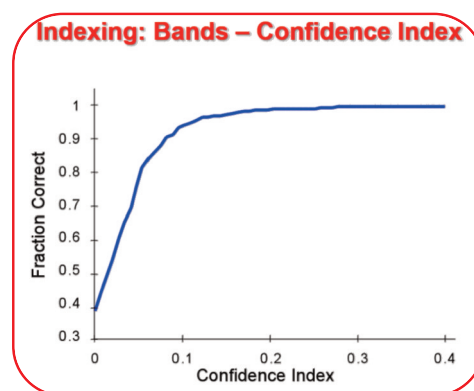


Figure 2. The fraction indexed correctly rapidly increases when the Confidence Index approaches 0.1. At around 0.2, the fraction correctness approaches 100%.

with our solution. With the combination of our Autophase Selection Routine and our indexing metrics, any user can quickly populate a phase list and confidently know that their resulting work will be the best.

## Calibration Strategies for Coating Measurements on the XLNCE X-ray Metrology Product Line

In making coating composition and thickness measurements, particularly in an industrial environment, i.e. quality and process control, questions regarding the accuracy of results are very common. This is often a difficult question to answer because in many instances there are no reference standards available to gauge the accuracy of the results, particularly when the material studied is a proprietary formulation. To begin to address the question, it is important to understand the calibration methodology for X-ray Fluorescence (XRF) coating measurements as there is often a focus on making “standardless” measurements.

The quantitative algorithm used for coating analysis on the XLNCE XRF product line is essentially the same type of routine as is used for bulk materials. Quantification of a bulk material assumes that the material is homogeneous. Various instrumentation factors such as geometry, X-ray tube type and detector characteristics are either entered or modeled. The algorithm then attempts to calculate all the physical interactions that take place within the sample when X-rays excite the sample and scattered photons and fluoresced characteristic X-rays travel to the detector. These types of algorithms are commonly referred to as “Fundamental Parameter” routines because the physical modeling of the measured sample is facilitated by a database of fundamental atomic parameters which characterizes the X-ray physics of each atomic element. A coating algorithm requires some additional information, i.e. the number of layers in the coating structure and assignment of all elements either to a specific layer or to the substrate. In addition, as the coating calculations are much more sensitive to the instrument’s geometry, coating routines are typically “calibrated” by measuring a single, pure element. In the XLNCE product series, this last step would take the form of measuring any element and assuming the calculated calibration coefficient is the same for all elements involved in the calculation.

In theory, the calibration coefficients are the same for all elements for a given set of excitation conditions; however, in practice this is not the case, which leads to the implementation of various calibration methodologies to improve the accuracy of the coating calculations. For the XLNCE product line, these calibration methodologies involve the use of either pseudo-standards or type standards. The simplest example of pseudo-standards involves measuring a pure element of “infinite” thickness to generate a calibration coefficient for every

element involved in the coating structure. The term, infinite, signifies that the thickness of the pure element standard is such that further increase in thickness produces no further increase in count rate of the relevant X-ray signal. This type of pure element calibration is achievable for many elements, but obviously becomes problematic in cases where the material is toxic, unstable or in a non-solid state at room temperature. In these cases, it is possible to measure the element in a stable compounded form, e.g. measuring potassium in the compounded form of potassium carbonate,  $K_2CO_3$ , to get a calibration coefficient for potassium. Another strategy is to use what could be referred to as a “nearest neighbor” element. One might measure an available pure element with signal energy near to the element which is not available, e.g. measuring the calibration coefficient of tin and using this for tellurium or using hafnium or tungsten to estimate the rare-earth coefficients.

In practice, pure element calibrations seem to work most accurately in the “thin” film regime, where “thin” is defined as that portion of the XRF signal response curve where increase in film thickness yields a somewhat linear response. Beyond the “thin” regime, unit increases in thickness yield less than unit increases in signal response until the point of saturation, i.e. where the material is infinitely thick.

Table 1 provides the results from a homogeneity study of an indium coated silicon wafer using the XLNCE SMX-BEN benchtop analyzer. Type standards, a standard which matches the sample to be measured in terms of layers and layer ordering, were not available in-house for this study, but a type standard of sorts was developed by cross-sectioning the indium film with a Focused Ion Beam (FIB) electron microscope. The FIB result (Table 1, “FIB ( $\mu\text{m}$ )” column) at the center of the wafer was used as the type standard and an SMX-BEN measurement at the center was set to 6.61  $\mu\text{m}$ , highlighted with green in Table 1.

Wafer Measurement Position	FIB ( $\mu\text{m}$ )	Type Std ( $\mu\text{m}$ )	Pure In(K) CC ( $\mu\text{m}$ )	Pure Sn(K) CC ( $\mu\text{m}$ )
Nominal Center	6.61	6.61 (from FIB)	6.56	6.44
6 mm off nominal center		6.65	6.60	6.48
12 mm off nominal center		6.71	6.65	6.53
68 mm off nominal center	6.7	6.52	6.47	6.35
90 mm off nominal center	6.22	6.42	6.37	6.25
95 mm off nominal center		6.29	6.25	6.13

Table 1. FIB and XRF thickness measurements of Indium deposition on a 200 mm Si wafer.

(Continued from Page 4)

Three sets of results are shown for the same data collection with three different calibrations applied: the “Type Std” column with a calibration as previously described; “pure In(K)” with a calibration based on a measurement of a pure, infinite sample of indium; and “pure Sn(K)” with a calibration based on a measurement of a pure, infinite sample of tin. Indium and tin are atomic numbers 49 and 50, respectively, in the periodic table. The difference between type standard results and calibration by pure indium is < 1% relative, while the difference using pure tin is about 2.6 to 2.7% relative. The FIB results don’t completely track with the XRF measurements at 68 mm and 90 mm off center; however, the FIB layer thicknesses are measured in cross-sections about 5  $\mu\text{m}$  wide, while the XRF measurements are made over an area of about 2.5 mm in diameter allowing for variations in FIB results that may be averaged by the XRF measurement area. The main idea here is simply to show how well type standard, matching pure element, and nearest neighbor pure element calibrations agree when making measurements in this thin film regime. (The limit of indium metal film XRF measurements using the In(K) line is approximately 90  $\mu\text{m}$ .)

As the layer thickness increases beyond the thin film regime, the calculations of the X-ray physics become more complicated and the errors increase. The same is true of multi-layer structures where the calculation errors in the upper layers propagate into the calculations on the subsurface layers. For optimum accuracy in these situations, it is best to apply single- and multi-layer type standard calibrations. For simple, single layer metal films, there are commercially available standards (e.g. [www.calmetricsinc.com](http://www.calmetricsinc.com)), both free-standing stackable metal foils and hard-plated standards. Stackable foils allow flexibility to stack them in varying order, while hard-plated standards are more durable. Hard-plated standards are typically available for very common industrial applications, such as electrical contact layer structures.

In many industrial metrology applications, measurements are made on performance coatings with proprietary formulations. The same rules apply between calibration strategies for thin film versus thick film measurements. Type standards will still provide the best accuracy and it is in this environment where the best accuracy is typically required. However, standards are not available for proprietary formulations. In this case, type standards are developed in-house using destructive testing methods or EDAX can provide support assistance in

characterizing proprietary materials to make type standards for the customer under a confidentiality agreement.

In making type standards for proprietary performance coating structures, these materials are often optimized by tuning the deposition processes. For example, the introduction of dopants into photovoltaic layers is often varied until the best photovoltaic conversion efficiency has been achieved. Variations in deposition processes can also impact the accuracy that a type standard provides in a calibration and it is best to use the same deposition process to produce the type standards as the final product. Experience has shown that matching deposition conditions in a multi-layer structure that appears essentially the same from an X-ray physics perspective can improve the accuracy of the type standard calibration from 2 to 3% relative down to about 1% relative.

Essentially standard-less coating measurements are possible with the XLNCE X-ray Metrology product series; however, the discussion quickly turns to the accuracy of these measurements as today’s performance coating structures are often tuned for best performance within a limited range of composition and thickness. Calibration strategies with the XLNCE X-ray Metrology product line range from simple, durable pure elements to type standards depending on the accuracy demanded. It is important to have that discussion regarding measurement accuracy up front when implementing a calibration strategy because the accuracy demands of one customer can be completely unacceptable for another.

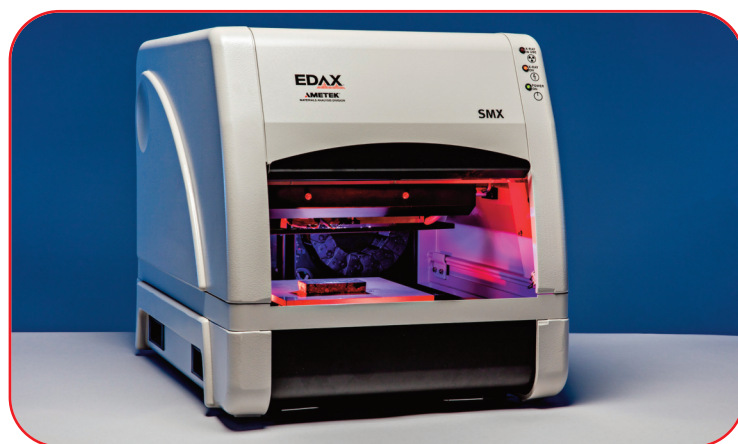


Figure 1. The XLNCE SMX-BEN XRF Benchtop Analyzer.

## 2017 Worldwide Events

### February 6-10

Australian Microbeam Biennial Symposium Brisbane, Australia

### February 13-18

American Academy of Forensic Sciences New Orleans, LA

### March 2

10th Annual FIB SEM Workshop Gaithersburg, MD

### March 20-23

ARABLAB 2017 Dubai, United Arab Emirates

### March 23-24

ICFSI 2017

### April 4-5

Royal Microscopical Society (RMS) EBSD 2017 Oxford, United Kingdom

### April 25-27

SEMICON Souteast Asia 2017 Penang, Malaysia

### May 3-4

Forensics Expo Europe London, United Kingdom

Please visit [www.edax.com/Event/index.aspx](http://www.edax.com/Event/index.aspx) for a complete list of our tradeshows.

## 2017 Worldwide Training

To help our present and potential customers obtain the most from their equipment and to increase their expertise in EDS microanalysis, WDS microanalysis, EBSD/OIM™, and Micro-XRF systems, we organize a number of Operator Courses at the EDAX facilities in North America, Europe, Japan, and China.

### EUROPE

TEAM™ EDS	
TEAM™ EDS	
February 13-15 March 7-9 March 20-22 May 29-31	Weierstadt# Tilburg* Weierstadt# Weierstadt#
Microanalysis (TEAM™ or Genesis)	
June 15-16	Tilburg*
TEAM™ EBSD	
February 15-17 March 22-24 June 12-14	Weierstadt# Tilburg* Tilburg*
TEAM™ Neptune (EDS & WDS)	
May 29-June 2	Weierstadt#
TEAM™ Pegasus (EDS & EBSD)	
February 13-17 June 12-16	Weierstadt# Tilburg*
TEAM™ WDS	
May 31-June 2	Weierstadt#

\*Presented in English  
#Presented in German

### JAPAN

EDS Microanalysis	
Genesis	
June 8-9 July 6-7	Tokyo Osaka
TEAM™ EDS	
February 21-22 April 13-14 October 12-13 November 9-10	Tokyo Osaka Tokyo Osaka

### CHINA

TEAM™ EDS	
March 7-9 June 6-8 September 5-7 December 5-7	Shanghai Shanghai Shanghai Shanghai
TEAM™ EBSD	
April 11-13 August 8-10 November 7-9	Shanghai Shanghai Shanghai

### NORTH AMERICA

TEAM™ EDS	
February 7-9 February 27-28 May 15-19	Mahwah, NJ Draper, UT Mahwah, NJ
TEAM™ EBSD	
March 1-3 June 20-22	Draper, UT Mahwah, NJ
TEAM™ Pegasus (EDS & EBSD)	
February 27- March 3	Draper, UT
TEAM™ WDS	
March 28-30	Mahwah, NJ
XRF	
April 4-6	Mahwah, NJ

Please visit [www.edax.com/support/training/index.aspx](http://www.edax.com/support/training/index.aspx) for a complete list and additional information on our training courses.

### FOLLOW US

Stay up to date with news and happenings through social media.  
Follow us on LinkedIn, Twitter, YouTube and at  
<http://edaxblog.com>.



## EMPLOYEE SPOTLIGHT



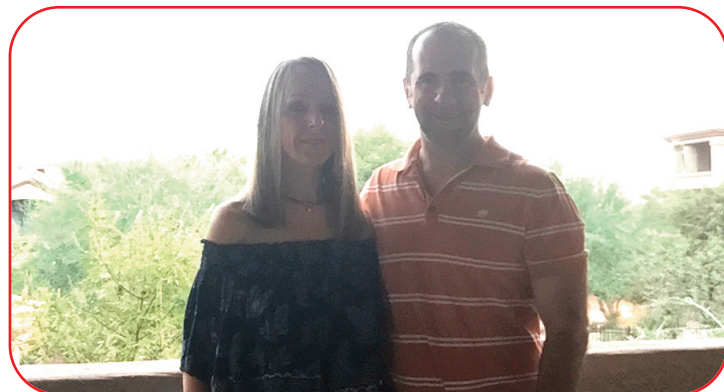
(left to right): Frank, Leo, and Lily Bian.

## Frank Bian

Frank joined EDAX as a sales manager in March 2015. Working out of the Shanghai, China office, he handles sales in eastern China. In addition to sales, his duties include developing new sales channels, identifying potential customers, maintaining relationships, collecting relevant market information, and participating in and arranging promotional events.

Prior to EDAX, Frank spent 10 months as a sales manager in the microscopy division at Carl Zeiss in Shanghai. From 2010-14, he was a sales engineer at Techcomp (China). Frank worked as a process engineer at the Carrier China Yileng Factory from 2006-10 and served as a product engineer at Shanghai Tianmei Scientific Instruments from 2001-06. Frank began his career in 2000 at Shanghai Liyong Automobile Lock, working as a product design engineer. He received his bachelor's degree in engineering from the Mechanical & Engineering College of Yangzhou University in 2000.

Frank lives in Shanghai with his wife, Lily, and their six year old son, Leo. In his spare time, he enjoys traveling and attending sporting events.



(left to right): Brenda Schimek and John Haritos.

## John Haritos

John joined EDAX in September 2016 as a regional sales manager in the southwestern United States. John is responsible for sales in Arizona, New Mexico, Colorado, Utah, Texas, Oklahoma and Kansas. His duties include teaching and informing customers and potential customers about how EDAX's products can help them solve their problems through various analytical techniques.

Prior to EDAX, John worked at Oxford Instruments for 18 years. As a regional sales manager in the southwestern region, he sold Energy Dispersive Spectroscopy (EDS), Electron Backscatter Diffraction (EBSD), Wavelength Dispersive Spectrometry (WDS) and Omniprobe systems. John graduated from Auburn University in 1988 with a Bachelor of Science degree in electrical engineering.

John currently resides in Phoenix, Arizona. In his spare time, he enjoys playing intramural soccer in a local league. John also likes going to the gym, participating in cardio kickboxing classes, and rollerblading. He often explores local restaurants and attends family gatherings with his girlfriend, Brenda. Together, they are fond of taking hikes on the vast number of trails around the neighborhood.

## The School of Earth and Climate Sciences University of Maine, Orono, ME

The School of Earth and Climate Sciences at the University of Maine focuses on research in four main areas: marine and coastal geology, environmental geology, climate change and glacial geology, and geodynamics. The department includes 30 tenure track and research faculty members and nearly 40 graduate students. The laboratory serves undergraduate and graduate Earth and Climate Sciences and Ecology and Environmental Sciences majors and faculty from various departments on campus.

The department utilizes its EDAX Pegasus Analysis System and OIM Analysis™ software to help come up with solutions to a number of problems. One of the challenges the department faces is determining bulk properties of polyphase/ polycrystalline materials<sup>1,2,3,4</sup>. With the information the department has gathered, it is developing a more accurate model of the distribution of mechanical properties within Earth. The model provides the team with a better understanding of the wide range of Earth processes, including sea level rise, seismic activity, landscape development, and Earth's tectonic history.

“We need high quality maps of mineral and crystallographic distributions,” said Associate Professor Christopher Gerbi. “To make these maps, we rely on ChI-Scan™.”

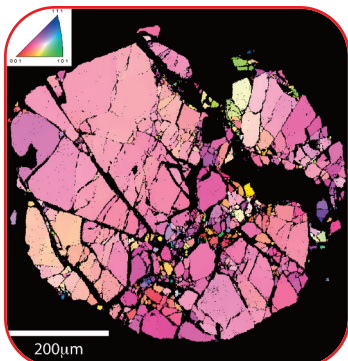


Figure 1. A map of shattered garnet. The garnet comes from south-central Maine, along a section of the Norumbega Fault system. The Norumbega Fault formed nearly 400 million years ago and was similar in scope and style to the San Andreas Fault of today. Roughly 10 km of rock has eroded from the Norumbega system since it was active, and as a consequence, by studying the rocks from there we can learn about inner workings of seismogenic faults. Collected by University of Maine Ph.D. student Bora Song.

The School of Earth and Climate Sciences is working on calculating the grain size distribution of fractured minerals, such as garnet, in ancient fault zones, in order to estimate the energy released during earthquakes (Figure 1). Knowing the patterns of energy released during earthquakes allows for a better prediction of shaking magnitude and secondary hazards, such as landslides, and improves interpretation of subsurface structures using seismic data.

“Some fractures are not visible optically or with BSE or CL. For some minerals, EBSD is the only available method for mapping out the fracture pattern in grains, so we can calculate a particle size distribution and thereby determine the mechanism for fracturing and

disaggregation in those minerals, which allows us to calculate the

energy release during earthquakes,” continued Gerbi. “Though the earthquakes we study happened in the past, we can make better assessments of seismic hazards along today’s fault lines.”

The department is also trying to quantify the composition of tephra (volcanic ash) retrieved from ice cores, in order to identify which volcanoes erupted and therefore determine atmospheric circulation during the Earth’s past. With climate change being a huge issue in today’s society, a large component of predicting the future involves learning what happened in the past. Mapping atmospheric circulation is a key component of reconstructing how past climate developed and responded to conditions that we may soon face in the future.

“For the tephra, highly accurate and precise EDS analysis is essential because we are working with particles too small to analyze using an electron probe,” stated Gerbi. “We chose EDAX because of both its hardware capabilities and software ease of use, plus the positive commitment to customer service.”

<sup>1</sup> Generating high quality maps of mineral distribution and orientation in rocks, in order to calculate their bulk geophysical properties,

<http://umaine.edu/mecheng/faculty-and-staff/senthilvel/software/aeh-ebbsd-toolbox/>.

<sup>2</sup> Vel, S.S., Cook, A., Johnson, S.E., and Gerbi, C., 2016, *Computational Homogenization and Micromechanical Analysis of Textured Polycrystalline Materials*, *Computer Methods in Applied Mechanics and Engineering*, v. 310, p. 749-779, doi:10.1016/j.cma.2016.07.037.

<sup>3</sup> Melosh, B., Rowe, C.D., Gerbi, C., Bate, C.E., and Shulman, D., 2016, *The spin zone: Transient mid-crust permeability caused by coseismic brecciation*, *Journal of Structural Geology*, v. 87, p. 47-63, doi:10.1016/j.jsg.2016.04.003.

<sup>4</sup> Culshaw, N.G., Gerbi, C., Ratcliffe, L., 2015, *Macro- and microstructural analysis of the North Tea Lake Mylonite Zone: an extensional shear zone in the Central Gneiss Belt, Grenville Province, Ontario*, *Canadian Journal of Earth Sciences*, v. 52, p. 1027-1044, dx.doi.org/10.1139/cjes-2015-0009.

**EDAX Inc.**  
91 McKee Drive  
Mahwah, NJ 07430  
Phone (201) 529-4880  
E-mail: [info.edax@ametec.com](mailto:info.edax@ametec.com)  
[www.edax.com](http://www.edax.com)

**Art and Layout**  
Jonathan McMenamin

**Contributing Writers**  
Christopher Gerbi  
Matt Nowell  
Dr. Bruce Scroggs  
Shawn Wallace

©2016 EDAX, Inc. All rights reserved.  
No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means without prior written permission of EDAX Inc.