VIII Development and Application of Microanalysis and Chemical Imaging to Research and Instruction in the Biological, Forensic, Materials, Earth, and Environmental Sciences.

Sabbatical Application, Dr. Derek D. Wright, Professor of Environmental Science

Abstract

Lake Superior State University faculty and collaborators have recently received two awards from the National Science Foundation to acquire major research instrumentation for microanalysis and chemical imaging to support research across the scientific disciplines. As facility coordinator of the newly established Micro Analysis and Spectroscopic Characterization (MASC) laboratory which will house the awarded instrumentations, I propose to develop the analytical imaging methods necessary to complete the proposed research, as well as advance my own research interests in bioaccumulation of metals, correlative chemical imaging of geological materials, and elemental characterization of atmospheric particulate matter and cannabis rolling papers. Additionally, the proposed activities will 1) Both advance knowledge in these disciplines and facilitate dissemination of scientific results, 2) Directly benefit my teaching through both engaging in scholarship and through the further development of technical proficiency, and 3) will enable the development and application of K-12 educational/outreach materials.

Project Description

Introduction

Microanalysis and Chemical Imaging have emerged in recent decades as increasingly important techniques for characterizing the chemical composition of microscopic specimens and for determining the spatial distribution of chemical species (elements, molecules, minerals, etc.) within biological, geological, and engineered materials. While classical bulk analysis techniques for chemical analysis continue to be important for determining (average) concentrations of chemical species, they don't provide insight as to the localization of species of interest unless the components can be manually separated, which is typically impossible at microscopic scales. Recently, LSSU faculty have received support from the National Science Foundation Major Research Instrumentation program (NSF MRI 2215270 and 2320397) to acquire a Scanning Electron Microscope equipped with an Energy Dispersive x-ray Spectrometer (SEM-EDS) and a micro X-Ray Fluorescence (μXRF) Spectrometer to enable high spatial resolution analysis of elements on or in specimens of interest. These instruments will be housed within the newly established Micro Analysis and Spectroscopic Characterization (MASC) lab at LSSU. As part of both awards, I will serve as facility coordinator of the MASC lab and have primary responsibility for operation and maintenance activities including user training, scheduling, data collection, and application development in addition to using the instruments for my own research. Additionally, we also recently acquired a Laser Direct Infra-Red (LDIR) Spectrometer which allows high resolution imaging of molecular and mineral species, complementing the NSF funded instruments.

These instruments enable a wide range of new research possibilities at LSSU, and when the methodologies are fully developed, will facilitate faculty scholarship, extramural funding, undergraduate research experiences, and improved achievement of student learning. If appropriately leveraged, they

also provide an opportunity to enhance University enrollment initiatives. If awarded, my sabbatical will allow me sufficient time to advance each of these areas while pursuing my research and will permit additional time for writing proposals and preparing additional manuscripts for publication.

Background

This sabbatical proposal is based on significantly expanding my current research activities where microanalysis and chemical imaging can be applied to yield significant new insights on the distribution of chemical species. These lines of research have already generated successful grant awards, several presentations, and manuscripts in the process of being published or in preparation for submission, as detailed in my CV. This sabbatical award would result in significant new research progress and result in additional grant applications, conference presentations, and publications.

In August 2023 we installed a JEOL JSM IT200LA Scanning Electron Microscope with an Energy Dispersive x-ray Spectrometer (SEM-EDS). This instrument will facilitate high resolution surface imaging (resolution up to 3nm) and elemental analysis (resolution of ~1-2μm) of dried, vacuum stable samples. The instrument is equipped with a secondary electron (SE) detector for topographic imaging, a backscattered electron (BSE) detector for providing compositional (atomic number) contrast, a STEM converter for transmission imaging, and a high count rate liquid nitrogen free EDS detector. The BSE detector permits detection of sample regions of compositional variations, while the EDS detector permits follow up analysis and mapping of element distribution (Be-U, better sensitivity for light elements).

In late 2023 or early 2024 we will install a Bruker M4 Tornado Plus micro X-Ray Fluorescence spectrometer (μXRF). This instrument will high resolution (~20μm) elemental imaging of large specimens, up to 16x19cm with as much as 1cm topographic variation. While the spatial resolution is ~10x less than SEM-EDS, μXRF permits rapid large area scans at significantly higher sensitivity (10-100x improvement for heavy elements). The improved penetration of the x-ray beam vs. the electron beam of the SEM will further allow the imaging of the internal distribution of elements facilitating studies of metal uptake, bioaccumulation, and homeostasis. Further, μXRF analysis does not require vacuum (though analysis of light elements requires either vacuum or helium purge to prevent absorption of low energy x-rays by air). This allows biological specimens to be analyzed intact, and plant specimens to be imaged alive, without sample preparation. This will be the only system of this type at any University in Michigan.

Additionally, an Agilent 8700 Laser Direct Infra-Red (LDIR) chemical imaging system was recently installed with support from private donors and Agilent Technologies. This system uses a tunable quantum cascade laser to collect infrared spectra in the mid-IR fingerprint region (975-1800 cm^{-1}) in either reflectance or transflectance mode, and enables multispectral imaging of molecular/mineral content over large areas (25x75mm, a whole standard microscope slide) at a resolution of ~10μm. This was the 3rd system of this type installed in the United States.

While SEM-EDS is a standard research technique and is available at most research intensive Universities, μXRF and LDIR are both relatively specialized research instruments. μXRF has traditionally been performed primarily at synchrotron light sources (particle accelerators) as high performance laboratory instruments with performance approaching that of synchrotron beam lines have only recently been

developed. Thus, μXRF has not been readily available for many research applications and has not to our knowledge been previously applied to some of our proposed sample types. As a result, it will require experimentation to determine the optimal imaging conditions and analysis protocols.

Similarly, Agilent Technologies was the first major instrument vendor to market a Infra-Red(IR) chemical imaging system based on a quantum cascade laser, and we were the first group to apply it to geologic specimens for mineralogic analysis (initial results will be presented at the American Geophysical Union Fall Meeting in December 2023). Like μXRF elemental analysis, high spatial resolution mineralogic studies have typically been performed at synchrotron beam lines using one of the X-ray Absorption Spectroscopy techniques, most often X-ray Absorption Near Edge Spectroscopy (XANES), or by conventional FTIR or Raman microscopy. Each or these techniques is expensive and relatively slow, limiting the area scanned to regions of a few mm^2 or less in practice. LDIR offers a possible alternative that is suitable for multispectral scanning of larger samples making large sample minerology/petrology and paleoclimate studies viable, especially when combined with large area μXRF analysis and SEM-EDS for more detailed study of anomalous features (correlative chemical imaging).

A summary of each technique and its capabilities is summarized in Table 1 and additional information including example images and data is available in the attached specification sheet for each instrument.

Table 1: Capabilities and limitations of SEM-EDS, μXRF, and LDIR for various sample types. Note: LOD's refer to the analyte concentration in the volume of sample being probed, not the bulk concentration, and are expressed on a mass fraction basis.

Technique	Excitation	Surface/internal	Analysis Area	Species	Lim. of Detection	Resolution	Analysis Condions	Specimen Prep
SEM-EDS	electron	Surface	a few mm^2	elements	0.10%	1-2μm (EDS)	Vacuum	Dry (vac. stable), ~flat
μXRF	x-ray	Internal for Bio	16x19 cm	elements	10-100ppm	20μm (Rh)	Air, He, or Vacuum	<1 cm height variation
LDIR	IR Laser	Mostly Surface	micrsocope slide	molecules	>10%	10μm (laser)	Air	Flat, <2 cm thick

Outcomes:

Outcomes from my proposed sabbatical will fall within three primary areas:

I. **Research Outcomes** resulting from the application of microanalysis and chemical imaging across several scientific disciplines,
II. **Improvements in instruction** resulting from knowledge and skills gained through the proposed research, and
III. **Engagement in K-12 outreach activities** which support the research and fulfill funding requirements of the supporting National Science Foundation awards.

(I) Research Outcomes: The proposed research activities during my sabbatical are centered around developing our capacity for and advancing our applications of microanalysis and chemical imaging. As part of this sabbatical, I also plan to prepare two proposals with colleagues to the National Science Foundation (NSF) and US Department of Agriculture (USDA) to: (1) Continue development of correlative imaging techniques (SEM-EDS, μXRF, and LDIR) for characterization of geologic specimens in minerology/petrology and paleoclimate studies, and (2) For the development of metal accumulating plants for phytoremediation applications. We will also present results at the American Geophysical Union Fall Meeting (Dec. 2024) and other conferences appropriate to the research areas, and I will prepare a manuscript for publication on Uranium geochemistry in the Jacobsville Sandstone (a geologic source of elevated Uranium in groundwater along the southern Lake Superior shoreline) and continue

development of a second relating to atmospheric pollution source apportionment in the Sault Ste. Marie region. Additionally, I will complete the advanced SEM-EDS course at JEOL USA headquarters (Peabody, MA), which will allow me to learn advanced techniques, and will be helpful in ensuring optimal data quality is achieved in the proposed research applications. This research will advance knowledge in these disciplines and can be applied to improve public health in our region.

A summary of the specific research activities and goals includes:

1. **Develop and apply μXRF and SEM-EDS chemical Imaging and microanalysis methods for the following research applications:**

    - **Biological Tissues** – I will apply μXRF imaging to determine the elemental distribution of nutrient elements and/or heavy metals in: Cannabis, Poplar and other trees, fish and fish otoliths, freshwater sponges, decaying animal tissue, *Arabidopsis thaliana*, and tomato plants. Data on the internal distribution of elements will be critical to understanding uptake, bioaccumulation, and mechanisms of homeostasis in these species. As different element groups and different sample types (live/hydrated/dehydrated) will require different imaging conditions, considerable time will be required to develop the required methodologies. While some there are published methods for a few of these sample types (mostly leaf tissue, fish otoliths, and a single study on fish tissue), several of these sample types will require development in-house (decaying tissue, Cannabis flower, freshwater sponges). This research will be performed in collaboration with: M. Zierden (LSSU), H. Clause (LSSU), S. Kolomyjec (LSSU), B. Evans (LSSU), B. Southwell (LSSU), W. Dew (Algoma, U.), R. Zalesney (USDA), H-H Chu (NMU), K. Pangle (CMU), and M. Miller (BRCC).
    - **Geologic and Environmental Samples** – I will apply μXRF and SEM-EDS imaging to geologic samples (iron containing rocks, Rare Earth Element (REE) geochemistry, and uranium geochemistry in the Jacobsville Sandstone, and atmospheric pollution (atmospheric particulate matter). Of these, I will devote the greatest efforts to our work on characterizing atmospheric Particulate Matter (PM) by SEM-EDS, as PM has been shown to have significant impacts on ecosystems and human health, and we have the unique opportunity to examine changes to local PM as Algoma Steel shifts from a traditional integrated mill (blast furnace) to electric arc furnace production. Likewise, I will devote significant efforts to examining Uranium geochemistry in the Jacobsville Sandstone, as we have previously documented a potentially significant impact on human health in our region. This research will be performed in collaboration with: P. Kelso (LSSU), H. Kandel (LSSU), W. Dew (Algoma, University), and Robin Bouschor (Sault Tribe).
    - **Engineered Materials & Archeological Artifacts** – I will apply μXRF imaging to determine the composition and distribution of elements in archeological artifacts recovered from ongoing excavations as Fort Michilimackinac and other sites under study by Mackinac State Historical Parks as well as the mobility of heavy metal contaminants sequestered within hempcrete. This research will be performed in collaboration with: B. Southwell (LSSU), L. Evans (MSHP), and C. Ley (Hemp for Humanity).
2. **Develop correlative imaging approaches using a combination of SEM-EDS, μXRF, and LDIR imaging as a novel tool to correlate element and mineral distributions in geologic samples for studies in mineralogy, petrology, and paleoclimate.**

- **Mineralogy and Petrology** – I am currently performing one of the first studies to explore the application of quantum cascade laser infrared imaging (LDIR) for research in minerology and petrology with collaborators P. Kelso (LSSU) and H. Handel (LSSU). We will present our first results at the AGU fall meeting in December 2023 (Two LSSU undergraduate students are co-authors). We will continue this study by exploring correlative imaging to yield additional insight on mineral formation and the effects of geologic processes such as weathering and metamorphic alteration.
- **Paleoclimate** – As part of this research I will collaborate with P.N. Ranasinghe (LSSU) to develop high resolution correlative imaging applications for analysis of corals and speleothems (stalactites and stalagmites) showing annual growth/deposition layers. XRF is a common technique used to examine elemental variations, which may act as a proxy for climactic variations (ex. Sr/Ca in shallow water corals is used as a sea surface temperature paleoproxy). μXRF can be used to generate this data at high spatial resolution, and SEM-EDS will be useful for analysis of inclusions. Elemental information is more useful when correlated with minerology, which is generally determined by x-ray absorption techniques such as x-ray absorption near edge spectroscopy (XANES) at synchrotron facilities. LDIR offers a potential alternative technique if it can be adapted for analysis of these samples, and our goal is to develop this for potential routine analysis at investigator labs, greatly enhancing sample throughput and enabling a corresponding improvement in data robustness.

3. **Metal Bioaccumulation and Metal Tolerance Mechanisms in Plants Growing in Metal Enriched Soil and Potential Identification of Novel Hyperaccumulators**
    - I will work with M. Zierden and B. Southwell to conduct a series of field and laboratory experiments to identify metal tolerant plants and potentially novel metal hyperaccumulators in several sites in the Upper Peninsula by exploring plants growing in metal enriched soils. Vegetation samples will be collected from the same (or adjacent, for small specimens) plants at multiple points though the growing season through senescence in the fall, as seasonal growth phase may affect metal distributions. Subsamples will be preserved for secondary metabolite (plant molecules that affect metal transport and storage) analysis by LC-TOF-MS and LC-MS/MS and bulk metal quantification by ICP-MS. This analytical approach will allow us to deduce plant tolerance mechanisms and their variation across the plant life cycle.

      I have currently identified several sites in the Western UP Copper and Iron mining districts that are suitable field sites due to naturally elevated metal concentrations or the impacts of previous mining activities. For instance, I have identified sites near Houghton MI (Torch Lake area) where soils contain up to 0.5% Cu (ore grade deposits) and are vegetated. SEM-EDS analysis indicates that the copper is present as small (several μm) discreet particles of native elemental copper in some soils, while it is present as inorganic salts or organic complexes in others. We have also identified a vegetated local site in the Eastern Upper Peninsula with elevated Pb due to historical use a firing range. These sites are promising natural experiments for identification of both hyperaccumulating/metal tolerant species and our proposed mechanistic studies of metal uptake, bioaccumulation, and homeostasis.

4. **Potentially Toxic Metals in Cannabis Rolling Papers**
    - I will collaborate with B. Southwell to continue investigations of sources of potentially toxic elements in Cannabis rolling papers. We have recently concluded an initial study where we documented significant potential exposure, up to an order of magnitude in excess of USP 232 and ICH Q3D exposure limits, to Cu, Ag, V, Cr, and Ni in a significant number of consumer rolling paper products (Wright et al. submitted to ACS Omega). Combining bulk characterization by ICP-MS with element localization by SEM-EDS, we have identified manufacturing practices (i.e. use of Cu based printing inks, Sb containing PETE components, etc.) that contribute to elevated exposure potential. The use of microanalysis techniques was critical in identifying which components (plastic, ink) contained the elements of interest. I will utilize the μXRF to continue and expand this work, which is currently limited by the inadequate sensitivity of SEM-EDS for localizing V, Cr, or Ni in any samples, and Cu in ~50% of the samples of interest. This work will benefit public health by enabling regulators and manufacturers to improve product safety and reduce consumer exposure.

Involvement of LSSU Undergraduate Research Students in the Proposed Activities: I am currently supervising the following undergraduate students who are involved in these research activities: J. Schemm, E. Hebert, and K. Kelley (Atmospheric Particulate Matter), H. Beaudoin and N. Gordon (LDIR Mineral ID and Correlative Microscopy), E. Hebert (Metal Accumulation in Fish), and A. Lesnock (Metals in Plants and Plant Compounds). Four of these students have presented or will present at national conferences this year (see my CV).

I am also working with several students supervised by collaborators H. Kandel (2, REE metals and Uranium in Sandstone), M. Zierden (1 student, metal bioaccumulation and secondary metabolites in plants), and J. Garvon (2 students, metal bioaccumulation in migratory waterfowl). I anticipate that this sabbatical would allow me to supervise several additional students directly and to work closely with several additional students supervised by collaborators. Additionally, this LSSU students would have increased opportunities to collaborate and network with students from collaborator institutions, particularly from W. Dew's group at Algoma University in Sault Ste. Marie, ON.

(II) Instructional Improvement Outcomes: My proposed sabbatical activities will directly enhance the quality of my instruction in the following courses: NSCI 103 (Environmental Science), EVRN 315 (Human Impacts on the Environment), EVRN 317 (Environmental Health Applications), EVRN 341 (Fate & Transport in the Environment), EVRN 389 (Environmental Research Methods), and MICR 315 (Electron Microscopy & Microanalysis). In NSCI 103, I teach fundamental concepts bioaccumulation and biomagnification, water pollution, air pollution, and climate. In EVRN 315, 341, and 389, I teach these topics at an advanced level. Additional time for research collaboration with W. Dew, an expert in aquatic ecotoxicology and environmental chemistry, will significantly enhance my ability to incorporate local examples of ecosystem impacts into my courses, and will give me greater familiarity with ecotoxicological experimental design which I can incorporate into laboratory design. In EVRN 317, I specifically teach the effects of the human environment on public health, which will similarly benefit from the opportunity for collaborative research, particularly in air pollution.

Engaging in the proposed research will allow me to increase my collaborations with faculty from other scientific disciplines while advancing my own research, which will enhance my expertise in the broad

range of interdisciplinary topics that I teach throughout the environmental science curriculum. It will also allow me to further develop my own technical proficiency through research and advanced training, which will directly benefit instruction in MICR 315. Further, advancing the collaborative research proposed here is likely to have additional benefits on courses taught by other LSSU faculty in the Biological, Chemical, and Earth Sciences as they can incorporate new findings in their instruction.

(III) K-12 Outreach Outcomes: As part of NSF 2320397 and NSF 2215270 we also proposed to develop K-12 outreach activities in coordination with the EUP-ISD (K. St. Onge), covering a broad range of STEM topics such as the composition of regional rocks and minerals, nutrient acquisition by plants of indigenous cultural importance, etc. This sabbatical will help to both accelerate this process and increase capacity, which will provide high impact educational opportunities to local K-12 students and support LSSU enrollment initiatives.

Required Travel: The proposed activities require travel as follows: 1) The advanced SEM course in Peabody MA (exact dates of the course have not yet been scheduled, but it is offered several times a year as needed), 2) Conference travel (AGU in Dec. 2024 and likely a second conference in the Spring semester), 3) Extensive field work across multiple sites in the western Upper Peninsula will require repeated trips from May-late October, and winter follow up sampling (evergreens) during the spring semester). I will also need to periodically spend time at Algoma University and Sault Ontario as part of my collaboration with W. Dew in order to assist with field data collection, laboratory experiments, project meetings, and to prepare results for dissemination (conference presentations and manuscript preparation).

In addition, depending on the results obtained in the Fall, there is significant likelihood I may need to travel to Wayne State University (Lumigen Instrument Center) to utilize X-Ray Photoelectron Spectroscopy (oxidation state and chemical bonding), Scanning Transmission Electron Microscopy (intracellular metal storage at ultra-high resolution), and/or Powder X-Ray Diffraction Spectroscopy (bulk mineralogy). We have recently utilized XPS at WSU to confirm the oxidation state and chemical identity of copper based inks in Cannabis rolling papers and additional collaboration could be required to confirm our findings.

Funding Support: Financial support for the proposed research: The proposed research is partially supported by NSF 2320397 ($384,660) and NSF 2215270 ($197,808). W. Dew has secured funding for the Canadian portion of our atmospheric pollution study, I have already secured the necessary experimental equipment etc. for our portion, and Sault Tribe has support for the Sault Ste Maire deposition sampling through the National Atmospheric Deposition Program. Additional funding for consumables, WSU facility charges, and travel not covered by these awards is available from my professional development funds.

Additional information about current funding, research activities and products, instructional experience, course assignments, etc. is available on my CV (attached) and my website: https://derekwrightlssu.com/

Timeline

The proposed workplan is summarized in Table 2.

Table 2: Proposed sabbatical workplan. Note: The final report summarizing the accomplishments achieved will be prepared at the end of the work period. Additionally, I hope to present findings at a second (currently unidentified) conference in S25.

	2024			2025				
	May-June	July-Aug	Sept-Oct	Nov-Dec	Jan-Feb	Mar-Apr	May-Jun	July-Aug
Develop Bio Imaging Methods	X	X						
Collect Plant Specimens	X	X	X		X	X	X	X
Plant Tissue Imaging		X	X			X	X	X
Animal Tissue Imaging				X	X	X	X	
Hempcrete							X	X
Paleo Climate/Mineral Application	X	X	X					
Uranium Geochemistry	X	X	X					
Atmospheric Particulate Matter	X	X	X	X	X	X	X	X
Present at AGU				X				
Metals in Rolling Papers				X	X			
Artifacts (or as needed)			X	X	X			
K-12 Outreach (As inst. time is available)	X	X	X			X	X	X
Writing proposals & manuscripts	X	X	X	X	X	X	X	X

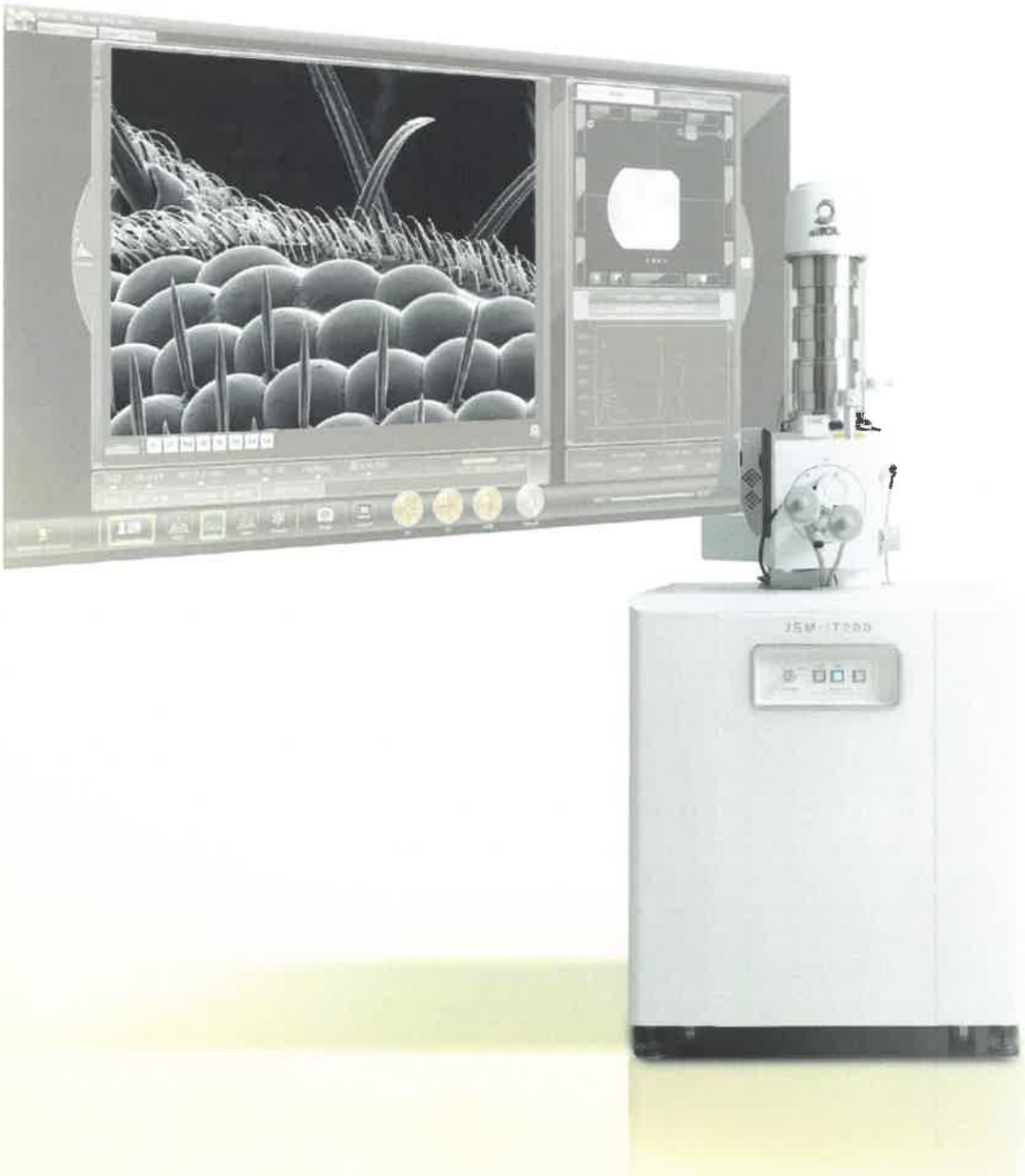
JEOL

Scientific / Metrology Instruments

Scanning Electron Microscope

Solutions for Innovation

JSM-IT200



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TouchScope™ series

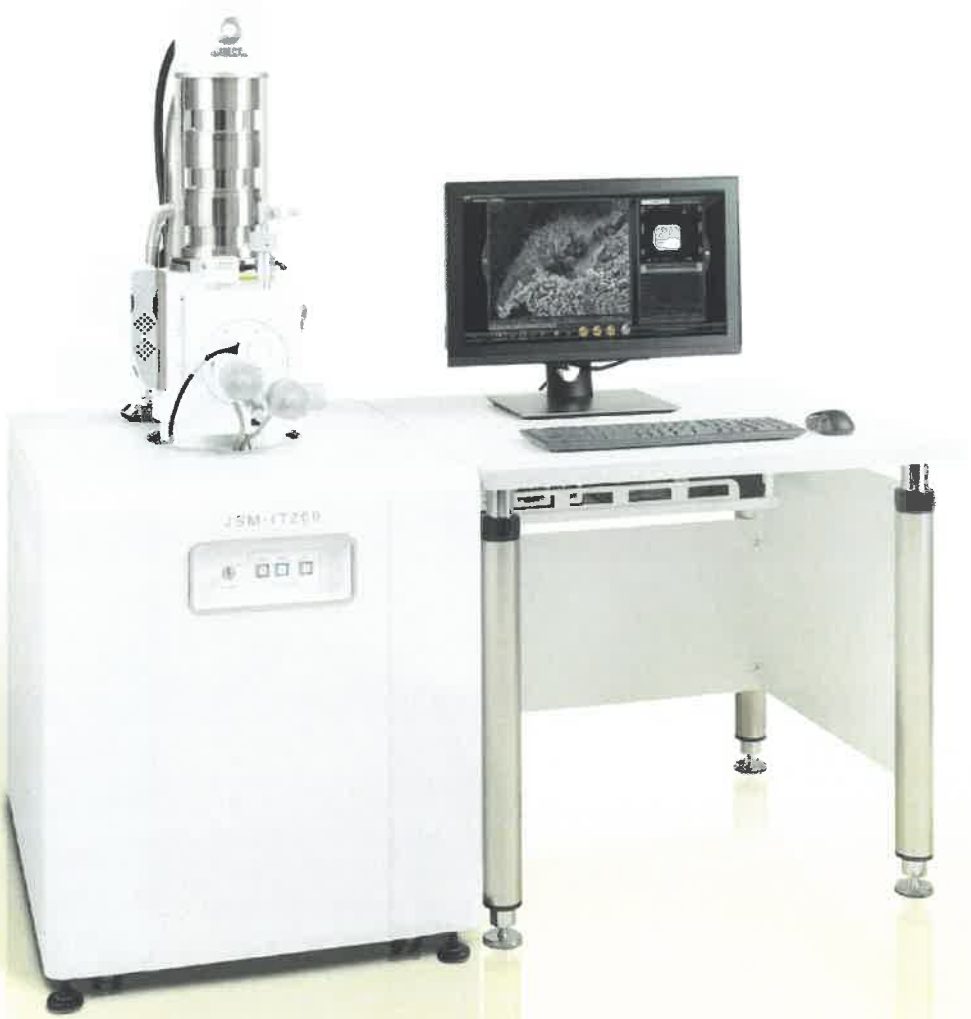
JSM-IT200 Series

Scanning Electron Microscope

Latest Advancements from JEOL

Fast Observation, Analysis and Report Generation !

High Performance Analytical Tool !



High Performance
With Faster and Easier Analysis

■ Main screen – Zeromag –

You can locate the specimen area or specify analysis positions with Holder Graphics or CCD image*1 displayed on the Main screen.

■ Element / Spectrum display – Live Analysis*2 –

The characteristic X-ray spectrum from the measurement area and the main constituent elements are always displayed.

■ Data management button – SMILE VIEW™ Lab: Integrated data management –

A single click of the data management button displays the Data management screen allowing you to generate a report of all images and analysis data, as well as review or re-analyze already-acquired data.

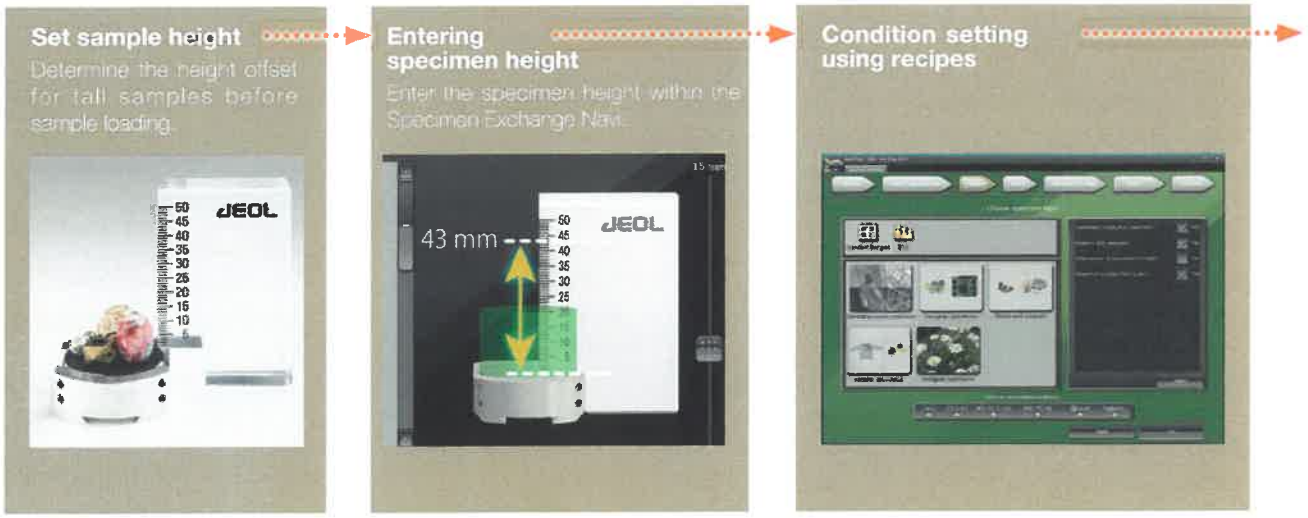
*1 To take a CCD image, SNS (option) is required.
*2 Applicable to (A) Analysis/(LA) Low Vacuum and Analysis versions.

Guided operation from sample introduction to observation

The JSM-IT200 navigation flow guides the user step-by-step from sample introduction to automatic image formation.

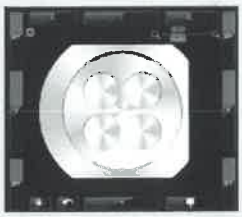
■ Specimen Exchange Navi

A step-by-step guide to sample exchange, condition setting and automatic image formation.



● Holder Graphics

Holder Graphics allows you to immediately observe the specimen position by showing the current specimen position including specimen tilt and rotation.



Top view

Side view

● Stage Navigation System (SNS) Option

Switch between the Holder Graphics and CCD (color) image. You can specify the observation area by double-clicking the acquired color image. Displaying the color image on the Zeromag screen allows for an easy search of the specimen area.

CCD image area: 6 × 4.5 cm
Number of pixels: 5,000,000
Digital zoom up to × 20

● Chamber Scope (CS) Option

Switch between Holder Graphic and Chamber Scope view.
A camera which displays the relationship of the specimen to the detectors and objective lens pole piece, is available.

Specimen loading

Draw-out method enables smooth exchange of any form or size of specimen

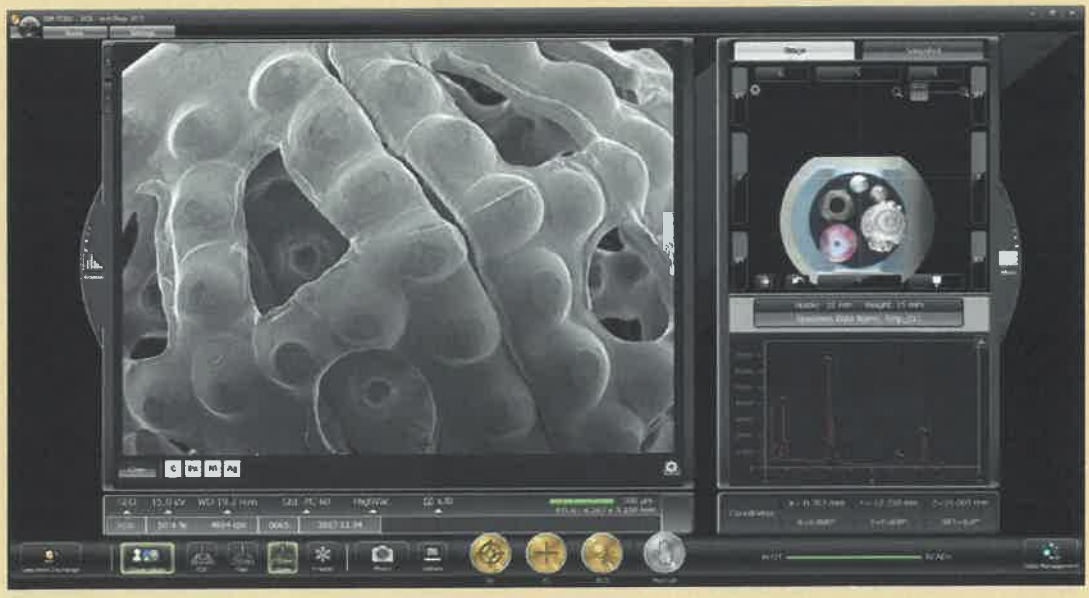
Maximum specimen diameter: 150 mm dia.
Maximum specimen height: 48 mm H

Chamber evacuation starts after acquisition of CCD image

Observation area can be specified on CCD image* during evacuation

Completion of chamber evacuation

Then, the target observation area is specified, observation conditions are set, image adjustment is completed. You can observe the image at designated magnification.



* To take a CCD image, SNS (option) is required.

True Integration of Optical and SEM imaging

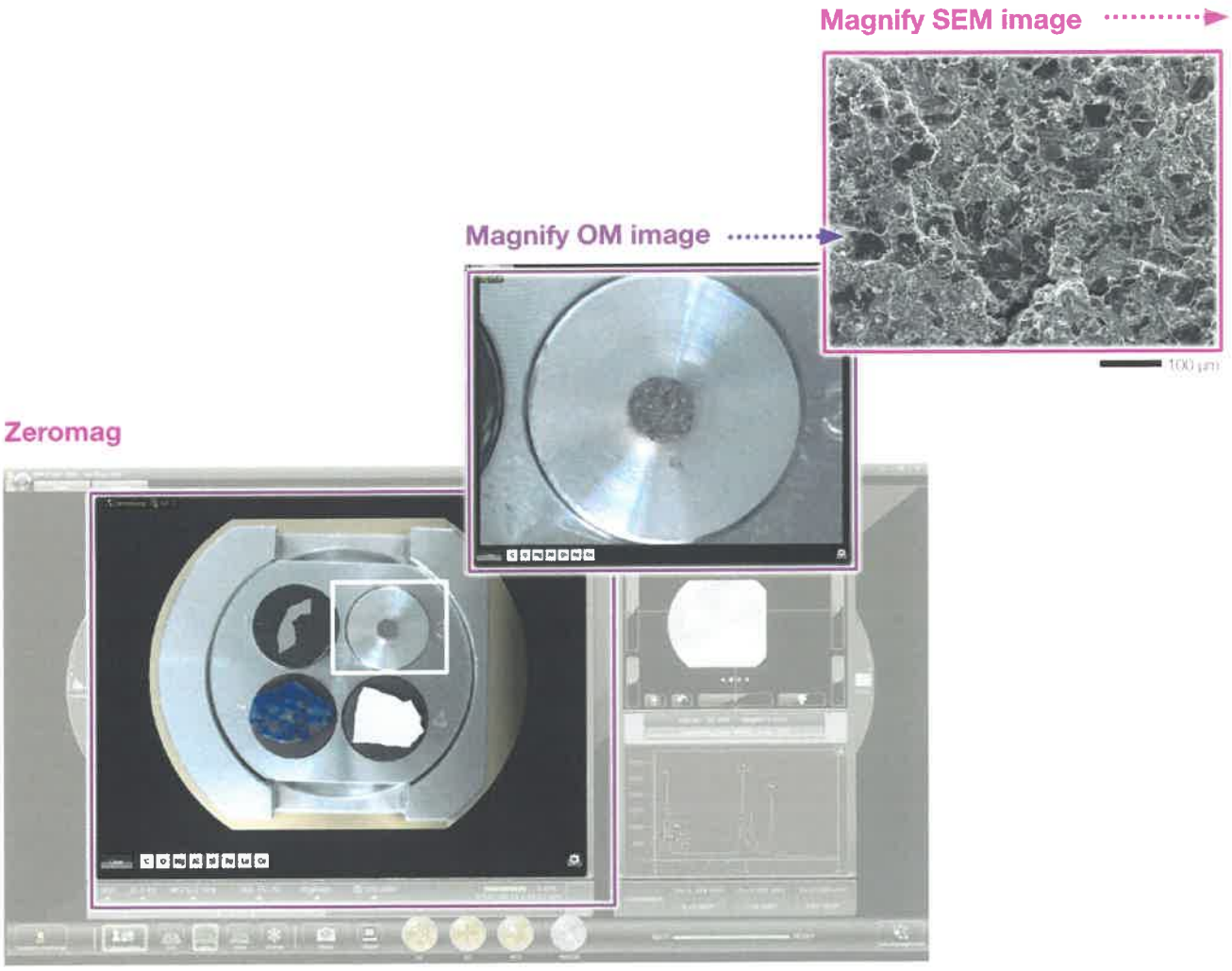
■ Zeromag

Smooth transition from optical to SEM imaging

Zeromag is a function that links the SEM image with Holder Graphics or CCD image* (optical image) where all are linked to the stage coordinates. This facilitates navigation with seamless transition from the CCD image to a high magnification SEM image.

Features of Zeromag

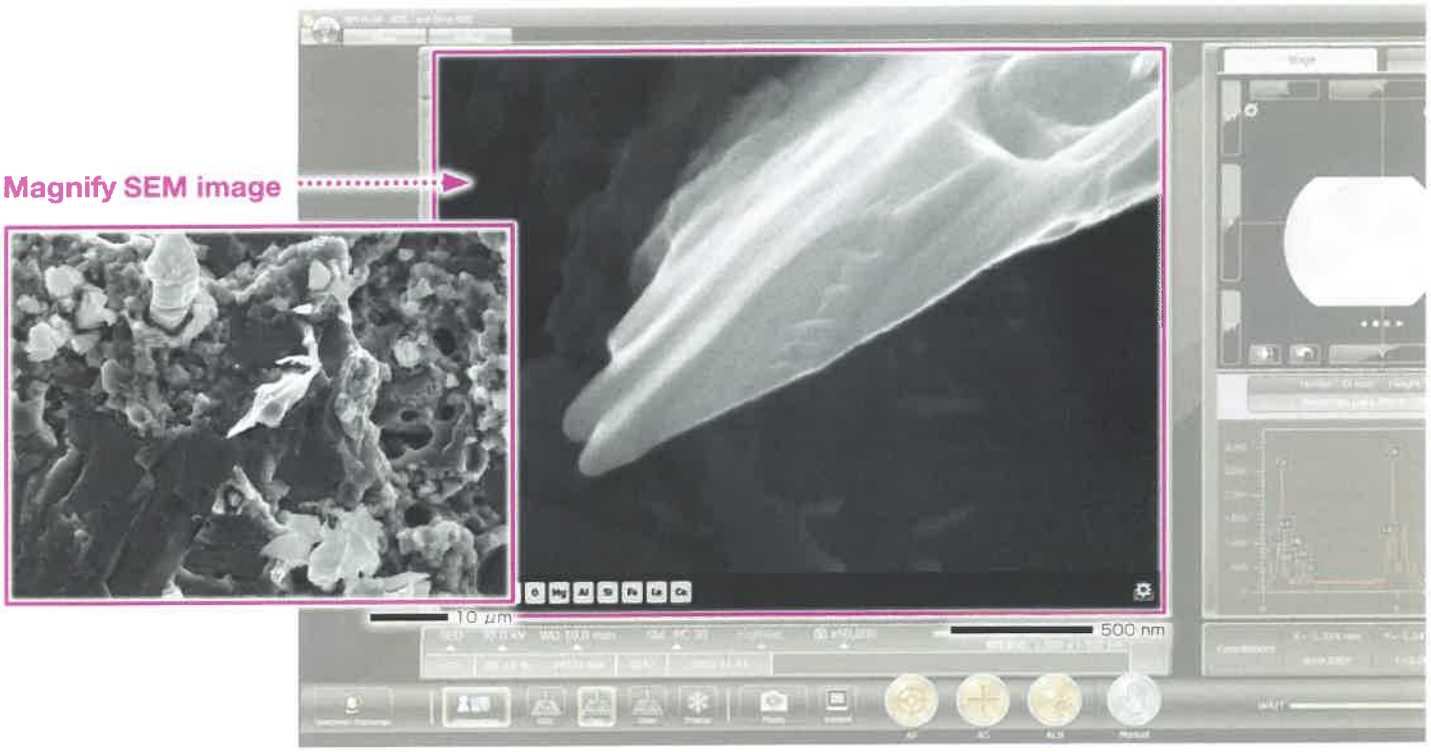
- Seamless transition from optical to SEM image.
- Can pre-set multiple analysis positions across your specimen set.
- Displays the areas analyzed for easy review or fast return for additional study.



Zeromag image displayed on the Main screen

Secondary electron image

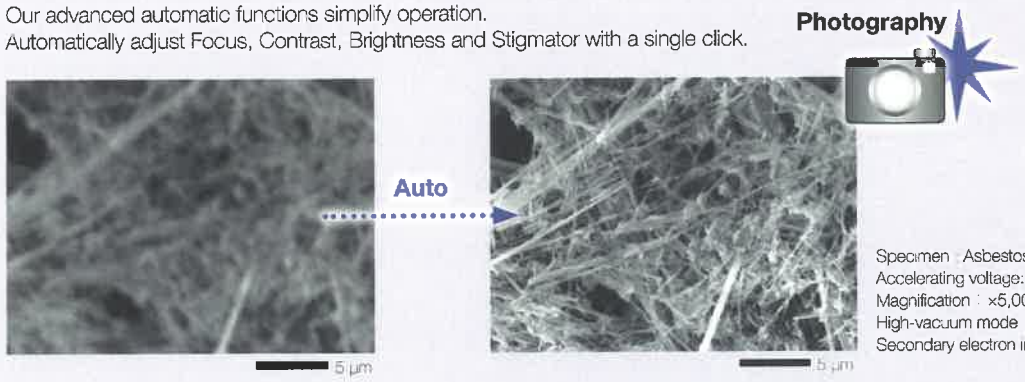
This high magnification image highlights fine surface morphology of the specimen.



Specimen: Ignition stone
Accelerating voltage: 30 kV
Magnification: ×200, 2,000 and 50,000 (left to right)
High-vacuum mode, Secondary electron image

● Auto functions

Our advanced automatic functions simplify operation.
Automatically adjust Focus, Contrast, Brightness and Stigmator with a single click.



Specimen : Asbestos
Accelerating voltage: 10 kV
Magnification : ×5,000
High-vacuum mode
Secondary electron image

* To take a CCD image, SNS (option) is required.

Easy Elemental Analysis

Live Analysis Standard for (A) / (LA)

Real time display of elemental analysis results during observation of a high-magnification SEM image.

With our Analytical series, seamless transition is made from high magnification SEM imaging to elemental analysis. The embedded EDS system shows a real time EDS spectrum during image observation, making it easy to find elements of interest or unexpected elements.

Features of Live Analysis

- Always displays the X-ray spectrum.
- Display of the main constituent elements.
- Alert display of elements of interest

SEM observation screen

Specimen: Wood metal, Accelerating voltage: 15 kV, Magnification: ×3,000
High-vacuum mode, Backscattered electron composition image

Toggle to SEM View

Spectrum
The X-ray spectrum from the measurement area and automatic qualitative analysis results are always displayed.

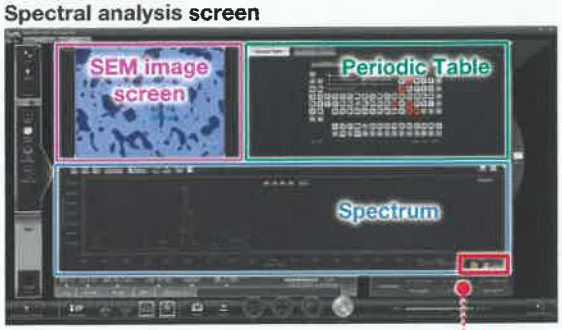
Single-click to switch the screen
Single-click enables you to switch between the SEM observation screen and analysis detail display screen.

Element
The main constituent elements detected in the measurement area are displayed.
You can display an "Alert" by specifying an element.

Analysis Detail display screen

The Spectrum screen, Map screen and other screens are displayed automatically.

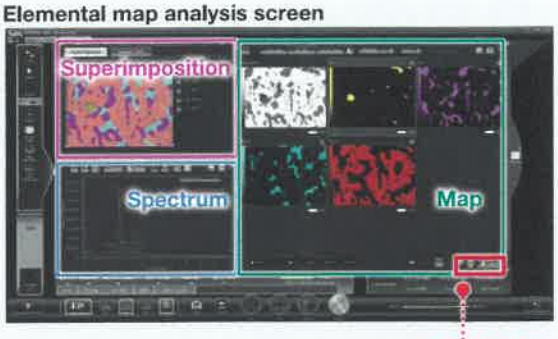
Spectral analysis screen



Specimen: Wood metal

Toggle to SEM View

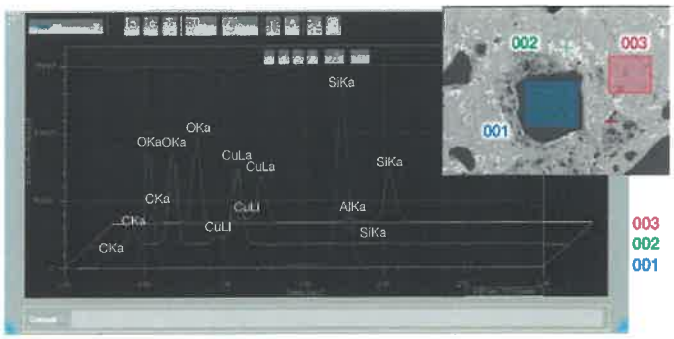
Elemental map analysis screen



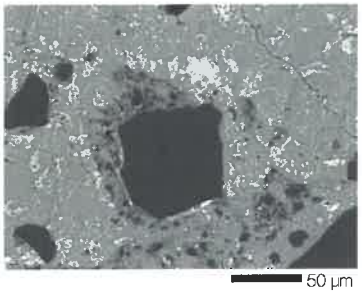
Toggle to SEM View

Qualitative & quantitative analysis

Select analysis areas directly in the SEM observation screen. After spectral acquisition, the Quantitative Result tab automatically displays the quantification results.



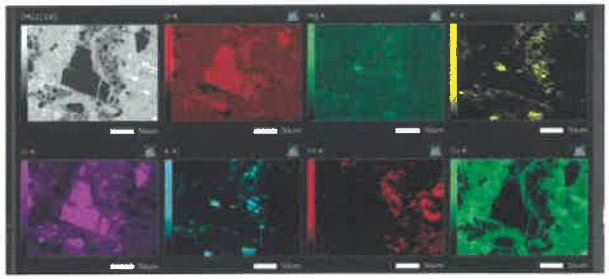
Spectra and qualitative analysis result



Specimen: Chrysocolla
Accelerating voltage: 15 kV
Magnification: ×500
High-vacuum mode:
C coating, Backscattered electron composition image

Elemental map

Using the Whole/Area icon on SEM observation screen, you can acquire elemental maps from the whole area or a specified area.



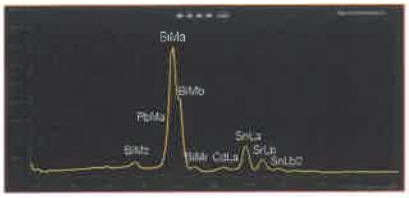
Backscattered electron composition image and elemental maps
Specimen: Chrysocolla

• Net map / Quantitative map

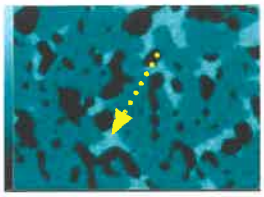
The Net map separates spectral peaks at each pixel and shows an elemental map with a reduced effect of overlapping peaks. Compared to the Count map which unavoidably reflects the peak intensity of other elements close to a specified element, the Net map enables a real-time display of an inherent intensity map even from a specimen containing many elements.
The Quantitative map is also available, which compensates for the Net map and displays the analysis results with the quantification values.

• Comparison of Count map and Net map

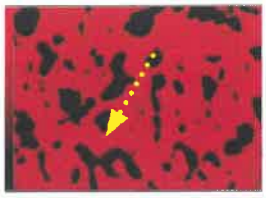
Spectral peaks of Pb-Mα (2.342 keV) are close to Bi-Mα (2.419 keV).
Thus in the Count (intensity) map, it is difficult to separate Pb from Bi. Applying the Net map enables you to confirm the inherent Bi distribution.



Peaks of Pb and Bi
Specimen: Wood metal



Pb intensity map



Bi intensity map

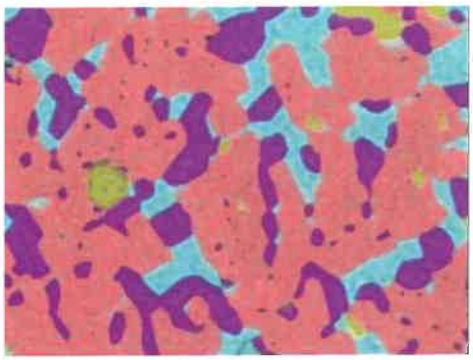
Bi net map

Easy Elemental Analysis

Elemental map

● Color-overlay display of an elemental map

The system allows you to overlay elemental maps on the SEM image in real time. The area is displayed with a composite color.



Specimen: Wood metal

Multi-color overlay display

Line analysis

Line analysis performs elemental analysis along a line set on the SEM image. The X-ray intensity of the specified elements is plotted to show the change in concentrations across the line. You can change elements to show during or after completion of data acquisition.

Line analysis result

■ Functions to improve analysis accuracy

Visual Peak ID (VID)

This function enables you to confirm whether the constituent elements are correctly identified in the qualitative analysis result. A spectrum is reconstructed based on the X-ray intensity of the elements identified.

Probe tracking

With long data acquisitions, the system periodically compares the SEM image at analysis start with the current image, so as to maintain the same analysis area. This capability helps you to monitor any change in a specimen or specimen drift during long acquisitions.

■ SMILE VIEW™ Lab for analysis

Pop-up spectrum

Since the stored map has spectral information, you can extract spectra from anywhere within the map data set.

SMILE VIEW™ Lab

- Re-specifies elements by spectrum, elemental map, line analysis, etc.
- Multi-color overlay display of elemental maps.
- Changes the colors of elemental maps, line analysis results, etc.

■ Other functions

Real-time filter

The system allows for image processing during a map acquisition to signal to noise ratio. This feature provides fast confirmation of the elemental distribution.

Pinpoint Navi

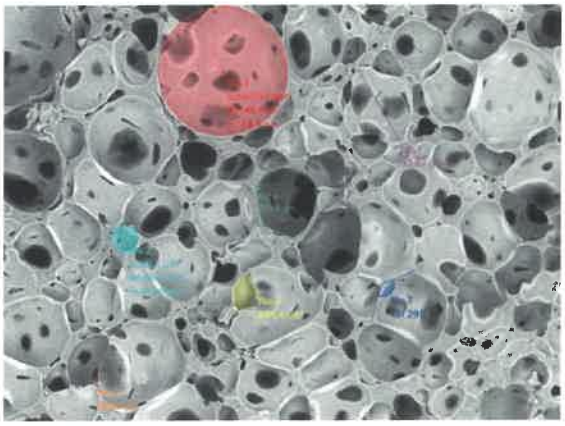
Automatic serial analysis can be made by specifying multiple areas in advance. Pinpoint Navi detects small image shifts by probe tracking, for precise repositioning of the analysis area.

Relocating analysis areas

The stage position and magnification are linked with the analysis data. Return to any analysis area on the SEM image screen for additional study.

Measurement

Measurements are performed on the observation screen, and their results (distance, angle, area, etc.) can be recorded and saved on SEM images.



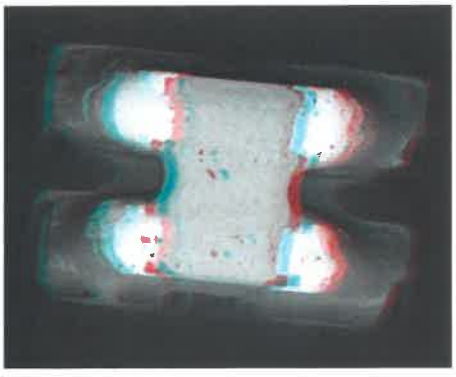
Specimen: Marshmallow

3D imaging

Optional software for creation of 3D image and analysis.

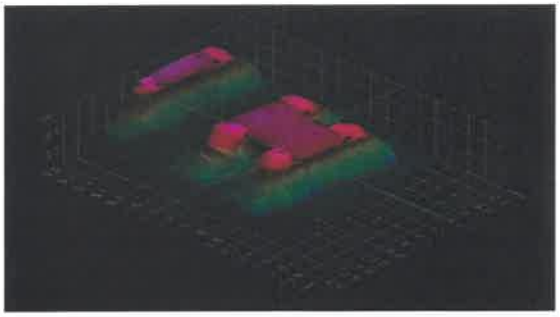
• Anaglyph

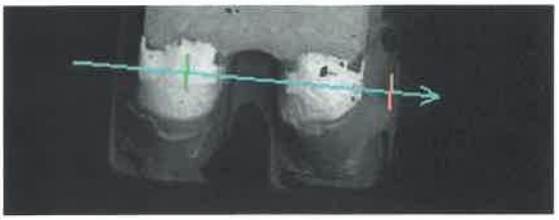
Step-by-step guide to collecting images for creation of an anaglyph image.

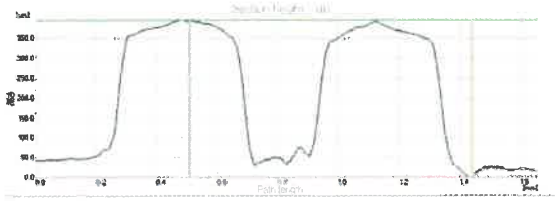


• 3D measurement image Option

Dedicated software for 3D measurement. A 3D image can be created from two SEM images.
The topographic status of the specimen surface can be measured.







Specimen: Memory device

Seamless report generation

■ Integrated data management software SMILE VIEW™ Lab

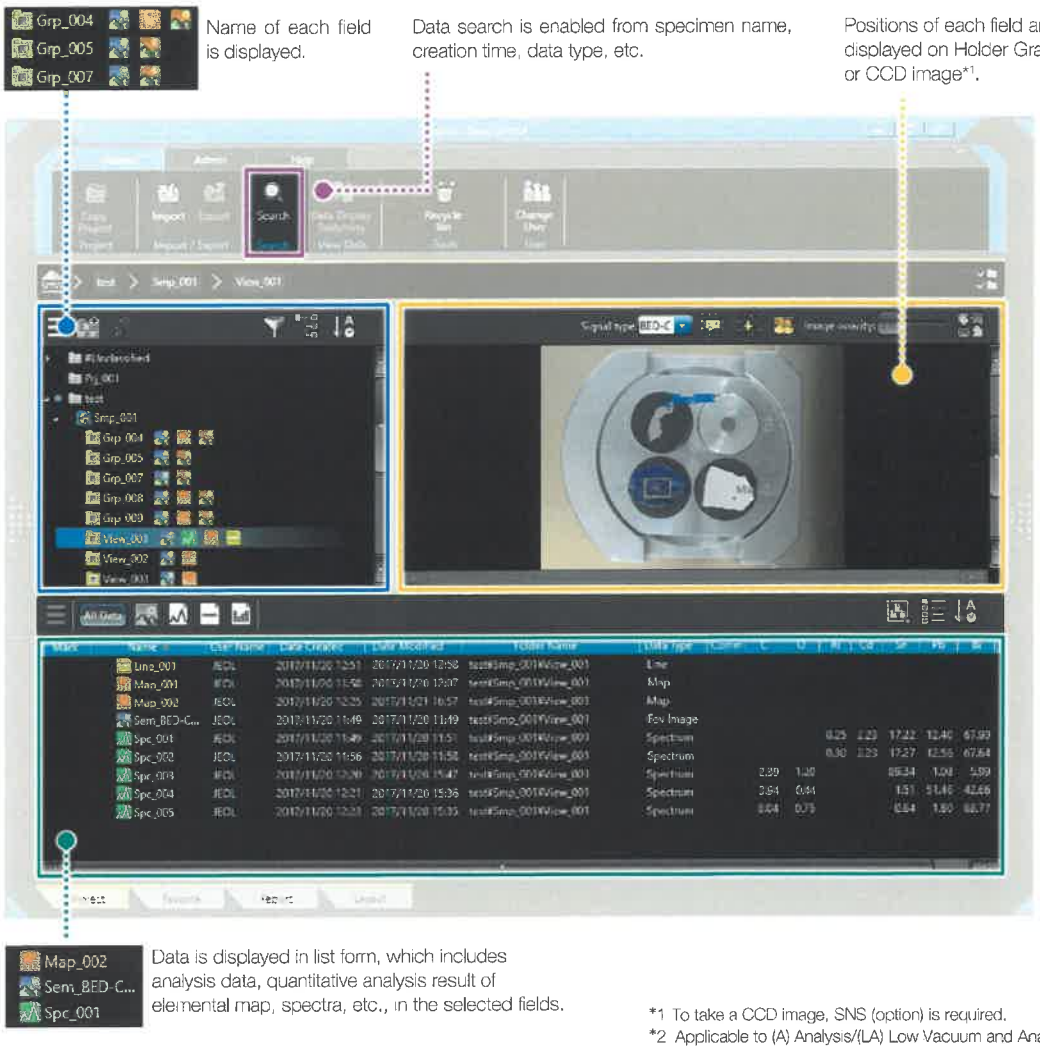
SMILE VIEW™ Lab is a fully integrated data management software which links the CCD image*1, SEM images, EDS analysis results*2, and corresponding stage coordinates for fast report generation or recall of specimen position for further study.

SMILE VIEW™ Lab Data management screen

SMILE VIEW™ Lab Data management screen allows you to easily handle all your data. Our data manager links the observation position, observation & analysis results, and a low magnification image acquired by Holder Graphics or CCD image*1. You can review or reanalyze already-acquired data and export selected data to a report.

Features of SMILE VIEW™ Lab

- Performs integrated management of CCD image*1 data, SEM image data and EDS analysis results*2.
- Allows for immediate understanding of data in each field.
- Enables data searching.
- Screen layout is easy to change.



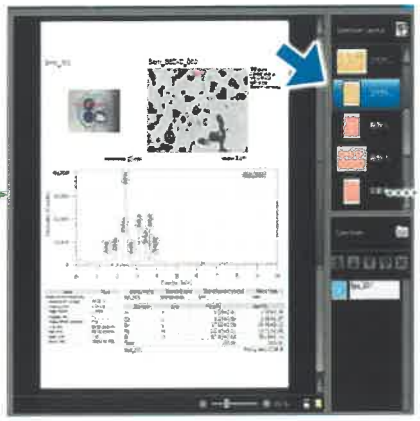
*1 To take a CCD image, SNS (option) is required.
*2 Applicable to (A) Analysis/(LA) Low Vacuum and Analysis versions.

Automatic layout function

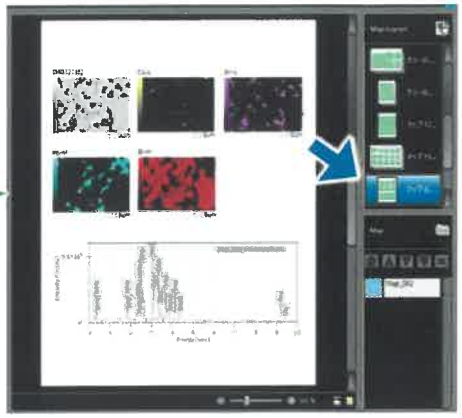
Patent applied for

The SEM image data is linked with its EDS data. The report is automatically laid out with all related data included.
If the data set is large, additional pages are allocated automatically. When you change the layout, all related data is updated with a single click.

Select the data for report generation and click "Add to the report".



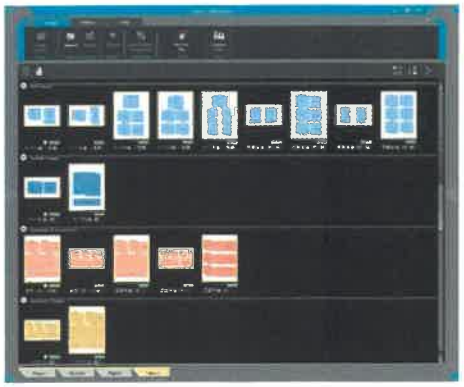
Based on the layout chosen, the linked data is automatically included.



When you select another layout button, only the layout is changed where the data is updated to the new format.

User layout

You can create templates for your reports.



User layout

■ Offline analysis software

Option

Improving productivity

Offline analysis software is available. You can process all your data offline and generate reports.
You can create quantitative maps and extract spectra (Pop-up Spectrum) from your map data sets.

Functions & Applications

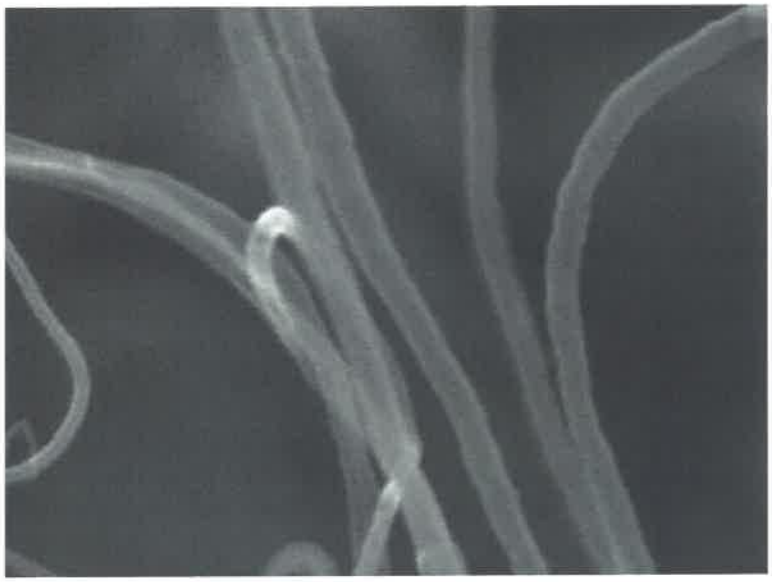
Various functions of the JSM-IT200 and their applications are presented.

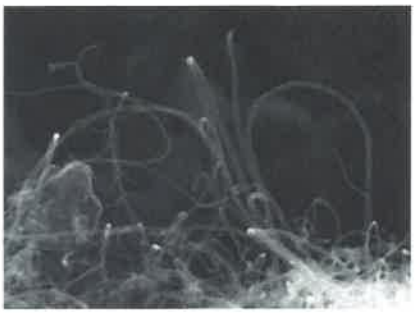
Secondary electron image

Secondary electron image is used most often to observe the surface morphology of a specimen.

The following secondary electron images show carbon nanotubes at high accelerating voltage. The sharp high magnification image to the left (×100,000) enables length measurement of each tube.

Accelerating voltage 30 kV



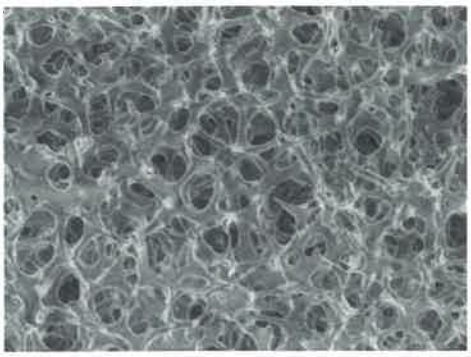


Specimen: Carbon nanotubes
Accelerating voltage: 30 kV
Magnification (left): ×100,000
(right): ×30,000
High-vacuum mode, Secondary electron image

This image shows a cross section of an insulator.

Specimen: Insulator
Accelerating voltage: 5 kV
Magnification: ×20,000
High-vacuum mode, Secondary electron image

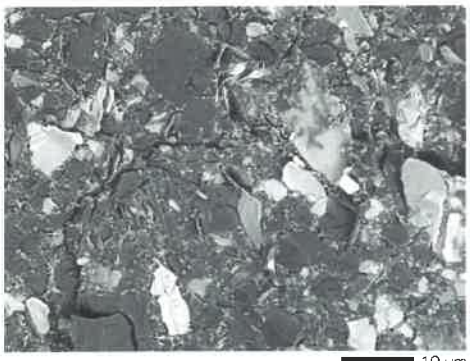
This hollow fiber specimen has a complicated pore structure. Executing CF scan mode at low voltage allows for clear observation without the need to add a conductive coating.



Specimen: Hollow fiber
Accelerating voltage: 1.0 kV
Magnification: ×10,000
High-vacuum mode, Secondary electron image

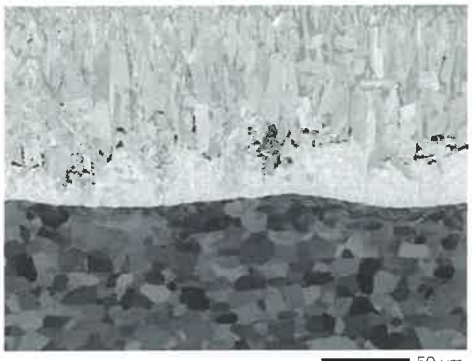
Backscattered electron image

Backscattered electron composition image shows differences in composition (average atomic number) with different intensity. The backscattered electron image enables confirmation of the distribution of lubricants on the surface of a vitamin pill.



Specimen: Vitamin pill (sugar portion)
Accelerating voltage: 5 kV
Magnification: ×2,000
High-vacuum mode, Backscattered electron composition image

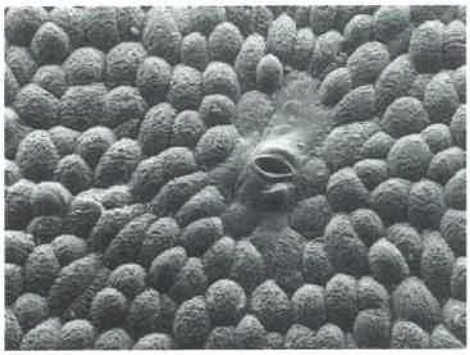
A flat surface prepared with our CROSS SECTION POLISHER™ (CP) was observed by a backscattered electron composition image at low accelerating voltage. The channeling contrast of zinc-plated and iron (substrate) was confirmed.



Specimen: Hot dip galvanizing on iron
Accelerating voltage: 5 kV
Magnification: ×500
High-vacuum mode, Backscattered electron composition image

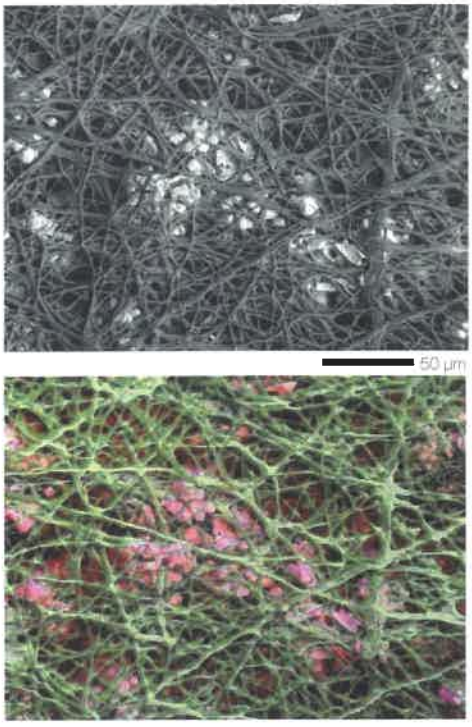
Low-vacuum (LV) mode

The JSM-IT200(LV)/(LA) comes with LV mode. The LV mode neutralizes charging on the specimen surface by introducing the air into the chamber, enabling observation of a non-conductive specimen in its native state.
Another merit of the (LA) version is easy elemental analysis without specimen pre-treatment.



Specimen: Peel of banana
Accelerating voltage: 5 kV
Magnification: ×500
Low-vacuum mode, Low-vacuum secondary electron image*

* To observe a low-vacuum secondary electron image, Low Vacuum Secondary Electron Detector (option) is required.



Specimen: Egg-shell membrane
Accelerating voltage: 10 kV, Magnification: ×500
Low-vacuum mode
Top: Backscattered electron stereoscopic image
Bottom: Composite elemental map (Green: C, Blue: O, Red: Ca)

Functions & Applications

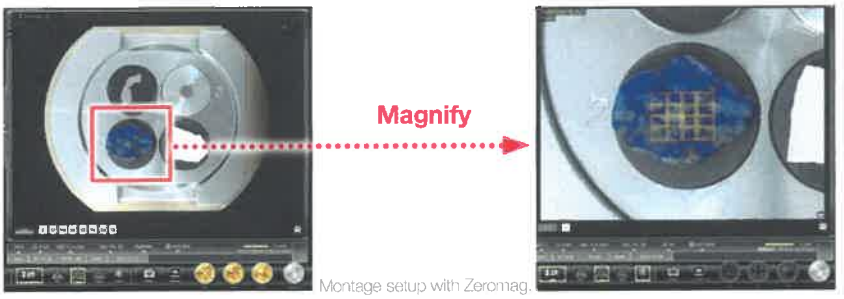
Low accelerating voltage

Observation at low accelerating voltage enables finer surface structures to be studied. Contaminants on the surface viewed with an optical microscope are difficult to observe at an accelerating voltage of 15 kV. Lowering the voltage to 2 kV clearly visualizes the contaminants.

Optical microscope image
Specimen: Micro SD
Magnification: ×3,000
High-vacuum mode, Secondary electron image

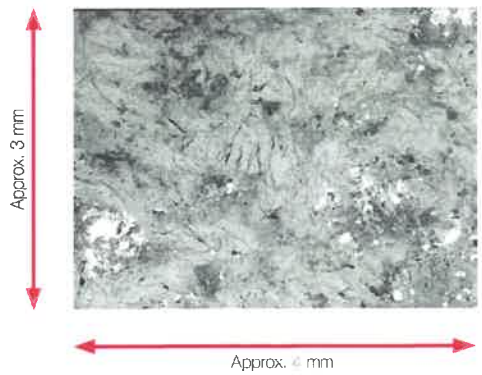
Montage: Automated large-area observation and analysis using Zeromag.

Montage is an effective function for analyzing materials over large areas (for foreign materials, ductile or brittle fracture, etc.).
With Zeromag, it is easy to set up one or more montage areas for imaging and analysis.
"Tilt Correction", "Field Overlap" and "Autofocus Point Setting" functions are built in.



Montage setup with Zeromag.

Montage is an effective function to acquire detailed information across a specimen area.



Montage result: 4 × 4
(Left: Backscattered electron composition image, Right : Na map)
Specimen: Lapis lazuli
Accelerating voltage: 15 kV, Low-vacuum mode

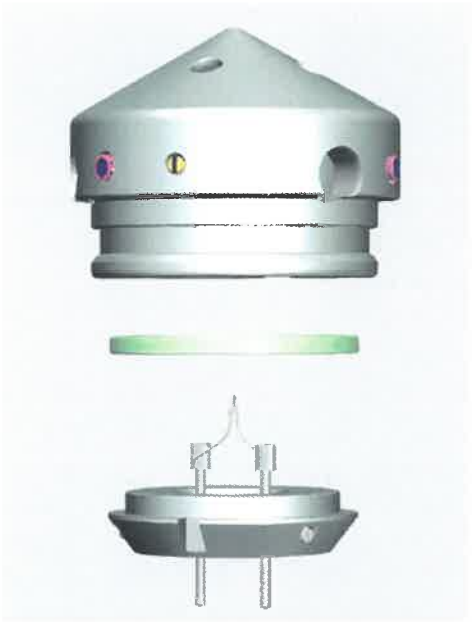
Maintenance

Filament

Filaments for the JSM-IT200 are pre-centered and require no centering by the operator.

Gun alignment

Fully automated alignment function is built in.



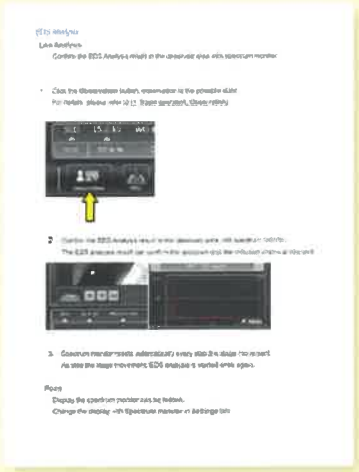
By simply inserting the filament into the Wehnelt and fixing it, the filament is automatically aligned to the center axis.

Help Guide for any operation

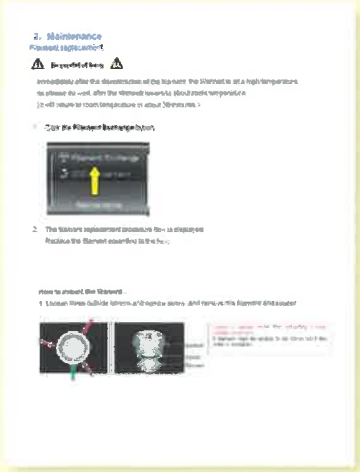
The help guide, makes it easy to understand operation methods of SEM and EDS, as well as maintenance procedures. With this guide, novice users can quickly achieve results.

Help guide

Condition setting



Analysis



Maintenance

Technical DATA

JSM-IT200 Series Can be equipped in the following 4 configurations: (BU) Base Unit / (A) Analysis / (LV) Low Vacuum / (LA) Low Vacuum & Analysis.

Main Specifications

Resolution High vacuum mode	3.0 nm (30 kV), 8.0 nm (3 kV) 15.0 nm (1.0 kV)
Low vacuum mode *1	4.0 nm (30 kV, BED)
Direct magnification	×5 to 300,000 (Print size of 128 mm × 96 mm)
Display magnification	×14 to 839,724 (Display size of 358 mm × 269 mm)
Electron gun	W filament, Fully automatic gun alignment
Accelerating voltage	0.5 to 30 kV
Probe current	1 pA to 0.3 μA*5
LV pressure adjustment*1	10 to 100 Pa
Objective lens aperture	1-stage, with XY fine adjustment function
Automatic functions	Filament adjustment, Gun alignment, Focus /Stigmator /Brightness /Contrast
Maximum specimen size	150 mm dia. × 48 mm (H)
Specimen stage	XY-2 axes motor-drive eucentric stage X: 80 mm, Y: 40 mm, Z: 5 to 48 mm Tilt: −10 to 90°, Rotation: 360°
Montage function	Built-in
Holder Graphic display range	127 mm dia.
Standard recipes	Built-in (includes EDS condition*2)
Image mode	Secondary electron image, REF image, Composition image*1, Topographic image*1, Stereoscopic image*1
Pixels for image acquisition	320 × 240 640 × 480 1,280 × 960 2,560 × 1,920 5,120 × 3,840
OS	Microsoft®Windows®10 64bit
Observation monitor	24-inch touch panel
EDS functions*2	Refer to EDS specifications.
Measurement functions	Built-in (distance between 2 points, between parallel lines, angle, diameter,)
Data management	SMILE VIEW™ Lab
Report generation	Output to Microsoft®Word*3 Output to Microsoft®PowerPoint®*3
Language switch	Operable on UI (Japanese/English)
Vacuum system	Fully automatic, TMP: 1 RP: 1

*1 Standard in JSM-IT200 (LV) / (LA).
*2 Standard in JSM-IT200 (A) / (LA).
*3 Microsoft® Office must be installed.
*4 The optional probe current compensation unit is required. Automatic monitoring of the probe current is possible only when EDS is connected to the microscope PC.
*5 When MP-30060 is used, probe current ranges from 1 pA to 1 μA.

Main Options

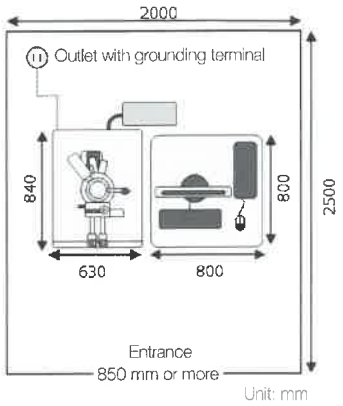
Backscattered Electron Detector (BED) *1
Low Vacuum Secondary Electron Detector (LSED)
Energy Dispersive X-Ray Spectrometer (EDS) *2
Motor Drive Stage (XYZ-3 axes, XYR-3 axes, 5-axes drive)
Stage Navigation System (SNS)
Chamber Scope (CS)
Operation Panel
3D Measurement Software
Table

Installation Requirements

Power	Single-phase 100 V AC, 50/60 Hz, 1.5 kVA (supplied by 3-pin outlet with grounding terminal)
Voltage regulation:	Within ± 10%
Grounding terminal:	100 Ω or less
Installation room:	Room temperature: 15 to 27°C Humidity: 60% or less
Room dimensions:	2,500 mm × 2,000 mm × 1,800 mm or more Door width: 850 mm or more

	W(mm)	D(mm)	H(mm)	Weight(kg)
EOS column unit	630	840	1480	Approx. 260
Rotary pump (RP): 1	530	230	320	Approx. 23
EDS unit*4				Approx. 5

Installation Room Example



Unit: mm

EDS Applicable to two configurations: (A) Analysis and (LA) Low Vacuum & Analysis.

Main Specifications

● : Standard ○ : Option

		Basic	Standard
SEM integration	Built into the SEM control software	●	●
	Integrated management of observation & analysis data		
	Specifying analysis positions on the SEM operation screen (direct analysis on UI for SEM)		
	Graphical display of analysis positions		
Detector	SDD type	Refer to "Details of DrySD™ detectors"	
Spectral analysis	Qualitative analysis (peak identification, automatic qualitative analysis)	●	●
	Visual Peak ID		
	Standard-less quantitative analysis (ZAF method)		
	Standard quantitative analysis (ZAF method) *4		●
	PHI-RHO-Z (PRZ) method: quantitative correction method		
Line analysis	Line analysis (parallel & arbitrary direction)	●	●
Real-time net count map	Elemental map (map with multiple colors, monochrome, multiple-color superimposition)	●	●
	Maximum pixel resolution: 4,096 × 3,072		
	Real-time pop-up spectrum		
	Deconvolution map (net count map, quantitative map)		
	Real-time net count map		
	Real-time filter		
	Line profile display		
	Probe tracking		
Serial analysis	Spectral analysis, line analysis, elemental map	●	●
	Comprehensive analysis of already-analyzed data (qualitative & quantitative analysis)		
Montage	Automatic montage (SEM image, elemental map)	●	●
	Serial elemental mapping for multiple areas		
Particle Analysis Software	Particle analysis (auto / manual) & EDS analysis	○	○
	Classification of particle analysis data		
	Graph display of statistical processed particle analysis data		
	Large-area serial particle analysis & EDS analysis		
	Specifying the measurement area on Stage Navigation System		
Data management function Report generation	SMILE VIEW™ Lab	●	●
Help function	Help guide	●	●
Offline function	Offline software for data analysis	○	○

Details of DrySD™ detectors

Detection area	Energy resolution	Detectable elements
25 mm²	130 eV or less	Be to U

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Microsoft Word is a product name of Microsoft Corporation.

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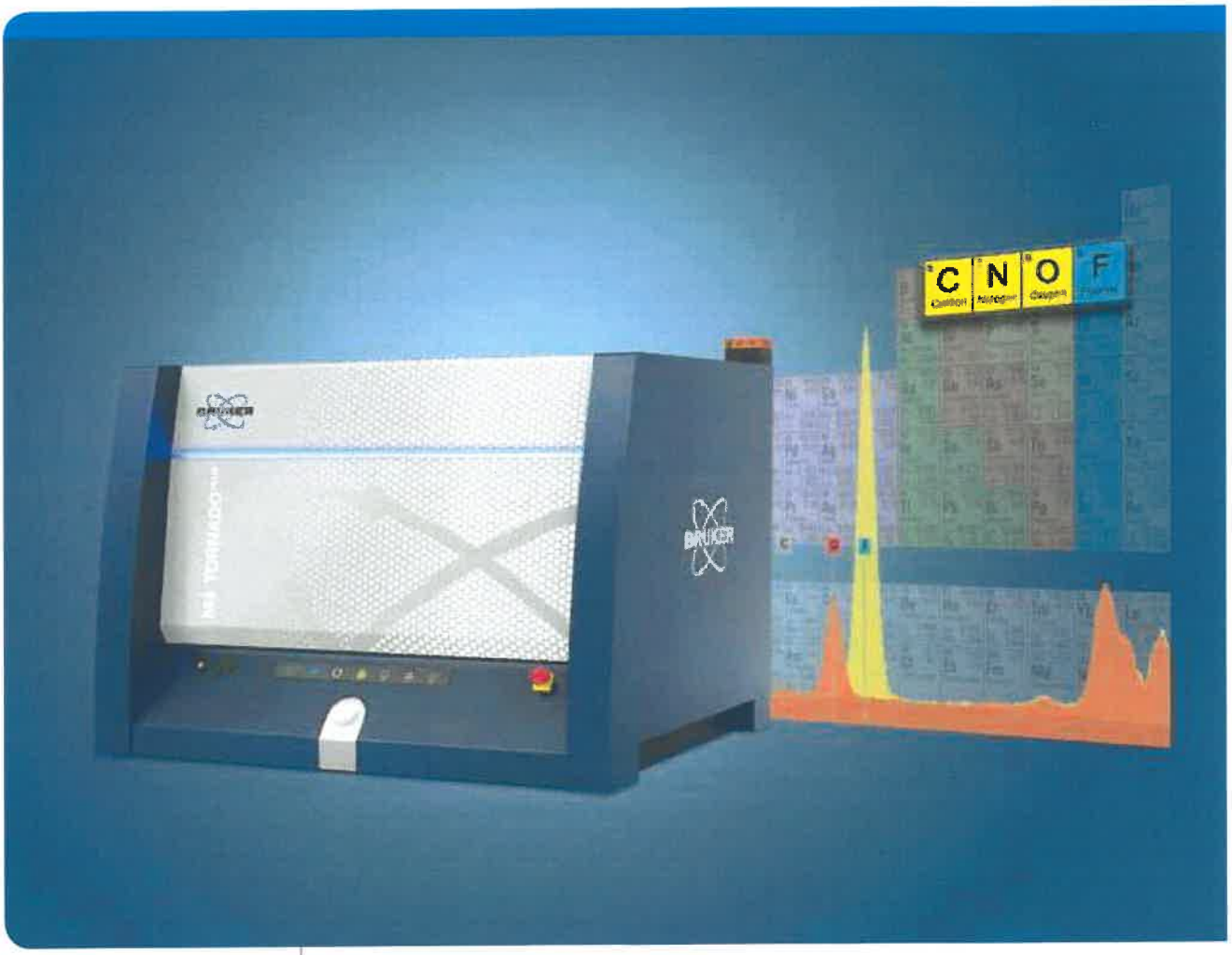


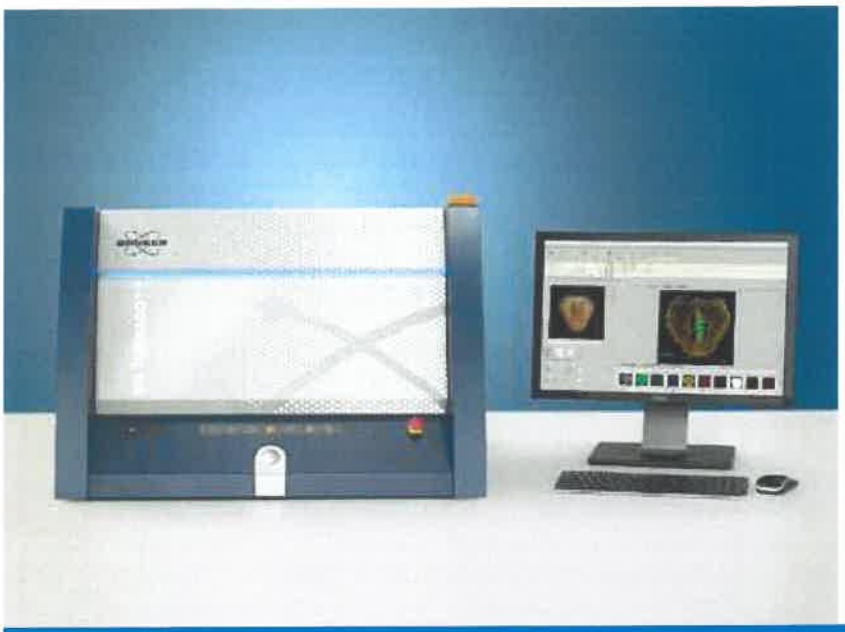
M4 TORNADO PLUS

- Super Light Element Micro-XRF Spectrometer

Micro-XRF

Innovation with Integrity

M4 TORNADO^{PLUS} - A New Era in Micro-XRF



M4 TORNADO^{PLUS} is the world's first Micro-XRF spectrometer that enables the detection and analysis of the entire element range from carbon to americium.
As the latest member of the proven, market leading family of M4 TORNADO Micro-XRF analyzers, the M4 TORNADO^{PLUS} also offers additional unique features, such as an innovative aperture management system, an ultra-high throughput pulse processor and a flexible quick-change sample stage.

Unique Features and Benefits of the M4 TORNADO^{PLUS}

Features	Benefits
Dual, large-area silicon drift detectors (SDD) with super light element window	Detection and analysis of light elements down to carbon
High throughput pulse processor	Reduced acquisition time, increased productivity
Innovative Aperture Management System (AMS)	High depth of field to keep more features and details in focus when investigating topographic samples
Quick-change stage with optional specimen holders	Reduced sample exchange and setup time
Second X-ray tube with automatic four position collimator changer (optional)	More flexibility for the analysis of high energy lines
Programmable He-purge system (optional)	Light element analysis at atmospheric pressure

Lighter, Faster, Deeper

The M4 TORNADO^{PLUS} enables the detection of light elements down to carbon by using large-area silicon drift detectors (SDD) with super light element window and offers vastly increased acquisition speed by performing ultra-high throughput pulse processing. Its patented aperture management system (AMS) provides an unmatched depth of field and allows analysis of samples with highly topographic surfaces.

Super Light Element Detection down to Carbon

Using two large-area silicon drift detectors with super light element window and a specifically optimized Rh X-ray tube, the M4 TORNADO^{PLUS} is the first Micro-XRF spectrometer ever to enable the analysis of light elements.

Unlike common Micro-XRF systems, which are suitable to detect elements from sodium up, the M4 TORNADO^{PLUS} allows to also measure elements with atomic numbers $Z < 11$, such as fluorine, oxygen, nitrogen and carbon, without compromising the performance and sensitivity in the higher energy ranges.

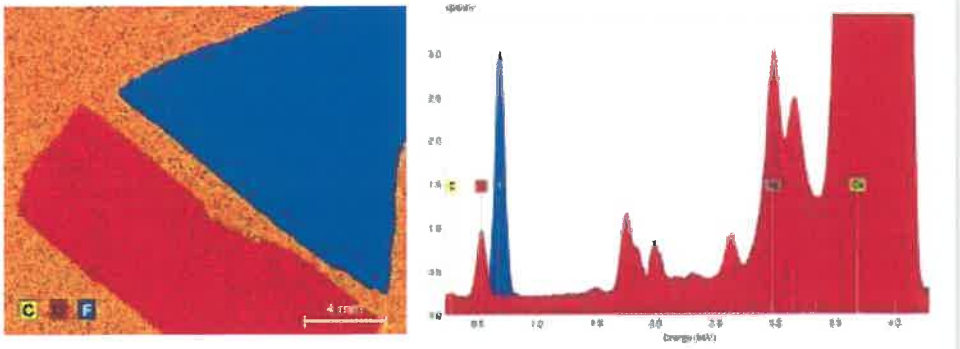
With this performance enhancement, new applications are opening up for Micro-XRF, e.g. in geoscience and mining, biology, polymer research or semiconductor industry.

Application Example - Differentiating Fluorite and Calcite

Both fluorite (CaF_2) and calcite ($CaCO_3$) are minerals with calcium as a main component. What differentiates them is the presence of the light elements fluorine and oxygen/carbon, respectively. Due to their inability to detect elements with $Z < 11$ (sodium), common Micro-XRF systems cannot distinguish between these two minerals, as both the fluorite and calcite spectrum would show the calcium line only.

With its super light element detectors and the light element X-ray tube, the M4 TORNADO^{PLUS} can detect fluorine, oxygen and carbon and thus reliably identify the two minerals.

Differentiating fluorite and calcite



Left: Element map of calcite (red) and fluorite (blue); image size: 20 x 12 mm²; scan resolution: 800 x 460 pixels; step size: 25 µm; dwell time: 25 ms/pixel; excitation: Ag LE tube, 50 kV, 500 µA.
Right: Light element spectrum region of the two minerals fluorite (blue) and calcite (red).

Lighter, Faster, Deeper

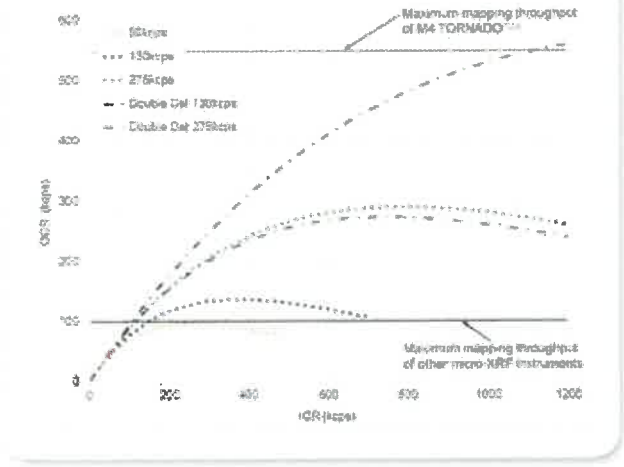
Ultra-High Throughput Pulse Processor for Fastest Measurements

While the highly brilliant micro-focus X-ray sources of most modern Micro-XRF systems are capable of generating very high X-ray fluorescence intensities, detectors and pulse processors limit the output count rate to typically 90–100 kcps.

Already the previous dual detector versions of the M4 TORNADO have been trendsetting in this regard, providing up to 260 kcps output count rate with excellent energy resolution.

With its unique ability to process up to 1,200 kcps and to deliver an output count rate of up to 550 kcps, the M4 TORNADO^{PLUS} pushes these limits significantly further, enabling unmatched acquisition speed and productivity.

Input vs. output count rate for the M4 TORNADO^{PLUS} pulse processors



Even if the nature of the sample does not allow the generation of correspondingly high X-ray fluorescence intensities, the pulse throughput will be superior due to the low pulse processor dead time. That means, in any measurement situation the M4 TORNADO^{PLUS} delivers more data in the same time, or produces a result with the same amount of data in less time, compared to competing instruments.

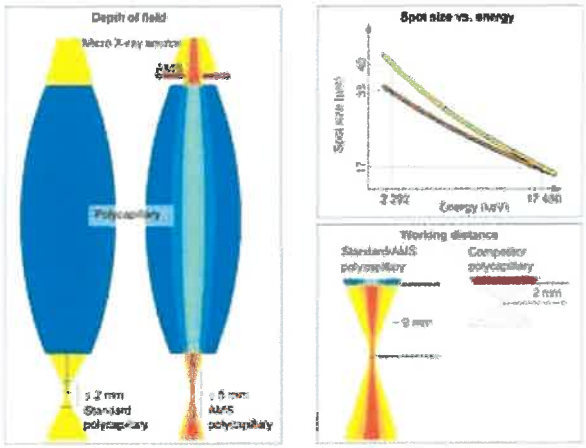
Aperture Management System (AMS) - Increasing Depth of Field and Spatial Resolution

Many specimens to be investigated using Micro-XRF have topographic surfaces, rather than being perfectly flat. Therefore, just like in photography, the depth of field becomes an important parameter for the X-ray optical system used to generate the small excitation spot on the sample surface.

Usually, in Micro-XRF analyzers with high spatial resolution X-ray optics (7 µm), the working distance needs to be as small as 2 mm and the achievable depth of field is less than 1 mm.

The innovative, software-controlled aperture management system (AMS) of the M4 TORNADO^{PLUS} enables a working distance of approx. 9 mm and provides a depth of field of up to ± 5 mm. That means, the spatial resolution does not get lost, and sample features are kept in focus, even if the sample surface varies over several millimeters. This makes the M4 TORNADO^{PLUS} the instrument of choice for the analysis of specimens with strong topography, e.g. in electronics, forensics, or geoscience.

AMS principle - Narrow beam, high depth of field and low energy dependence

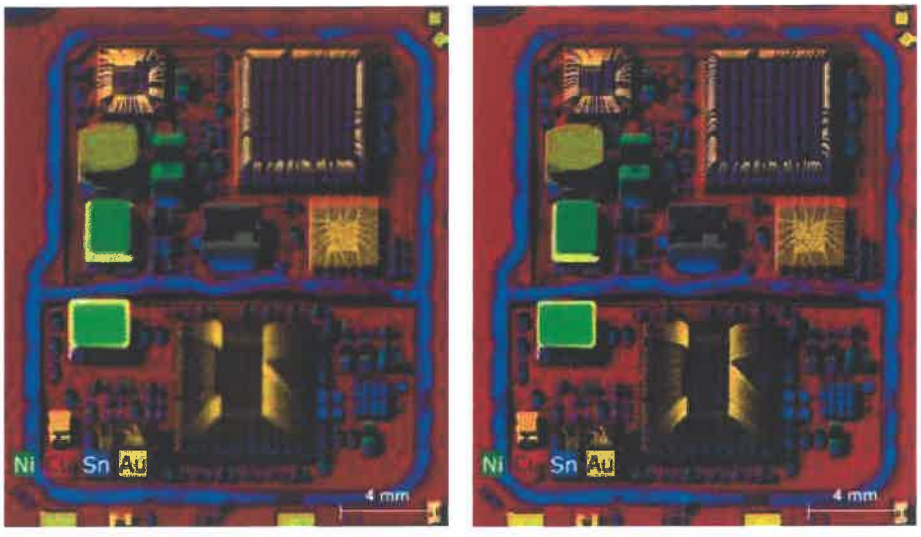


The reduction of the radiation entrance angle into the polycapillary results in a significantly larger depth of field. With polycapillary and AMS, the energy dependent variation of the spot size becomes negligible.

Application Example - PCB Mapping

Due to the extremely deep depth of field with AMS, the corresponding X-ray image of a mobile phone circuit board has far more details in focus than the image of the same circuit board acquired without AMS. In addition, the energy dependence of the spot size becomes less pronounced because of the reduced entrance and exit angles of the excited X-ray photons.

Circuit board analyzed without and with AMS



Left: The standard polycapillary spot was focused on the board level of the PCB, hence the tall components and bond wires are out of focus and appear blurred. Right: AMS image showing high depth of field with all components in focus over a larger depth range.

Easing, Expanding, Extending

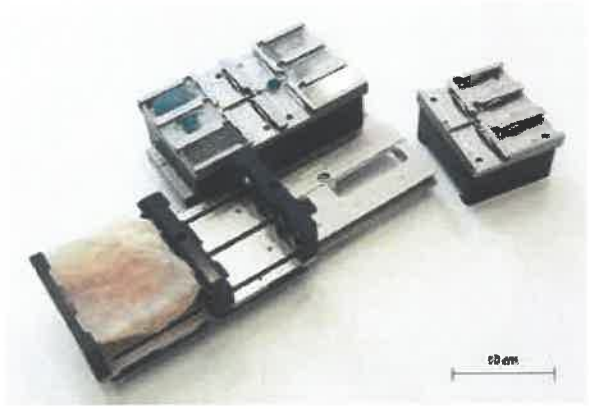
The M4 TORNADO^{PLUS} eases the exchanging, positioning and fixing of samples with the quick-change stage, expands the spot size and intensity range of the (optional) second X-ray tube with a collimator changer and extends the range of application in the light element analysis even for sensitive or hydrated specimens using He-purging.

Quick-Change Stage for Fast and Easy Sample Exchange

In most analytical labs, there is pressure on the analyst to maximize the sample throughput and to minimize the time the instrument sits idle. Besides that, the secure attachment of large, irregularly shaped specimens, or of a large number of thin sections in a repeatable manner, can be challenging and time-consuming tasks.

The M4 TORNADO^{PLUS} comes with a modular quick-change stage interface. The dovetail coupler enables the stage plate to be removed and reinserted easily and quickly without any tools, providing for convenient and secure placement of samples onto the stage plate.

Quick-change stage interface with drill core holder and thin section holders



Adjustable sample holder with whole, half or quarter plugs for drill cores and other irregular shaped samples as well as for thin sections.

Standard quick-change stage interface

Standard quick-change stage interface for easy placement of a sample outside the sample chamber.

Optionally, there is an additional base plate, which supports drill core holders or thin section carriers.

The drill core sample holder is configurable and can be adjusted to hold up to HQ sized (2.5 inch) drill cores. It can be set up with one or two halves, each being able to hold two or three half or quarter drill cores, as well as end pieces or plugs. Alternatively, the base plate can be equipped with up to four thin section carriers, each being able to hold five thin sections, secured by two wave springs.

Regardless if using drill core holders, thin section carriers or a combination of both, the measuring plane is always the same, meaning less time spent with setting up measurements. The entire stage load can be analyzed without changing focus.

Second X-ray Tube with Collimator Changer for Intensity Gain at Higher Energies

In order to effectively excite the high-energy lines of heavy or Rare Earth Elements (REE), an X-ray source with collimator is the better choice as it does not suffer from the attenuation of the higher energy portion of the tube spectrum that can be observed with polycapillary lenses.

For the analysis of larger specimen volumes, it may also be beneficial to have a larger spot size.

The M4 TORNADO^{PLUS} can therefore be equipped with a second (fine-focus) X-ray tube (W) combined with a fully software-controlled four position collimator changer. The collimator changer can be set to spot sizes of 500 µm, 1 mm, 2 mm, and 4.5 mm, enabling either a small spot analysis, albeit with lower intensity, or close to bulk XRF analysis with a large high intensity spot.

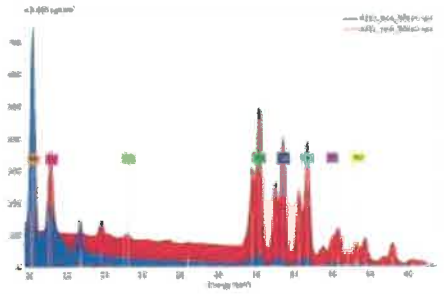
He-Purge System for Increased Intensity at Lower Energies

For certain specimens, measurement under vacuum poses an issue because they are sensitive to pressure variation or may dry out. Even though working at ambient air is always possible, X-ray fluorescence from the light elements below Ca is strongly attenuated or even completely absorbed. In order to detect light and super light elements down to carbon also in vacuum-sensitive samples, the M4 TORNADO^{PLUS} offers an optional, computer-controlled He-purge system to extend the analysis range under atmospheric pressure.

Two different purging modes can be employed, depending on the specific analytical requirements. For a quick single or multi-point analysis, local high-flow purging of the measurement position is sufficient to reliably acquire the low energy X-rays.

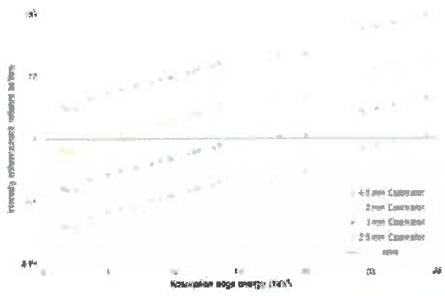
When performing X-ray mapping however, stage movement may cause turbulences, resulting in instable detection conditions for light elements. In this case, a second purging mode is available in which the entire measurement chamber is filled with He, ensuring constant and repeatable conditions for the detection and analysis of light elements during the acquisition process.

Collimator vs. lens sensitivity on REEs



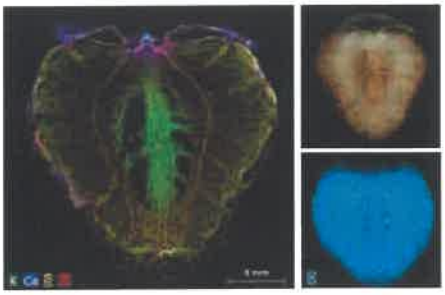
Comparison of rare earth element lines excited with polycapillary lens (blue) and collimator (red). The excitation with collimator yields higher sensitivity for the high energy lines.

Intensity gain with collimator



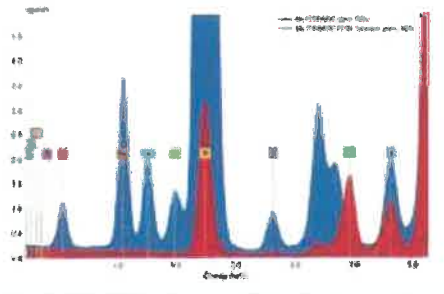
Gain of the primary X-ray intensity for the different collimator sizes in comparison to a polycapillary lens (line at 1).

Element map with He-purge



Mosaic image and single element maps of a strawberry. Image size: 31.2 x 30.5 mm², scan resolution: 1560 x 1525 pixels; step size: 20 µm; dwell time: 10 ms/pixel; excitation: Rh tube, 50 kV, 600 µA.

Spectra comparison of NIST glass



Spectra comparison of NIST 620 glass samples measured with a standard M4 TORNADO in air (red) and a M4 TORNADO^{PLUS} with He-purge (blue).

Technical Specifications

Sample types	Solids, particles, liquids
Sample chamber size	WxDxH: 600 mm x 350 mm x 260 mm
Stage	WxD: 330 mm x 170 mm, Max. weight load: 7 kg
Measurement media	Air or oil free vacuum, 20 mbar in 2 min, optional He-purge system
Sample travel	
Max. travel	WxDxH: 200 mm x 160 mm x 120 mm
Mapping travel	WxD: 190 mm x 160 mm
Travel speed	Up to 100 mm/s with TurboSpeed stage
Sample view	2 simultaneous live images from above with different magnifications for sample overview and precise positioning Lateral fisheye camera for the sample chamber overview
Excitation	High brilliance, light element micro focus X-ray tube with polycapillary X-ray optics and aperture management system (AMS) Optional: 2nd fine focus X-ray tube with four position collimator changer from 0.5 to 4.5 mm
Excitation parameters	
Target material	1st tube: Rh (optionally Ag), 2nd tube: W (optionally Rh, Mo, Cu, Cr)
Tube parameters	50 kV, 30 W (40 W for collimator)
Spot size	Less than 20 µm for Mo Kα (17.5 keV) with polycapillary lens
AMS filters	500 µm and 1 mm apertures, plus 6 filters
Filters	8 filters for collimator
Detection	XFlash® super light element silicon drift detectors, detection from C to Am, simultaneous use of two detectors
Detector parameters	
Sensitive area	2 x 60 mm²
Energy resolution	< 145 eV at 600,000 cps input count rate
Throughput	up to 550,000 cps output count rate
Instrument control	State-of-the-art PC, Windows 10
Instrument control functions	Complete control of tube parameters, filters, optical microscopes, sample illumination and sample positioning
Spectra evaluation	Peak identification, artifact and background correction, peak area calculation, FP quantification, calibrated quantification with standard-based and standardless models using XMethod
Distribution analysis	"On the fly" measurement, HyperMap capability
Result presentation	Quantification results, statistical evaluation, element distribution (line scan, mapping)
Power requirements	100–240 V (1P), 50/60 Hz
Dimensions	WxDxH: 815 mm x 680 mm x 580 mm, 130 kg*
Quality & safety	DIN EN ISO 9001:2008, CE certified Fully radiation protected system; radiation < 1 µSv/h

*Depending on configuration

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Agilent

Trusted Answers

Agilent 8700 LDIR Chemical Imaging System

Bringing Clarity and Unprecedented Speed to Chemical Imaging.

What if you could save time and achieve better results?

The Agilent 8700 Laser Direct Infrared (LDIR) chemical imaging system provides a sophisticated new approach to chemical imaging and spectral analysis. Designed to be used by both experts and nonexperts alike, the 8700 LDIR provides a simple highly automated approach for obtaining reliable high-definition chemical images of constituents on a surface.

The 8700 LDIR uses the latest Quantum Cascade Laser (QCL) technology coupled with rapidly scanning optics to provide fast, clear, high-quality images and spectral data. This technology is combined with intuitive Agilent Clarity software, for rapid and detailed imaging of large sample areas with minimal instrument interaction via a simple load and go method.

Using the 8700 LDIR, you can analyze more samples, in greater detail, in less time. This robust solution provides you with more statistical data than ever to aid in the compositional analysis of tablets, laminates, tissues, polymers, and fibers. With more meaningful information available, you can make more informed, faster decisions in product development reducing both costs and analysis time.

(From Left to right) Agilent Sample Planer, Agilent 8700 LDIR chemical imaging system and Agilent Clarity software analysis window

LDIR Spectroscopy – How it works

The 8700 LDIR works in either reflectance or Attenuated Total Reflectance (ATR) mode, automatically switching between these two modes by directing the incident beam to the appropriate objective. The movement of the sample relative to the beam is fully automated. The 8700 LDIR has two visible channels: a large field of view camera to obtain an entire view of the sample and a microscope grade objective to capture high magnification detail.

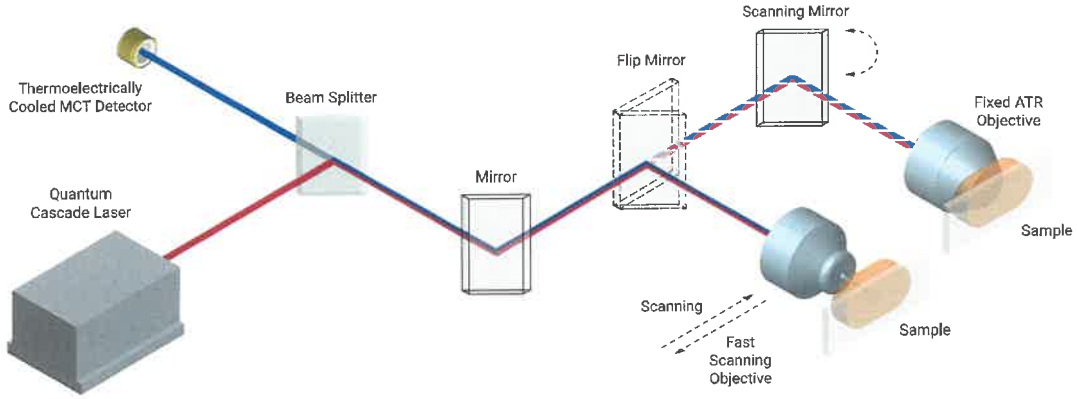


Figure 1. 8700 LDIR instrument optics

Infrared light from the QCL (shown in red) is directed to the sample. Infrared light reflected by the sample is then directed to the detector via either of the selected optical paths (shown in dark blue).

In reflectance mode (solid line), infrared light from the laser is focused by the fast scanning objective system that is rapidly scanned back and forth. Concurrently, the sample is automatically moved in a perpendicular plane, and the infrared light reflected by the sample is directed back to the thermoelectrically cooled mercury cadmium telluride (MCT) detector. This process yields a high-quality two-dimensional molecular image in a remarkably short time period.

In ATR mode (dashed line), infrared light from the laser is directed onto a scanning mirror that rapidly moves the light across the fixed ATR element, which is in contact with the sample. Totally internally reflected light is directed to the thermoelectrically cooled MCT detector.

The key benefits

- Automated sample analysis.
- Ability to survey large sample areas and then explore smaller areas of interest in more detail without changing any optics.
- Full software control allows changing the field of view from microns to centimeters or the pixel size from 1 to 40 µm.
- Acquire ATR imaging data with pixel size as small as 0.1 µm for unmatched image detail and spectral quality.
- Rapidly identify unknowns using either commercial or custom libraries via ATR capabilities.
- Obtain relative quantitative information of sample constituents without complex method development.
- No requirement for liquid nitrogen reduces operating costs and simplifies maintenance.

The Agilent 8700 LDIR Chemical Imaging System handles both your routine and challenging applications

The 8700 LDIR is suitable for a range of applications including pharmaceutical, material science, polymer analysis and life science research.

Pharmaceutical

- Tablet content distribution – image the spatial distribution of Active Pharmaceutical Ingredients (APIs) and excipients to ensure consistency, quality, and to aid in formulation development and troubleshooting.
- Investigation of factors affecting polymorphism, crystallization and salt exchange.
- Analysis of multi-layer tablets – monitor inter- and intra-layer consistency.
- Analysis of single and multilayer coatings for consistency.
- Correlation of drug formulations (chemical and physical structure) with dissolution studies.
- Identification of extraneous particles and impurities.
- Counterfeit drug analysis – create spectral and image databases of drug tablets to support anti-counterfeiting efforts.

Figure 2. A high spatial resolution chemical image of a generic headache tablet consisting of three APIs (acetaminophen, aspirin and caffeine) and four excipients. All seven components were imaged across the entire tablet (11 mm diameter) with 10 micron pixel size in only 1 hour.

Accelerate pharmaceutical drug development

In the pharmaceutical industry, time is a critical factor when releasing products. Problems that arise during drug formulation take time and resources. With the 8700 LDIR, an entire tablet can be quickly and easily analyzed, speeding up your troubleshooting process.

Formulation and batch release testing are complex and critical processes. In addition, consistency is required, batch after batch. The 8700 LDIR system provides high sensitivity chemical composition analysis. With this system, you can now quickly and easily obtain qualitative and semi-quantitative information about APIs (polymorphs, salts), excipients, and impurities.

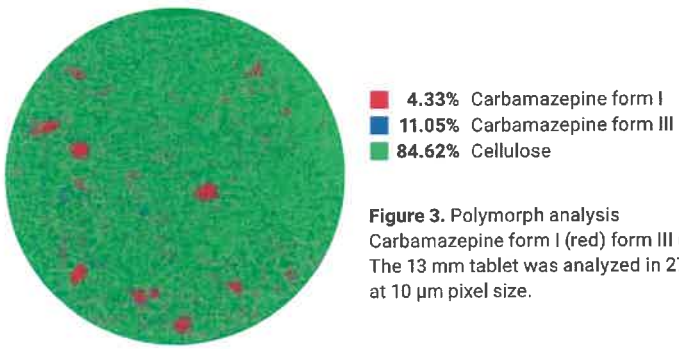


Figure 3. Polymorph analysis
Carbamazepine form I (red) form III (blue)
The 13 mm tablet was analyzed in 27 minutes at 10 µm pixel size.

Biomedical/Life science research

- High-quality imaging and infrared spectra of cells, tissues, cartilage, bone, and other biological materials.
- Rapidly survey specimens to find and then interrogate areas of interest.
- Analysis of biopolymer surfaces to further understand activity and support quality assurance.
- Find and identify defects, impurities, and extraneous particles in biopolymer matrices.

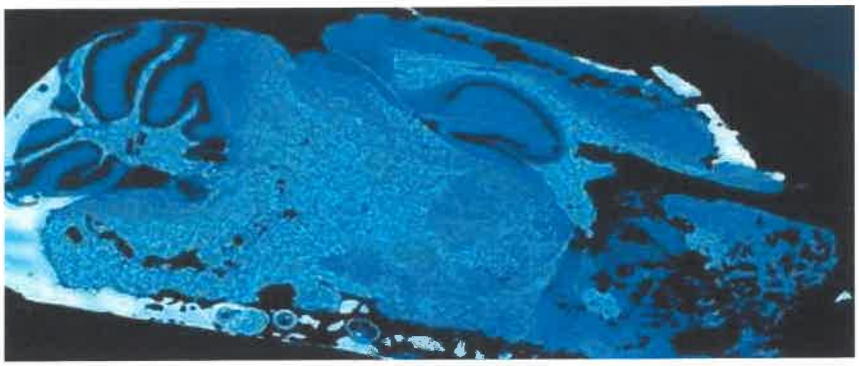


Figure 4. A chemical image of a mouse brain slice showing lipid distribution (12mm x 7mm) at 1 µm pixel measured in 1 hour.

Materials science/polymer analysis

- Packaging/laminates analysis – rapidly image and determine layer identity and thickness for functional and tie (adhesive) layers, down to ~ 3 µm.
- Rapidly identify defects within polymers and multilayer films.
- Analysis of extraneous surface particles and impurities on materials including semiconductors and electronic components.
- Determine and identify the authenticity of components.

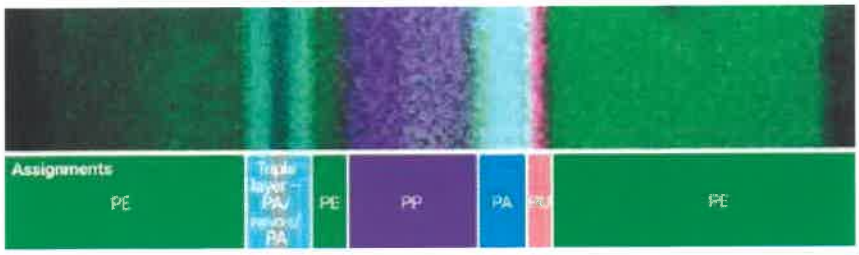
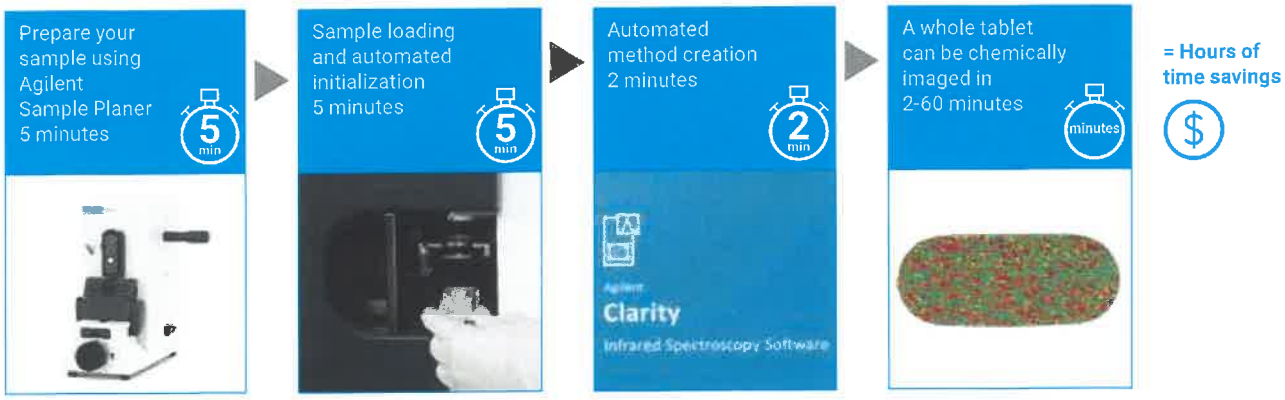


Figure 5. A chemical image showing layers of the laminate sample (120 µm width) consisting of polyethylene (PE), polyamide (PA), poly (ethylene vinyl alcohol) (P(EVOH)), polypropylene (PP) and polyurethane (PU). The thinnest layer observed was only 2.6 µm thick.

Automated. Intuitive. Fast.

Sample preparation and automated analysis is now accessible

The instrument control and software tools of the 8700 LDIR allow both expert spectroscopists and trained technicians to analyze and characterize samples rapidly and accurately. Simply load the sample in the instrument and allow Agilent's Clarity software to reveal complex statistical data in a rapid and intuitive manner.



Breakthrough IR Technology

Agilent's innovative design uses Quantum Cascade Laser (QCL) light, high spatial imaging, and intuitive Agilent Clarity software to create detailed chemical images. Unlike other QCL imaging systems that use 2D Focal Plane Array (FPA) detectors, the 8700 LDIR employs a single-element electrically cooled detector to eliminate laser coherence artifacts from images and spectra.

Agilent Clarity software

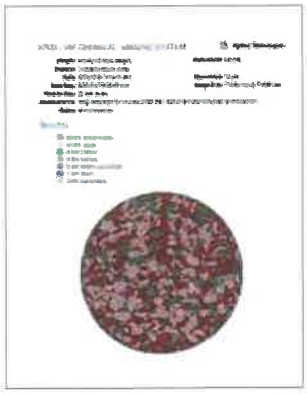
Redefining chemical imaging software

Innovative Agilent Clarity software, built from the ground up and designed with the user experience at the forefront, is simple and easy to use. This intuitive visualization software facilitates complex data interrogation and reporting.

The software totally redefines the chemical imaging software user experience by providing high spatial resolution compositional analysis together with spectral library matching.

Key software analysis features include:

- Fast, easy method creation.
- Spectral analysis including mathematical functions (e.g. variance, addition, averaging) and spectrum transformations.
- Create and search libraries which enables compound identification.



Simple report generation

Agilent Sample Planer

The Agilent Sample Planer is used to prepare samples for analysis using the Agilent 8700 LDIR Chemical Imaging System. Preparing a flat surface has never been easier.

- Prepares flat sample surfaces.
- Simple manual adjustment to control sample thickness.
- Requires no power supply enabling portability.
- Maintenance free.

Learn more:
www.agilent.com/chem/8700-ldir

Buy online:
www.agilent.com/chem/store

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Agilent
Trusted Answers

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Education

2008. Ph.D. in Environmental Sciences, Rutgers University, New Brunswick NJ. (Environmental Chemistry Option). John Reinfelder, Advisor

Dissertation Title: "The transport, transformation, and trophic transfer of bioactive metals in an urban impacted buoyant river plume".

2001. B.S. Environmental Chemistry (magna cum laude) - Lake Superior State University (LSSU), Sault Ste. Marie, MI.

Professional History

- **2023-Present** – Facility Coordinator, Micro Analysis and Stereoscopic Characterization (MASC) Lab, College of Science and the Environment, Lake Superior State University
- **2023-Present** – Professor, College of Science and the Environment, Lake Superior State University
- **2022-2023** – Chair, School of Natural Resources & Environment, Lake Superior State University
- **2013-2023** – Associate Professor, School of Natural Resources & Environment (Previously, School of Physical Sciences)
- **2013-2016** – Chair, School of Physical Sciences, Lake Superior State University
- **2008-2013** – Assistant Professor, Dept. of Chemistry and Environmental Sciences (School of Physical Sciences)
- **2007-2008** – GAANN Fellow, Dept. of Environmental Sciences, Rutgers University.
- **2003-2007** – Graduate Assistant, Dept. of Environmental Sciences, Rutgers University.
- **2002-2003** – GAANN Fellow, Dept. of Environmental Sciences, Rutgers University.
- **2001-2002** – Environmental Sanitarian, LMAS District Health Dept., St. Ignace, MI.

Research Interests

- Development of spectroscopic imaging techniques with applications in Environmental, Earth, Forensic, and Life Sciences
- Biogeochemical cycling and bioavailability of trace metals and nutrients in aquatic systems
- Impact of societal practices and anthropogenic activities on public health and ecosystem integrity

Teaching Experience

- CHEM 115/116 - General Chemistry laboratory sections
- CHEM 341 - Environmental Chemistry I
- CHEM 342 - Environmental Chemistry II
- CHEM 395 - Junior Seminar
- EVRN 311 - Environmental Law
- EVRN 313 - Solid & Hazardous Waste
- EVRN 315 - Human Impacts on the Environment
- EVRN 317 - Environmental Health Applications
- EVRN 341 – Fate & Transport in the Environment
- EVRN 389 – Environmental Research Methods
- EVRN 435 – Environmental Systems
- EVRN 499 - Senior Thesis
- GEOG 108 - Physical Geography: Meteorology and Climatology
- MICR 315 – Electron Microscopy and Microanalysis (S24)
- NRES 199 - Freshman Seminar
- NRES 399 - Research Project Design
- NSCI 103 - Environmental Science
- NSCI 104 - Environmental Science Lab
- NSCI 116 - Oceanography
- USEM 101 - University Seminar I

Fellowships and Honors

- Inclusive Education Award, 2021-22
- 25 most cited authors, 2011 – Journal of Great Lakes Research
- Nominated, Organization Advisor of the Year (Chemistry and Environmental Sciences Club), Spring 2011
- Nominated, Distinguished Teaching Award, 2010-2011, 2021-2022 AY
- Nominated Michigan Distinguished Professor, 2022
- LSSU Student Government Professor of the Year, 2022
- GAANN Fellowship (US Dept. of Ed.), 2007-2008.
- GAANN Fellowship (US Dept. of Ed.), 2002-2003.
- Graduated with an honors degree from LSSU in 2001, including 21 credits of honors courses and an honors senior thesis.
- Alpha Chi National Honor Society, 2000

Grants and Contracts

$769,852 Renewal: SARS CoV-2 Surveillance of Wastewater in the Eastern Upper Peninsula of Michigan, Michigan Department of Health and Human Services, PI: B Southwell, D. Wright, and T. Nguyen. (2023-2024)

$384,660 Equipment: MRI: Track 1 Acquisition of a Micro X-ray Fluorescence Spectrometer to Support Multidisciplinary Research and Education in the Upper Midwest. NSF 2320397 PI M. Zierden LSSU (10/23-9/26)

$947. LSSU Enrichment Grant. Investigation of PFAS levels in Great Lakes Fishes. PIs: B. Southwell, D. Wright, J. Garvon, B. Wesolek (2023)

$197,808 MRI: Acquisition of a low vacuum scanning electron microscope (SEM) with EDS detector and STEM capability to advance research and undergraduate research training, National Science Foundation MRI 2215270, PI: S. Kolomyjec, D. Wright, B. Southwell, H. Kandel, H. Clause, project period: (8/2022 - 8/2025)

$21,600 In situ Comparison of Commercial Cannabis Grow Platforms, Flowrite, Inc., PI: B. Southwell and D. Wright, (2022)

$6,000 Identification and Source Attribution of Foreign Particulate Matter in Cannabis & Cannabis Products, PI: D. Wright and B. Southwell. Lion Laboratories, award# LSSU_001, (5/2022 - 8/2022)

$2,192,977 SARS CoV-2 Surveillance of Wastewater in the Eastern Upper Peninsula of Michigan, Michigan Department of Health and Human Services, PI: B Southwell, D. Wright, and T. Nguyen. (2021-2023)

$318,000 Pilot Scale Evaluation of Digital PCR for the Detection of SARS COV2 in Wastewater, Michigan Department of Environment, Great Lakes, and Energy (2020-2021)

$ 500 Paradise Lake Water Quality Follow Up Study, 2012 – Contract from the Paradise Lake Association through the LSSU Environmental Analysis Lab.

$ 8,000 Judy Westrick, Derek Wright 2010-2012. LSSU Sub-Award #RC065511LSSU from "Integrated Beach Sanitary Surveys Using qPCR tools". PI Dr. Joan Rose, Michigan State University. **EPA 2010-7205**.

$ 15,000 Munuscong River Watershed Study, 2010-2011 – Subcontract from the Chippewa East Mackinac Conservation District through the LSSU Environmental Analysis Lab.

$ 4,100 Paradise Lake Water Quality Study, 2010 – Contract from the Paradise Lake Association through the LSSU Environmental Analysis Lab.

$ 45,000 Judy Westrick, Derek Wright, Geoffrey Steinhart, Nancy Kirkpatrick. 2009. Acquisition of a Thermal Cycler and qPCR Instrument to Incorporate Molecular Biochemistry into Undergraduate Research and Education – NSF-MRI -0959425 (2009-2012)

I have also supervised two undergraduate students (Jordan Ernst and Gina Fitzgerald) who's projects received **$500** each from the LSSU Undergraduate Research Grants

Publications

Derek D. Wright, Hannah, Clause, Benjamin Southwell, and Mark Zierden The elemental composition of hemp flower: sources of elemental impurities and implications for consumer product safety. Invited manuscript for submission to *The Journal of Testing and Evaluation,* Special Issue on Contaminants in the Cannabis and Hemp Industry and Their Impact on Consumer Safety.

Hari Kandel, **Derek Wright**, Jonathan Doubek, and Benjamin Southwell. Uranium Geochemistry in Drinking Water Wells in Sugar Island, Michigan. In Preparation for submission to *Geochemistry*.

Derek Wright, Michelle M. Jarvie, Benjamin Southwell, Carmen Kincaid, Judy Westrick, S. Sameera Perera, David Edwards, and Robert B. Cody. The Elemental Composition of Commercially Available Cannabis Rolling Papers. Submitted to *ACS Omega*.

Michelle M. Jarvie, Moriah Reed, Benjamin Southwell, **Derek Wright** and Thu Nguyen. 2023. Monitoring of COVID-19 in wastewater across the Eastern Upper Peninsula of Michigan. Submitted to *Environmental Advances*.

Hank Bonnah, Chris Gioia, Sean Burnetter, Garrett Harris, Steven Johnson, **Derek Wright**, and Benjamin Southwell. 2023. Tracing Water Consumption for Guaranteed Cannabis Growth Outcomes: Shift to RDWC provides plants with precision feeds and minimal waste.

Wright, Derek D. 2022. Trace Metals & Contamination: How Did it Get There? Article in Virtual Symposium Recap: Grow Your Skills in the Budding Cannabis Industry. e-book, published by Cannabis Science and Technology and LC-GC.

Keller, B.J., Back R.C., Westrick, J., Werner, M., Evans, B., Moerke, A., Zimmerman, G., **Wright, D.**, Grenfell, E., Courneya, J. 2011. Sediment Quality at Select Sites in the St. Marys River Area of Concern. Journal of Great Lakes Research DOI: 10.1016/j.jglr.2011.02.003.

Derek D. Wright. 2011. Water Quality Study of Paradise Lake Michigan, Summer 2010 - Final Report. Paradise Lake Association. Carp Lake, MI.

Derek D. Wright, Thomas K. Frazer, John R. Reinfelder. 2010. The influence of river plume dynamics on trace metal accumulation in calanoid copepods. Limnology and Oceanography, 55(6): 2487-2502.

Medina M., A. Chatziefthimiou, N.S. Bloom, G.W. Luther III, **D.D. Wright**, J.R. Reinfelder, C. Vetriani, and T. Barkay. 2009. Interactions of chemosynthetic bacteria with mercury at deep-sea hydrothermal vents. Limnology and Oceanography, 54(1): 41–49

Wright, Derek D. 2008. THE TRANSPORT, TRANSFORMATION, AND TROPHIC TRANSFER OF BIOACTIVE METALS IN AN URBAN IMPACTED BUOYANT RIVER PLUME. A dissertation submitted to the Graduate School-New Brunswick Rutgers, The State University of New Jersey

Posters and Presentations

Applications of Laser Direct Infrared (LDIR) Spectroscopy in Mineralogy: A Comparative Study to Conventional Methods. Submitted to the American Geophysical Union Fall Meeting. Hayley L Beaudoin, Nicholas J Gordon, Hari P Kandel, Paul Kelso, and **Derek D Wright**. Dec. 2023.

Effects of fireworks displays on air quality and metal deposition fluxes. Submitted to the American Geophysical Union Fall Meeting. Kyra Kelley, Hari Kandel, and **Derek D. Wright**. Dec. 2023

The Elemental Composition of Hemp Flower: Sources of Elemental Impurities and Implications for Consumer Product Safety. **Derek D. Wright**, Hannah, Clause, Benjamin Southwell, and Mark Zierden. SYMPOSIUM ON CONTAMINANTS IN THE CANNABIS AND HEMP INDUSTRY AND THEIR IMPACT ON CONSUMER SAFETY, Sponsored by ASTM Committee D37 on Cannabis. Oct 2023

Detecting Microplastics in Cannabis: Analysis Using LDIR Spectroscopy. B. Southwell and **D. Wright**. Labrulez sponsored by Agilent Technologies. Aug 2023.

Monitoring of COVID-19 in wastewater across the Eastern Upper Peninsula of Michigan. Michelle M. Jarvie, Moriah Reed, Benjamin Southwell, **Derek Wright**, Thu N.T. Nguyen. Go with the Flow Conference, May 17-18, 2023

Accumulation of Metal Ions in Closed Loop Aquaponics. B. Evans, **D. Wright**, B. Southwell, and E. Hebert. World Aquaculture Society meeting, Feb. 2023

Uranium in Groundwater Wells in Sugar Island, Michigan: A Public Health Concern. American Geophysical Union Fall Meeting. Hari P Kandel, **Derek D Wright**, Jonathan Doubek and Benjamin Southwell. Dec. 2022.

Factors influencing Beach Water Quality in Chippewa County Michigan Inland Lakes. Great Lakes Beaches Association. C. Maas, **D. Wright**, and B Southwell. November 2022.

Factors influencing Beach Water Quality in Chippewa County Michigan Inland Lakes. Great Lakes Beaches Association. C. Maas, D. Wright, and B Southwell. November 2022

Bioaccumulation and Bioregulation of Trace Elements within Freshwater Sponges, 11th International Sponge Symposium – World Sponge Conference. Mallory McNulty, Roger Willford, Benjamin Southwell, **Derek Wright**, & Stephen Kolomyjec October 2022

Summer Science Series, "Keeping it Clean: Contamination Control in the Cannabis Industry", Southwell, B. and **Wright, D.**, Cannabis Science and Technology, 8/16/2022

Summer Science Series, "Recruiting Lab Staff that will Grow your Business", Southwell, B. and **Wright, D.**, Cannabis Science and Technology, 6/7/2022

"Trace metals and Contamination" at Grow your skills in the budding Cannabis industry – Cannabis Science and Technology, **Wright, D.**, – Invited Speaker, 3/10/2022

Lambert, K., A Scarton, **D. Wright**, and S Johnson. Analysis of gunshot residue by thin film hydride generation microwave plasma atomic emission spectroscopy. American Chemical Society National Meeting 2017

D. Wright. Mercury Pollution in the Great Lakes: Will new EPA rules make the fish safe to eat? Michigan Political Science Association annual conference (Oct 2012)

D. Wright. Climate change and its impacts in the Great Lakes region. Three Lakes Chapter, Sierra Club. (Oct 2012)

Murray, E, J. Westrick, **D. Wright**, and B. Ockenfels. Blystomyces dermatitidis: a Digging Man's Disease. (Oral Presnetation) American Water Works Association – Michigan Chapter Annual Conference. 2012

McPhail, B., J. Westrick, B. Southwell, and **D. Wright**. (Oral Presentation). Stakeholders Concern of Using 2, 4, D Treatment to Reduce Eurasian Milfoil. American Water Works Association – Michigan Chapter Annual Conference. 2011

Westrick, J., **D Wright,** B. Southwell, and R. Cunningham. (Invited Oral Presentation). *Blastomyces dermatitidis* in the Les Cheneaux region of Northern Michigan. Clark Township Hall, 2011.

Wright, D. (Invited Presentation). Mercury in the Great Lakes. Sault Area High School, 2011.

Wright, D., J Westrick, B. Southwell, and R. Cunningham. (Invited Oral Presentation). *Blastomyces dermatitidis* : A Drummond Island Case Study – Reearch Update. Drummond Island Public Meeting, 2010.

Westrick, J., **D Wright,** B. Southwell, and R. Cunningham. (Invited Oral Presentation). *Blastomyces dermatitidis* : A Drummond Island Case Study. Drummond Island Public Meeting, 2009.

Wright D.D.,T.K. Frazer, M. Moline, O. Schofield, and J.R. Reinfelder. (Oral Presentation, Presenter). Trophic transfer of trace metals in a buoyant river plume. Ocean Sciences Meeting, 2008.

Reinfelder J., **D. Wright**, T. Frazer, M.A. Moline, and O. Schofield. (Oral Presentation, Coauthor). Trace Metal Accumulation in Zooplankton of the Hudson River Buoyant Plume. ASLO Winter Meeting, 2007.

Wright D.D., T.K. Frazer, S.R. Keller, F. Reig, and J.R. Reinfelder. (Poster, Presenter). Trace Metals in Zooplankton from the Hudson River Plume. CEBIC Summer Workshop, 2007.

Reinfelder J., **D.D. Wright**, and L. Smith. (Oral Presentation, Coauthor) Production, oxidation, and volatilization of dissolved gaseous mercury in the Hudson River buoyant plume. Ocean Sciences Meeting, 2006.

Wright D.D., D.J. Loeffler , and J.R. Reinfelder. (Poster, Presenter) The distribution and speciation of trace metals in the Hudson River plume. Ocean Sciences Meeting, 2006.

Wright D.D., and J.R. Reinfelder. (Poster, Presenter). Biogeochemical cycling of mercury in the Hudson River plume. Eight International Conference on Mercury as a Global Pollutant, August 2006.

Chen R.F., G.B. Gardner, X.C . Wang, S.M. Rudnick, Z. Wang, L. Litz, D. Cobb, H. Saffert, **D. Wright**, R. Sherrell. (Oral Presentation, Coauthor) The schmutz of New York. ASLO Aquatic Sciences Meeting, 2005.

Gardner B., R.F. Chen, and **D. Wright**. (Oral Presentation, Coauthor) Transport and fate of hydrocarbons in the low salinity region of the Hudson River estuary. ASLO Aquatic Sciences Meeting, 2005.

Reinfelder J.R., and **D. Wright**. (Oral Presentation, Coauthor) Speciation and transport of mercury and other trace metals in the Hudson River buoyant plume. Estuarine Research Federation meeting, 2005.

J R Reinfelder, **D Wright**, R Chant, S Glenn, O Schofield, J Wilkin, R W Houghton, R F Chen, M Moline and T K Frazer. (Oral Presentation, Presenter) Trace Metals and Nutrients in the Hudson River Buoyant Plume. AGU Fall Meeting, 2004

Analytical Expertise

- **Atomic Spectroscopy & Elemental Analysis:** ICP-MS (quadrupole & magnetic sector field), ICP-OES, MP-AES, FAAS, ETV-AAS, CV-AFS, CV-AAS, ASV, IC, hydride generation techniques, ISE

- **Molecular Spectroscopy:** UV-Vis, FTIR, Fluorescence Spectroscopy

- **Microscopy, Microanalysis, & Chemical Imaging:** SEM-EDS, light microscopy (brightfield, darkfield, phase contrast, Nomarski DIC, polarized light, Epi-fluorescence), IR Chemical Imaging, μXRF

- **Additional Techniques –** I have a working knowledge of and/or received instrument training on the following: HPLC, LC-MS/MS, LC-TOF-MS, GC-MS, GC-MS/MS, qPCR/ddPCR, ad-CSV

University Service

- University Curriculum Committee (2021-current)
- University General Education committee (2009-2015)
  - Chair (2013-2015)
  - Chair, Senior Assessment Testing subcommittee (2011)
  - Member, Communications subcommittee (2009-2011)
  - Member, Natural Sciences subcommittee (2012-2013)
  - Chair, Mathematics & Course Evaluation subcommittees
- University Late Withdrawal Committee (2021-2023)
- Human Studies Institutional Review Board (2009 – 2013)
- Co-author HLC Accreditation Assurance Argument, 2016
- Faculty advisor of the Chemistry and Environmental Sciences Living Learning Community and Student Organization (2009-2020)
- Proctor for the University Gen Ed assessment exams (2009-2015)
- LSSU Planning Committee for MindTrekkers Science Expo at LSSU w/Michigan Technological University (~1500 elementary/secondary students from Michigan and Ontario attended in May 2011 and May 2012).
- Faculty Instructor and planning committee member for the LSSU Tall Ships Program w/ the Inland Seas Education Association.
- 16 search committees for faculty and university staff

Community Service & K-12 Outreach

- Microplastics in the Great Lakes, outreach project with Inland Seas Education Association analyzing microplastics collected on K-12 educational cruises (ongoing)
- Instructor and co-coordinator, ISD Workshop Series at LSSU (numerous, including four events in the past 12 months)
- ISD Externship host (2 teachers, summer 2021)
- EUP Regional Science Fair planning committee and judge - 2020
- Sault Ships and Sailibration planning committee (2011-2012)
- Served as a science fair judge at St. Mary's School (2009-2012)
- Served as an Ask a Scientist panelist at the EUP Regional Science Fair (2009)
- Served as a Judge at the EUP Regional Science Fair (2010-2011)
- Presented 3-day teacher education workshops at the Eastern Upper Peninsula Intermediate School District (2010 w/Dave Myton, and 2011)