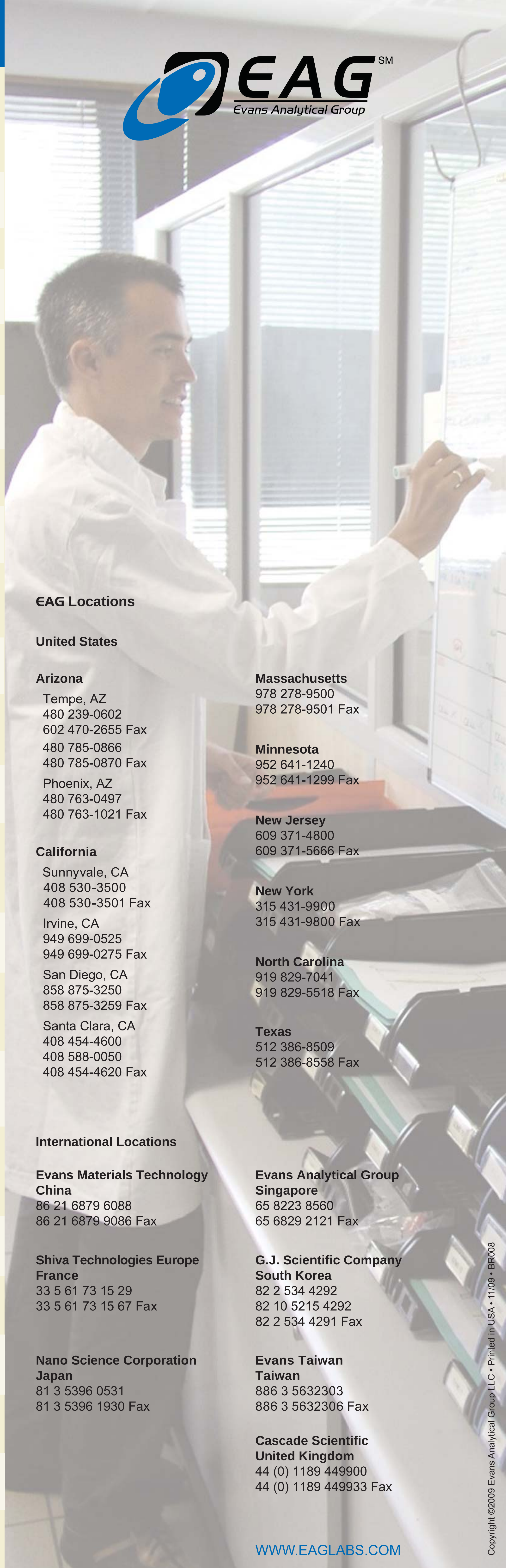
ANALYTICAL TECHNIQUE	TYPICAL APPLICATIONS	SIGNAL DETECTED	ELEMENTS DETECTED	DETECTION LIMITS	DEPTH RESOLUTION	IMAGING/ MAPPING	LATERAL RESOLUTION/ PROBE SIZE
Accelerator Techniques Rutherford Backscattering Spectrometry Particle Induced X-ray Emission Nuclear Reaction Analysis Hydrogen Forward Scattering Spectrometry Channeling	Thin film composition/thickness Quantitative dose measurement Quantitation without standards Hydrogen in thin films Defects and lattice locations	Backscattered He atoms Emitted X-rays Nuclear reaction products Forward scattered H atoms Emitted X-rays	B - U S - U light elements (Li - F) ^{1}H, ^{2}H Li - U	RBS 0.001 – 10 at% Z dependent NRA > 1 x 10^{14} at/cm^{2} 0.1 at% 0.001 – 2 at%	5 – 20 nm (±1 nm precision) – – ~30 nm ~5 – 20 nm (±1 nm precision)	No No No	≥1 mm ≥1 mm x 5 mm ≥1 mm
Auger (with Zalar Rotation) Auger Electron Spectroscopy	Surface, particle, defect analysis, and large and small area depth profiling	Auger electrons from near-surface atoms	Li - U	0.1 – 1 at% submonolayer	2 – 20 nm (Depth profiling) 3 nm (Surface analysis)	Yes	≥0.2 µm (LaB_6 Source) ≥10 nm (Field Emission)
FIB/SEM Dual Beam and Single Beam	Cross section preparation, imaging	Ejected electrons	n/a	n/a	n/a	Yes	1 nm
FTIR Fourier Transform Infrared Spectroscopy	Identification of polymers and organics; contamination identification, particles	Infrared photons	Molecular functional groups	0.1 – 1 wt%	0.1 – 2.5 µm	No	≥15 µm
GC/MS Gas Chromatography/Mass Spectrometry	Identification and quantification of volatile organic compounds in mixtures, outgassing, residual solvents, liquid or gas injections	Molecular ions/characteristic fragment ions	Molecular ions up to mass 800	400 ng (full scan) 10 ng (outgassing)	–	–	–
HR-GDMS High Resolution Glow Discharge Mass Spectrometry	Bulk trace and ultra-trace elemental survey analysis, depth profiling	Ions	Li - U	10 ppt wt - 100%	0.5 - 50 µm	No	5 - 15 mm
ICP-OES Inductively Coupled Plasma Optical Emission Spectrometry	Bulk composition analysis	Emitted Photons	Li - U	1 ppm wt - 100%	n/a	n/a	n/a
IGA Instrumental Gas Analysis *(Combustion and fusion gas analysis)*	Bulk analysis of H, C, N, O and S, fractional gas analysis	Infrared absorption (for C, O, S), thermal conductivity (N and H)	H, C, N, O, S	0.1 ppm - 50%	n/a	n/a	n/a
LA-ICPMS and ICPMS Laser Ablation Inductively Coupled Plasma Mass Spectrometry	Bulk composition, trace and ultra-trace elemental analysis, impurity distribution mapping, depth profiling	Ions	Li - U	10 ppb wt - 100%	5 - 100 µm	Yes	5 µm
LEXES Low Energy X-ray Emission Spectrometry	Dosimetry/mapping of ion implants. Thin film characterization	Characteristic X-rays	B - U	5x10^{13} at/cm^{2}	0.5 nm	Yes	30 µm
Raman Raman Spectroscopy	Identification of organics and inorganics; particle identification, Si stress, carbon identification	Raman scattered photons	Chemical and molecular information	≥1 wt%	confocal mode 1 – 5 µm in	Yes	≥1 µm
SEM (with EDS) Scanning Electron Microscopy Energy Dispersive X-ray Spectroscopy	Imaging, elemental identification	Secondary electrons, backscattered electrons, X-rays	B - U	0.1 %	0.3 – 5 µm (EDS)	Yes	1 nm imaging 0.5 µm EDS
SIMS Secondary Ion Mass Spectrometry	Dopant and impurity depth profiling, surface, bulk and microanalysis, insulating films, ultra low energy/ultra shallow depth profiles	Secondary ions	H - U	10^{12} – 10^{16} at/cm^{3}	2 – 30 nm	Yes	≥20 µm (Depth profiling) 1 - 5 µm (Imaging mode)
SPM/AFM Atomic Force Microscopy Scanning Probe Microscopy	3 dimensional imaging of surfaces, magnetic field, grain size, capacitance	Topography	–	–	0.01 nm	Yes	1.5 – 5 nm
STEM (with EDS and EELS) Scanning Transmission Electron Microscopy Energy Dispersive X-ray Spectroscopy Electron Energy Loss Spectroscopy	Imaging, Z-contrast, elemental mapping elemental identification, EELS line scans, lattice imaging, BF, DF	Transmitted electrons, secondary electrons, X-rays	B - U	1 %	Prepare samples 30 - 2000 nm	Yes	0.25 nm
TEM (with EDS and EELS) Transmission Electron Microscopy Energy Dispersive X-ray Spectroscopy Electron Energy Loss Spectroscopy	Imaging, elemental identification, crystallographic information, lattice imaging	Transmitted electrons, X-rays, diffraction patterns	B - U	0.5 %	Prepare samples 30 - 100 nm	Yes	0.19 nm
TGA/DTA Thermogravimetric Analysis Differential Thermal Analysis	Thermal stability and composition of organic/ inorganic composite materials; glass transition, crystallization, melting, clustering, curing, chemisorption, and etc.	Mass and temperature change	Bulk composition/phase transition (morphology)	0.01 – 200 °C/min; 20 - 1100 °C; ±0.1 mg – ±200 mg; ±2.5 µV – ±2500 µV	n/a	n/a	n/a
TOF-SIMS Time-Of-Flight Secondary Ion Mass Spectrometry	Surface microanalysis of organic and inorganic materials, chemical mapping	Secondary ions of atoms and molecules	H - U Molecular species	10^{7} – 10^{10} at/cm^{2} submonolayer	1 – 3 monolayers (Static mode)	Yes	≥0.20 µm
TXRF Total Reflection X-ray Fluorescence	Metallic surface contamination on semiconductor wafers, non-destructive	Fluorescent X-rays from wafer surface	S - U	10^{9} – 10^{12} at/cm^{2}	3 – 8 nm (Sampling depth)	Yes	~10 mm
XPS/ESCA (with Zalar Rotation) X-ray Photoelectron Spectroscopy Electron Spectroscopy for Chemical Analysis	Surface analysis of organic and inorganic materials, depth profiling	Photoelectrons from near-surface atoms	Li - U Chemical bonding	0.01 – 1 at% submonolayer	2 – 20 nm (Depth profiling) 1 – 10 nm (Surface analysis)	Yes	10 µm – 2 mm
XRD X-ray Diffraction	Identification of crystal phases, crystal orientation and crystal quality	Diffracted X-rays	H - U	1 at%	5 - 20 µm	No	50 µm
XRF X-ray Fluorescence	Composition and impurities in thick films and bulk materials, wafer mapping	Fluorescent X-rays	Na - U	10 ppm	5 - 20 µm	Yes	100 µm
XRR X-ray Reflectivity	Determination of film density and thickness	Reflected X-rays	n/a	n/a	0.1 nm	Yes, with XRF	5 mm



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Accelerator Techniques

RBS/HFS/NRA/PIXE — National Electrostatics Corp (NEC) and General Ionex Accelerators

Rutherford Backscattering Spectrometry (RBS) is a non-destructive technique that can quantitatively measure thickness / composition of thin films on samples up to about 2 µm in depth. Typical materials analyzed with RBS include dielectric, interconnect, and barrier films in semiconductor devices, high temperature superconductors (HTSC), optical/glass coatings, and magnetic media.

Related techniques include:

- Channeling is used to measure the crystallographic quality of a sample with respect to depth. Applications include profiling crystal quality after ion implant, anneal or crystal growth.
- Hydrogen Forward Scattering (HFS) is a non-destructive technique used to quantitatively measure H in thin films. It is often used to measure the amount of H in CVD oxide and nitride films, and the amorphous carbon layer of hard disk media.
- Nuclear Reaction Analysis (NRA) is used to measure low-Z elements (such as carbon, nitrogen, oxygen, and boron) in thin films. These elements can be measured at a much lower concentration with NRA than with standard RBS.
- Particle Induced X-ray Emission (PIXE) is usually performed simultaneously with RBS. It can be used to distinguish between two elements that are close in mass, and therefore emit a single signal using traditional RBS.

AES — Eight PHI Auger Systems, including 660; 670; 680; SMART 200 & SMART Tool

The field emission Auger Electron Spectroscopy systems feature a thermal field emitter for exceptional spatial resolution down to less than 10 nm. The primary applications for Auger are for the elemental analysis of micrometer and sub-micrometer size features (i.e., particles, defects, residues). The SMART-200 and SMART-Tool are defect review tools used for defect and particle analysis on whole wafers (200 mm and 300 mm, respectively) and photomasks. Both instruments can read defect maps from optical defect detection systems, and are equipped with a focused ion beam (FIB) gun that can be used to cross section defects or to expose buried defects. The SMART-Tool also has an EDS. Applications of Auger include:

- Particles and small area analysis (down to 25nm)
- Films too thin for EDS (sub-monolayer detection)
- Thin film compositional depth profiling

Several of the Auger systems have been modified for improved performance:

- Zalar™ rotation – improves depth resolution during depth profiling
- Fracture attachment – for generating in-situ fractures of metallurgical specimens

FIB & FIB/SEM — Three FEI Single Beams, Six FEI Dual Beams

Single Beam FIB (Focused Ion Beam) instruments provide excellent sample preparation, and imaging capabilities and sample throughput using a single ion beam. They can be used productively in conjunction with separate SEM instrumentation for electron beam imaging. Dual Beams instruments integrate the imaging capability of a field emission SEM and the sample preparation capabilities of a Single Beam. The ability to produce very precise cross sections coupled with in situ SEM imaging capabilities permits the characterization of samples that would otherwise require two instruments.

Examples of applications include: observation and elemental identification of particles under thin film stacks, film thickness measurements, STEM, TEM and Auger sample preparation, characterization of thin film conformality and other applications where site-specific cross sections are needed. In additional, we have several single beam FIB tools dedicated to circuit edit use.

FTIR — Three Nicolet 500 Series with Microscope attachments

In Fourier Transform Infrared Spectroscopy, an infrared beam interacts with a sample, causing vibrations of IR-active chemical bonds. Changes in the intensity of the infrared beam can be used to identify the types of bonds and often the specific compounds present. Our FTIRs can analyze areas as small as 15 µm. They are capable of analyzing samples in transmission, reflectance, and attenuated total reflectance modes. The instruments are used for bulk and surface identification of organic materials, including fibers, thin films, particles, and liquids. An extensive library of reference spectra makes the technique particularly useful for identifying organic and some inorganic materials.

GC/MS — Two, HP 5973 and HP5975C, both with thermal desorption

Gas Chromatography/Mass Spectrometry is the industry standard technique for identifying and quantifying trace organic compounds in mixtures. GC/MS combines gas chromatography, which separates various components in a mixture according to their relative affinity for the column coating, and mass spectrometry, which obtains mass spectra of components as they exit the GC. Outgassing analyses are routinely performed using thermal desorption. This can be done in both purge-and-trap (dynamic) and headspace (static) modes.

HR-GDMS — Thirteen, including VG9000 and Element GD

High-Resolution Glow-Discharge Mass Spectrometry offers direct trace and ultra-trace element analysis of inorganic solids. GDMS measures ion currents that are produced via cathodic sputtering of the sample surface in an argon plasma (direct atomization and ionization are achieved). The GD ion source exhibits relatively uniform elemental response and is capable of measuring from Li to U. These ion currents are converted into element concentration with the use of relative sensitivity factors (RSFs.)

Ceramics, oxides, and other insulating materials can also be analyzed with the use of an electrically conductive supporting electrode or binder material.

Although GDMS is primarily a bulk analytical technique, it has the capability to characterize the composition of outer (microns thick) layers like scales, coatings, and thick films, as well as provide depth profiles with high sensitivity. The ease of operation, high sensitivity to all elements, reproducibility of analysis, and span of application make HR-GDMS a versatile and powerful bulk analytical technique.

ICP-OES — Two Perkin Elmer Optima Systems, Perkin Elmer ELAN DRC II

Inductively Coupled Plasma - Optical Emission Spectrometry is a mature technique with well known advantages such as multi-element measurement capability, high dynamic linear range, and limits of detection below 1 ng/mL. Traditional ICP-OES accuracy is +/- 5% to 10% relative, but with close control of the analytical parameters, it is possible to provide ICP-OES measurements with concentration uncertainties on the order of 0.1% relative. This High Performance protocol (HP ICP-OES) was developed by NIST and is used in our laboratory. The high performance method is more accurate than almost any other instrumental technique, with accuracy nearly comparable to gravimetric techniques.

IGA — Three Jobin Horiba Systems

In Instrumental Gas Analysis performed using Horiba-JY EMIA and EMGA series instruments, specific elements are measured in the gas phase. Carbon and sulfur mass fractions are evaluated based on combustion and infrared technology. Nitrogen, Oxygen and Hydrogen mass fractions in solids are evaluated using principles of inert gas fusion or solid extraction, in combination with infrared or thermal conductivity detectors.

With the improved control of the extraction furnace in the Horiba JY instruments, it is possible to precisely ramp the furnaces, which allows for determination of different species that are released at different temperatures. The instruments provide a high precision analysis which suits a broad range of user needs and provides real-time monitoring of sample heating and gas extraction.

ICPMS & LA-ICPMS — Varian 820MS ICP-MS, New Wave UP-213 Laser ablation system

Laser Ablation Inductively Coupled Plasma - Mass Spectrometry is a micro analytical technique for the determination of major and trace elements (wt%-µg/g) in solid materials. A pulsed laser beam is used to sample a small quantity of material by ablation, and the sampled material is transported into an argon plasma (ICP) for ionization. Approximately 70 elements can be detected at concentration levels ranging from sub-µg/g to wt%-level in one analysis. LA-ICP-MS is well suited for the elemental analysis of totally unknown samples, even if very little material is present.

Solutions can also be analyzed by the ICP-MS, whereby material is dissolved into an aqueous solution, aspirated into the argon plasma and analyzed. Solution mode analyses offer great accuracy and sensitivity in the same analysis.

LEXES — Cameca Shallow Probe

Low Energy X-ray Emission Spectrometry is a non-destructive technique that can quantify the dose of dopants in the upper 500nm of samples. LEXES can also measure the composition of thin films as well as measure impurities in thin films. Small samples, as well as full wafers up to 300mm in size, can be analyzed and mapped. Samples are bombarded with low energy electrons from 0.5keV to 10keV which produce characteristic X-rays. These X-rays are analyzed using high resolution crystal spectrometers which allow the X-ray peak of interest to be resolved from interference peaks from other elements.

Raman — JY Horiba LabRam

Raman Spectroscopy measures the intensity of light scattered by a sample as a function of wavelength. An incident laser causes chemical bonds in the sample to gain or lose characteristic amounts of energy corresponding to different vibrational modes in the bonds. With our microscope attachment, we can analyze areas as small as 1 µm. We use Raman to determine the structural properties of inorganic and organic materials, particularly carbon, crystalline materials, polymers, and biomolecules, and to determine stress in semiconductors. We can also map surfaces and depth profile for molecular species.

SEM/EDS — Ten, including Hitachi 4800, 4700, various JEOL systems

In Scanning Electron Microscopy, a finely focused electron beam is rastered over a sample surface. An image is formed from the signals produced (e.g., secondary electrons and photon emission). Combined with Energy Dispersive Spectroscopy, elemental quantification is possible. Our SEMs have some of the best capabilities in the industry, including spot sizes as small as 1 nm and electron impact energies as low as 500 eV. We have 200mm capable SEMs, as well as tools with active voltage contrast.

These tools' capabilities, coupled with our extensive sample preparation experience, allow for the analysis of a wide range of samples, including integrated circuits, flat panel displays, biomedical implants, nanomaterials, powders, and all types of mechanical and electrical parts and products. Many of our SEMs are equipped with EDS to allow elemental identification and mapping.

SIMS — Twenty-six Cameca systems IMS 6f, 5f, 4f and 3f; Eighteen PHI Model systems 6300; 6600; 6650; PHI ADEPT-1010; Atomika 4100; 4500

Secondary Ion Mass Spectrometry has excellent detection sensitivity and depth resolution to provide quantitative trace level profiling in an extensive array of solid materials. Typical applications include:

- Depth profiling of impurities and dopants in Si
- Dopants and impurities (including H, C, N, O) in thin films, dielectrics, barrier metals, Si, SiC,SiGe, III-V, III-N and II-VI materials.
- PCOR SIMS™ for low energy ion implant characterization
- Surface impurities by SurfaceSIMS™ analysis
- High Precision Implant Characterization (HPIC SIMS™)
- Small area analysis of devices and patterned wafers
- Alkali and metal contamination in multilayer passivation structures
- B, C, N and O bulk analysis in Si
- SiON, FuSi, HfO_x
- DLC Hard Disk overcoats

The breadth of SIMS instruments in our labs gives us high capacity and allows us to configure instruments for particular analyses to dramatically improve analytical capabilities. Our latest SIMS instrumentation incorporates low energy ion bombardment and improved vacuum systems to meet the needs of ever decreasing device geometries.

SPM/AFM — Three Digital Instrument Systems

In Atomic Force Microscopy/Scanning Probe Microscopy, an analytical tip, typically located within a few angstroms of the surface, is rastered over a sample surface. Using appropriate tip designs, the surface morphology and physical properties can be measured. AFM is used to quantitatively measure surface roughness with nominal 1.5–5 nm lateral and 0.1 Å vertical resolution on all types of samples.

Typical applications include measuring the surface roughness of semiconductor wafers, optical components, and hard disks. We have a wide assortment of measuring heads to perform AFM/STM (ambient), magnetic capacitance, and tapping mode SPM analyses. One AFM can accept full 200 mm (8 inch) wafers.

TEM/STEM — Nine, including (With EDS) TOPCON, JEOL 2010, Hitachi HD 2000 & 2300, Hitachi HF 2000, Tecnai F20 w/ EELS

Transmission Electron Microscopes and Scanning Transmission Electron Microscopes provide the ultimate in image resolution. Point to point resolutions can be better than 2Å, and lattice images are routinely obtained for crystalline solids.

Both techniques use a high energy (~200 keV) electron beam to image a sample. Typically transmitted electrons are detected, either in bright field, dark field or diffraction mode. In addition, the auxiliary EDS detects x-rays for elemental identification and mapping. EELS is used for elemental ID with 1nm resolution. Information obtained includes images of ultra fine features, quantitative measurements on the single nanometer scale, crystallographic information, atomic number contrast imaging, elemental identification and maps.

Many types of samples are characterized including: semiconductor thin film stacks, interfacial layers, nanoparticles, nanotubes, alloys & metals. Applications include determining gate oxide thickness, investigating crystallographic phases and materials separation, characterizing crystallographic defects, identifying particles, and evaluating contamination and adhesion issues.

TGA/DTA — Model TG/DTA 220 with SSC/5200 Station (SEIKO Instrument, Inc.)

TG is a destructive thermal analysis technique which measures mass changes in a material as a function of temperature (or time) under a controlled surrounding atmosphere (inert/reactive gas, or vacuum). DTA and DSC are calorimetric techniques recording temperatures and heat flows associated with thermal transitions in a material. Typical applications include:

- Thermal degradation and compositional analysis of organic/inorganic, polymeric and composite materials
- Phase transitions (glass transition, clustering, crystallization and melting)
- Reaction kinetics (curing, chemisorption, and etc.)

TOF-SIMS — Five PHI TRIFT™ systems

Time-of-flight Secondary Ion Mass Spectrometry offers high mass resolution and mass accuracy for identification of organic compounds and high sensitivity analysis of inorganic elemental contamination on surfaces. TOF-SIMS can analyze over a mass range of one to several thousand daltons and provides information about the lateral distribution of chemical species with an optimum spatial resolution of ~200 nm. Applications include:

- Surface characterization of organic and elemental materials
- Mapping lateral distributions of surface species
- Low level elemental and molecular contaminant identification
- Failure analysis – adhesion, bond pads, coatings
- Identification of stains, discolorations, and hazes

Select instruments have been optimized for specific types of analyses:

- Large sample stage – accepts full 200mm wafers
- Liquid nitrogen cold stage – permits analysis of semi-volatile organic compounds
- Depth profiling ion sources - used for small area depth profiling

TXRF — Four Technos systems

As a survey technique, Total Reflection X-Ray Fluorescence provides high sensitivity, multi-element, non-destructive surface contamination measurements on whole wafers in a cleanroom environment. TXRF is used primarily for surface contamination on semiconductor wafers and other optically flat samples. The TREX 610T and 630T are advanced instruments from Technos featuring both W and Mo anodes to cover a wider element range (S to U), with excellent detection limits.

Detection limits for these instruments have been improved to 3×10^9 atoms/cm^2 for Fe, for example. The TREX 630T accommodates 200 and 300 mm wafers. The TREX 610T accommodates 100, 125, 150 or 200 mm wafers, but can also analyze other smaller pieces of optically flat materials.

XPS/ESCA — Twelve Instruments, including Quantera/Quantum 2000 & PHI 5000 series

X-ray Photoelectron Spectroscopy, also known as Electron Spectroscopy for Chemical Analysis (XPS/ESCA), is a versatile technique capable of providing quantitative elemental and chemical state analysis on virtually any vacuum compatible surface. The Quantera and Quantum 2000 instruments offer practical analysis on features as small as 30 µm, making them useful for a range of applications such as bond pad analysis. Other applications include:

- Identification of stains and discolorations
- Compositional analysis of powders and debris
- Characterization of cleaning processes
- Determination of oxidation state and oxide thickness
- Analysis of carbon functionality of polymers
- Characterization of surface functionalization
- Depth profiling of thin films for matrix level constituents

Several of our systems have been modified for specific applications:

- Advanced charge compensation system – aids in the analysis of insulating materials
- Large sample stage – accepts full 200mm wafers
- Hot/cold stage – for studies at elevated temperatures or to analyze semi-volatile species.
- Zalar™ rotation – improves depth resolution during depth profiling

XRD — Three including Bruker, Rigaku, Panalytical

X-ray Diffraction is a non-destructive technique that can identify crystalline phases, determine crystallite size and percent crystallinity, and measure the texture and stress of bulk materials and thin films. High energy X-rays are diffracted by the crystalline structure present in the sample, and the position, intensity and shape of the diffracted peaks are analyzed to determine properties such as phase, orientation and size. These material properties can typically be measured without the need for reference standards.

XRF — Two including Technos and Kevex

X-ray Fluorescence is a non-destructive technique that can identify and quantify elemental constituents of solids, liquids and thin films. XRF is sensitive to elements with atomic numbers from Na to U and concentrations from tens of ppm to 100%. With appropriate reference standards, accurate quantifications of the elemental composition of both solids and liquids can be performed. Mapping of full wafers up to 300mm in size can also be performed.

XRR — Three including Technos, Rigaku, Panalytical

X-ray Reflectivity is a non-destructive technique that can quantitatively determine the thickness, density and roughness of thin films up to 5,000Å thickness, without the need for calibrations standards. Small wafer pieces, as well as full wafers up to 300mm, can be analyzed. Using low incident angles, X-rays are reflected off the various layers in the film stack. X-rays reflected from layers with varying densities, as well as from interfaces between films and/or the substrate, generate an interference pattern that allows exact determination of the layer thicknesses. Measurement of the critical angle where total reflection of the X-rays occurs allows for determination of the material density.

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