Delta-X™

Versatile X-Ray Diffractometer and Reflectometer

X-Ray Metrology For Your Research and Development Needs
**Introduction**

Jordan Valley’s Delta-X is the latest generation of flexible X-ray diffraction instruments for materials research, process development, and quality control. Featuring fully automated source and detector optics with a horizontal sample mounting, the system can switch between standard and high resolution X-ray diffraction, and X-ray reflectivity modes under full computer/recipe control without the need to manually change configurations. This ensures the optimum tool configuration is used every time, without requiring experts to set-up the tool for use.

Measurements can be run partially or fully automated, with user-customizable scripts handling the routine work. It is also possible to run the tool in a completely manual mode, to enable the development of new methods or to investigate new materials.

Analysis of the data can be fully automated as part of the measurement routine, or analyzed off-line if required. Using RADS and REFS in automated mode, developed for semiconductor manufacturing lines, allows routine analysis to be performed and reported without any user intervention. RADS and REFS can also be installed off-line to allow more detailed analysis.

**Delta-X meets the needs of research and development institutes for a wide range of materials**

**Delta-X Features and Benefits**

- Automated alignment, measurement and analysis of samples
- Degree of automation of measurement is defined by user
- High precision sample positioning and scanning with 300mm Eulerian cradle
- Full 300mm wafer horizontal mounting and mapping
- Pole figures and residual stress measurements possible due to 100° tilt (Chi) and unlimited azimuthal rotation (Phi)
- Intelligent automatic tool alignment and re-configuration based on the measurement requested
- Industry-leading equipment control and analytical software
- Accurate and precise measurements due to the high resolution goniometer
- Fast measurements due to high intensity source and optics
- Wide range of techniques and parameters available
- Built by world experts in High Resolution X-ray diffraction, with over 30 years of experience, and a large global install base
**Delta-X Features and Benefits**

**Automated Optics:**
The incident beam of the Delta-X system includes a number of standard features to obtain complete versatility and ease of use of the system. The crystal choice is optimised by material:

- Parallel beam multilayer mirror as standard on all systems
- Four additional optic combinations can be installed
  - Bragg-Brentano mirror (Johannson optic)
  - Bragg-Brentano mirror (Johannson optic) and one 2-bounce crystal
  - Two independent 2-bounce crystals with different resolutions from a wide selection of crystals to best match the resolution to the experiment
  - Two crystals in Bartels configuration
- Switching between all crystals and mirrors is performed automatically
- No mirrors or crystals are removed manually from the system to ensure they cannot be damaged or mis-aligned
- The initial alignment of the system is performed easily and safely without open beams being present in the cabinet.
Sample Stage

Support for 300mm Wafers or Multiple Smaller Wafers / Samples

The Eulerian cradle on the Delta-X is designed for accurate, repeatable placement of single or multiple wafers over a wide range of motions

- Horizontal sample mounting
- XY sample mapping of 300mm for full mapping without edge exclusion of all wafers
- Long range Z axis (10mm) to adjust the height of the wafer to the correct location even for thick samples
- Vacuum clamping in different locations to allow light, even, distortion-free mounting for larger wafers or multiple, independent mounting of smaller wafers.
- Wide tilt range (100°) for pole figures and residual stress
- Unlimited azimuthal rotation for pole figures and in-plane diffraction

Edge-to-Edge FULL Measurement (No Edge Exclusion)

Delta-X supports FULL Wafer Measurement, with no edge exclusion.

Environment Stages

The Delta-X can accommodate an optional hot stage for a variety of measurements

- Samples up to 25mm in size
- XRR / XRD / HRXRD all possible
- Temperature up to 1100°C
- Environment can be vacuum, air, gas
- Computer control of the temperature is possible
Delta-X Features and Benefits

Detector Stage

High Performance Point Scintillator Detector

The detection system includes a number of features to enhance the capability of the system:

- EDRc (Enhanced Dynamic Range) detector has a dynamic range of > 2x10^7, extending beyond 5x10^8 with fully automated attenuator.
- Auto-aligning triple axis crystal and Soller slits are essential to obtain required resolution for all measurement types.
- Motorized detector slit allows control on system resolution without changing modules by hand.
- Ultra-fast software scanning engine to allow large scans in as little as 5 seconds.

State of the Art Linear Detector

The optional 1D detector enables parallel measurement capability and can provide significant speed increases for certain XRD applications. Typically this is used with a small spot for XRD and fast HRXRD reciprocal space maps:

- Automatic alignment into beam
- Compact size
- High capture angle
- High frame rate
- Air-cooled

Robot Option

Fully automated wafer loading and measurements
for all wafer sizes up to 300mm

An optional robot is available for the Delta-X, which allows fully automated measurements from wafer cassettes.

Automation (robot) support:

- Allows for robot loading of either 2” to 200mm wafers or 200 & 300mm wafers, with the associated software.
- Any combination of recipes for any number of slots
- Increased wafer cleanliness by removing manual handling of wafers
- Automatic software detection of wafer cassette sizes
- Increased productivity for larger wafer sizes
- Designed to comply with SEMI standards
Control and Data Acquisition
The Delta-X system can be used in several modes, from fully automated recipes through to complete manual alignment and scanning of any axes.

Flexible, easy to use tools to create recipes
Recipes contain all of the information to automatically align, measure and analyze the samples on the stage. No manual alignment is required: all of the work is done automatically by the tool recipes.

Recipe creation is typically performed by a tool owner / engineer using the built-in recipe creation wizards.

- Covers all common measurements performed on the system
- Creation time typically < 1 minute using a graphical wizard
- Default parameters can be customized on installation to suit the customer.
- Recipes can include multiple measurements on multiple wafer sites
- All recipes allow automated analysis and reporting into the log file.

Reports automatically created for fast information and notification
Reports allow a summary report to be saved recording all of the key parameters measured for that particular wafers, along with statistical analysis across the wafer.

- Parameters include thickness and composition for all layers, MQW period and peak separations, individual peak information (width, separation, intensity, position), wafer bow and curvature amongst others.
- Customized reports can be created for each wafer, batch and chamber.
- Individual reports are automatically saved locally and can be copied to a network or host computer.
- **NEW:** PDF reports are now available for auto-creation
Advanced Users

The system can be run by operators with limited experience under recipe control, but more advanced users have full access to the system’s advanced functionality. The software is fully flexible to allow all modes of operation, from fully automated to fully manual alignment and measurement.

Automated Alignment

Typically samples are automatically aligned during measurement recipes. However, occasionally advanced users prefer to align troublesome samples by hand. The Control software’s alignment interface allows the user to use built in functions to align samples for any measurement type

- Built in functions for half-cut, peak-finding and 2-axis optimize
- Choose the axis you wish to align. All axes are supported.
- Select any secondary alignment axes
- Start alignment

Advanced scanning possible in any direction!

Using the Control interface it is possible to simply set up scans on any installed axis, or combination of axes on the system:

- Choose the axis you wish to scan
- Select the stepping size and acquisition time (multiple regions of different values are allowed)
- Select any looping axes
- Start scan
- Scan Omega-2Theta in any ratio of Omega and 2Theta to enable complex scans in both real and reciprocal space without the user having to calculate!

Powerful Scripting

It is possible to automate the whole measurement and analysis process, including the scan alignment, measurement and analysis for single wafer sites or full wafer maps using the in-built Visual Basic-like interface. Standard scripts are included, or custom scripts can be developed to automate any measurement type or process.
**HRXRD and Relaxation**

**Materials:** Single crystal substrate (e.g. Si, GaAs, InP, GaN) and epi-layers, including multi-layer structures

**Parameters:** layer thickness, composition and relaxation, strain, area uniformity, mismatch, dopant level, miscut, layer tilt.

- Direct measurement of relaxation / strain / composition of layers within a multilayer structure
- Automated sample alignment, measurement, analysis and reporting
- Analysis performed by the JV-RADS software.
- Symmetric, asymmetric and skew symmetric reflections possible

*Omega-2Theta scan of SiGe epi-layer.*

*Sample courtesy Hitachi-Kokusai Electric*
**Triple Axis & Reciprocal Space Maps**

**Materials:** Single crystal substrate (e.g. Si, GaAs, InP, GaN) and epi-layers, including multi-layer structures

**Parameters:** layer thickness, composition and relaxation, strain, area uniformity, mismatch, dopant level, miscut, layer tilt.

- Direct measurement of relaxation / strain / composition of layers within a multilayer structure
- Automated insertion and alignment of triple axis analyzer crystal into the beam
- Automated sample alignment, measurement, analysis and reporting
- Reciprocal space maps performed in minutes and created using Contour software
- Triple axis diffraction scans can be simulated using JV-RADS analysis software

Reciprocal space map of GaN multi-quantum well, showing clear satellite peaks. These highlight the well controlled growth of the multilayer structure.

RSMs can be collected in only a few minutes to allow for fast fault diagnosis during production.

www.jvsemi.com
HRXRD Examples

GaN-based MQW

Standard measurements for GaN-based materials are generally a combination of two major scans: an Omega scan on the 102 reflection to give the GaN buffer quality, and an Omega-2Theta scan on the 002 reflection to give information about the epilayers, typically the MQW period and composition of InGaN and AlGaN.

These measurements can be performed within the same recipe, including all sample alignment, measurement and analysis, and a simple report of the results automatically displayed.

III-V on Si

Combination of (004) and (115) scans for the structure shown were used to determine the In content (47.7%) and relaxation (94%) of the InGaAs layer.

HRXRD is increasingly being used for the analysis of complex III-V on Si work, for future generation transistors in Si logic. HRXRD is ideal to determine the strain—relaxation and composition of these III-V layers deposited on Si.
X-Ray Reflectivity

**Materials:** Thin films

**Parameters:** layer thickness, density and roughness.

**Scanning Axes:** Omega-2Theta, Omega-only, 2Theta-only

- First principles, non-destructive measurement
- XRR is not sensitive to material quality so layer can be amorphous, polycrystalline or epitaxial
- Metals, nitrides, oxides, organic, polymers....
- Automated sample alignment, measurement, analysis and reporting
- Thickness range from 1nm to 1µm, depending on absorption

XRR spectrum and fit for multiple layer structure. Thickness, roughness and density of each individual layer can be determined automatically using first principles theory
Overview of XRD

Materials: Measure polycrystalline and nano bulk materials and thin films. For ultra-thin layers and nano-layers, Grazing Incidence diffraction can be employed.

Parameters: Phase, texture, grain / particle size, unit cell, amorphous %, residual stress

X-ray diffraction has been utilised for nearly 100 years to characterize the structural properties of materials. The main focus of the Jordan Valley systems is in the characterization of the microstructure of thin films.

The Delta-X system is the ideal choice for all of these measurements. With the highest resolution goniometer commercially available on the market, wide Chi (tilt) and Phi (azimuthal rotation) ranges for residual stress and texture measurements, and the automated configuration of the system along with fully automated measurements, the Delta-X is perfect for all of your thin film XRD needs.

The fundamental principle is that of Bragg's law, where the position of the peak is related to the lattice spacing. However, using this simple principle gives the possibility to determine a number of key characteristics of the film, including:

- Crystallinity from peak intensities
- Phase from peak positions/intensities
- Grain size/strain from peak widths
- Texture from peak intensities as the sample is tilted and rotated
- Residual stress from peak positions at different tilt values

The following pages illustrate the configurations and some of the applications possible on the Jordan Valley Delta-X system. These are not an exhaustive list, so please contact one of our experts to define your exact requirements and to determine the best Delta-X configuration for you.
XRD of Polycrystalline Films

**Materials:** Measure nearly all possible polycrystalline and nano bulk materials and thin films. For ultra-thin layers and nano-layers, grazing Incidence diffraction can be employed.

**Parameters:** Phase, lattice parameters, grain size

**Scanning Axes:** Linked 2Theta-Omega

- Wide >150° 2Theta range to enable high order peaks to be observed
- Wide >90° Omega range
- Omega can be offset by any value to allow removal of substrate peaks
- Automated sample alignment and measurement
- Multiple detector optics available
- Automated detector optics allows switching between each configuration
- Soller slits and automated single detector slit available

XRD 2Theta scans on 2 different textured metal films. Growth conditioned were varied and the films show differing amounts of α and β phases. The phase is critical to control the resistivity of the metal.
Grazing Incidence XRD of Polycrystalline Films

**Materials:** Measure polycrystalline and nano bulk materials and thin films. For ultra-thin layers and nano-layers, Grazing Incidence diffraction can be employed.

**Parameters:** Phase, texture, amorphous fraction for thin films

**Scanning Axes:** 2Theta only (GI-XRD)

- Wide >150° 2Theta range to enable high order peaks to be observed
- Omega from 0° to beyond 90° to allow any incident angle
- Phi rotation to remove substrate asymmetric peaks
- Automated sample alignment and measurement
- Multiple detector optics available
- Automated detector optics allows switching between each configuration
- Soller slits for precise angular measurement

XRD 2Theta scan of a polycrystalline SiGe layer. By indexing the SiGe peak positions, the layer is confirmed to be a cubic phase.
Pole Figures of Polycrystalline Films

Materials: Measure polycrystalline and nano bulk materials and thin films.

Parameters: Texture

Scanning Axes: Chi & Phi

- 100° Chi range and full Phi range for wide pole figures and residual stress measurement
- Automated sample alignment and measurement
- Multiple detector optics available
- Automated detector optics allows switching between each configuration
- Soller slits and automated single detector slit available

Pole figure of Cu film with mixed (111) and (110) texture.
Residual Stress of Films

**Materials:** Measure polycrystalline and nano bulk materials and thin films.

**Parameters:** Residual Stress

**Scanning Axes:** 2Theta & Chi

- 100° Chi range and wide 2Theta range >150° for residual stress measurements
- Different detector optics for different applications
- Automated detector optics allows switching between each configuration
- Automated sample alignment and measurement
- Soller slits for precise angular measurement
- Analysis software for residual stress available.

Peaks from W(220) for different tilt values. The shift in position as a function of tilt indicates the residual stress. This can be calculated using Jordan Valley Stress Analysis software.
XRD Examples

Ultra-thin High-k Materials
The latest generation of logic devices use novel materials for the high-k dielectric. One of the critical parameters for this layer is the crystalline fraction of the layer. This example is an XRD scan from a layer thickness of less than 5nm. By comparing the peak area from the broad amorphous peak with with the sharper crystalline peaks, the crystalline fraction can be determined to be 46%.

Residual Stress of Thin Films
The residual stress of thin films is becoming a critical parameter in the optimisation of thin films for many applications. XRD is an ideal technique for measuring the local stress, rather than the global stress as measured by optical techniques.

A polycrystalline film of W was measured using the (222) reflection and a compressive stress of 748 MPa was determined.

A Heavily Textured 50nm Cu film was measured. The heavy texture of the film results in the peak only being present for two tilt values. Using this method a tensile stress of 530 MPa was determined.

The examples above show the final stress plots. A series of 2Theta-Theta scans are taken for multiple tilts of the sample, and the lattice parameter is calculated for each tilt value. By plotting the lattice parameter as a function of tilt the residual stress can be determined. The opposite gradients indicate one film being tensile and the other being in compressive stress.
Analysis Software

The Jordan Valley suite of analysis software builds on 30 years of experience in X-ray characterization and metrology of thin-films. Based on Bede Scientific’s analytical software suite, the Jordan Valley analysis package includes industry-leading simulation software for high resolution X-ray diffraction (HRXRD) and X-ray reflectivity (XRR), along with general analysis and mapping software.

**JV RADS** is the most trusted software in the industry to analyze HRXRD data from epitaxial thin-film structures on single crystal substrates. It is the software of choice throughout industry for R&D and production, as well as academia, for detailed analysis of simple and complex structures.

- Fast and accurate parameter determination using the Mercury engine, a patented Genetic Algorithm method
- Layer parameter linking and equations to simplify the analysis of complex multi-layer structures and graded profiles
- Models epitaxy on 001 and non-001 cubic materials, and c-plane oriented hexagonal materials.
- Extensive built-in, user customizable materials database
- Supports bonded substrates, for example SOI, GaN on Si (new in version 5)
- Enhanced the defect scattering models for mosaic and ion-implantation modelling (new in version 5)

**MDI JADE** is the latest addition to the Jordan Valley analysis software suite. Coupled with the latest PDF database, this powerful XRD analysis software allows pattern viewing, processing and analysis with great emphases on phase identification and quantification. For more advanced analysis, full pattern matching using either the Pawley method or Rietveld refinement can be used.

The example shows the one-click analysis of a five-phase mixture.
**JV REFS** is the popular software for analyzing X-ray reflectivity profiles. The software is both easy-to-use and powerful and has been used for both R&D and production application.

- Fast and robust parameter determination from specular measurements using a patented Genetic Algorithm method
- Layer parameter linking to simplify the analysis of complex multi-layer structures
- Extensive built-in, user customizable materials database
- Diffuse scatter curves can be simulated for advanced characterisation

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**JV Contour** for creating and displaying 2D and 3D maps.

Contour uses intuitive wizards to step through the creation of reciprocal space maps, wafer maps and pole figures. The plotting software allows a variety of plotting styles and methods.

RSMs can be plotted in native axis units or reciprocal space units for ease of interpretation and analysis.

Contour also includes an orientation distribution function package for the analysis of pole figures.

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**JV PeakSplit** provides a collection of tools for the direct analysis of HRXRD and XRD data. X-ray spectra can be displayed graphically and peak-fitting performed.

PeakSplit can calculate the composition and relaxation from the peak positions in multiple HRXRD spectra. Additionally a simulation mode is possible where peak positions can be calculated based on composition and relaxation.
### Delta-X — Specifications

<table>
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<tr>
<th>Item</th>
<th>Specification</th>
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<td>5” - 25” (Bartels)</td>
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<td>Omega Range resolution</td>
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<td>2Theta Range resolution</td>
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### Software

**RADS**

The original and still the best dynamical HRXRD simulation and fitting software. Allows simulation of symmetric, skew symmetric and asymmetric spectra. RADS uses a patented genetic algorithm to ensure robust and precise data analysis with results you can trust.

**REFS**

X-ray reflectivity simulation and fitting software, using a powerful genetic algorithm.

**PeakSplit**

General HRXRD calculation software. It can be used either to analyze data or predict where peaks are likely to occur to efficiently plan data scans.

**Contour**

Mapping software, for area maps, reciprocal space maps and texture maps (including ODF).

### Control and Acquisition

Control and acquisition software to control the instrument. Standard measurements can be easily defined, and custom routines implemented for all applications and materials. Provides an interface for either robot loading or multiple wafers per sample.