XTRAIA® MF Series

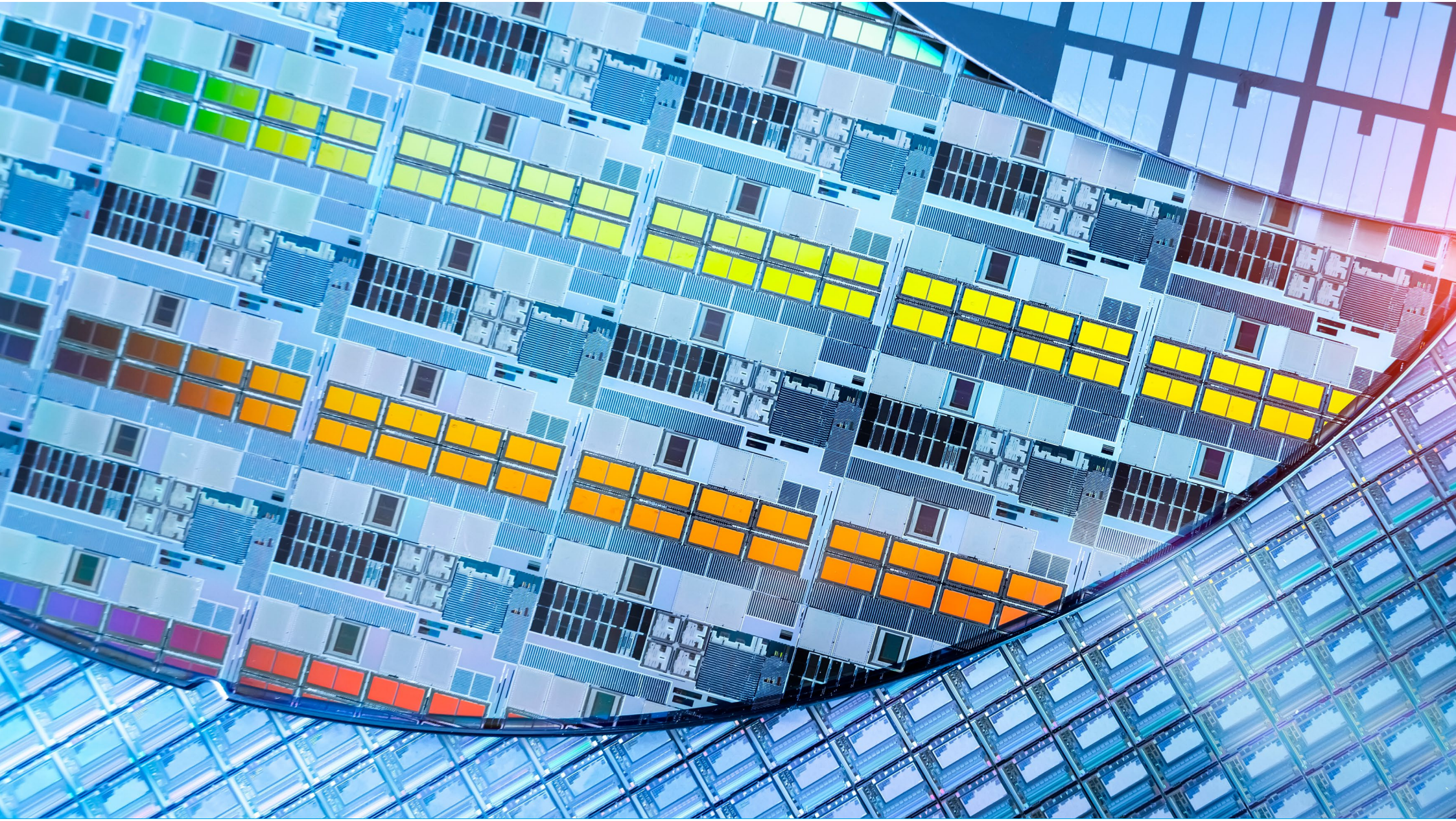
Improved X-ray wafer metrology for metal film monitoring

ED-XRF, XRR, and XRD metrology tools for blanket and patterned metal layer thickness and composition

Rigaku

Semiconductor Metrology Solutions

RIGAKU.COM



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XRF: X-ray fluorescence

When X-rays illuminate a wafer, fluorescence X-rays of different wavelengths are excited depending on the elements present. Film thickness is calculated using the calibration curve between the intensity and the film thickness for these fluorescent X-rays, having energy inherent to each material.

XRR: X-ray reflectometry

This glancing-angle X-ray technique is applicable to thin films of all material types: transparent or opaque, amorphous, polycrystalline, or single-crystal. XRR provides film thickness, density, surface and interface roughness information from single films or complicated film stacks. During an XRR measurement, copper X-rays strike the wafer surface at a shallow angle, and the incidence angle is increased over the range of a few degrees. Below a certain incidence angle known as the critical angle, that depends on the surface material, the X-rays are totally externally reflected. As the incidence angle increases beyond the critical angle, the X-rays penetrate into and interact with the film(s) resulting in the measured fringe pattern. The critical angle in an XRR pattern is related to the density of the top film. The frequency of the fringes in an XRR pattern is related to the film thickness: the higher the frequency, the thicker the film. Film density and roughness affect the amplitude and decay of the fringe intensities.

Industry challenges

Advanced semiconductor devices often incorporate ultra-thin films up to several nanometers thick. Film thickness can dramatically affect product quality and, therefore, should be monitored with suitable metrology.

Metrology solution

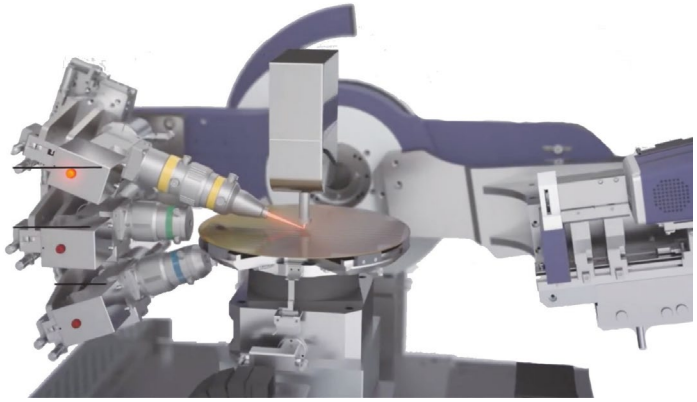
Film thickness is measured with X-rays in two ways.

The Rigaku XTRAIA® MF SERIES Metrology Tools perform high-precision measurements not possible by optical or ultrasonic techniques.

This sophisticated X-ray metrology tool series makes it practical to perform high throughput measurements on product and blanket wafers ranging from ultra-thin single-layer films to multi-layer stacks.

COLORS™ enabling technology

Rigaku developed COLORS™ X-ray optics for the XTRAIA® MF SERIES, enabling measurements from small areas. COLORS™ beam modules couple X-ray tube sources with optimized optics to provide monochromatic, high-brightness illumination in small spots for various thin film applications. With its own X-ray optics business, Rigaku is well positioned to develop and manufacture X-ray sources for current and future market needs.



COLORS™ X-Ray Optics

HyPix®-3000

Designed for high-volume manufacturing

The XTRAIA® MF SERIES is designed with high-volume 200mm (and smaller wafer) manfacturing in mind: high-throughput thickness measurement by XRR and XRF, low-contamination wafer handling, and pattern recognition-based position control for product wafer measurements, CE marking, and SEMI S2/S8 compliance for semiconductor production clean room operation, SECS/GEM communication, high-reliability machine performance, and low power consumption and cost of ownership. Available with open cassette and SMIF pod configurations.

Film thickness and density monitor

The XTRAIA® MF SERIES is equipped with a HyPix®-3000, two-dimensional, direct photon-counting detector for XRR and XRD measurements with multiple modes (OD, 1D, 2D) of operation. This detector has ~300,000 pixels with a 100 µm x 100 µm pixel size. When an X-ray photon is an incident, each pixel sensor becomes conductive and can count the number of incident photons one by one.

XRR detection is five times faster

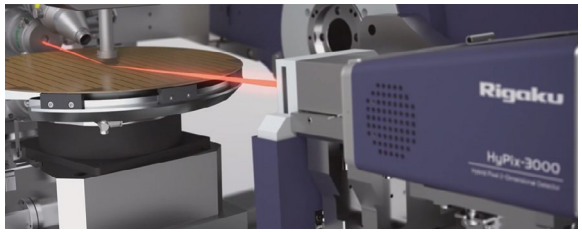
High resolution and high dynamic range (108) enable XRR to characterize a wide range of film thicknesses, from ultra-thin film (sub-nm) to thick film (450 nm) Using a two-dimensional detector, the measurement speed of the XTRAIA® MF SERIES has been improved five times compared with the conventional model.

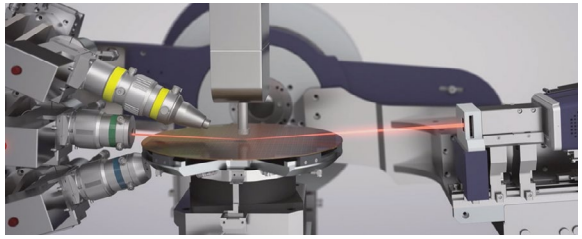
Microcrystalline thin films with low crystallinity

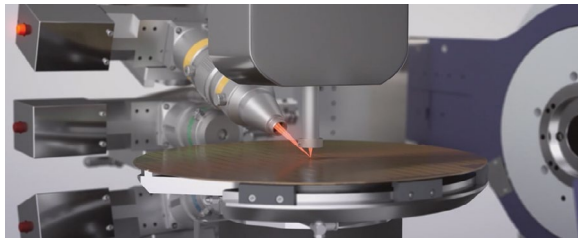
In addition, XRR and X-ray diffraction (XRD) capability enable the measurement of very thin and low-crystallinity films, for which the demand is increasing.

High-precision measurements

Rigaku Semiconductor Metrology Tools XTRAIA® MF SERIES perform high-precision measurements not possible by optical or ultrasonic techniques. This sophisticated X-ray metrology tool makes it practical to perform high-throughput measurements on product and blanket wafers ranging from ultra-thin singlelayer films to multi-layer stacks.



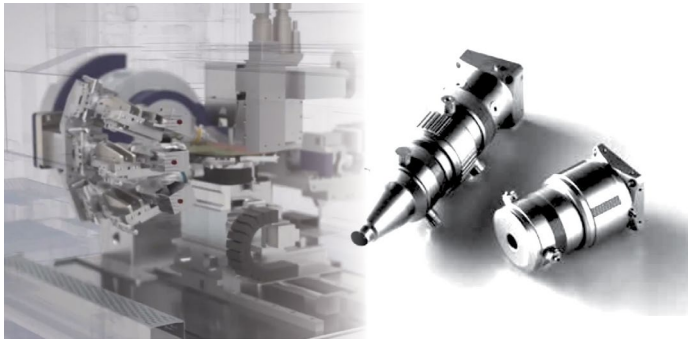




XTRAIA® MF series applications optimization with up to 3 COLORS™ X-ray beam modules

Rigaku's unique multi-layer mirror technology realizes high-brilliance, monochromatic, micro-spot X-ray beams. The newly developed X-ray module COLORS™-t can reduce the irradiation diameter to 20 µm. The X-ray intensity lessen as the irradiation diameter is reduced. However, the power is improved by the multi-layer mirror's processing technology and coating technology. Initially, the XTRAIA® MF SERIES was implemented mainly for memory applications. The XTRAIA® MF SERIES has also been adopted for the market of logic semiconductors applications for much broader use in semiconductor manufacturing processes. Memory cells have a relatively large area of several millimeters, but logic semiconductors have only a small and narrow space. A measurement pattern with 50 µm square on a scribe line should be irradiated, requiring a smaller beam spot (irradiation diameter). With conventional equipment, the diameter was limited to 35 µm. The newly developed X-ray module COLORS™-t can reduce the irradiation diameter to 20 µm.

		FWHM (µm)	XRF	XRR	XRD
COLORS™	**Cu**	85	o	o	o
COLORS™	**Au**	85	o	-	-
COLORS™	**Mo**	85	o	-	-
COLORS™	**Rh**	85	o	-	-
COLORS™ -n	**Cu**	50	o	-	-
COLORS™ -i	**Au**	35	o	-	-
COLORS™ -i	**Mo**	35	o	-	-
COLORS™ -t	**Cu**	20	o	-	-
COLORS™ -t	**Au**	20	o	-	-
COLORS™ -t	**Mo**	20	o	-	-



COLORS™-i | COLORS™ Cu

Monochromatic, micro-spot X-ray beam modules COLORS™

Rigaku's unique multi-layer mirror technology realizes a high-brilliance monochromatic, micro-spot X-ray beam. Select the X-ray beam best suited for XRR, XRF, and XRD applications of interest.

Applications

XTRAIA® MF SERIES can handle a variety of FEOL and BEOL films ranging from single layer to multi-layered stacks.

- **FEOL:** SiGe, CoSix, NiSix, SOI, Al, SiON, Hi-k dielectric/metal gate
- **BEOL:** Cu seed, Cu barrier, Cu plating, Ti/TiN, Ta/TaN, W
- **Others:** MgO, CoFeB, Ru, Pt, PZT

Cu interconnects
XRD evaluation of preferred crystal orientation of the Cu-plated layer.

Barrier metals
XRR evaluation of film thickness, density, and roughness of each layer on a multi-layer film. e.g. Ta/TaN, Ti/TiN (CVD, PVD)

Gate dielectrics
XRR evaluation of film thickness, density, and roughness of various gate dielectric films, e.g. HfSiOx.

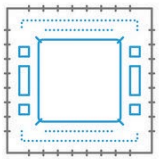
CMP
XRF evaluation of film thickness, dishing and erosion of the wafer after Cu CMP

Silicide films
XRR evaluation of film thickness and density of WSix, CoSix, NiSix, etc.

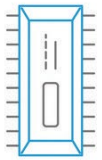
Ferroelectrics films
XRF composition evaluation of PZT films, BST films, etc. as well as XRD crystallinity determination.

Others
Film thickness and composition evaluation of SiGe, XRD evaluation of preferred crystal orientation of Ta, W, WSix, Ti, TiN, etc.

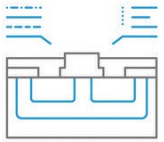
Memory



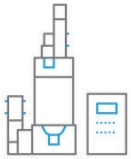
MEMS



Power Devices



Advanced Packaging



Applicable to microscopic measurement pads
Evaluation of Cu thickness on small pads

Micro-XRF

Ultra-fast X-ray detector HyPix®-3000
High precison by 8-order dynamic range

XRR

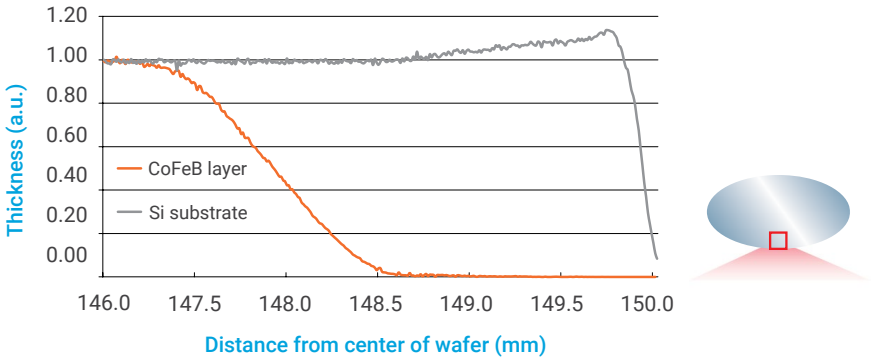
Pattern navigation
High-performance pattern recognition reducing cost and wafer monitor requirements

Efficiency

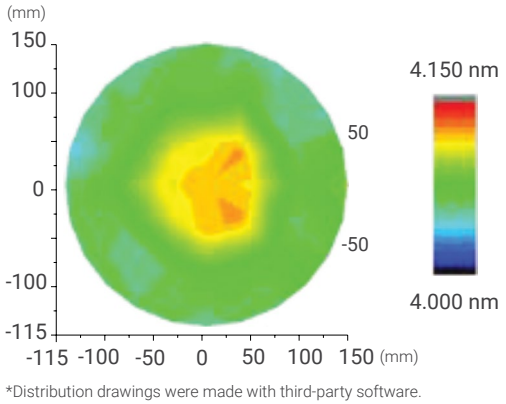
XRF measurement of thickness variation in MRAM process

Low-incidence angle measurements enable a high-speed analysis of thin films like those found in MRAM devices. Flexible recipe settings cover a variety of film stacks and applications .

Micro-XRF measurement example: Cu/Ta/TaN



WIW thickness variation of CoFeB



Conditions

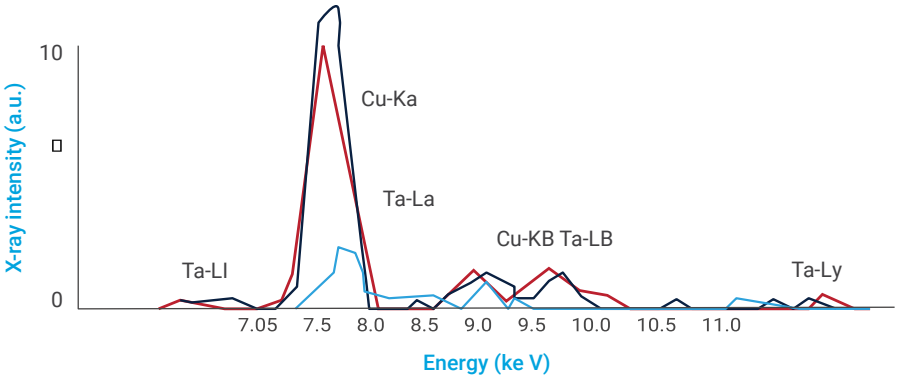
Measured Point: 49 pts
Measured Time: 5 sec/pt
Applied Tube: COLORS™ Au
Incident Angle: 5 deg
Element: Co

Throughput 5 WPH

*Distribution drawings were made with third-party software.

Micro-XRF measurement of thickness and composition

Using a monochromatic, micro-spot X-ray beam module and a high-sensitivity, energy-dispersive silicon drift detector (SDD), high-throughput and high-precision thickness and composition measurements by X-ray fluorescence (XRF) are realized.



Micro-XRR measurement of thickness

High-throughput X-ray reflectivity (XRR) measurements are realized thanks to an ultra-fast X-ray detector. It enables simultaneous measurement of a multi-layer film over an 8-order dynamic range of intensity.

	Density (g/cm^3)	Thickness (nm)	Roughness (nm)
Cu	8.60	153.83	1.51
Ta	15.85	16.43	0.00
TaN	14.02	9.81	8.70
SiO_2	2.2	300.00	0.00

Advantages

Pattern navigation

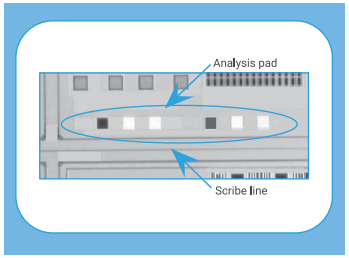
Low-incidence angle measurements enable a high-speed analysis of thin films like those found in MRAM devices. Flexible recipe settings cover a variety of film stacks and applications .

Measurment pads

Low-incidence angle measurements enable a high-speed analysis of thin films like those found in MRAM devices. Flexible recipe settings cover a variety of film stacks and applications .

Applicable to microscopic measurement pads

- Micro-XRF measurement enables the evaluation of Cu thickness on small pads.
- Ultrafast X-ray Detector HyPix®-3000
- High-precision, fast XRR measurements are realized thanks to an 8-order dynamic range.



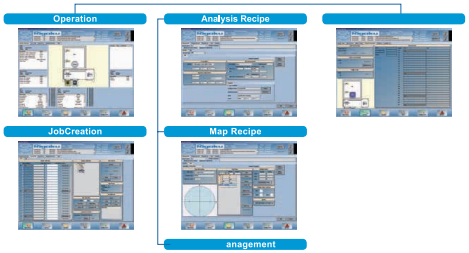
Analysis pad

Safety Standards Compliance: SEMI S2 and SEMI S8
Communication Standards Compliance: GEM300 and SECS/GEM
Quality Standards: ISO 9001 and ISO 14001 approved

Left: Rigaku Auburn Hills, Michigan (USA) **Right:** Rigaku Yamanashi Factory (Japan)

User-friendly interface

A new user interface enables a faster operational, engineering, and maintenance setup.



Ultra-fast X-ray detector HyPix®-3000

Developing fundamental technologies

The HyPix®-3000 detector is produced at the Rigaku's Yamanashi factory. A Rigaku subsidiary in Auburn Hills, Michigan (USA), manufactures a multi-layer mirror in which the incidence angle can be changed by controlling the film thickness. Because an optical mirror does not reflect X-rays, they are collected and reflected by a multi-layer film of 1,000 layers of molybdenum or silicon with properly adjusted film thickness. This X-ray mirror is based on the unique technology of making a mirror surface with a curve at t he Angstrom level. The company has also developed the equipment for manufacturing such curved mirrors.

200 mm
Wafers

XTRAIA® MF-2000 system parameters

Metrology type
Energy-dispersive X-ray fluorescence (ED-XRF), X-ray reflectivity (XRR), and X-ray diffraction (XRD)

Wafer size
Up to 200 mm

Wafer type
Blanket and patterned wafers

Benefit
High-throughput measurement of product wafers from ultra-thin films to micron-order films, applicable to a wide range of film types

Sample handling
Magazine robot

Automation
Full wafer capability with dual automatic loader

Computer
External PC, MS Windows® OS

SW user interface
Auto calibration

X-ray tube energy
Up to 50 kv, 50 w

X-ray optics
COLORS™ monochromatic X-ray optics

Beam spot size
20 - 85 µm

Detector type
Silicon drift detector (SDD) for XRF
Photon counting detector (HYPIX-3000) for XRR, XRD

XRF detector resolution
123 ± 5 eV with a large solid angle

Specifications and appearance are subject to change without notice.
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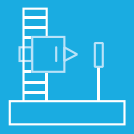
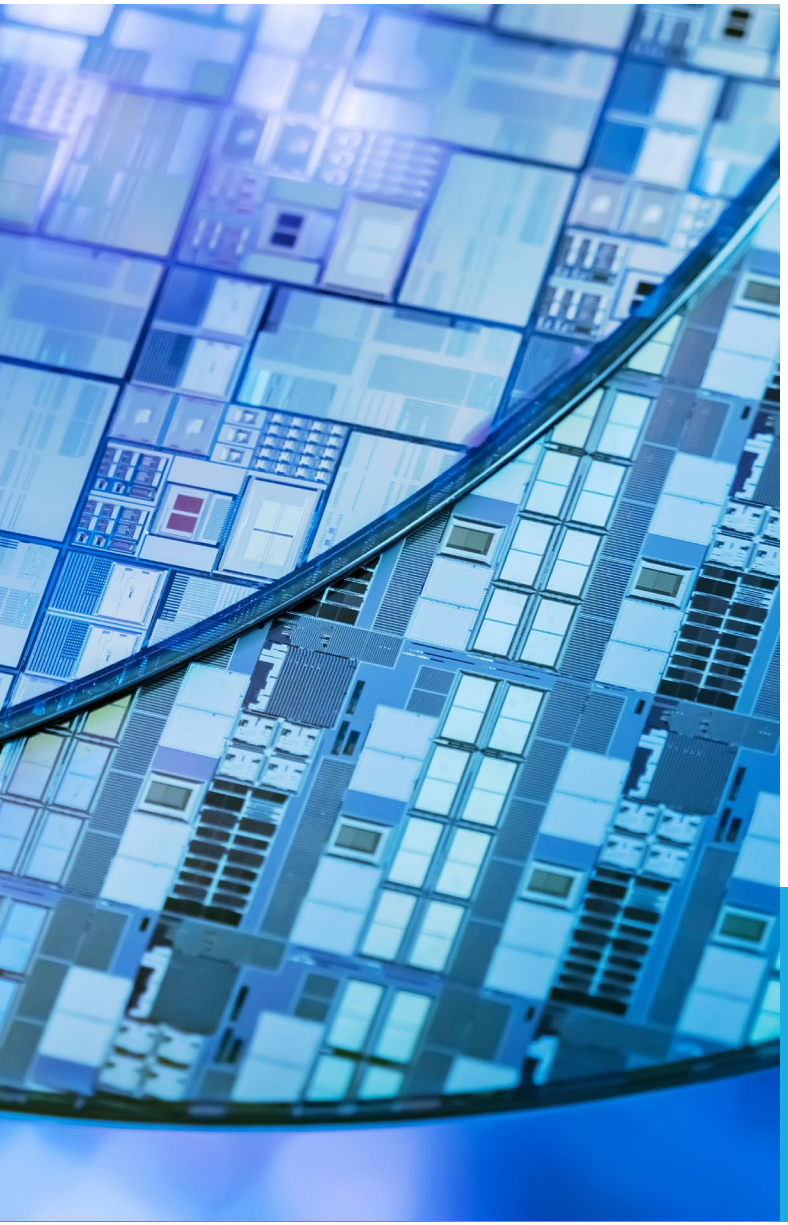


Small Platform Process XRR, ED-XRF, and XRD Metrology Fab Tool

Metal layer thickness and composition by ED-XRF

Blanket and patterned metal layer thickness and composition

Simultaneous evaluation of film thickness, density, and roughness by XRR



Up to
300 mm
Wafers

XTRAIA® MF-3000 System Parameters

Metrology type
Energy-dispersive X-ray fluorescence (ED-XRF), X-ray reflectivity (XRR), and X-ray diffraction (XRD)

Wafer size
Up to 300 mm

Wafer type
Blanket and patterned wafers

Benefit
Micro-spot X-ray beams and pattern recognition
High-throughput measuremen of product wafers from ultra-thin films to micron-order films, wide range of materials and applications

Sample handling
Magazine robot

Automation
Full wafer capability with dual automatic loader

Computer
External PC, MS Windows® OS

SW user interface
Auto calibration

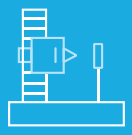
X-ray tube energy
Up to 50 kV, 50 W

X-ray optics
COLORS™ monochromatic X-ray optics

Beam spot size
20 - 85 µm

Detector type
Silicon drift detector (SDD) for XRF
Photon counting detector (HYPIX-3000) for XRR, XRD

XRF detector resolution
123 ± 5 eV with a large solid angle



ED-XRF, XRR, and XRD Metrology Optimized for High-Volume Manufacturing

Blanket and patterned metal layer thickness and composition

Micro-spot X-ray beams and pattern recognition

- High-throughput, product-wafer measurements
- Wide range of materials and applications
- High resolution and precision covering thicknesses from Å to µ

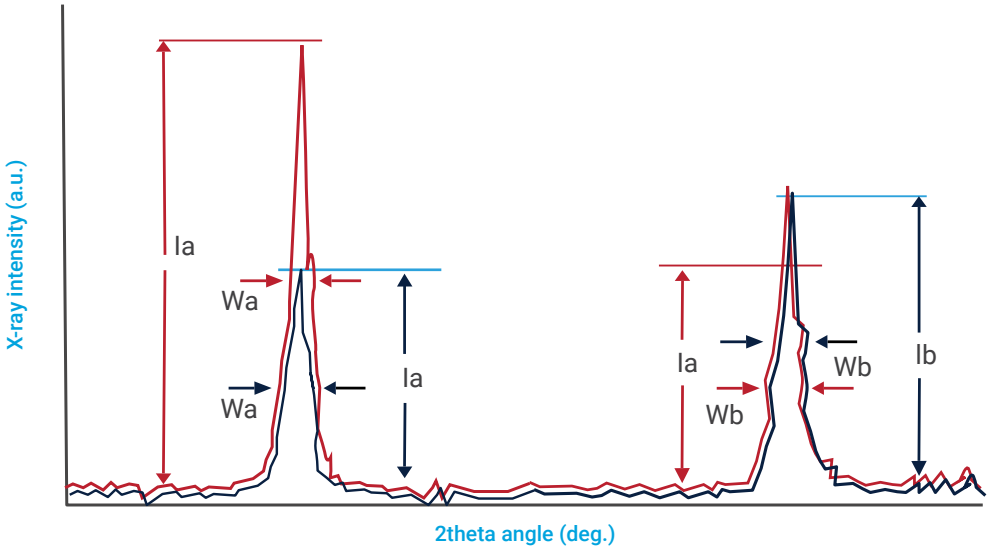
XRR measurement of physical characteristics in MTJ film stack

XRR is applicable for multiple alternating stack structures for which XRF is unable to distinguish each layer of the same composition.

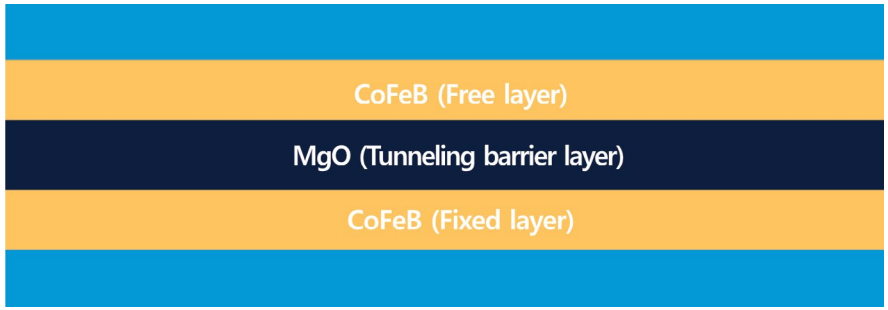
Evaluation of crystallinity and orientation by micro-XRD

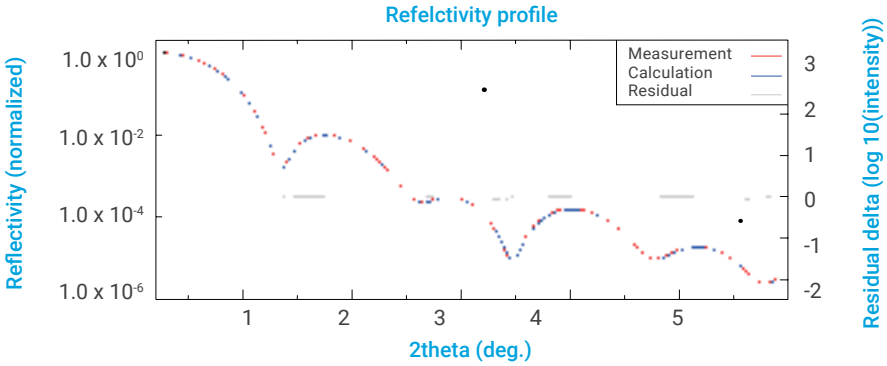
By X-ray diffraction (XRD), crystalline phase identification, crystallinity, and crystal orientation can be evaluated from peak locations, peak shapes, and intensities in the diffraction pattern.

XRD measurement example: CoFeB/MgO/CoFeB



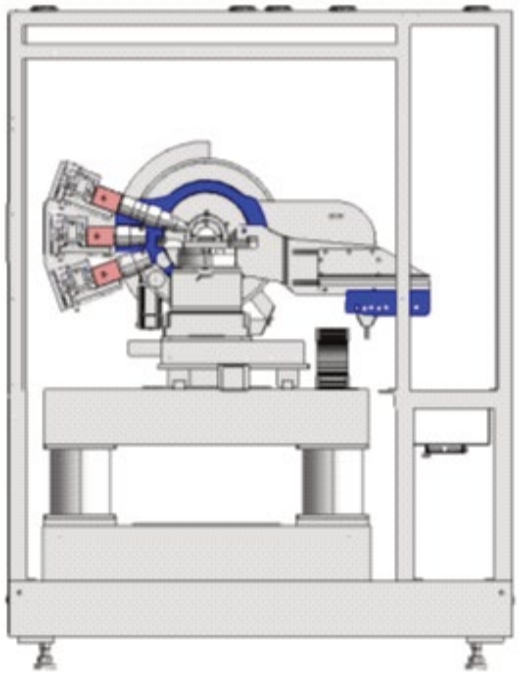
XRR measurement example: CoFeB/MgO/CoFeB

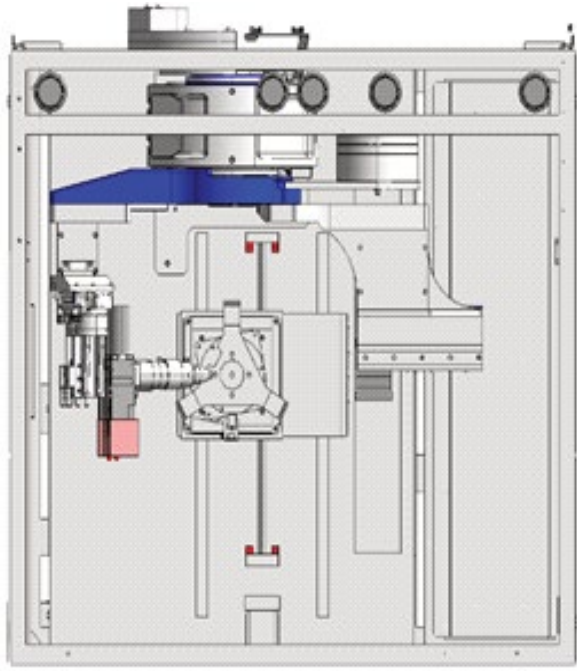




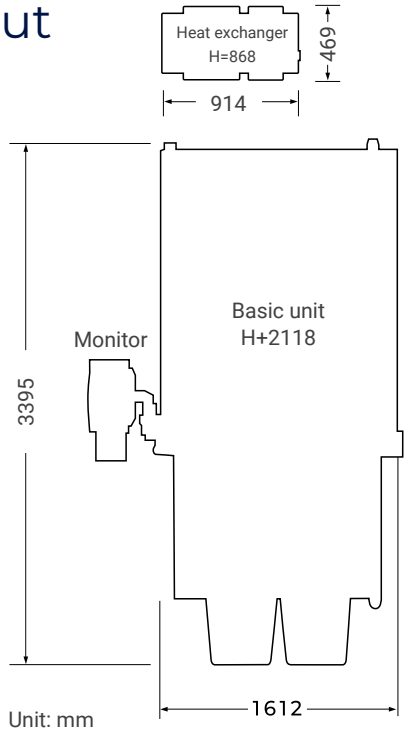
Layer Name	Thickness (nm)	Density (g/cm3)	Roughness (nm)
$CoFeB_2$	2.89	8.28	0.3
MgO	1.195	3.78	0.5
$CoFeB_2$	3.44	8.5	0.4

Schematics





Layout



Typical floor arrangement

Requirements

Space

Main Unit: 63.46 in W x 133.66 in D x 83.38 in H

Heat Exchanger: 18.46 in W x 35.98 in D x 34.17 in H

Utilities

Power Supply Main unit: 3 phases 208 V, 20 A, avg. 2 kVA

Power Supply Heat Exchanger: 1 phase 208 V, 8 A, avg. 0.5 kVA

CDA 0.5~0.7 MPa 20 L/min

Vacuum -80 kPa 20 L/min

About Rigaku

Founded in 1951 in Tokyo, Japan, Rigaku is an analytical and industrial instrumentation leader. With numerous innovations, the Rigaku group of companies is now a global authority in several fields, including X-ray diffraction (XRD), thin-film analysis (XRF, XRD, and XRR), X-ray fluorescence spectrometry (TXRF, EDXRF, and WDXRF), small-angle X-ray scattering (SAXS), protein and small molecule X-ray crystallography, Raman spectroscopy, X-ray optics, semiconductor metrology (TXRF, XRF, XRD, and XRR), X-ray Topography Imaging, X-ray sources, computed tomography, non-destructive testing, and thermal analysis While X-ray and related technologies are the foundation of Rigaku's business, its true strength lies in its commitment to working with customers. By fostering partnerships and driving innovation, Rigaku powers new perspectives and tailor-made solutions to meet the diverse needs of industry, academia, and government.

With a global presence and over 2,000 employees worldwide, Rigaku values collaboration between users and employees to ensure alignment with customer needs and market trends. Its products and services drive innovation in fields as diverse as semiconductor chip design, drug discovery, and nanotechnology research.

We value our customers, value our people, and value our technology. The company's mission is to contribute to the enhancement of humanity through scientific and technological development.

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