TFXRD™

X-ray Diffraction System for Thin Films

—X-ray diffractometer for large-diameter wafers and thin-film evaluation—

1. Introduction

X-ray diffraction measurements have been widely used for evaluating functional thin-film materials, particularly in the semiconductor field. With recent advances in the field of electronics, the growing demand for semiconductor chips has driven efforts to reduce production costs. Those efforts include the trend toward larger-diameter substrate materials. More recently, the expanding market demand for power supply systems and AI servers has accelerated the adoption of GaN power semiconductors, leading to the use of larger silicon wafers as substrates. The "TFXRD" X-ray diffraction system for thin films was developed in response to the need for measuring large-diameter wafers in their original state. TFXRD is equipped with a high-precision goniometer specialized for thin-film evaluation and a large XY stage designed to accommodate large-diameter wafers. These features enable highly accurate evaluation of advanced materials by X-ray diffraction. Models equipped with an automatic wafer handling robot have also been added to the lineup, enabling automated continuous measurements of multiple wafers. In this article, we present the configuration of the TFXRD system, which is specifically designed for thin-film materials evaluation.

2. TFXRD System Configuration

In thin-film material evaluation by X-ray diffraction, specialized techniques are employed. These techniques include reflectivity measurement for evaluation of film thickness and density; rocking curve measurement for evaluation of crystallinity of epitaxial films and the composition of compound layers; and reciprocal space mapping measurement for analysis of lattice strain (or relaxation). TFXRD is a four-circle X-ray diffractometer system designed specifically for thin-film materials evaluation. In addition to an ω axis to control the incident angle of X-rays with respect to the sample and a 2θ axis to control the diffraction angle, the system incorporates a φ axis to control sample surface rotation and a χ axis for tilt control. To accommodate large-diameter wafers of 300 mm and 200 mm, the system is equipped with a large χ cradle, XY axes for full mapping, and a Z axis that allows precise thickness adjustment during measurement. Combinations with various optical devices, such as monochromators and analyzer crystals, make the system suitable for high-resolution measurements required for thin-film materials where precision is critical. The TFXRD system incorporates several distinctive structural components, which are outlined below.

High-precision goniometer

The system is equipped with a 2θ–θ type horizontal goniometer. With fully closed encoder control directly linked to the main axis, measurements of both 2θ and ω can be performed with a minimum step of 0.0001°. Combinations with various high-resolution optical devices enable acquisition of even more precise data (Fig. 1).

High-brilliance X-ray tube

In addition to the standard sealed X-ray tube, a rotating anode X-ray tube with maximum output of 9 kW is available. The use of a high-output X-ray source enables high throughput in multi-point measurements of large-diameter wafers.

Large χ cradle and XY stage for full mapping of large-diameter wafers

Two models are available: TFXRD-300, which supports wafers up to 300 mm in diameter (supports 300 mm and 200 mm wafers), and TFXRD-200, which supports wafers up to 200 mm in diameter (supports 200 mm and 150 mm wafers). Each is equipped with an XY mapping stage with a dedicated wafer vacuum chuck holder. Both models are equipped with a large χ cradle that supports large-diameter wafers. The cradle can move within the range of −5° to 95° (Fig. 2).

Vacuum sample suction stage (patent pending)

A dedicated sample stage has been newly developed to accommodate samples with relatively large warpage, such as heteroepitaxial films. In addition to suction near the backside and edges of a wafer, the central suction nozzle is adjusted vertically according to the degree of warpage to secure the wafer. This mechanism ensures secure wafer hold during measurements with vertical retention (Fig. 2).

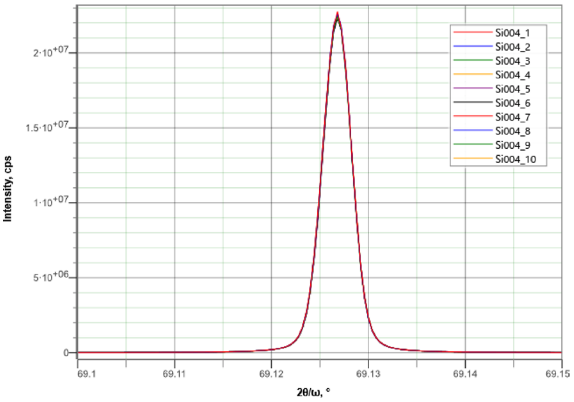

Fig. 1. Measurement repeatability.

Results of repeated $2\theta/\omega$ measurements around Si 004. High repeatability is achieved. (Measurement optics: incident Ge 400 2-bounce monochromator, receiving HyRES400 (Ge 400 2-bounce analyzer))

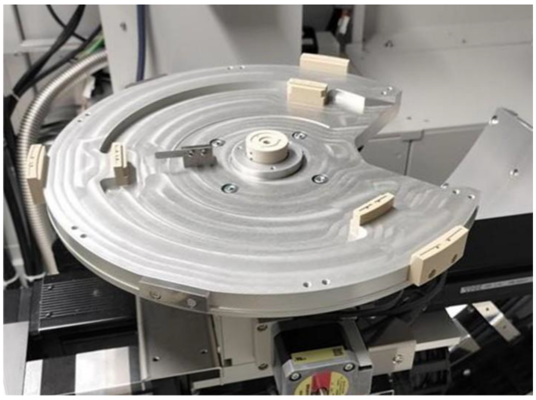

Fig. 2. Picture of vacuum suction stage.

New suction stage. Retains warped wafers by moving the vertical mechanism of the central wafer suction section.

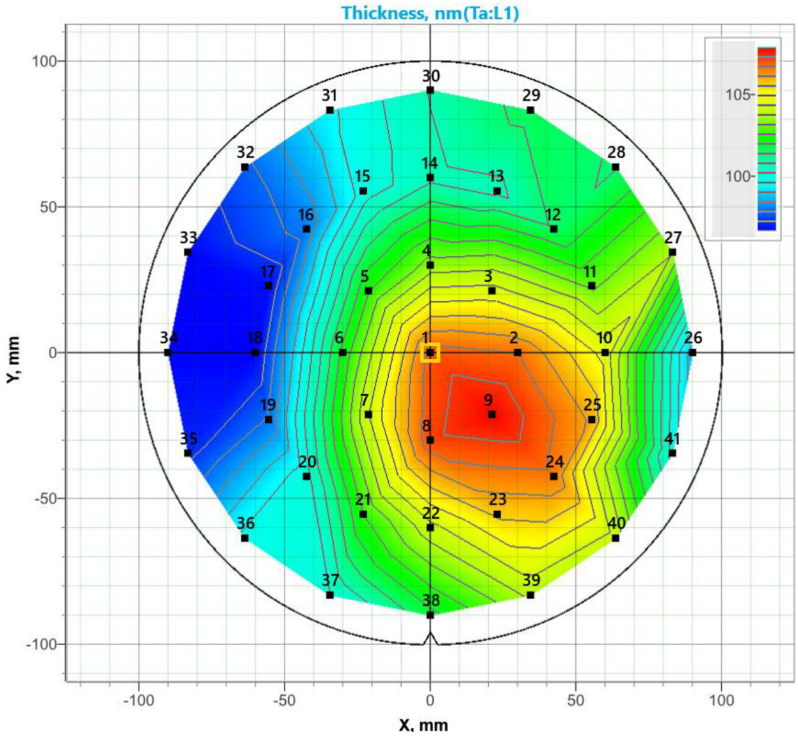

Fig. 3. Reflectivity mapping diagram.

Example of the evaluation of thickness distribution of Ta thin film on a 200 mm Si substrate. Mapping display with Data Visualization plugin of the SmartLab Studio II integrated X-ray analysis software.

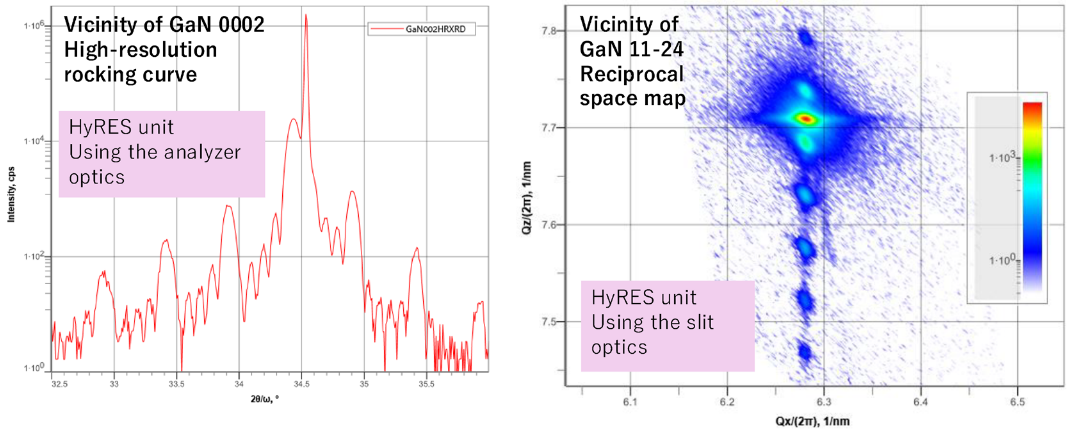

Fig. 4. Example of rocking curve and high-speed reciprocal space mapping measurements.

High-resolution rocking curve profile of an InGaN/GaN sample with an MQW structure on a sapphire substrate (left) and the result of a high-speed reciprocal space mapping measurement around GaN 11–24. Installing the optional HyRES unit enables consequent performance of high-resolution rocking curve measurements using an analyzer crystal (triple-axis) and high-speed reciprocal space mapping using the one-dimensional mode of the detector.

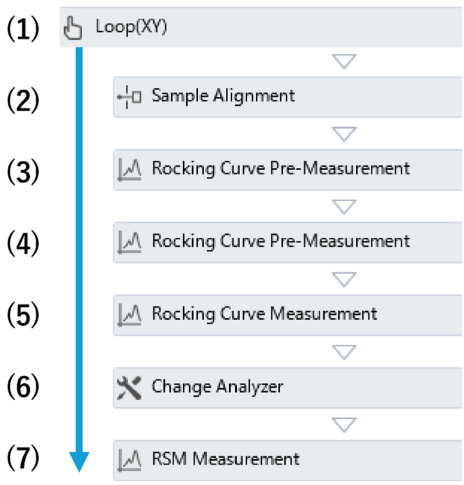
(1) Loop(XY)
(2) Sample Alignment
(3) Rocking Curve Pre-Measurement
(4) Rocking Curve Pre-Measurement
(5) Rocking Curve Measurement
(6) Change Analyzer
(7) RSM Measurement

Fig. 5. Example of a macro for rocking curve and high-speed reciprocal space mapping measurements.

Example of a measurement macro using SmartLab Studio II. Continuous measurements can be performed by switching between the receiving slit optics and the high-resolution optics with the analyzer crystal.

(1) Measurement position specification (X, Y),
(2) Sample height adjustment (Z),
(3) Sample crystallographic axis adjustment (φ),
(4) Sample crystallographic axis adjustment (ω, χ),
(5) High-resolution rocking curve measurement (with the analyzer crystal),
(6) Switching of the receiving optics,
(7) High-speed reciprocal space mapping with the slit optics.

Hybrid multidimensional pixel detector and receiving analyzer switching unit (optional)

The system is equipped with the multidimensional pixel detector HyPix-3000 and supports high-speed reciprocal space mapping measurements using the one-dimensional mode for evaluating lattice relaxation in epitaxial films. Adding the optional HyRES 220/400 analyzer switching unit enables direct switching from the software interface between receiving slit optics and high-resolution optics with the analyzer crystal. This enables continuous measurements with both optics by macro control. (Figs. 4, 5)

3. TFXRD Series Lineup with Automatic Wafer Transfer Capability

In addition to automated multi-point measurements across the wafer surface using the XY stage, the lineup also includes models equipped with an automatic wafer handling robot. Models with a handling robot enable continuous automatic multi-point measurement of multiple wafers. The automatic transfer mechanism can be equipped with up to two load ports, supporting FOUP for 300 mm wafers as well as open cassettes for 200 mm and 150 mm wafers. To meet the requirements for use in semiconductor fabrication plants, models compliant with various SEMI standards (S2, S8, SECS/GEM for host communication) are also available under the product names XTRAIA™ TF-3000/-2000 (Fig. 6).

4. Summary

TFXRD was developed as an X-ray diffraction system for thin-film evaluation capable of measuring large-diameter wafers. It is designed to excel in the field of thin-film measurement, where high precision and evaluation through multiple measurements are required. The lineup ranges from models equipped with large doors for research and development applications to models designed for semiconductor manufacturing environments, offering the optimal instrument for each process.

(TFXRD series)		
TFXRD-300 **TFXRD-200**	**TFXRD-WL300** **TFXRD-WL200**	**XTRAIA-TF3000** **XTRAIA-TF2000**
		
Designed for laboratory applications, this model features a large door for easy access and supports the measurement of small or irregularly shaped samples by simple manual placement.	Equipped with a transfer mechanism, this model enables automated measurement of multiple wafers thanks to automatic transfer of wafers.	Model equipped with a transfer mechanism compliant with SEMI standards S2, S8, and SECS/GEM.

Fig. 6. TFXRD lineup table.