Transmission X-Ray Diffraction Imaging (XRDI) Topography System

R&D and Production dedicated XRDI system for Substrate Analysis

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Introduction

Jordan Valley’s QC-TT™ is the most advanced Transmission XRDI (X-Ray Diffraction Imaging) Topography tool in the long running range of QC-family instruments.

The QC-TT is a dedicated quality control tool, used for the detection of non visual defects (NVD), cracks and other crystalline defects by semiconductor wafers manufacturers. It is suitable for the characterization of all common semiconductor substrates, including Si, GaAs, InP, Sapphire, SiC and others.

Measurements can be run partially or fully automated, with user-customizable scripts handling the routine work. A reflection XRDI channel can be added optionally to the tool. Both channels are available at standard or high resolution.

Wafers handling can be fully automated with the optional open-cassette robot, or manually by incorporation of a sample plate with multiple locations for smaller wafers. Software allows recipes to be assigned to different wafers in the batch, reducing the user intervention within the system.

QC-TT meets R&D and Mass-Production needs of Wafer Substrate Manufacturers by detecting non-visual and other crystalline defects
QC-TT Overview

Features and Benefits

QC-TT can be configured with both Transmission and optional Reflection channels:

- Transmission channel images bulk and buried-defects throughout the wafer (up to ~ 1000µm wafer thickness)
  - Best suited for most substrate defect detection, to isolate critical defects for either slip, wafer breakage
  - Used to isolate good region within an ingot

- Materials:
  - Single crystal substrate (e.g. Si, GaAs, InP, Sapphire, SiC) and epi-layers

- Detectable defects: Dislocations, Slip-Lines, Micro-Pipes, Micro-Cracks, precipitates, sub-grains, surface scratches and anything that induces lattice strain

- Reflection channel (optional) can be added. This enables: a number of additional features, including
  - Imaging “near-surface” defects, typically up to 5µm—30µm depth
  - Rapid edge measurement for surface defects
  - Isolation of top surface damages
  - Separation of defects in highly-mismatched epi-layers, such as III-V layers on Si
  - Surface defect detection even on thick substrates (> 5mm)

- Fully automated alignment and measurement of wafer
- Batches of wafers can be measured using an optional robot
- Camera resolution switching from 3µm to >100µm without manual intervention, optimizing performance and measurement efficiency
- Full-wafer scan with no edge exclusion to identify critical defects at the very edge of the wafer
- Selective-region scan modes are supported
- Wafers / ingot slices up to 300mm diameter as standard; 450mm support is optional
- Simple to use Recipe creation and running
- Optional JV-SAI Advanced Image Analysis and Defect Detection Software with export to KLARF
Robot Automation

Fully automated wafer loading and measurements for all wafer sizes up to 200, 300

An optional robot is available for the QC-TT, which allows fully automated measurements from cassettes of wafer.

Automation (robot) support:

- Allows for robot loading of 2” to 200mm / 300mm wafers, with the associated software
- Roadmap for 450mm wafer handling
- Designed to comply with SEMI S2 and S8 standards
- Up to 3 cassettes can be loaded (option)
- Increased wafer cleanliness by removing manual handling of wafers
- Automatic software detection of wafer cassette sizes
- Increased productivity for larger wafer sizes

Measurements of wafers loaded using the robot can be performed with the same recipes as for the manual tool.

- Recipes are assigned and started through a simple user interface
- Any combination of recipes for any number of slots is possible
  - Multiple recipes per wafer
  - Different recipes for each wafer
- All alignment and measurement is performed on all wafers without user intervention

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Measurements

Methodology

A survey scan is normally taken at a resolution to identify the majority of defects, typically 70µm—100µm. These survey scans take a few minutes for even the largest wafers. As the QC-TT is imaging the strain fields due to defects, this resolution can still identify regions where smaller defects are present.

Once defects have been identified, either manually or through the optional defect identification software, higher resolution images can be performed in the small areas around the defect for closer inspection of the detail within the defect. The resolution is generally 10µm or smaller, and can image single dislocations. This mode of operation is typical for fault analysis and detailed research, rather than defect detection.

Resolution Options

A range of cameras are available, with different resolutions and capture areas. All cameras can enable binning, which groups pixels into an effective, larger pixel to enable faster read-out (for example, a 10µm camera at binning 2 has an effective resolution of 20µm). The system is supplied with a single camera, with an additional camera fitted if required. Switching between cameras is automatic.

<table>
<thead>
<tr>
<th>Camera Type</th>
<th>Native Resolution</th>
<th>Available binnings</th>
<th>Capture Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey Camera</td>
<td>85µm</td>
<td>1</td>
<td>&gt; 100mm x 60mm</td>
</tr>
<tr>
<td>Medium Resolution</td>
<td>10µm</td>
<td>1, 2</td>
<td>13mm x 10mm</td>
</tr>
<tr>
<td>High resolution</td>
<td>3µm</td>
<td>1, 2</td>
<td>3.5mm x 2.7mm</td>
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</table>
X-Ray Diffraction Imaging (XRDI)

Principles

X-Ray Diffraction Imaging (XRDI) is the fundamental technique behind the QC-TT. It has been used for many years to image crystalline defects that introduce tilt or strain within single crystal materials.

Among the types of defects which create a strain or tilt are:
- isolated dislocations and dislocation bunches
- slip due to thermal processing
- dopants and precipitates
- mechanical damage in the bulk and at the surface / edge of wafers
- grinding and polishing damage

The QC-TT images the strain field, and this is normally much bigger than the defect. This allows images with resolutions of >2µm to image single dislocation loops, even though the dislocations are created from the absence of a single atom!

In Practice

- The X-ray source and detector are located so that the wafer is in the diffraction condition (Bragg condition), either in reflection or transmission geometry
- The wafer is then scanned across X, Y while the detector on the QC-TT collects the frames and builds the full image of the requested scanned area

- XRDI is the variation in diffracted X-ray intensity across the sample due to strain fields and tilted regions in the sample
- Defects imaged by their effect on X-ray diffraction
Modes of Operation

Transmission

Transmission imaging is performed where the source and detector are placed either side of the wafer, and the X-rays penetrate though the full thickness of the wafer.

- Defects throughout the whole thickness of the wafer are imaged
- No sample preparation is required
- Non-destructive, non-contact

An additional measurement can be performed to image the cross section of the wafer without having to break the wafer

- Add additional source slit close to wafer surface
- Non-destructive Wafer Cross-Section images
- Depth resolutions down to 5µm (using 3µm camera)

Reflection

The optional reflection channel images “near surface” defects, typically up to 5µm-30µm depth. It uses a second X-ray source on the same side of the wafer as the camera.

- Rapid edge measurement for surface defects
- Isolation of top surface damages
- Separation of defects in highly-mismatched epi-layers, such as III-V layers on Si
- Surface defect detection even on thick substrates (> 5mm)

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A major issue in the semiconductor industry is that of wafer breakage, particularly from process induced damage, typically from wafer handling. For 300mm wafers there are yield losses, which are expected to increase significantly with the implementation of 450mm wafers into production.

- A 450mm wafer will contain 225% more dies than a 300mm wafer. A single wafer breakage has a 2.25x impact on yield
- Larger diameter of wafers increases risk of wafer breakage
- Increased processing of wafers increases risk of wafer breakage

Jordan Valley have developed a method of determining the breakage probability of a wafer during a rapid thermal anneal process. The images above show the stress modelling, used to enable the prediction, for a wafer with known damage and the right hand image shows the result of the annealing step, with the wafer breaking along the predicted path.
Optimize Wafer Slicing

**Substrate Manufacturer: Optimizing ingot slicing (Si and other materials)**

A common application for X-ray topography is in searching the first “known good wafer” in the ingot. The general process is

- Slice the ingot at a location where defects are expected and use the QC-TT to scan to detect dislocations
- Identify the location and length of defects, and estimate where the defects begin.
- Slice again and check this location.
- Repeat until “known good wafer” is found

This is often performed using optical inspection after defect etch. Using the QC-TT eliminates the “defect-etching” process and the use of hazardous & expensive etching chemicals (Cr based acid)

**Identifying Damaging Slip**

*Defects detection: Slip in Wafer*

- Wafer slip causes movement of the substrate
- Slip is often induced by existing defects during thermal processing
- If slip occurs after some patterning then overlay issues will occur for further patterning
- Slip through devices can cause performance failure
- Can be performed on both blanket and patterned wafers
Additional Applications

Non-Destructive Cross Sections

Non-Destructive Wafer Cross Sections can be performed on the tool in transmission geometry by closing the source slits close to the sample. The image across the stripe is then the cross section of the wafer to identify the location through the wafer of the defects.

- Non-Destructive Cross-Section Images
- Images can be collected in 1-2 minutes (depending on defects and material)
- Depth resolutions down to 5µm (using 3µm camera)

Optional Reflection Mode

- Images “near-surface” defects, typically up to 5µm—30µm depth
- Rapid edge measurement for surface defects
- Isolation of top surface damage
- Separation of defects in highly-mismatched epi-layers, such as III-V and GaN layers on Si
- Surface defect detection even on thick substrates (> 5mm)
Defect Reporting Using JV-SIA Software

QC-TT reports valuable scanning information through Image Analysis & Defect Detection Software

Image enhancement and analysis is included within the system:

- Reporting: defects’ location (X,Y), area, aspect-ratio
- Defects are highlighted on the wafer image and listed in a table
- Images are saved as .TIF (export to .jpg is supported)

The optional, comprehensive JV-SAI software suite supports:

- Automatic Image Analysis
- Automatic Defect Detection, based on pre-defined rules
- Creating Defect-Map & Defect-List
- Export industry standard KLARF™ format files to 3rd party ADC (Automatic Defect Classification) systems

KLARF is a trademark of KLA-Tencor Corporation.
Software

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 plate.

Image Processing Software

Creation of the final images is performed using the image processing software. This allows fully automated creation of the final image, a guided creation following a image creation wizard or, for expert users, fully manual construction of the image to highlight the defects of interest, along with statistical analysis, false colour and other image effects for analysis and presentation.

Defect Detection Software

Industry standard image analysis software is used to perform analysis on the resultant images. This allows defect types to be identified and displayed in industry standard image maps and used in defect classification software.