



## CHADA for Electron Channeling Contrast Imaging (ECCI)

|                           |  |
|---------------------------|--|
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| Abstract | Structured documentation of CHAracterization DATA (CHADA) gained by carrying out Electron Channeling Contrast Imaging experiments within the AddMorePower project. The structure is based on the final draft of the CWA 17815 created within the framework of the CEN/CENELEC Workshop "Materials characterisation — Terminology and structured documentation". The draft was submitted on Dec. 16, 2024 to CEN/CENELEC. |
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## Based on

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## Disclaimer

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## Executive Summary

The AddMorePower consortium is dedicated to developing characterization and modelling methods that can meet the unique needs of upcoming power semiconductor technology generations. To achieve effective and efficient research and innovation, a seamless interoperation between materials characterization, materials modelling, and data science is required. This goal can only be accomplished using FAIR and open data practices.

AddMorePower employs the CHADA and MODA methodologies to achieve FAIR data management. These systematic description and documentation methods are used for materials characterization data and materials modelling data, respectively. They are based on a common terminology, concepts and relationships defined by the community, providing a holistic approach to combine data from various materials characterization and modelling techniques, which allows analysing and modelling of complex structures.

In this document a CHADA for Electron Channelling Contrast Imaging (ECCI) experiments is presented, based on the final draft of the CWA 17815 created within the framework of the CEN/CENELEC Workshop “Materials characterisation — Terminology and structured documentation”. The draft was submitted on Dec. 16, 2024, to CEN/CENELEC.

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## Chapter 1 Introduction

The manufacturing industry is facing new challenges with the advent of Industry 5.0. Innovative solutions are required to meet these challenges. The AddMorePower consortium focuses its research on developing necessary characterization and modelling techniques to meet the needs of upcoming power semiconductor technology generations. One backbone to foster research and innovation in this field is the integration of materials characterization, materials modelling, and data science. To enable the fluent interoperation, FAIR and open data practices are needed.

FAIR data management requires harmonized data treatment and harmonized data documentation, not only within the facilities where the simulations and experiments are performed, but across communities. The [EMCC](#) and the [EMMC](#) developed two methodologies for a systematic description and documentation of materials CHAracterization DAta (CHADA) and materials MOdelling Data (MODA). In AddMorePower we make use of the developed concepts and terminology from CHADA and MODA to describe the produced data in a harmonized way and to share the gained knowledge in the community.

CHADA is a systematic description and documentation method for material characterization experiments, including user case, raw data generation and post-processing of the data. It enables the systematic investigation of materials. A harmonized experiment documentation is essential for managing material science data and for guiding the development of e.g. new materials that meet specific requirements. CHADA provides the basis for a holistic approach to combine data from different characterization techniques, which enables the analysis and modelling of complex structures and links between different experiments. It is based on a common terminology, concepts and relationships defined by the community [1]. In 2024 the common terminology and structured documentation was revised by a consortium within the CEN/CENELEC workshop “Materials characterisation — Terminology and structured documentation”, resulting in the final draft CWA 17815, which was submitted to CEN/CENELC on Dec. 16, 2024.

The CHADA terminology and structured documentation presented in this document is based on the final draft of the CWA 17815 from Dec. 2024. This CHADA is called “CHADA v2”

## Chapter 2 What is Electron Channelling Contrast Imaging (ECCI)?

Electron contrast channelling imaging (ECCI) is an electron diffraction technique performed in a Scanning electron microscopy (SEM). It is used primarily to visualize and characterize defects in materials such as dislocations, stacking faults, grain boundaries, inclusions, etc. An Electron channelling pattern (ECP), which carries the reciprocal space information from the crystal, can be used to orient the sample into a diffraction condition, also sometimes known as a channelling condition. In this geometry, with the incident beam near a Bragg condition, the contrast arising from defects will be visible. There are two main types of diffraction conditions: (1) the electron beam is diffracted from a single set of planes in a 2-beam diffraction condition, or (2) from multiple sets of planes, in a multi-beam condition. By orienting the sample into a 2-beam condition, with the incident electron beam near the Bragg condition, information from a single set of planes is probed and this can be used to determine information from defects, where contrast rules depend on diffraction vector and the crystallographic information of the defect – for example the Burgers vector of a dislocation.

## Chapter 3 Terms and definitions from CHADA v2

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at <http://www.iso.org/obp/>

— IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1 Batch

Specific quantity of material produced or processed at one time, under the same conditions.

Note 1 to entry      The term batch is often used in manufacturing and production industries to track, control, and ensure the quality of materials. Each batch typically has a unique identifier and may be subject to quality control measures to ensure consistency and compliance with quality standards.

### 3.2 Calibration data

Output data of a measurement on a reference sample by a specific measuring instrument/device/system.

Note 1 to entry      Calibration data are post-processed into corrections to be used to correct measured characterization data or to perform uncertainty calculations.

### 3.3 Calibration process

Operations/actions under specified conditions that are needed to obtain the correction used to convert the signal of the characterization measurement (as produced by the detector) into the raw characterization data.

EXAMPLE 1      In nanoindentation, the electrical signal coming from capacitive displacement gauge is converted into a calibrated raw-displacement data.

EXAMPLE 2      In nanoindentation, the electrical signal coming from capacitive displacement gauge is converted into a real raw-displacement signal after using a proper calibration function (as obtained by the equipment manufacturer). Then, additional calibration procedures are applied to define the point of initial contact and to correct for instrument compliance, thermal drift, and indenter area function to obtain the real usable displacement data.

Note 1 to entry      Within this workflow, a possible way is to use a reference sample (with pre-defined, specific, and stable physical characteristics and known properties) for the interaction with the measurement probe, in order to extract characterization data to be compared to predefined values. In this way, the accuracy of the measurement tool and its components (for example the probe) is evaluated and confirmed.

### 3.4 Materials CHAracterization DATA documentation (CHADA)

Set of forms that document materials characterization.

### 3.5 Characterisation data filtering

In data processing, process on a dataset to exclude, rearrange, or apportion data according to certain criteria.

Note 1 to entry      Preprocessing of raw data (for example, compacting data, removing outliers, filtering noise, interpolating missing data) is one type of characterization data filtering.

Note 2 to entry      The processing can include hardware filters (such as low pass filters "hardwired" to the sensor/probe).

### 3.6 Characterisation data post-processing

Data analysis and transformation that allows to calculate the material property/behavior from the calibrated primary data.

Note 1 to entry      Characterization data post-processing involves the application of a method, based on some theory or model, to primary data to calculate the secondary data that provide information about the characterization property or behavior.

Note 2 to entry      Characterization data post-processing includes digital image processing to enhance or extract useful information.

EXAMPLE 1      In nanoindentation testing, the Oliver-Pharr method is used, which allows calculating the elastic modulus and hardness of the sample by using the load and depth measured signals.

EXAMPLE 2      Analysis of Scanning Electron Microscopy (SEM) (or optical) images to gain additional information, for example microstructural analysis, grain size evaluation, digital image correlation procedures.

### 3.7 Characterisation data processing through calibration

Process that describes how signal data are corrected and/or modified based on calibrations into raw data.

### 3.8 Characterisation experiment

Execution of one specific characterization workflow.

Note 1 to entry      The term "test case" is typically used for a characterization experiment carried out to assess quality or performance against a defined reference or standard.

### 3.9 Characterisation instrument

Device used for executing characterization actions to characterize a material, alone or in conjunction with one or more supplementary devices.

### 3.10 Characterisation laboratory

Laboratory where a whole process or some of its stages take place.

### 3.11 Characterisation measurement process

Process of experimentally obtaining data (values) that are attributed to a sample.

### 3.12 Characterisation outcome

Digestion and/or judgement of the output of one or several tests given as feedback to the owner of the user story.

### 3.13 Characterisation primary data

Data resulting from applying corrections to normalize and/or harmonize characterization raw data, in order to prepare them for post-processing.

### 3.14 Characterisation raw data

Output data of the characterization measurement given by the measuring instrument.

### 3.15 Characterisation secondary data

Data resulting from the application of characterization data post-processing.

Note 1 to entry      Characterization secondary data may represent a property or a behavior.

Note 2 to entry      Characterization secondary data may be used to establish a materials relation for a simulation model.

### 3.16 Characterisation signal

Result (effect) of the interaction between the sample and the probe or between the samples, which usually is a measurable and quantifiable quantity.

Note 1 to entry      Characterization signal is usually emitted from a characteristic "emission" volume, which can be different from the sample/probe "interaction" volume and can be usually quantified using proper physics equations and/or modelling of the interaction mechanisms.

Note 2 to entry      According to IUPAC Compendium of Chemical Terminology, a "signal" is "A representation of a quantity within an analytical instrument".

### 3.17 Characterisation workflow

process composed of all necessary steps (for example, sample preparation, calibration, measurement, post-processing) to establish the property, behavior or image of a material or materials system.

### 3.18 Data pre-processing

process of curation (or preparing) data, which may come from disparate data sources, to improve their quality or reduce bias in subsequent analysis.

Note 1 to entry      If this process is applied to characterization the input is raw data and the output is primary data.

### 3.19 Data processing

computation that provides a data output following the elaboration of some input data, using a data processing application possibly exploiting a data processing model.

### 3.20 Detector

physical device (or chain of devices) that is used to measure, quantify and store the signal generated by interaction of the probe with the sample.

EXAMPLE 1 Back Scattered Electrons (BSE) and Secondary Electrons (SE) detectors for SEM.

EXAMPLE 2 Displacement and force sensors for mechanical testing.

### 3.21 Environment

Surrounding medium.

EXAMPLE 1 Environment of the material or materials system that appear(s) in the user story.

EXAMPLE 2 Medium that surrounds the characterization sample in the experiment.

### 3.22 Hazard

set of inherent properties of a substance, mixture of substances, or a process involving substances that, under production, usage, or disposal conditions, make it capable of causing adverse effects to organisms or the environment, depending on the degree of exposure (that is, a source of danger).

### 3.23 Interaction volume

The volume of material, and the surrounding environment, that interact with the probe or samples and generate a detectable (measurable) signal (information).

Note 1 to entry In some cases, the volume of interaction could be different from the volume of detectable signal emission. For example, in SEM, the volume of interaction between the electron probe and the material is different from the volumes that generate the captured signal.

EXAMPLE 1 In x-ray diffraction, the interaction volume is the volume of material that interacts directly with the x-ray beam and is usually smaller than the volume of the entire sample. Depending on sample's structure and microstructure, the interaction between the sample and the x-ray incident beam generates a secondary (reflected) beam that is measured by a detector and contains information on certain sample's properties (for example, crystallographic structure, phase composition, grain size, residual stress).

EXAMPLE 2 In SEM, the interaction volume is the volume of material that directly interacts with the incident electron beam, it is usually much smaller than the entire specimen's volume and can be computed by using proper models. The interaction between the scanning probe and the sample generates a series of detectable signals (for example back scattered electrons, secondary electrons, x-rays, specimen current) which contain information on, for example, sample morphology, microstructure, and composition.

### 3.24 Level of automation

Degree to which tasks are executed by machines using a specified protocol.

### 3.25 Level of expertise

Specific experience, education, training and/or certifications required to carry out a task.

Note 1 to entry      This field is typically relevant only for materials testing in regulated environments.

Note 1 to entry      The level of expertise in the CHADA may just be specified as low/medium/high or in a more de- tailed way with respect, for example, to operator qualifications or certifications for certain test techniques.

### 3.26 materials system

Two or more materials that are in contact and/or interacting.

EXAMPLE      Tribological properties (such as friction and wear) are not properties of a material, but properties of a system of two or more interacting bodies (for example, samples or components interacting with test probes or interfacial surfaces, non-destructive testing of machine components, inspection of materials in manufacturing processes). Consequently, multiple materials might be involved (for example, a polymeric and a metallic sample moving in a lubricated contact, or a sample subjected to chemical treatment).

### 3.27 Measurement parameters adjustment

Set of operations carried out on a characterization measurement system using a sample which is not a reference sample so that it provides values considered to be correct for a quantity being measured.

Note 1 to entry      Adjustment of a measuring system is different to calibration, which is sometimes a prerequisite for adjustment. Adjusting/tuning a measuring instrument is an activity without a reference sample (which would be a calibration). The output of this process can be a specific measurement parameter to be used in the characterization measurement process.

Note 2 to entry      After an adjustment of a measuring system, the measuring system is usually recalibrated.

### 3.28 Measurement uncertainty calculation

In data processing, the determination of the statistical dispersion of the values attributed to a measured quantity.

### 3.29 Operator

The human person who takes care of the entire process or any of its sub-processes/stages, including operating the test equipment.

### 3.30 Probe

A physical device or radiation (matter or field, together called a physical) that interacts with the sample and generates a response called signal.

|                 |  |
|-----------------|--|
| Note 1 to entry | The probe is used to acquire information on the specimen's behavior and properties.  |
| Note 2 to entry | In tribological characterization and other techniques that investigate systems, a probe may be hard to define.   |
| EXAMPLE 1       | In x-ray diffraction, the probe is a beam of x-rays with known energy that is properly focused on the sample's surface with a well-defined geometry.   |
| EXAMPLE 2       | In electron microscopy (SEM or TEM), the probe is a beam of electrons with known energy that is focused (and scanned) on the sample's surface with a well-defined beam-size and scanning algorithm.  |
| EXAMPLE 3       | In mechanical testing, the probe is a force actuator that is designed to apply a force over-time on a sample. Many variants can be defined depending on way the force is applied (for example, tensile/compressive uniaxial tests, bending test, indentation test) and its variation with time (for example, static tests, dynamic/cyclic tests, impact tests).  |
| EXAMPLE 4       | In dynamic light scattering, temporal fluctuations of backscattered light due to Brownian motion and flow of nanoparticles are the probe, resolved as function of pathlength in the sample. From fluctuation analysis (intensity correlations) and the wavelength of light in the medium, the (distribution of) diffusion coefficient(s) can be measured during flow. The Stokes-Einstein relation yields the particle size characteristics. |
| EXAMPLE 5       | In spectroscopic methods, the probe is a beam of light with pre-defined energy (for example in the case of laser beam for Raman measurements) or pre-defined polarization (for example in the case of light beam for Spectroscopic Ellipsometry methods), that is properly focused on the sample's surface with a well-defined geometry (specific angle of incidence).   |

**Commented [CC(M1)]:** it is only a focused and scanned probe in SEM or STEM. In TEM the beam is not focused or scanned.

### 3.31 Raw data normalisation

Data processing which involves adjusting raw data to a notionally common scale.

|                 |   |
|-----------------|---|
| Note 1 to entry | It involves the creation of shifted and/or scaled versions of the values to allow post-processing in a way that eliminates the effects of influences on subsequent properties extraction. |
| Note 2 to entry | Raw data normalization is one type of preprocessing of raw data.  |

### 3.32 Reference sample

Sample that is sufficiently homogeneous and stable with reference to one or more specified property(ies), which has been established to be fit for its intended referencing use in measurement or in examination.

### 3.33 Sample

Portion of the material or materials system selected for characterization or testing.

|                 |  |
|-----------------|--|
| Note 1 to entry | The term 'sample' implies the existence of a sampling error, that is, the results obtained on the portions taken are only estimates of the property/behavior present in the parent material. |
|-----------------|--|

|                 |  |
|-----------------|--|
| Note 2 to entry | Typically, the term is further qualified, for example, bulk sample, representative sample, primary sample, bulked sample, test sample. |
| Note 3 to entry | An alternate term is specimen. Sample and specimen are sometimes used interchangeably, or also with slightly different meanings.       |
| Note 4 to entry | In fields such as composites, the term coupon is used to denote a sample.  |

### 3.34 Sample extraction

Act of extracting a portion (amount) of material from a larger quantity of material. This operation results in obtaining a sample representative of the batch with respect to the property or properties being investigated.

|                 |   |
|-----------------|---|
| Note 1 to entry | The term can be used to cover either a unit of supply or a portion for analysis. The portion taken may consist of one or more sub-samples and the batch may be the population from which the sample is taken. |
| Note 2 to entry | This operation is meant to obtain a sample representative of the material with respect to the property or properties being investigated.  |
| Note 3 to entry | The portion taken may consist of one or more sub-samples and the (sub-) samples may be the population sample representing the material.   |
| Note 4 to entry | This can be applied to a batch of materials produced (population from which the sample is taken).   |

### 3.35 Sample holder

An object which supports the specimen in the correct position for the sample preparation.

EXAMPLE An example of sample holder is microtome holder.

### 3.36 Sample inspection

Analysis of the sample to determine information that is relevant for the subsequently applied characterization method.

EXAMPLE In the nanoindentation method, sample inspection is carried out by means of scanning electron microscopy to determine the indentation area.

### 3.37 Sample preparation

Sample preparation processes (for example, machining, polishing, cutting to size) are executed before actual observation and measurement.

### 3.38 Sample preparation parameter

Settings of devices used for sample preparation.

### 3.39 Test case

Characterization experiment carried out to assess quality or performance against a defined reference or standard.

### 3.40 User story

A high-level description of the problem, including the material, the environment in which it functions and the properties/behavior to be determined or explained.

Note 1 to entry      There are no details related to the characterization process, which is to be decided on by the characterization expert.

## Chapter 4 Terms and definitions from ECCI

For the purposes of this document, the following terms and definitions apply.

### 4.1 <a>-type, <c>-type, <a+c>-type dislocations

<a>, <c>, and <a+c> refer to the dislocation Burgers vectors  $b=1/3\langle 11-20 \rangle$ ,  $b=\langle 0001 \rangle$ , and  $b=1/3\langle 11-23 \rangle$ , respectively. These are the expected dislocation Burgers vector types for dislocations at the GaN surfaces analysed.

### 4.2 B/C adjustments

Brightness and contrast (B/C) adjustments made to acquired images

### 4.3 Stub

A small, non-magnetic platform to which the sample is affixed, which is then attached to the microscope stage.

### 4.4 Threading dislocations (TD)

Dislocations which span the device layers and have a line direction nominally parallel to the wafer growth direction,  $\langle 0001 \rangle$ .

### 4.5 Wafer notch and anti-notch

Processed wafers have multiple levels of alignment features. The most obvious, is the wafer notch. This is the 6 o'clock position of the wafer. The anti-notch is the 12 o'clock position. The crystallographic direction of the wafers produced for AddMorePower are  $\langle 11-20 \rangle$ , from the notch to the anti-notch.

...

# Chapter 5 CHADA v2 for ECCI

In this chapter the CHADA for ECCI experiments performed in the project AddMorePower is presented. The CHADA is based on the common terminology defined in the CEN Workshop Agreement 17815 [1] and the revised templates provided by the CEN/CENLEC Workshop from 2024.

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**Version:**

V1.0

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## 5.1 CHADA Section 1: User story

### 5.1.1 General

Table 1 —User story

| User story       |  |
|------------------|--|
| Name             | ECCI Acquisition                               |
| Description      | Generate a multi-image ECCI two 2-beam dataset |
| Client/requester | Jakob König                                    |

### 5.1.2 Material /materials system

Table 2 —Material/materials system

| Material              |  |
|-----------------------|--|
| Name                  | C:GaN                                      |
| Description           | A carbon doped GaN LUT structure           |
| Reference to standard | <i>(Add reference to standard, if any)</i> |
| Further documentation | Wafer with stack:                          |

|  |               |         |
|--|---------------|---------|
| (Link to a relevant document/web resource) | C-GaN         | 80 nm   |
|  | n-GaN         | 1000 nm |
|  | Si/GaN buffer |         |
|  | AlN           |         |
|  | Si (111)      |         |

### 5.1.3 Environment and operating conditions

Table 3 — Environment and operating conditions

| Operational context   |  |
|-----------------------|--|
| Description           | ThermoFisher Scientific Apreo 2S SEM operated in immersion mode at 15kV, 1.6nA, 5mm WD. A scan rotation is applied so that <11-20> is always horizontal. |
| Further documentation | (Link to a relevant document/web resource)   |

## 5.2 CHADA Section 2: Rationale

Table 4 —Rationale

| Rationale             |  |
|-----------------------|--|
| Description           | ECCI is used to research dislocations in materials |
| Further documentation | (Link to a relevant document/web resource)         |

## 5.3 CHADA Section 3: characterisation workflow overview

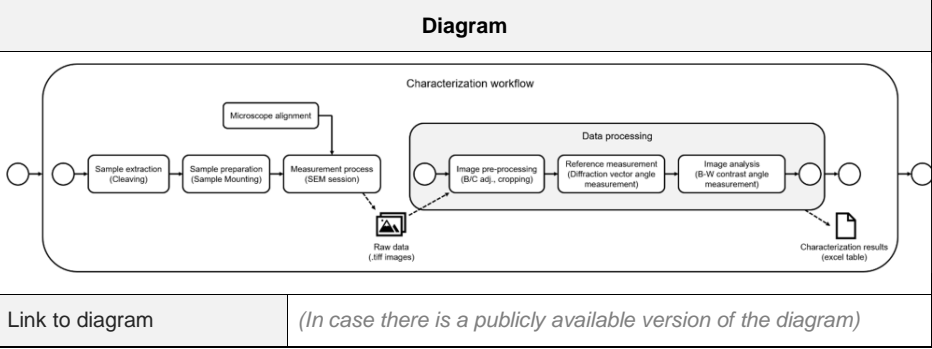
Table 5 — Characterization workflow metadata

| Characterization Workflow metadata |  |
|------------------------------------|--|
| Name                               | C:GaN threading dislocation characterization       |
| Description                        | Two 2-beam ECCI TD analysis workflow, beta version |
| Sample(s) to be tested             | 5 digit sample ID                                  |
| Test method(s) and environment(s)  | ( see Table 6                                      |
| Reference to standard              | (Add reference to standard, if any)                |
| Laboratory                         | KAI MSS  |
| Operator                           | KAI MSS ECCI expert                                |

Further documentation

(Link to a relevant document/web resource)

Table 6 — Characterization workflow diagram



## 5.4 CHADA Section 4: characterisation experiment/ test case documentation

### 5.4.1 General

Each experiment and/or test procedure should be documented by using the following template tables. If several materials or samples are tested at one time or if a time series is measured, the measurements can be kept together by considering entities to be lists or arrays.


Time series measurements can be document by considering all boxes to be arrays. In this way, all measurements in a set can be documented together in one CHADA.

Table 7 and table 8 document the material/materials system and sample(s) to be investigated in some detail. These have grey headers.

In tables 9 to 16, and in the BPMN diagram, the characterisation workflow is documented, consisting of different processes (shown with blue headers) and datasets (magenta) as inputs and outputs. Here the material(s) and sample(s) are referenced just by data their unique identifier and/or unique name.

### 5.4.2 Material/materials system

Table 7 —Material/materials system

| Material/materials system                      |   |
|--|---|
| Name   | C:GaN   |
| Identifier(s)                                  |   |
| Description                                    | A carbon doped GaN LUT structure  |
| Process history                                | <i>(including manufacturing steps or other prior processing information that describes the state of the material)</i> |
| Physical structure                             | Wafer with stack:                  |
| Composition / Chemical structure               | GaN<br>Hexagonal  |
| Properties known prior to the characterisation |   |

### 5.4.3 Sample

Table 8— Sample

| Sample |
|--------|
|--------|

|   |   |
|---|---|
| Name                                      | carbon doped GaN LUT structure  |
| Identifier                                | 5 digit sample ID   |
| Description                               | The sample is cleaved from the wafer and attached to aluminium stub with silver paint. The <11-20> (direction from wafer notch to anti-notch) is noted on the stub. |
| Reference to standard                     | <i>(Add reference to standard, if any)</i>  |
| Further documentation                     | <i>(Link to a relevant document/web resource)</i>   |
| Dimensions                                | ~1cm x ~2cm   |
| Physical structure                        | GaN LUT   |
| Material composition / Chemical structure | See <b>Table 7 —Material/materials system</b>   |
| Other sample properties                   |   |
| Hazard                                    | <i>(link to a relevant document/web resource)</i>   |

#### 5.4.4 Sample extraction

Table 9— Sample extraction

| Sample Extraction     |  |                               |
|-----------------------|--|-------------------------------|
| Name (unique)         | Cleaving                                     |                               |
| Description           | The sample is cleaved by hand from the wafer |                               |
| Input: materials data | Material                                     | C:GaN LUT                     |
|                       | Provider                                     | Infineon Technologies Austria |
|                       | Identifier                                   | 1                             |
|                       | Description                                  | Wafer piece                   |
| Laboratory            | KAI MSS                                      |                               |
| Operator              | KAI MSS ECCI expert                          |                               |
| Instrument            | Name   | None, manual step             |
|                       | Manufacturer                                 | None, manual step             |
|                       | Model  | None, manual step             |

|  |  |                   |
|--|--|-------------------|
|  | Unique ID  | None, manual step |
| Level of expertise of the operator and/ or laboratory capabilities | Experienced staff<br>(with reference to relevant standards)                |                   |
| Level of automation  | Manual; not automatable<br>(Describe what can be automated in the process) |                   |
| Reference to standard  | (Add reference to standard, if any)  |                   |
| Further documentation  | (Link to a relevant document/web resource)                                 |                   |
| Output (Sample)  | 5 digit sample ID  |                   |

#### 5.4.5 Sample preparation

Table 10 — Sample preparation

| Sample preparation |  |  |
|--------------------|--|--|
| Name (unique)      | Sample Mounting  |  |
| Description        | After the sample is cleaved from the wafer, it is attached to aluminium stub with silver paint. The <11-20> (direction from wafer notch to anti-notch) is noted on the stub. |  |
| Input: sample data | 47562<br>(unique name or ID of sample, see also sample section for a detailed description of the sample)   |  |
| Input              | (from other steps of this characterisation procedure, other procedures or external data)   |  |
| Laboratory         | KAI MSS  |  |
| Operator           | KAI MSS ECCI expert  |  |
| Instrument         | Name   |  |
|                    | Manufacturer   |  |
|                    | Model  |  |
|                    | Unique ID  |  |
| Holder             | Al pin stub  |  |
| Parameters         | (settings for the preparation)   |  |

Commented [CC(M2)]: Same comment as above

|   |  |  |
|---|--|--|
| Environment   | Description  |  |
|   | Properties   |  |
| Level of expertise of the operator and/or laboratory capabilities | Expert electron microscopist<br>(with reference to relevant standards) |  |
| Level of automation   | Manual; not automatable  |  |
| Reference to standard   | (Add reference to standard, if any)                                    |  |
| Further documentation   | (Link to a relevant document/web resource)                             |  |
| Output: prepared sample data                                      |  |  |

#### 5.4.6 Sample inspection

For the ECCL experiments sample inspection is not carried out.

Table 11— Sample inspection

| Sample inspection  |   |  |
|--------------------|---|--|
| Name (unique)      |   |  |
| Description        |   |  |
| Input: sample data | (unique name or ID of sample, see also sample section for a detailed description of the sample) |  |
| Input              | (from other steps of this characterisation procedure, other procedures or external data)        |  |
| Laboratory         |   |  |
| Operator           |   |  |
| Instrument         | Name  |  |
|                    | Manufacturer  |  |
|                    | Model   |  |
|                    | Unique ID   |  |
| Parameters         | (settings for the preparation)  |  |

|   |   |
|---|---|
| Level of expertise of the operator and/or laboratory capabilities | <i>(with reference to relevant standards)</i>     |
| Level of automation   |   |
| Reference to standard   | <i>(Add reference to standard, if any)</i>        |
| Further documentation   | <i>(Link to a relevant document/web resource)</i> |
| Output  |   |

### 5.4.7 Calibration

**Table 12 – Calibration**

| Calibration   |  |                                  |
|---|--|----------------------------------|
| Name (unique)   | Microscope calibration   |                                  |
| Description   | The SEM is already calibrated  |                                  |
| Input: reference sample data                                      | <i>(specify in case of a reference sample, reference material or a certified reference material)</i> |                                  |
| Input   | <i>(from other steps of this characterisation procedure, other procedures or external data)</i>      |                                  |
| Laboratory  |  |                                  |
| Operator  |  |                                  |
| Instrument  | Name   | ThermoFisher Scientific Apreo 2S |
|   | Manufacturer   | ThermoFisher Scientific          |
|   | Model  | Apreo 2S                         |
|   | Unique ID  |                                  |
| Parameters  | <i>(settings for the preparation)</i>  |                                  |
| Level of expertise of the operator and/or laboratory capabilities | <i>(with reference to relevant standards)</i>  |                                  |
| Level of automation   |  |                                  |
| Reference to standard   | <i>(Add reference to standard, if any)</i>   |                                  |
| Further documentation   | <i>(Link to a relevant document/web resource)</i>  |                                  |
| Output: calibration data  |  |                                  |

#### 5.4.8 Measurement parameters adjustment

Table 13 – Measurement parameters adjustment

| Measurement parameters adjustment                                 |  |                                  |
|---|--|----------------------------------|
| Name (unique)   | SEM alignment  |                                  |
| Description   | Standard microscope alignment procedure is performed at the start of the session, after tilting near to the tilts used for ECCI (~14deg) and a stage bias of 600V was applied. |                                  |
| Input: sample data  | <i>(unique name/id of the sample, see also sample section)</i>   |                                  |
| Input   | <i>(from other steps of this characterisation procedure, other procedures or external data)</i>  |                                  |
| Laboratory  | KAI MSS  |                                  |
| Operator  | KAI MSS ECCI expert  |                                  |
| Instrument  | Name   | ThermoFisher Scientific Apreo 2S |
|   | Manufacturer   | ThermoFisher Scientific          |
|   | Model  | Apreo 2S                         |
|   | Unique ID  |                                  |
| Parameters  | <i>(settings for the preparation)</i>  |                                  |
| Level of expertise of the operator and/or laboratory capabilities | Experienced electron microscopist<br><i>(with reference to relevant standards)</i>   |                                  |
| Level of automation   | Manual steps; some could be automated  |                                  |
| Reference to standard   | <i>(Add reference to standard, if any)</i>   |                                  |
| Further documentation   | <i>(Link to a relevant document/web resource)</i>  |                                  |
| Output: adjusted settings for the instruments                     |  |                                  |

### 5.4.9 Measurement Process

Table 14 – Measurement Process

| Measurement Process   |   |                                  |
|---|---|----------------------------------|
| Name (unique)   | SEM session   |                                  |
| Description   | Acquire a set of SEM images at two different diffraction conditions.                            |                                  |
| Input: sample data  | 5 digit sample ID   |                                  |
| Input   | <i>(from other steps of this characterisation procedure, other procedures or external data)</i> |                                  |
| Laboratory  | KAI MSS   |                                  |
| Operator  | KAI MSS ECCI expert   |                                  |
| Instrument  | Name  | ThermoFisher Scientific Apreo 2S |
|   | Manufacturer  | ThermoFisher Scientific          |
|   | Model   | Apreo 2S                         |
|   | Unique ID   |                                  |
| Parameters  | <i>(settings for the preparation)</i>   |                                  |
| Probe   | Electrons   |                                  |
| Interaction volume  |   |                                  |
| Detector  | T1, T2, T3  |                                  |
| Environment   | Description   | High vacuum                      |
|   | Properties  |                                  |
| Characterisation signal   |   |                                  |
| Level of expertise of the operator and/or laboratory capabilities | Expert electron microscopist<br><i>(with reference to relevant standards)</i>                   |                                  |
| Level of automation   | Manual (could be automated)   |                                  |
| Reference to standard   | <i>(Add reference to standard, if any)</i>  |                                  |
| Further documentation   | <i>(Link to a relevant document/web resource)</i>   |                                  |
| Output: raw data  | Images in .tiff format  |                                  |

#### 5.4.10 Data processing

**Table 15 — Data processing (1)**

| Data processing (1)   |   |
|---|---|
| Name  | Image pre-processing  |
| Description   | Register the g1 and g2 images, number each dislocation, crop an area (~100pixels) around each dislocation, adjust the B/C to make the TD B-W contrast obvious |
| Input   | SEM images in .tiff format<br>( <i>raw data, primary data</i> )   |
| Type of data processing   | Image registration, numbering of TDs, cropping, B/C adjustments   |
| Data processing model   |   |
| Data processing software  |   |
| Laboratory  | KAI MSS   |
| Operator  | KAI MSS ECCI expert   |
| Level of expertise of the operator and/or laboratory capabilities | Experienced electron microscopist<br>( <i>with reference to relevant standards</i> )  |
| Level of automation   | Manual, but could be automated  |
| Reference to standard   | ( <i>Add reference to standard, if any</i> )  |
| Further documentation   | ( <i>Link to a relevant document/web resource</i> )   |
| Output  | Pre-processed SEM images in .tiff format  |

**Table 16 – Data processing (2)**

| Data processing (2)      |   |
|--------------------------|---|
| Name                     | Diffraction vector angle measurements                           |
| Description              | Diffraction vector angle measurements                           |
| Input                    | Pre-processed SEM images in .tiff format                        |
| Type of data processing  | Image registration, numbering of TDs, cropping, B/C adjustments |
| Data processing model    |   |
| Data processing software |   |

|   |   |
|---|---|
| Laboratory  | KAI MSS   |
| Operator  | KAI MSS ECCI expert   |
| Level of expertise of the operator and/or laboratory capabilities | Experienced electron microscopist<br>(with reference to relevant standards) |
| Level of automation   | Manual, but could be automated  |
| Reference to standard   | (Add reference to standard, if any)   |
| Further documentation   | (Link to a relevant document/web resource)                                  |
| Output  | List of diffraction vectors angle measurement                               |

Table 17 – Data processing (3)

| Data processing (3)   |  |
|---|--|
| Name  | Image analysis – B-W contrast measurements   |
| Description   | Measure B-W contrast direction from white to black. A +/- 5deg allowance from orthogonal to the diffraction vector is considered orthogonal. |
| Input   | Pre-processed SEM images in .tiff format & diffraction vector angle measurement  |
| Type of data processing   | Measurement of B-W contrast direction and comparison to g1 and g2  |
| Data processing model   |  |
| Data processing software  | MS Excel   |
| Laboratory  | KAI MSS  |
| Operator  | KAI MSS ECCI expert  |
| Level of expertise of the operator and/or laboratory capabilities | Experienced electron microscopist<br>(with reference to relevant standards)  |
| Level of automation   | Manual, but could be automated   |
| Reference to standard   | (Add reference to standard, if any)  |
| Further documentation   | (Link to a relevant document/web resource)   |
| Output  | List of angle measurement  |

## 5.5 CHADA section 5: results analysis

| Characterisation results   |                       |  |
|----------------------------|-----------------------|--|
| Characterisation results 1 | Input                 | List of diffraction vectors angle measurement  |
|                            | Method                | <p>If B-W_angle1 is orthogonal to g1 AND if B-W_angle2 is orthogonal to g2, then the TD is c-type. Please note, a +/- 5deg allowance from orthogonal to the diffraction vector is considered orthogonal.</p> <p><i>(description including method by which results were obtained across several characterisation procedures or test series)</i></p> |
|                            | Output                | List of c-type TDs   |
|                            | Further documentation | <i>(Link to a relevant document/web resource)</i>  |
| Characterisation results 2 | Input                 | List of diffraction vectors angle measurement  |
|                            | Method                | <p>If B-W_angle1 is EQUAL TO B-W_angle2, then the TD is a-type. Please note, there is a +/- 5deg angle allowance.</p> <p>The a-type B-W contrast is also quite a bit smaller than the a+c and c-type TDs.</p>  |
|                            | Output                | a-type TDs   |
|                            | Further documentation | <i>(Link to a relevant document/web resource)</i>  |
| Characterisation results 3 | Input                 | List of diffraction vectors angle measurement  |
|                            | Method                | If the TD is not c-type and it is not a-type then it is a+c type.  |
|                            | Output                | a+c type TDs   |
|                            | Further documentation | <i>(Link to a relevant document/web resource))</i>   |

## Chapter 6 List of Abbreviations

| Abbreviation  | Translation   |
|---------------|---|
| B/C           | Brightness/Contrast                                 |
| B-W           | Black-White   |
| BSE           | Back-scattered Electron                             |
| CHADA         | Materials Characterization Data                     |
| ECCI          | Electron Channelling Contrast Imaging               |
| ECP           | Electron Channelling Pattern                        |
| EMCC          | European Materials Characterization Council         |
| EMMC          | European Materials Modelling council                |
| g1, g2        | Diffraction vector #1, diffraction vector #2        |
| GaN           | Gallium Nitride                                     |
| LUT structure | Layer Under Test structure                          |
| KAI           | Kompetenzzentrum Automobil- und Industrieelektronik |
| kV            | kilovolt  |
| ms            | milliseconds  |
| MSS           | Materials Science and Simulation                    |
| SE            | Secondary Electron                                  |
| SEM           | Scanning Electron Microscopy                        |
| Si            | Silicon   |
| TD            | Threading Dislocations                              |
| TEM           | Transmission Electron Microscopy                    |
| WD            | Working Distance                                    |

## Chapter 7 Bibliography

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