

Product-Category Rules (PCR)
for Preparing an Environmental Product
Declaration (EPD) for

Silicon Substrate

PCR 2012:1.0

Wafer Works Corp.

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1. General Information

This document is to be used as the product category rules (PCR) for the manufacturing of silicon substrate (“product”) by the semiconductor industry. The requirements specified in this PCR are intended to be used for EPDs certified in accordance with ISO 14025 standard. This document shall be valid until December 31, 2014.

This PCR was prepared by the Wafer Works Corp.. Representatives from major Taiwanese manufacturers of similar products and stakeholders were invited to the open consultation meeting on August 1, 2012, to participate in the discussion and review of this PCR. Environment and Development Foundation (EDF) then reviewed and approved this PCR.

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2. Company and product description

The EPD shall include information about the manufacturing company/organization. The information may include manufacturing process related information, and environmental related information, such as the environmental management system information. The information may also include special issues which the company/organization would like to emphasize, such as the products meeting certain environmental criteria, or environmental safety and health related information.

This PCR is applicable to business-to-business (B2B) communications. While conducting certification of environmental impact assessment, the inventory of silicon substrate products also includes the raw materials and packaging materials.

2.1 Product group function

Silicon substrate refers to the silicon carrier used by the semiconductor industry in the production of integrated circuits. Silicon substrate is produced from slicing long cylindrical silicon ingot into thin slices/wafer which then go through the grinding and polishing process. Although the silicon wafer itself does not conduct electricity, its conductive property can be modified through addition of some appropriate dopants, and control of flow of electrons through the silicon wafer can also be achieved through applying external electric field. Take advantage of this feature, the semiconductor industry is able to manufacture electronic components for use in various applications through surface treatment of the silicon substrate.

Common types of silicon substrate:

- Classification based on dopants: P-type (boron), N-type (phosphorus, arsenic, antimony) single crystal silicon wafer;
- Classification based on electrical resistance: light dopant ($> 1\Omega\text{-cm}$), heavy dopant ($<1\Omega\text{-cm}$)

2.2 Product components/constituents

The main components/constituents of the silicon substrate include:

- Primary/main material: pure silicon;
- Secondary/other materials: dopants (e.g., boron, phosphorus, arsenic, antimony etc.);
- Packaging materials (used during product shipping): cushion material, packaging bag, aluminum foil bag, cardboard box, etc.

The data quality requirements for the main components/constituents are described in Section 9 on calculation rules and data quality requirements. The EPD shall also include the other constituents of the product, but their data quality requirements are different from those of the main constituents.

2.3 Product technical description

The product technical description part of the EPD may include but not limited to the following information:

- Crystal growth: e.g., Czochralski (CZ) method, Float Zone (FZ) method
- Orientation: e.g., 100, 110, 111
- Type: P, N
- Dopant: Boron, Phosphorus, Arsenic, Antimony, etc.
- Diameter: e.g., mm
- Thickness: e.g., μm
- Resistivity: e.g., ohm-cm
- Oxygen content: e.g., ppma
- Carbon content: e.g., ppma

3. List of materials and chemical substances

The contents of the following materials and substances in the product shall be declared:

- All materials of the product (excluding packaging material);
- All materials of the packaging with weight ratio (material weight/packaging weight) $\geq 1\%$;
- All substances/materials in the product restricted/regulated by legal, customer and environmental requirements. For example, banned/restricted substances.

The declaration of halogen-free flame retardants, lead-free solders and no RoHS-regulated substances may only be made when appropriate evidences are available (for example, test reports from accredited laboratories/testing facilities). The following organizations may provide accreditation for testing facilities: Taiwan Accreditation Foundation (TAF), (Asia Pacific Laboratory Accreditation Cooperation (APLAC), International Laboratory Accreditation Cooperation (ILAC) or ILAC Mutual Recognition Arrangement (ILAC MRA). For definitions of testing methodology and confirmations of regulated hazardous substances based on the accredited laboratories' product testing methods, please refer to IEC 62321 Standard.

4. Declared unit

The declared unit is one (1) piece of silicon substrate wafer, with the indication of wafer diameter (e.g., 100 mm (4-inch), 125 mm (5-inch), 150 mm (6-inch), 200 mm (8-inch) and 300 mm (12-inch)), as the silicon substrate products are marketed and sold in such a unit.

5. System boundaries

The main system boundaries for the declared product system are presented as follows:

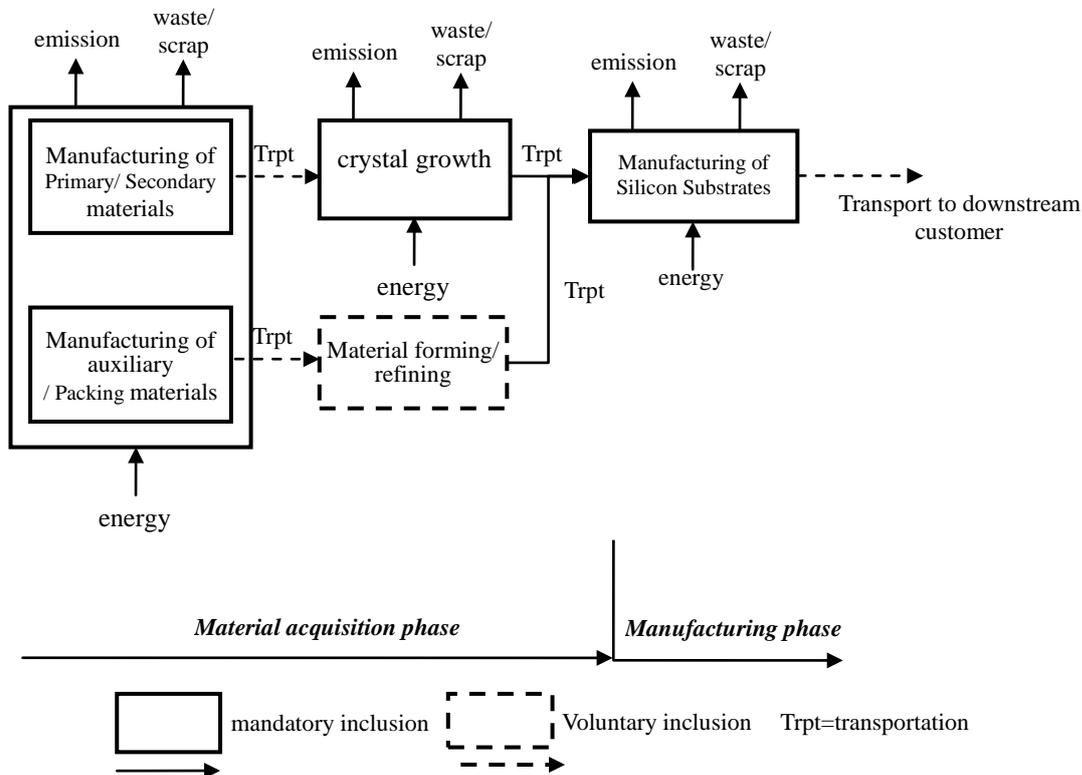


Figure 1 System boundary of the silicon substrate product system

As noted in Figure 1 above, the life cycle of the silicon substrate covers two life cycle stages: raw material acquisition and product manufacturing. The reporting of the distribution (to downstream manufacturers) stage information is considered optional (see Section 9). The data quality requirements for the raw materials/constituents are described in Section 9 on calculation rules and data quality requirements.

Raw Materials Acquisition Stage

The LCA shall include information for the following unit processes:

- Relevant extraction and production processes for the main and secondary materials;
- Relevant processes for the auxiliary and packaging materials;
- Relevant processes related to crystal growth of silicon substrate.

Reporting of information regarding raw material forming and refining, as well as transportation for raw materials is optional (voluntary).

Manufacturing Stage

The LCA shall include information for the following unit processes:

- Relevant processes for product manufacturing which may contain silicon ingot slicing, edge rounding, polishing, etching, crystal back-side processing, polishing, cleaning, inspection (testing), epitaxy, packaging and other related processes;
- Relevant processes for production of consumable supplies, such as grinding wheels, crucibles, and wire saws used during the product manufacturing processes;
- In-plant transportation of main/secondary materials and semi-finished products during the product manufacturing processes; and
- Relevant processes for the treatment of wastewater, waste and waste gas generated from the manufacturing stage; for the recycling part, the transportation to the recyclers shall be included; information regarding intermediate processing prior to the final disposal and transportation to the landfill site shall also be included.

Distribution and Marketing Stage

This stage includes the transportation of products from the manufacturing plant to the distribution sites and may include reporting of optional information for the following processes:

- Reporting of information regarding transportation of products from the manufacturing plant to the downstream manufacturers is optional;
- Relevant processes regarding downstream manufacturers' transportation and waste treatment are not included.

Use Stage

The scope of the product's inventory is B2B in nature, thus the reporting of information for this stage is not included.

Recycling/end-of-life Stage

The scope of the product's inventory is B2B in nature, thus the reporting of information for this stage is not included.

5.1 Specification of different boundary settings

Boundary in time

The validity period for the LCA results presented in the LCA report shall be defined.

Boundary towards nature

If the manufacturing processes are located within Taiwan, the solid waste categories as defined in Taiwan's Waste Disposal Act shall be adopted. If the processes are located in other countries, equivalent legal requirements shall be considered.

The natural boundary of the system shall describe the boundary where the materials and energy resources flow from nature into the system, and where the water and air emissions and waste are released out of the system.

Only the quantity of the disposed waste needs to be considered; landfilling process does not need to be considered. If the waste is generated through wastewater treatment or incineration process, such waste should be included into the wastewater treatment or incineration process.

Boundaries in the life cycle

The boundaries in the product life cycle are described in Figure 1. The construction of the site and infrastructure, as well as the production of manufacturing equipment do not need to be included.

Boundaries towards other technical systems

Boundaries towards other technical systems describe the inputs of material and other components towards other systems, as well as outputs of materials towards other systems. For the inputs of recycled materials and energy towards the product manufacturing stage, the transportation between the recycling process and use of recycled materials shall be included in the data set. For the production of recyclable products during the manufacturing stage, the transportation towards the recycling process shall be included.

(Note: Further explanations are provided in Section 7 on open-loop recycling)

Boundaries regarding geographical coverage

The manufacturing stage may cover manufacturing processes located on any sites around the world. For processes located in a specific region, the data used should be representative of the region. The data for the main constituents shall be the specific regional data for the region where the process takes place (see Section 9). For ease of comparison, no matter where the emissions are generated, the same environmental impact parameters should be used for life cycle impact assessment (see Section 10).

6. Cut-off rules

For any impact category, if the sum of various impacts from a specific process/activity is less than 1% of the impact equivalent in that category, such a process/activity may be neglected during the inventory analysis. Nonetheless, the accumulated impact of neglected process/activity may not exceed 5%. Components and materials omitted from the LCA shall be documented.

(Note: This judgment for this “1% Rule” is based on the environment relevance assessment of material input to the system, and does not consider special and exceptional environmental impacts.)

7. Allocation rules

The main allocation rules shall be valid for the entire product system. For other secondary processes, other allocation rules may be defined; however, the use of these rules should be justified. Product-specific information should be preferentially collected in order to avoid the need for allocation. While selecting allocation rules, the following principles are recommended.

- **Multi-output:** The allocations are based on the changes in the resource consumption and pollutant emissions (for example, adopted quantity allocation for some main component, or surface allocation for some components), following the changes in the studied system’s output product or function or economical relationship.

- **Multi-input:** The allocation is based on actual relationship. For example, the manufacturing process's emissions may be affected by the change in waste flow input.
- **Open loop recycling:** For the input of recycled materials or energy during the manufacturing stage of the product system, the transportation between the recycling process and the recycling to material use shall be included in the dataset. For the product which shall be recycled during the manufacturing stage, the transportation towards the recycling process shall be included.

Notes:

- *Allocation may be avoided through avoidance of dividing processes, for example as described in Section 6.3 of ISO/TR 14049; or through expansion of system boundary (for example as described in Section 6.4), so that the amended system shares the same product exchanges as the original system.*

8. Units

The base units and derived units of the International System of Units (SI, *Système International d'unités*) shall be used preferentially.

Power & energy units:

- power unit: W
- energy unit: J

Specification units:

- length unit: m
- capacity unit: m³
- area unit: m²
- weight unit: kg

If necessary, prefixes may be used before the SI units.

- 10⁹ = giga, symbol "G"
- 10⁶ = mega, symbol "M"
- 10³ = kilo, symbol "k"
- 10⁻² = centi, symbol "c"
- 10⁻³ = milli, symbol "m"
- 10⁻⁶ = micro, symbol "μ"
- 10⁻⁹ = nano, symbol "n"

9. Calculation rules and data quality requirements

Data quality requirements for the raw material acquisition stage

- Generic data may be used for the raw material acquisition and manufacturing of the silicon substrate's main/secondary/auxiliary materials and packaging materials. Please refer to Appendix I for the common sources of generic data.
- Site specific data shall be used for the crystal growing process of the product. If other types of information are used, description of the information and rationale for using the information shall be provided.

Data quality requirements for the manufacturing stage

- Site specific data (for example, specific data for manufacturing plant or transportation) shall be used for the manufacturing stage. If other types of information are used, description of the information and rationale for using the information shall be provided. For site specific data of main component manufacturing plants, specific data from a plant representative of such a site may be used.
- Generic data may be used for the manufacturing of other materials for the silicon substrate, and based the calculation on actual consumption. Please refer to Appendix I for the common sources of generic data.
- When generic data are used, the equivalence between the chemical and/or physical process, as well as the technology and system boundaries of the referred generic system with the declared product system shall be considered. Moreover, it is also recommended to consider the date or geographic aspects of the data quality when feasible.
- Generic data may also be used when suppliers refuse to provide specific data, or when even if generic data are used in place of specific data, there is only minor impact to the results. The general rule is that if generic data are used in place of specific data, their combined contribution for all life cycle stages shall not be greater than 20% of total impacts for each impact category. But there may be certain exception to specific products, and such exceptions shall be explained.
 - The data shall be representative for the average of a specific year. If the average data for a specific year cannot be obtained, the average data for a specific time period may be used, the data shall be representative, and the reason for using such data shall be provided.
- The electricity mix for the manufacturing stage should be site specific data. If site specific data cannot be obtained, the official electricity mix for the country where the site is located may be used as approximate value. The electricity mix should be documented.
- For the definition of hazardous waste, the definition as defined in Taiwan's Waste Disposal Act shall be used for sites located in Taiwan. For sites located outside Taiwan, legal requirements for the host country shall be observed.
- For the transportation of main components/constituents to the manufacturing plant, the actual transportation modes used and distance traveled shall be considered.

Data quality requirements for the distribution and marketing stage

- Reporting of information for this stage is optional.

10. Parameters to be declared in the EPD

The following parameters shall be declared in the EPD:

Energy use

- The energy consumption during each product life cycle stage shall be declared. If the product is intended for end-users, the power consumption during the use stage shall also be declared.
- The following units shall be used preferentially:
 - kW or W for power; J or MJ for energy.

Resource use

The information on resource input during the product life cycle stages shall be declared.

Impact equivalents expressed as potential environmental impacts

-Global warming	kg CO ₂ equivalent
-Acidification	kg SO ₂ equivalent
-Photochemical oxidant formation	kg C ₂ H ₄ equivalent
-Eutrophication	kg PO ₄ ³⁻ equivalent
-Ozone depletion	kg CFC-11 equivalent

Note: For characterization factors of each impact category, please refer to *EPD Supporting Annexes*, Version 1.0 (2008-02-29), The International EPD Cooperation, downloadable from www.environdec.com.

Additional information

- Recyclable materials (optional)
- Information on secondary materials (optional)
- Waste (classification):
 - Hazardous waste as defined in Taiwan's Waste Disposal Act. Follow host countries' laws for sites outside Taiwan.
 - Other waste.
- Plastic parts marking: Where technologically possible, plastic parts of the vehicle weighing ≥ 25 g shall be marked in accordance with the ISO 11469 and ISO 1043 Part 1/2/3/4, SPI or other international standard label to facilitate their identification and recovery at the end of life.
- Plastic packaging material marking: The Plastic packaging materials shall be labeled on the parts with SPI or other international standards for ease of sorting.

11. Recycling information

If practical, information for the constituents which can not be recycled and therefore should be disposed of properly during the end-of-life stage may also be included.

12. Other environmental information (Optional)

The EPD may cover information including technology adopted, site of product manufacturing and assembly, as well as information on other working environment, health and risk-related aspects.

If this PCR is to be used for product carbon footprint declaration purpose, in the declaration, information regarding commitment on GHG reduction should be included and shall ensure that the commitment is measurable, reportable and verifiable. The organization may also list environmental

and energy management related information, such as awards, commendations and system certifications (e.g., ISO 14001, ISO 14064-1, IECQ HSPM) etc.

14. References

The EPD shall make reference to the following documents:

- EPD General Program Instructions, Version 1.0 (2008-02-29), The International EPD Cooperation, downloadable from <http://www.environdec.com/>;
- Relevant PCR documents;
- The underlying LCA report.

When available, the following documents shall also be referenced:

- Other documents and recycling instructions which verify and complement the EPD.

Appendix I – Generic Data Sources to Refer to

For processes located within Taiwan, Taiwan generic data or the data published by the commercial, industrial and energy competent authorities of the Republic of China (ROC) government, may be used. However, for other regions (such as EU), if there are more relevant generic data available, these data should be used instead. When data from the following generic databases are used, the most current and updated data should be used.

Material	Database
Packing materials, transport, Waste treatments	BUWAL 250
Steel, Primary copper, Copper products, Electricity, Fuels, Aluminum, Chemicals, Transports, Waste management	ELCD EIME (Environmental Information and Management Explorer) EcoBilan
Plastics	PE Plastics Europe (Association of Plastics Manufacturers in Europe) ELCD EIME (Environmental Information and Management Explorer) EcoBilan
Electronic components	ELCD EIME (Environmental Information and Management Explorer) EcoBilan
General Database	Ecoinvent The Boustead Model PE-GaBi DoITPro (Taiwan)

Appendix II – Reporting Format for the EPD

This appendix provides guidance information for the titles of sections, types of data and required information to be reported in the mandatory reporting part of the EPD. As a generic reporting template, the following titles and sub-titles are recommended:

(Refer to the PCR manual for the section numbering, the information in Italics are the recommended data/information for inclusion)

Introductory part

Each EPD should have an introduction part on the top part of the EPD which includes the following information:

- *Company/organization name*
- *Product name*
- *EPD registration number*

Description of the company/organization and product/service

Company/Organization

- *Description of company/organization*
- *Description of overall working environment, existing quality system and environmental management system*

Product and services (see Section 2)

- *Product's main applications*
- *Description of product specification, manufacturing process, manufacturing sites (if there are several sites)*
- *For product's environmental performance aspects, characteristics which may improve the usefulness of product*
- *Other types of relevant information, for example, special manufacturing processes with special advantages to the environment*

List of materials and chemical substances

- *Content declaration (see Section 3)*

Presentation of the environmental performance

- *Outline of the LCA methodology, for example, period of LCA, declared units, system boundaries (graphical presentation), cut-off and allocation rules, and data sources.*

Manufacturing stage (see Section 10)

Use stage (see Section 10)

- *Geographical region for product delivery*
- *Transportation data*
- *End-of-life information*

Information about Company and Certification Organization

Recycling information (see Section 11)

Other environmental information (see Section 12)

Information regarding certification (see Section 13)

- *Names of certification and verification organizations*
- *Validity of certification certificates*
- *Compliance with legal and relevant requirements*

References (see Section 14)

- *relevant PCR documents*
- *EPD General Program Instructions, Version 1.0 (2008-02-29)*
- *underlying LCA study*
- *other supporting documents for LCA information*
- *other relevant documents regarding company/organization's environmental activities*

Appendix III Abbreviations

Acronym	Common Name
APLAC	Asia Laboratory Accreditation Cooperation
CFP	Carbon Footprint of Product
EPD	Environmental Product Declaration
ErP	Energy Related Product
ILAC	International Laboratory Accreditation Cooperation
ILAC MAR	International Laboratory Accreditation Cooperation Mutual Recognition Arrangement
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
PCR	Product Category Rule
RoHS	The Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
SPI	Society of the Plastics Industry
TAF	Taiwan Accreditation Foundation
TEC	Typical Energy Consumption
Trpt	Transportation
WEEE	the Waste Electrical and Electronic Equipment Directive
CZ	Czochralski method
FZ	Float Zone method