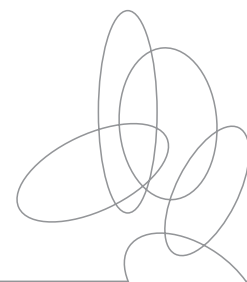


APPLICATION NOTE



PV-FZ™ SILICON WAFERS FOR HIGH EFFICIENCY SOLAR CELLS

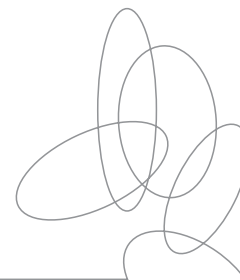
PV-FZ™ monocrystalline silicon wafers are recognised for their superior quality by the Photovoltaic (PV) industry. Float Zone (FZ) technique is used for growing the monocrystals emphasising tight process control. Hence, all important parameters for process control and high efficiency solar cells are optimised.

The continuous demand for higher efficiency pushes the PV development towards standard semiconductor process control methods. PV-FZ™ wafers are offering quality levels similar to the standard for semiconductor components production. The PV-FZ™ material has the highest quality and is outperforming all other types of ordinary PV material such as Czochralski, monocrystalline silicon and multicrystalline silicon (mc-Si).

In 2003, Topsil introduced PV-FZ™ silicon wafers to support the development and making of high efficiency silicon solar cells, now used worldwide by major manufacturers and research laboratories. PV-FZ™ silicon wafers are available as n- and p-type material with bulk resistivity targets in the range from 0.5–30 Ωcm . The material's superior properties are based on the following critical parameters:

- High minority carrier bulk lifetime
- Low oxygen content
- Low resistivity variation

All these parameters are precisely controlled in the PV-FZ™ process as demonstrated in the following, justifying the use of PV-FZ™ in a variety of applications.



PV-FZ™ Applications:

- a) Process and product development
- b) Prototyping/manufacturing
- c) Process control

A. PROCESS AND PRODUCT DEVELOPMENT

FOCUS ON THE DEVELOPMENT TARGET

When new processes and cell designs are under development, it is important to keep focus on the innovative approach and the conditions imposed by the new process itself. If the Key Performance Indicators measured are limited by the substrate quality (low lifetime) or blurred by large wafer-to-wafer resistivity variations, it becomes difficult to make conclusions on the true potential of the design or process change under development.

To avoid such problems, wafers of stable high quality should be used in the development work, where high purity, high lifetimes and narrow resistivity specification will increase sensitivity towards inherent design and processing issues in the development phase.

PV-FZ™ wafers are ideal for developing and testing new emitters, new doping sources, new drive-in recipes, new surface passivation, new metallisation, etc. The true process and design controlled limitations can fast and better be understood from respective and relevant characteristics such as emitter current density, open circuit voltage, surface recombination velocity, minority carrier lifetime, carrier mobility, IQE, etc.

B. PROTOTYPING/MANUFACTURING

A ROBUST MANUFACTURING SEQUENCE

Before a new product is brought into mass production, a stepwise mapping of the robustness of the overall process sequence is required. This is needed in order to determine the final product tolerances and variability/binning, as it is important to be able to distinguish between the inherent process variability and the influence of the substrate on this variation.

For specialty products like high efficiency solar cell and concentrator cells, it might be of advantage to shift the entire production to the PV-FZ™ platform, as this will ensure higher overall performance and less wafer induced variability.

PV-FZ™ wafers are ideal when implementing new processes or designs in production environment or executing minor speciality production series of demanding high quality products.

C: PROCESS CONTROL

FURNACE CLEANLINESS AND STABILITY

REDUCE THE IMPACT OF WAFER VARIATIONS ON YOUR SPC MEASUREMENTS

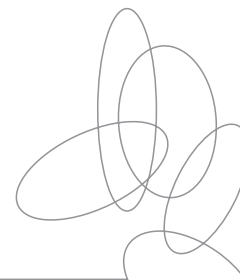
Over time, your furnace and gas supply system will be contaminated by gas condensates, and both heating elements and furnace insulation materials will degrade. Hereby also important properties of the device being processed will change. In order to monitor the overall process stability and detect any change or drift in the process Key Performance Indicators (KPI), monitor wafers are added to the production batches or dedicated standard test recipes are executed to monitor this performance. When applying this type of Statistical Process Control (SPC), it is important to reduce the impact of the wafer material itself to achieve a measurement that truly represents the status of the process – and which not merely mirrors the actual batch of dummy wafers used.

INCREASE THE SENSITIVITY OF YOUR SPC MEASUREMENTS

In high-class R&D labs or production environment, high contamination levels or large step-changes in furnace or process characteristics are rarely observed. Instead small changes and a slow performance drift that is hard to detect are observed. In order to distinguish minor details in a process control chart, it is important that the measurement is as sensitive as possible and does not become blurred by the intrinsic variations of dummy wafer characteristics. To increase SPC system sensitivity, Topsil PV-FZ™ can be used as reference wafers for process control. When the reference wafer is of high purity, high resistivity and high lifetime, SPC system sensitivity is improved as regards the ability to detect even small changes in the process characteristics. PV-FZ™ wafers can be used to monitor the performance of oxidation furnace, PECVD furnace, emitter formation, metallisation, etc.



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PV-FZ™ Material

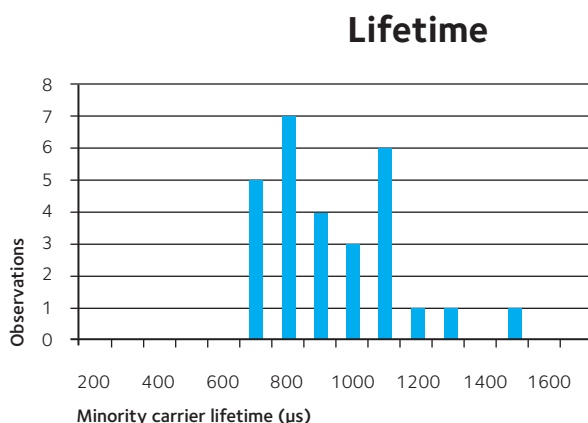
Minority carrier lifetime (μs)*	100-6000
Oxygen concentration (cm^{-3})	$< 2 \cdot 10^{16}$
Resistivity variation	20%

* Minority carrier lifetime depending on resistivity.

Lifetime

The main reason for the supremacy of FZ silicon is the longer bulk lifetimes as compared to other PV substrate materials. At 2 Ωcm , the bulk lifetime exceeds 1000 μs and the bulk lifetime monotonically increases to 4000 μs at 30 Ωcm . Even at resistivities below 1 Ωcm , the bulk lifetime is high; at 1 Ωcm between 350-550 μs and at 0.5 Ωcm between 80-100 μs . These high bulk lifetimes enable the fabrication of monocrystalline silicon solar cells with efficiencies well above 20%.

Figure 1 shows bulk lifetime measurements on p-type 1.5 Ωcm PV-FZ™ ingots. N-type PV-FZ™ ingots have more than a two times higher bulk lifetime than p-type PV-FZ™ material. Figure 1 shows measurement from the seed end, the non-seed end and mid-point of the ingot (axial). The measured bulk lifetime is significantly higher than bulk lifetimes measured on ordinary PV silicon crystals of the same resistivity.



Oxygen

Oxygen in the silicon bulk has been identified as one of the major obstacles in the making of stable silicon solar cell systems. Light induced degradation and thermal donor activation is attributed to the formation of B-O metastable complexes. For ordinary p-type solar cells, a 10% decrease can be expected, relative to the initial efficiency level, due to light induced degradation. FZ silicon based solar cells, on the other hand, do not suffer from light induced degradation. .

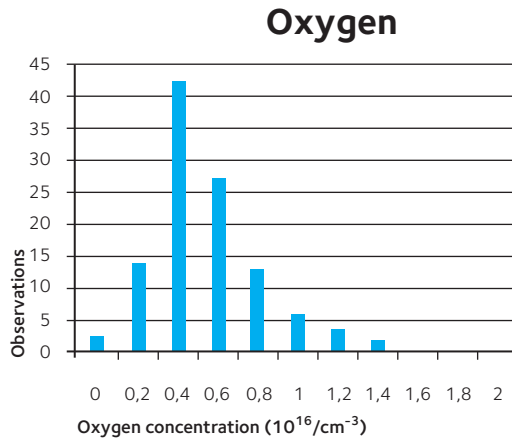
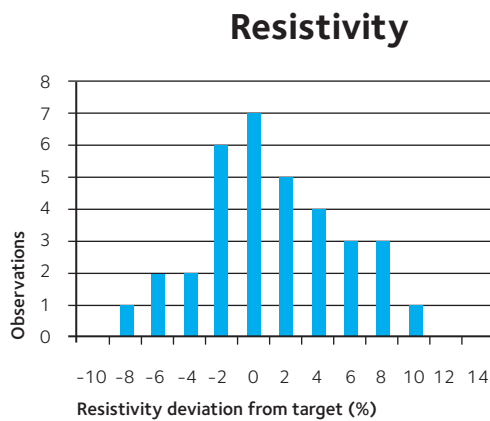


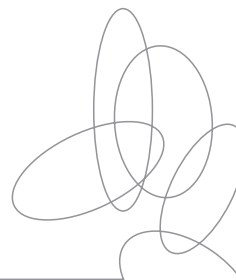
Figure 2 shows the distribution of oxygen amongst several FZ ingots, including PV-FZ™ ingots. The oxygen content is below 10^{16} cm^{-3} for most of the ingots. A few are above 10^{16} cm^{-3} , but that is still two orders of magnitude lower than what is observed in ordinary silicon crystals. Thermal donor activation in high oxygen content silicon changes the apparent resistivity of the bulk silicon material and this, combined with the actual bulk resistivity variation, will cause an unpredictable solar cell efficiency output.

Resistivity

Ordinary PV crystal material has a large spread in bulk resistivities coming from many different contributors that are difficult to control in the crystallisation/solidification as well as variation in feedstock quality. These resistivity variations from ingot to ingot, from wafer to wafer and within one wafer, must be taken into account in the early design phase of the solar cell system, because the wafer resistivity is an important optimisation parameter in the solar cell design. Variations in the bulk resistivity thus result in larger variations of solar cell efficiencies, and most manufacturers are therefore forced to test every single solar cell.



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PV-FZ™ material has a much lower spread in bulk resistivities because it is always manufactured from high quality feedstock material and the FZ process provides direct axial control of the resistivity. Figure 3 shows the resistivity tolerance for a (150mm) PV-FZ™ ingot. The resistivity variation is low and in the order of +/- 10%. Combined with a small production variance from ingot to ingot, the minimum resistivity variation is kept very low for the PV-FZ™ product, in contrast to ordinary silicon crystals which often have minimum variation in the order of 50%. The large spread in solar cell efficiency can thus be minimised by using PV-FZ™ material because of the lower resistivity variation of the PV-FZ™ batches.

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The Topsil Group is a leading supplier of high performance silicon wafers to the power market and specialty wafers for the MEMS, detector, communication and the Photo Voltaic markets. Topsil's leading position in the high power market combined with Cemat's strong position in the low power market, ranks Topsil Group as one of the top five manufacturers of silicon wafers to the Power market on a global scale.

The Topsil Group forms strong partnerships with customers and suppliers and bases the R&D efforts on future customer needs. With production facilities in Denmark and Poland, the group employs around 400 specialists and other highly committed staff. The Topsil Group is publicly listed at the Nasdaq OMX Copenhagen stock exchange.