Manufacturers of silicon wafers and cells are challenged to deploy indepth material analysis in order to optimize material performance and increase the efficiency and quality of their products. Fraunhofer ISE provides customized Efficiency Analysis packages including experimental results as well as detailed expert reports based on our unique methodology. The spatially resolved analysis allows a separation of the efficiency potential in the best wafer areas or a separation of losses due to e. g. crystal defects. Additional measurements of metastable defects, such as interstitial iron or chromium, in combination with a detailed efficiency analysis, lead to a deeper understanding of the origin of material related efficiency limits.

Efficiency Analysis Package

With our unique analysis method ELBA we are able to determine the efficiency potential of silicon material produced with a specific solar cell process. The analysis is based on wafers before or after gettering. Active layers (e. g. emitter diffusion) are etched away and the surface is passivated by a high-quality surface passivation layer. To ensure an injection-independent surface recombination, Al₂O₃ is used for p-type Si wafers and SiNx is used for n-type Si wafers. The spatially resolved charge carrier lifetime is measured at varying generation rates. The realistic injection conditions of the solar cell provide the basis for the efficiency analysis. A solar cell simulation model is required in order to relate the measured material quality to achievable cell efficiencies. Corresponding to the customers’ demands, different models can be evaluated. Besides the efficiency, the specific material related losses in open-circuit voltage, fill factors and short-circuit currents can be investigated quantitatively (Fig. 1). The origin of losses can also be traced back quantitatively. Compared to IV-measurements on finished cells this analysis method shows very good agreement.
Quantification of Loss Mechanisms

A spatially resolved analysis of different wafer regions permits a detailed quantification of the origins of losses in the specific material (Fig. 2 and 3). With regard to multicrystalline silicon we quantitatively separate losses due to dissolved impurities, decorated crystal defects and the edge region of solid-state impurity in-diffusion. This allows for a deeper understanding of the origins of efficiency losses in order to identify further material optimization potentials.

Impact of Metastable Defects

In addition to the charge carrier lifetime spatially resolved images of impurities from metastable defect imaging can also be used to calculate the efficiency limits originating from a specific defect (Fig. 3).

Injection-Dependent Impact of Metastable Defects on Cell Parameters

Spatially resolved and injection-dependent analyses of certain defects also enable us to assess its impact on different cell parameters in various parts of the wafer (Fig. 4).

Efficiency Analysis Package

- Sample preparation: High quality surface passivation of silicon wafers: Al₂O₃ for p-type Si and SiNₓ for n-type Si
- Measurement of spatially-resolved and injection-dependent charge carrier lifetime
- Imaging of metastable defects (Fe, Cr, BO)
- Determination of the fraction of charge carrier recombination via the investigated defects
- Efficiency analysis for different cell models on the basis of spatially resolved lifetime and impurity measurements
- Report of results and conclusions

Optionally Available Analysis or Processing

- Local dislocation density mapping (etch pit density)
- Light element analyses (FTIR)

Efficiency analysis of two multicrystalline wafers crystallized in different crucibles. Different regions used for the analysis of Fig. 3 are marked.

Detailed separation of different origins of efficiency losses. The overall bulk recombination losses are separated into losses stemming from the dissolved impurities in the melt, the decorated crystal defects and the edge region of solid-state impurity in-diffusion. Furthermore specific efficiency losses due to interstitial iron are evaluated.

Spatially resolved and injection-dependent impact of interstitial iron on cell parameters. Due to the strong injection dependence, the impact of interstitial iron on $J_{sc}$, $V_{oc}$ and the fill factor differ significantly.