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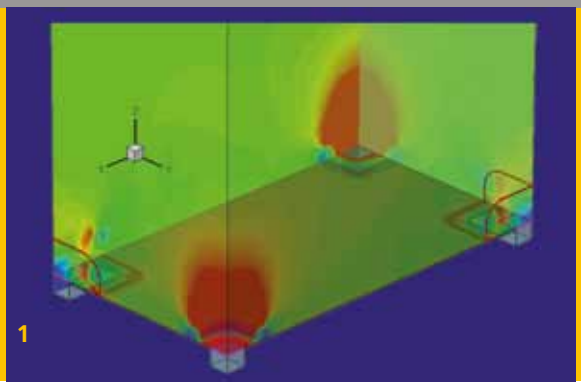
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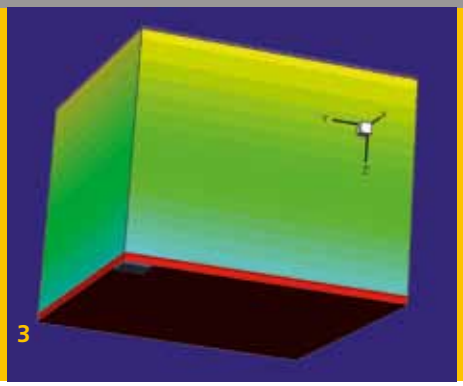
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1 *Current density of minority carriers for an n-type back-junction back-contact solar cell.*
2 *Optical simulation of the absorbed photon density in a symmetry element (quarter of an inverted pyramid).*
3 *Simulated minority carrier density for a symmetry element of a solar cell with point contacts and aluminium emitter at the back side.*

DEVICE AND PROCESS SIMULATION FOR SILICON SOLAR CELLS

In the quest for further efficiency increase of solar cells at reduced costs, new cell concepts are getting strongly into focus. Such concepts are often complex and exhibit a large number of processing steps. The numerical modelling of the production processes and the complete solar cell provide here the decisive key to reduce the time to market, as they can dramatically reduce the number of required experimental tests.

Device Simulation

With the solar cell simulator "PC1D", the determination of the performance-limiting factors of a solar cell are often possible simply by performing a simultaneous adjustment to the quantum yield and the current-voltage characteristic. Complex solar cell structures, however, are no longer possible to be described one-dimensionally or even analytically. Multidimensional properties like point contacts or "wrap-through" emitter can only be precisely investigated with two- and three-dimensional simulation tools. For this purpose, we use, and have developed several years of experience with the semiconductor simulation environment "Sentaurus TCAD" to investigate electronic properties. The use of this complex simulation program makes it especially possible to correctly model and analyze highly doped surface layers. For the electrical modelling, the results of a three-dimensional optical simulation usually serve as input parameters.

A constant expansion and improvement of the models in close cooperation with technologists at the institute ensure that novel solar cell concepts can also be described and subjected to a detailed loss analysis. E. g., the analysis of solar cells with an aluminium Back Surface Field was improved by the implementation of incomplete ionization of the aluminium atoms. Currently, in addition to the description of crystalline solar cells, an improved modelling of hetero junctions is being developed.

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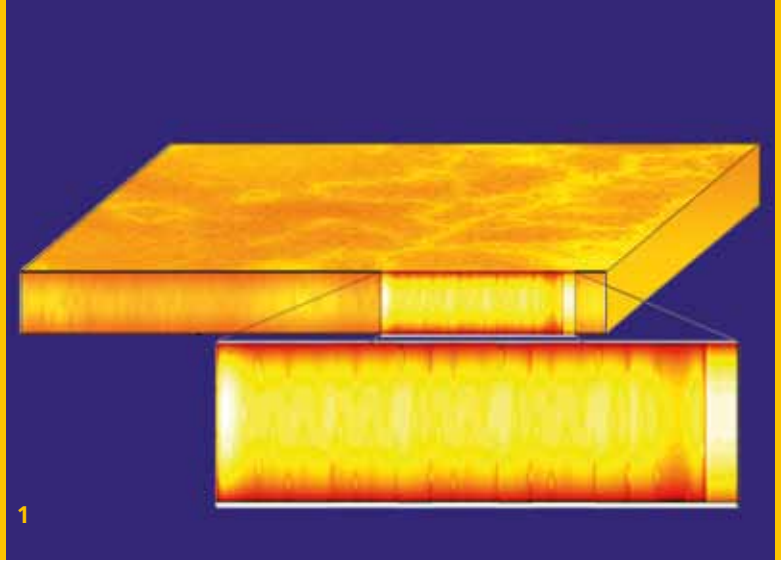
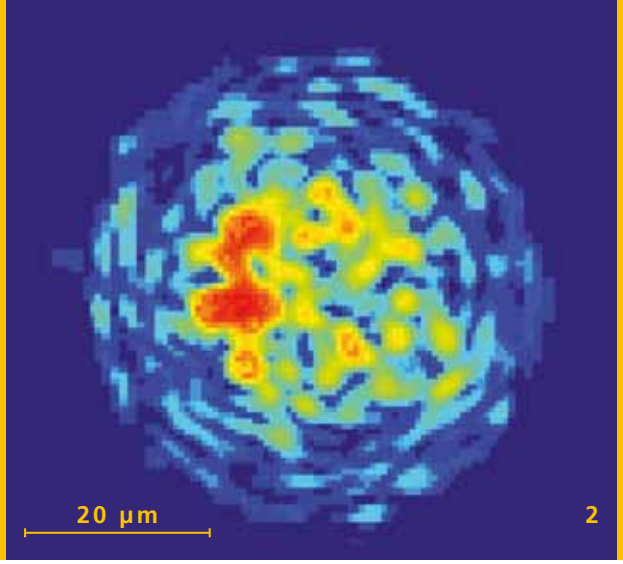


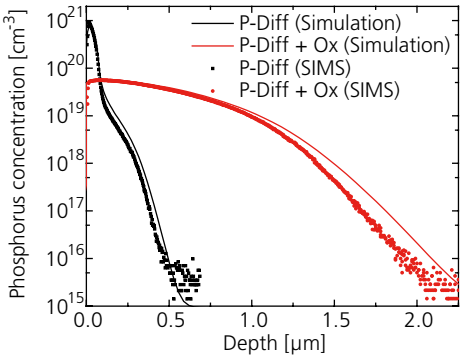


1 *Comparison of measured (perspective surface) and simulated dissolved iron concentration after phosphorus diffusion and contact firing (initial iron concentration 2 x 10^{14} cm^{-3}).*

2 *Simulated depth of the doping profile after a single laser pulse during laser-chemical-processing (LCP).*

Process Simulation

The simulation of diffusion of dopants is of great interest from a technological point of view. For this purpose, at Fraunhofer ISE, models have been developed with the help of "Sentaurus TCAD". Finding processing conditions for desired dopant depth profiles can be greatly speeded up with the simulations, even for multi-step diffusion conditions. In order to take the finite qualities of the dopant source into account and to enable predictability, the simulation of phosphorous dopant in a tube furnace also accounts for the growth of the phosphorous silicate glass. This model is currently being adapted for doping with boron, which is used in n-type solar cells. The models also enable us to simulate oxidation and overcompensation processes.



Comparison of the secondary ion mass spectrometry (SIMS) measurements and the simulated phosphorus depth profiles after emitter diffusion as well as after additional oxidation.

The diffusion and gettering behaviour of metallic impurities, from crystallization up to the finished solar cell, are numerically investigated. The simulations allow an optimization of the high temperature processes regarding the impurity distribution. For multicrystalline silicon, a specially designed two-dimensional model structure is used, which accounts for the varying precipitation and gettering behaviour in the vicinity of crystal defects. The models developed for iron are being tested for other important metals in solar silicon. The models can be combined with each other, as well as with the device simulations. Even before the first experiment is started, this allows estimation of doping profiles and two-dimensional iron distributions as well as of resulting solar cell parameters. An additional important requirement here is the knowledge about the material properties, which is constantly being further improved with the help of the corresponding working groups at Fraunhofer ISE.

The simulation activities at Fraunhofer ISE additionally include specific solar cell processes, such as doping with laser-chemical-processing. Both the laser-induced melting and the dopant diffusion in the melt can be simulated for this process, allowing the optimal laser parameters to be found.

Major Fields of Research

- analysis and evaluation of novel solar cell concepts
- predictive modelling of dopant profiles
- simulation and optimization of gettering processes
- optimization of laser doping processes
- improvement of the physical understanding of solar cell behaviour and identification of the limiting factors