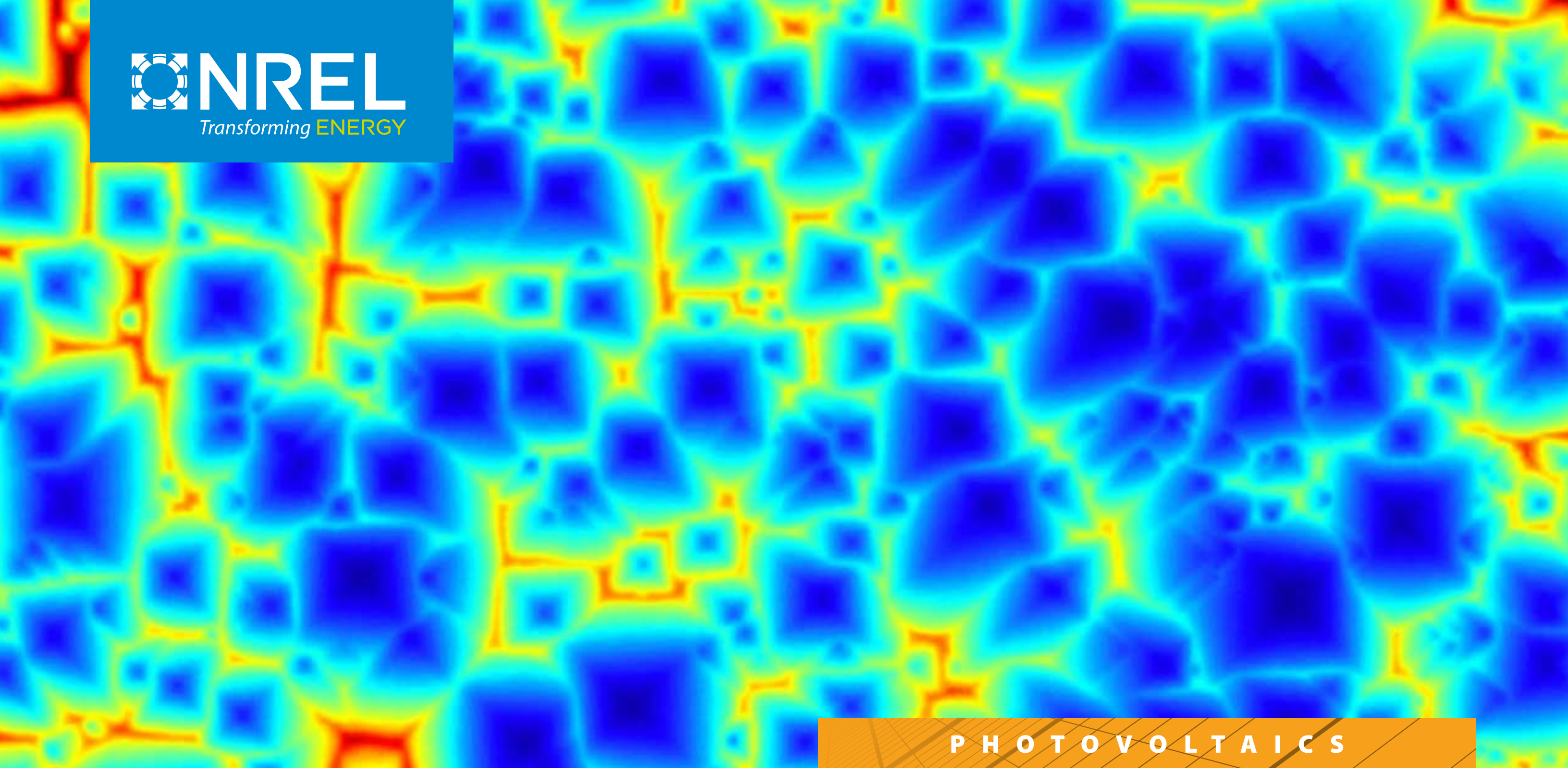


Electron-beam-induced current map of a pyramid-textured poly-Si/SiO_2 passivated-contact cell. *Image by Harvey Guthrey, NREL*

Silicon Materials and Devices

To contribute to the U.S. Department of Energy's involvement with the U.S. photovoltaic (PV) industry's efforts to meet very competitive PV efficiency, cost, and reliability goals, NREL's Silicon PV program focuses on next-generation, high-efficiency silicon (Si) PV.

Our main research thrust advances cell efficiencies by developing new concepts, materials, structures, and methods. Our integrated approach combines scientific research, production-worthy processes, and reliability testing of relevant technologies.

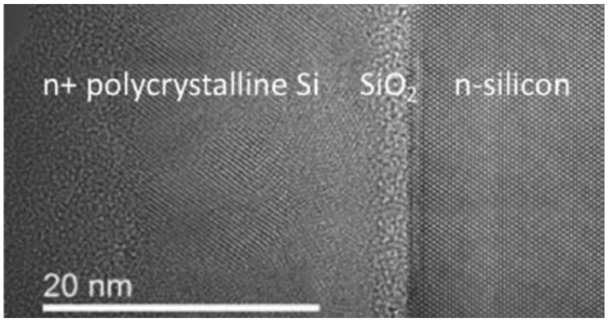
The Silicon Group strives to develop a solid scientific foundation and applied science for Si PV both in the near and long term, interacting with and helping U.S. industries to advance their manufacturing, process development, research, and reliability. We also team up with academia to tackle difficult barriers to high cell efficiencies and novel, Si-based PV materials and device structures. NREL's Si PV facilities and tools for both device processing and advanced characterization enable close interaction with industry and academia and training of the next generation of scientists and engineers for the U.S. PV industry. Over a third of our team are graduate students from, e.g., the Colorado School of Mines and Arizona State University (ASU). They acquire a unique set of skills that are highly relevant for both the solar and electronics industries.

The current focus of our team is on high-efficiency, wafer-based Si cells—both single-junction and tandem. This focus reflects the strategic goal to increase cell efficiencies to a new level, while keeping costs down in industrially relevant ways. Since the beginning of our new Si program in 2013, we have established core capabilities and world-recognized expertise in the following three areas of Si PV:

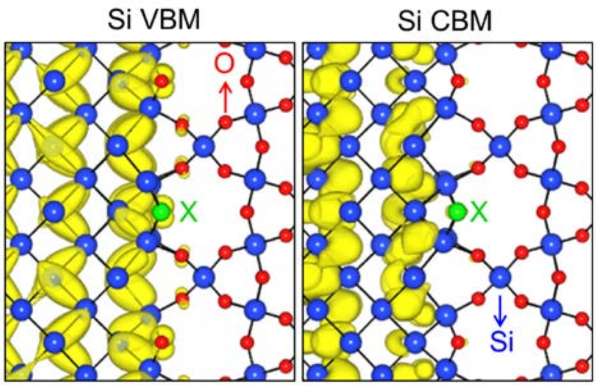
1. High-lifetime, reproducible, and stable bulk Si for wafers by research-based engineering of defects in n- and p-type Cz wafers.
2. Fundamentals of passivated contacts and their incorporation into devices (materials science, metallization, and reliability).
3. Core device fabrication capabilities for high-performance passivated contact-based Si solar cells.

Our achievements include: developing clean, reproducible Tabula Rasa treatments to both n-Cz and p-Cz wafers to suppress process-induced bulk lifetime degradation, with the responsible O-precipitate and vacancy-type defects identified and mitigated; pursuing advanced lifetime spectroscopies in collaboration with ASU; and using ESR and cryo-FTIR to identify light- and temperature-induced defects in industrially relevant p-Cz Si. In the poly-Si passivated contact field, which we jointly entered in 2014 with Fraunhofer ISE and the Georgia Institute of Technology, we have developed solid source layer hydrogen passivation and interface engineering; doping and doping-patterning techniques for those contacts; and engineered nano pinhole contacts on textured surfaces. We hold several patents in these areas. Our special strength is integrating advanced analytical tools in our research, such as TOF-SIMS, EBIC, TEM, EELS, and SEM, as well as atomistic theory.

In addition, the Silicon Materials and Device Group has expertise in thin-film silicon materials such as hydrogenated amorphous Si (a-Si:H) and crystalline Si cells with a-Si:H heterojunction contacts; nanocrystalline Si, thin-crystal epitaxial Si, and nanoparticle Si. We also have expertise in advanced light management and trapping in both thick and thin Si cell applications.



Transmission electron microscopy image of a poly-Si/SiO_2 passivated contact to an Si wafer. *Image by Andrew Norman, NREL*



Atomistic simulations of engineered interface defects that facilitate carrier transport through passivated contacts. *Illustrations by Yuanyue Liu*

Core Competencies and Capabilities

- Automated wet chemistries for Si wafer processing
- Wafer Si cell process based on thermal diffusion as well as poly-Si-based passivated contact approaches (PECVD, LPCVD)
- Passivation with PECVD nitride and ALD alumina, as well as liquid and superacid passivation for wafer diagnostics
- Cell processing (lithography, screen printing, thermal PVD metallization)
- Multiple deposition capabilities in thin-film Si cluster tool for large-area (156-mm x 156-mm) devices (a-Si:H heterojunctions, a-Si for poly-Si contacts, TCO, nitride)
- Cell characterization (J-V, QE, Suns-Voc, Sinton lifetime), C-V, lifetime mapping with photoluminescence; photothermal deflection spectroscopy, micro-Raman and micro-PL mapping; transient capacitance; DLTS; rapid thermal annealing; H-effusion mass spectrometry; electron spin resonance; EBIC integrated with TEM sample preparation; TEM-EELS/EDS; SEM; LBIC; cryo-FTIR; TOF-SIMS (with 2D mapping) and dynamic SIMS; RBS; XPS; and Auger mapping.

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