Tunneling metal oxide layers combined with industrially applicable novel cleaning methods can boost the current efficiency limit, which corresponds to approximately 22% in production, of crystalline silicon (c-Si) solar cells. Within the scope of this dissertation, extremely thin tunneling layers (1-3nm) of Aluminum Oxide (Al2O3) is studied in conjunction with the development of wet cleaning procedures that are feasible in production lines currently exist today. These tunneling stacks are deployed to serve as exceptional surface passivation layers due to the inherent built-in charge provided by Al2O3. This capability is further strengthened by the introduction of extremely well controlled wet chemical oxide which not only saturates the dangling bonds at the interface but also enables conformal growth of the aforementioned tunneling oxide layers. Therefore, the interplay between Al2O3 thickness, which effects the passivation quality tremendously, and carrier extraction capability (contact resistance) is also taken into account by the choice of ultimate boron doping profile and the optimization of the cleaning procedure. The resulting hole collecting surface passivation stack applied on doped surfaces provided record values of recombination current densities (35-40 fA/cm2), with highly applicable contact resistivity values, enabling one-dimensional carrier transport, (≈15 mΩ ·cm2). This dissertation is also concerned with spatially resolved characterization methods of such industrial c-Si solar cells given the importance of defects that can exist in these large area devices. Analytical image processing algorithms pertaining to biased-photoluminescence (PL) measurements are conducted to portray 2D maps of physical significant devices parameters such as dark saturation current density and efficiency. Finally, Fourier analysis is added into the analysis of raw PL images to pick up only the defected regions of the cells.