# Residual layer etching techniques for NIL in photovoltaics

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Silicon, as indirect bandgap semiconductor, suffers from weak absorption especially in the near IR. In photovoltaics, this necessitates photon management schemes in order to prolong internal light paths. Such photonic concepts gain even more in importance when realizing silicon-based tandem solar cells. We already demonstrated the importance of light trapping in a multi-junction device (GaInP/GaAs//Si) by raising the cell efficiency from 31.4% to 33.3% just by adding a nanoimprinted rear side diffraction grating [1]. This is to date the highest conversion efficiency reached for a two-terminal silicon-based tandem solar cell [2].
The mentioned photonic structure was realized using interference lithography. The resulting crossed grating with a period of 1 µm was replicated onto the rear of solar cells by applying a thermally assisted UV-Roller-NIL process to pattern SU8 [3,4] with subsequent plasma etching to remove the residual layer. This resist pattern was coated with silver (thermal evaporation), leading to a photonic mirror that additionally acts as the rear side contact of the solar cell.
A detailed examination of the cells of the photonic rear side structure from Ref. [1] revealed the following improvement potentials. We found that the plasma removal of the residual layer causes two potentially negative aspects: (i) the remaining resist pattern shows a nano-rough surface, which might give rise to enhanced parasitic absorption (see Fig. 1) [5]; (ii) the surface passivation and thus the electrical quality of solar cells can degrade strongly. Therefore, we established a wet chemical process using the so-called piranha solution ($H_2O_2$:$H_2SO_4$) to remove the residual layer without surface roughening and to avoid plasma damages.
The influence of dry and wet chemical etching of residual layers was studied on single junction silicon solar cell architectures. Optical properties were characterized via quantum efficiency measurements. For both techniques, plasma and piranha etching, we found an integrated gain of the short circuit current density ($j_{sc}$) very similar to the 1.1 mA/cm² reported in [1] (Fig. 2., left). Thus, we cannot confirm any harmful effects caused by the nano-roughness in the plasma etching process and degradation of the passivation for 100 nm thick poly Si layers. However, we found that thinner poly-silicon passivation layers (15 nm), which have a lower free carrier absorption, strongly degraded due to plasma etching of the residual layer. Using the wet chemical etching of residual layers no degradation was found (Fig. 2, right). Altogether, an improved wet chemical residual layer etch leads to a comparable optical and a superior electrical performance for the presented photonic rear concept based on NIL.

References:

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[3] H. Hauser et al., “Honeycomb texturing of Silicon via nanoimprint lithography for solar cell applications,” IEEE Journal of Photovoltaics 2, 114–122 (2012).
[4] N. Tucher et al., “Characterizing the degradation of PDMS stamps in nanoimprint lithography,” Microelectronic Engineering 180, 40–44 (2017).
[5] S.-K. Kim et al., “Surface-plasmon-induced light absorption on a rough silver surface,” Appl. Phys. Lett. 98, 11109 (2011).

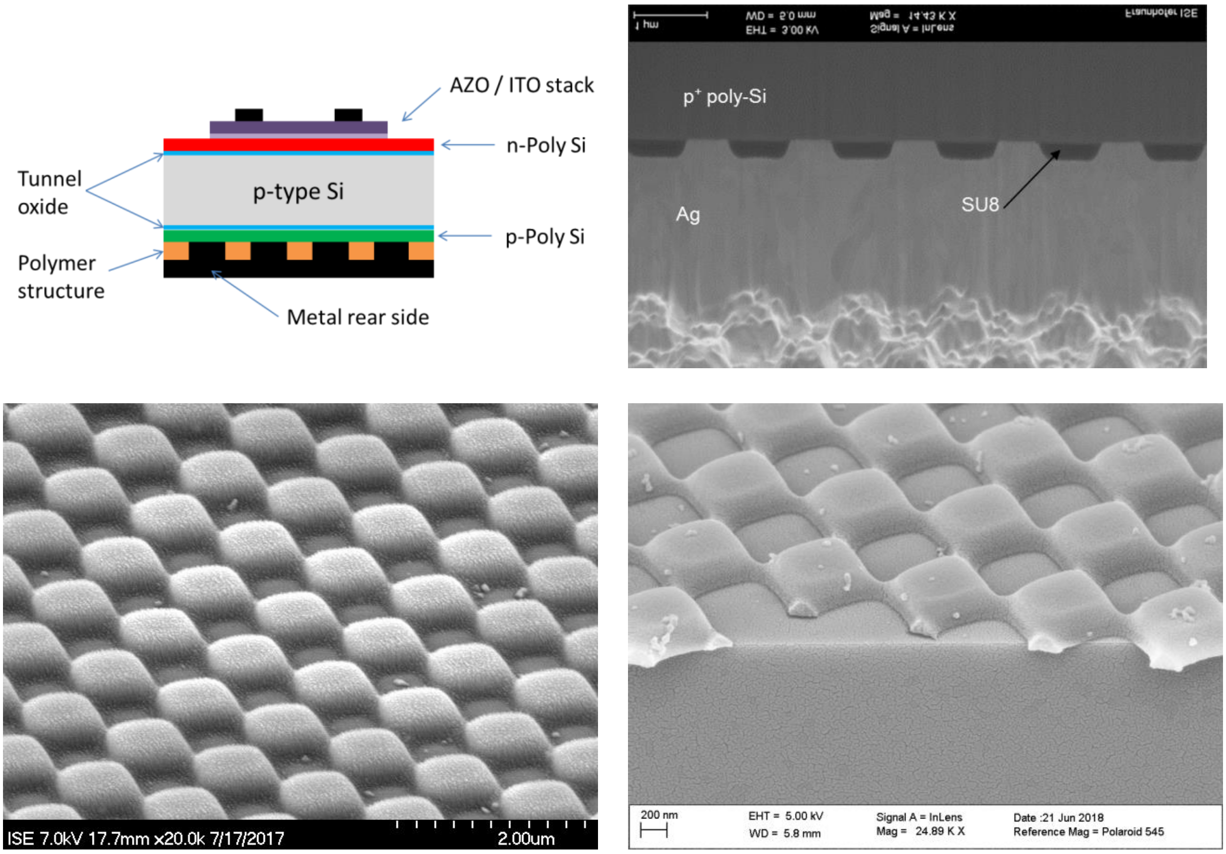


**Figure 1.** Top left: Sketch of the solar cell structure applied for this study consisting of a p-type base with both sides passivated poly-silicon contact layers. On the rear side the partially opened polymer structure can be seen. Top right: Cross section SEM of the rear poly-silicon / SU8 / silver interfaces. Bottom row: SEM micrographs of via NIL structured resist layers after plasma (left) and Piranha (right) treatment for the opening of the residual layer.

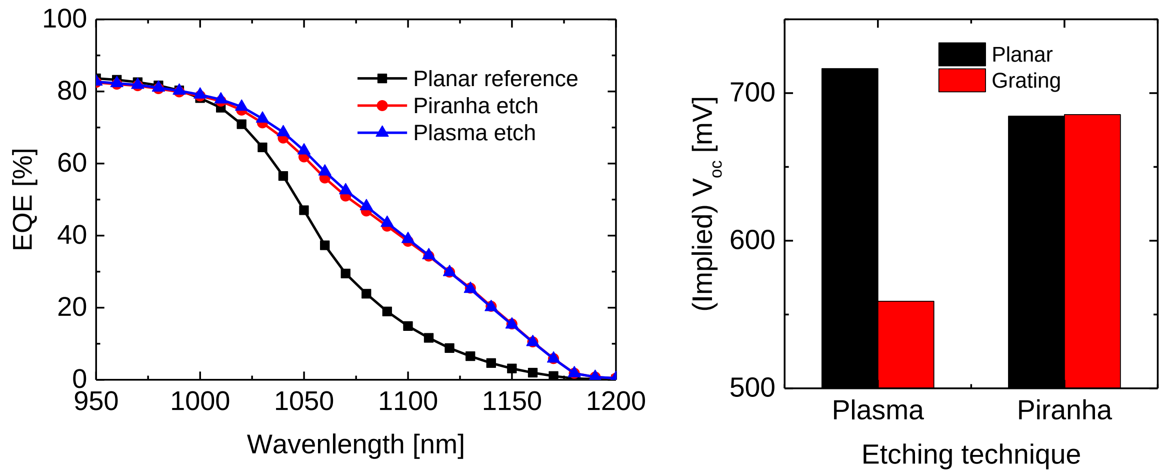


**Figure 2.** Left: External quantum efficiency (EQE) measurement of single junction silicon solar cells with plasma or piranha etched residual layer as well as a planar reference. Both etching techniques lead to a gain in $j_{sc}$ of 1 mA/cm². Note: In this case, 100 nm thick passivation layers were applied. Right: A graph visualizing influence of the residual layer etching technique on the passivation quality for a 15 nm thick poly-silicon layer. While the passivation and thus the (implied) open circuit voltage drastically degrades for the plasma treatment (based on minority carrier lifetime measurements), no effect can be seen for the wet chemical approach (based on solar cell measurements).