On the use of polymer blend lithography for light-trapping in ultra-thin silicon solar cells

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Achieving efficient light trapping in ultra-thin silicon solar cells remains a key challenge in the pursuit of high-performance, low-cost photovoltaic technologies. Periodic nano-patterning methods can provide more efficient light-trapping than conventional random texturation, but they require complex and expensive fabrication techniques. In this context, polymer blend lithography emerges as a promising alternative, offering a low-cost, scalable, and versatile strategy to fabricate pseudo-periodic nano-structures that offer directional light scattering. Our approach relies on the spontaneous phase separation of two immiscible polymers, polystyrene (PS) and PMMA, dissolved in a common solvent and spin-coated onto a silicon substrate. Upon solvent evaporation and thermal annealing, this binary mixture self-organises into nano-structured domains whose geometry depends on processing parameters such as spin speed, polymers molar mass and polymer ratio. By selectively removing one of the polymer phases, we create a mask that can be transferred into the underlying silicon or silicon dioxide layers (used as a hard mask to enable deeper etching) through a dry etching process, resulting in a pseudo-periodic nanostructure optimised for light trapping.

Through a detailed experimental study, we demonstrate that the morphology and size of the pattern can be controlled by tuning fabrication conditions (Figure). In particular, the fraction factor, pseudo-period, and circularity of the domains can be modulated. Fourier analysis confirms the pseudo-periodic nature of the structures (blue insets), and we highlight the reproducibility of the method on Si substrates. To better understand the physical mechanisms behind the self-organisation process and the observed limitations, such as the failure to form domains at high PS concentration (e.g., 70 PS:30 PMMA) with polymers of 100 kg/mol molar mass, a Cahn–Hilliard-based phase-field simulation model has been developed. The model qualitatively captures key experimental trends, such as domain morphology and observed asymmetries, and offers insights into the origin of certain limitations. These insights open the door to new strategies for tuning the final morphology, such as adjusting polymer molar masses or solvent content, which will be investigated experimentally. Overall, our work establishes polymer blend lithography as a viable route for nano-patterning large areas with tunable pseudo-periodic structures, suitable for light -trapping in ultra-thin silicon photovoltaics. Future efforts will focus on integrating these structures into complete solar cells.

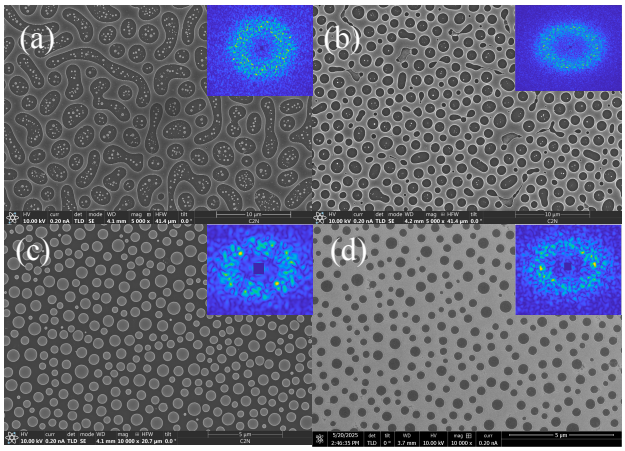

Fig 1 : SEM images of the quasi-random patterns transferred to the Silicon layer ; insets: Fourier transform of images evidence scattering at high angles (ring in the phase space, defined by a pseudo-period). The PB is spin-coated at 6K rpm, the polymer ratio PS/PMMA is 50/50 (a), 60/40 (b), 40/60 (c), 30/70 (d)

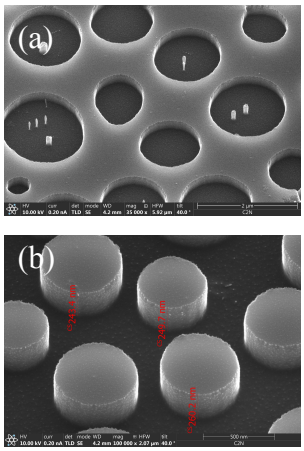

Fig 2: 40° tilted SEM images of the quasi-random patterns transferred to the Silicon layer. The PB is spin-coated at 6K rpm, the polymer ratio PS/PMMA is 60/40 (a), 40/60 (b)

References: Buencuerpo. Jeronimo, et al. Nano Energy, vol. 96, 2022, article 107080.