Correlated disordered nanostructures for light trapping in ultrathin solar cells

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Designing high-efficiency solar cells without significantly increasing manufacturing costs is a major challenge. Thin film/silicon tandem cells are a potential solution, but innovations are required to achieve a conversion efficiency over 30%. Improving absorption using advanced light-trapping strategies is an important task. Common approaches are based on random texturation, but absorbing most photons with energy above the band gap still requires a thickness of 100 to 200 µm of silicon [1]. Significant efforts have been made to further improve light trapping using alternative nanostructuring techniques [2], with a growing interest in correlated disorder. This approach allows tailoring the propagation direction and path length enhancement factor of light scattering. Recent studies have shown that this method outperforms traditional random texturing, offering improved efficiency and control over optical behaviour [3].

Here, we develop low-cost and scalable to large wafer surfaces nanopatterning processes compatible with their integration into ultrathin solar cells. We chose colloidal lithography for its scalability, and ability to create well-defined correlated disorder patterns. This method enables precise control over the spatial organization of nanostructures, making it particularly suitable for enhancing light trapping in ultrathin silicon solar cells [4]. We have developed a low-cost and large surface (4 cm²) colloidal lithography process to create an etching mask with a correlated disorder pattern. Figure 1 a) shows an SEM (Scanning Electron Microscopy) of a disordered array of 210 nm diameter polystyrene beads fabricated through colloidal lithography. Through lift-off process of the beads, an Ti hard mask served to develop several dry and wet etching processes, two of which can be seen in Fig. 1 b) and c).

The nanopatterns are characterized using specific metrics such as the structure factor (Fig. 1 d), the pseudo-period and the distribution of the nearest neighbors, which provide information on the degree of order. These metrics are particularly relevant to correlate the patterns with their optical effects in ultrathin silicon films. By bridging structural and optical properties, we aim to gain insight into the effect of spatial organisation on light-trapping for solar cell applications. The nanopatterns are currently integrated in ultra-thin silicon layers in order to carry out optical measurements. The diffuse and specular reflection, transmission and absorption enhancement impacts will be used to quantify the light-scattering effects and to determine the best patterns, before their integration into complete ultrathin solar cells.

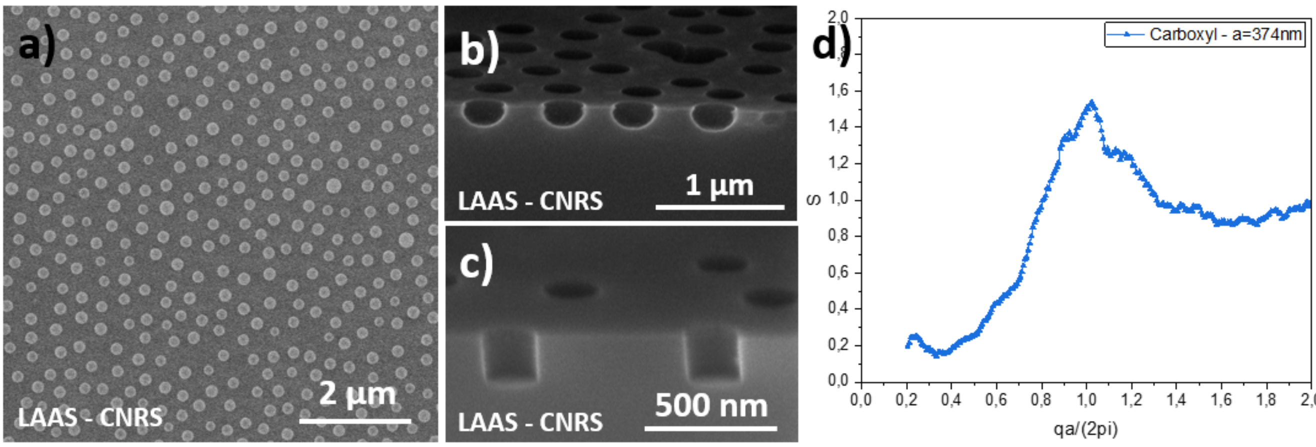

Figure 1: Example of disordered patterning obtained with 210 nm-large particles a) SEM image of the arrangement after self-assembly of colloids on silicon b) Profile obtained after transfer of the pattern in silicon by isotropic dry etching c) Profile obtained after transfer of the pattern in silicon by anisotropic dry etching d) Structure factor

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