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Method Article

Fabricating ordered 2-D nano-structured arrays using nanosphere lithography

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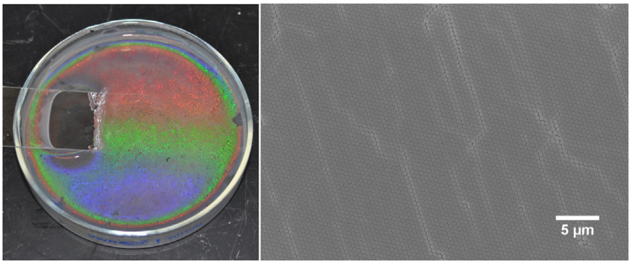
GRAPHICAL ABSTRACT



ABSTRACT

Recent advances in the use of plasmonic metamaterials to improve absorption of light in thin-film solar photovoltaic devices has created a demand for a scalable method of patterning large areas with metal nanostructures deposited in an ordered array. This article describes two methods of fabricating ordered 2D nanosphere colloidal films: spin coating and interface coating. The two methods are compared and parameter optimization discussed. The study reveals that:

- For smaller nanosphere sizes, spin coating is more favorable, while for larger nanospheres, the angled interface coating provides more coverage and uniformity.
- A surfactant-free approach for interface coating is developed to fabricate zero-contamination colloidal films.
- Each of the methods reaches an overall coverage of more than 90% and can be used for nanosphere lithography to form plasmonic metamaterials.

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Method details

There is substantial interest in the use of plasmonic metal nanostructures to form metamaterials for improving light absorption in thin-film solar photovoltaic (PV) devices [1,2]. Sophisticated light management in thin-film solar PV devices has become increasingly important in that they ensure absorption of the entire solar spectrum while reducing semiconductor absorber layer thicknesses, which in turn reduces deposition time, material use, embodied energy and greenhouse gas emissions, and economic costs [2]. Metal nanostructures have a strong interaction with light, which enables unprecedented control over the propagation and the trapping of light in the absorber layer of thin-film PV [3–5]. This has created a demand for a scalable method of patterning large areas with metal nanostructures deposited in an ordered array. Common methods to fabricate such arrays (e.g. e-beam lithography) are expensive and not practical for such large areas. Nanosphere lithography has been considered an alternative way of fabricating scalable plasmonic arrays [6] in an inexpensive and scalable fashion. With care in subsequent etching and evaporation processes, geometries from simple triangle arrays to more complex structures such as rings, dots, and rods can be fabricated [7]. In the past two decades several nanosphere coating techniques have been developed to acquire nanosphere masks, including spin coating [8,9], dip coating [10], and interface coating [11], all aimed at attaining high order uniformity and fewer defects. Spin coating is most common at the lab-scale due to its high efficiency in producing self-organized particle monolayers, as well as its flexibility in controlling the process, allowing sophisticated manipulation on colloidal crystal geometry, double- or multi-layer colloidal crystals, and even non-closed packed crystals [12,13]. However, the spin coating process is not simple as it involves fine tuning several parameters, which have interdependent effects on the evaporation process. Finding these parameters is an art, largely dominated by empiricism. For researchers who want to use spin coating in their nanosphere lithography related research they often have to develop their own recipes, and generally the optimal recipe varies depending on sphere size [14].

Interface coating, also known as the Langmuir-Blodgett method, refers to the process of forming a monolayer on the liquid-air interface, which is then transferred to a solid substrate. With the assistance of surfactants [11], 2-D colloidal spheres self-assemble into monolayer domains. Interface coating is attractive to industry because of its insensitivity to substrate materials and relative ease of implementation. However, additional processes like surface modification are often necessary to acquire well-ordered patterns [15].

Using 500 nm and 1000 nm polystyrene nanospheres, this article compares the two methods in detail and proposes two novel and convenient recipes for both nanosphere sizes. The hexagonal close-packed (HCP) coverage is determined from the scanning electron microscopy (SEM) and quantified with the free and open-source image-processing software ImageJ (https://imagej.nih.gov/ij/). The results show two methods to obtain >90% surface coverage with a defect-free close-packed domain area up to 1 mm^2. Additionally, this is the first time an interface coating method has been described that does not require any additional surfactants or surface modification. The plasmonic 2-D silver nanotriangle arrays are fabricated in subsequent steps and their size tuned by annealing the substrate in dry nitrogen flow.