SELF-ASSEMBLING LARGE-SCALE COLLOIDAL LATTICES FOR A 3D MATERIAL NANOPRINTER

Principal Investigator: Prof. Michael Short, MIT; co-PI: Prof. Robert Simpson, SUTD

Research Team: Max Carlson, PhD candidate, MIT; Ka-Yen Yau, UROP student, MIT

October 28, 2015

Colloidal Lattices

Microspheres, spherical particles approximately a micron ($1x10^{-6}$ m) in diameter, are an attractive option for the creation of micro-patterned surfaces. By controlling the interaction between the microspheres through macroscopic parameters such as ion concentration, temperature, and surface tension, it is possible to generate a temporary self-assembled microscopic pattern rapidly and easily. Subsequently, methods such as lithography, sputter coating, and etching can be used to generate a variety of permanent microstructures such as pillars, rods, and rings [1].

The present research aims to explore the formation of a new self-assembled structure - a non-close packed microsphere lattice on a water-air interface. This is achieved by controlling both the pair potential that particles experience when landing on the water surface, and the pair potential existing between the particles prior to deposition. A novel "microsphere mist" system greatly reduces the agitation associated with microsphere deposition onto the water surface, and therefore enables the microspheres to be placed in shallower, large-spacing potential wells representative of the new lattice structure.

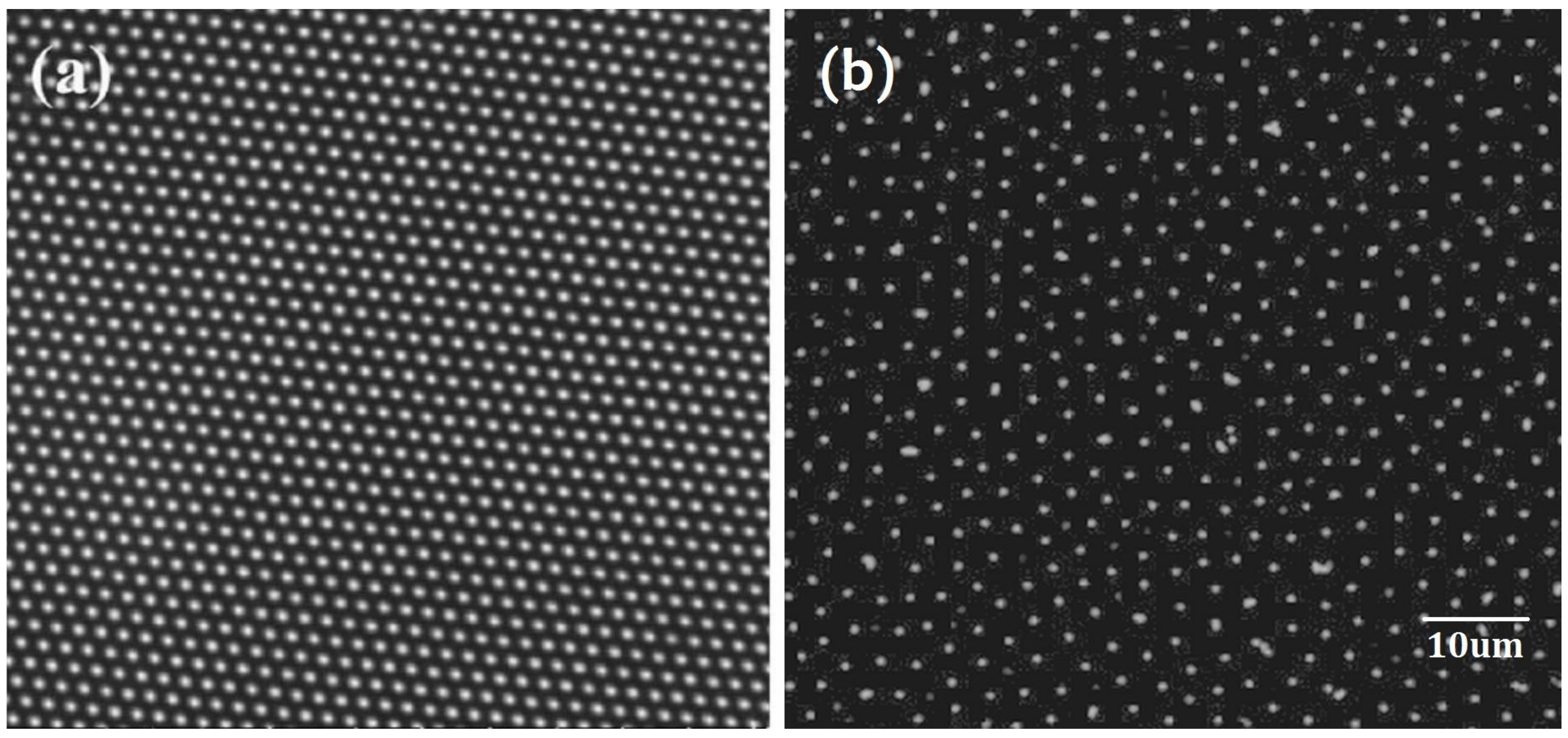

Figure 1 (a) a close packed microsphere monolayer [2] formed by sedimentation (b) a non-close-packed microsphere monolayer formed by microsphere mist

Tools for Microsphere Deposition

The primary tool that enables the new lattice structure is an ultrasonic nebulizer, of the same type that can be found in some humidifiers to make a water mist. In this project, a solution of methanol and polystyrene microspheres is nebulized, creating a "microsphere mist". A syringe pump is used for slow (few mL/hour) and constant mist generation rates. Next, a barrier filters out all large mist droplets by only allowing the most buoyant (least dense) droplets to exit, similar in principle to the action of a mass spectrometer (see Figure 2). After the microspheres land on the water surface, an optical microscope is used to observe the surface directly. Optical analysis is performed on images and video captured by a camera on the optical microscope.

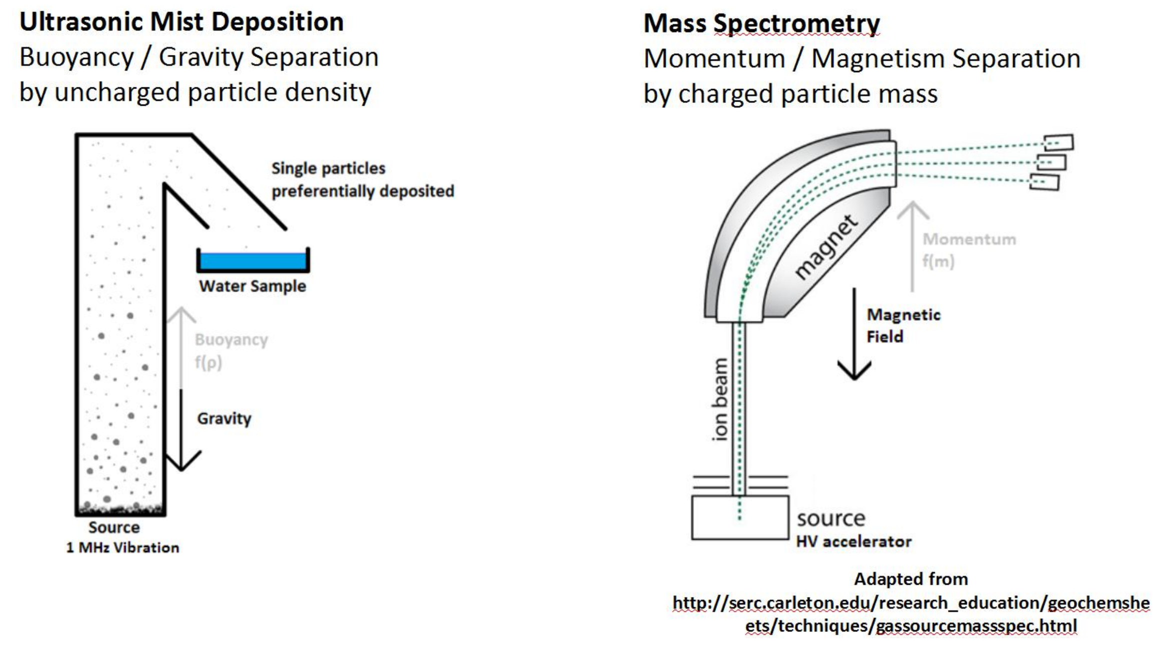

Figure 2 (left) buoyancy/gravity separation in the ultrasonic mist deposition system (right) a mass spectrometer, displaying similar source and separation features

3D Material Nanoprinter

The field of 3D printing continues to make leaps and bounds, with successive implementations pushing the frontiers of resolution and widening the diversity of printing media. However, currently used techniques are fundamentally limited by effects of surface tension of the fusing medium, an ability to remove heat from the sintering volume, or the quality of the optical mask for stereolithography. In addition, all the current methods have the fundamental limitation of homogeneous media, meaning that one type of material and composition must be the medium for construction.

Our printer aims to change the paradigm of 3D printing to include the possibility of directly printing materials, by including both very high resolution (40 nm) positioning and greatly reduced limitations for building block choices (to include metals, plastics, and ceramics, or a combination in a single print). We borrow the pick-and-place methodology from PCB assembly machines, and laser sintering from SLS systems. We have designed and nearly completed building the first prototype of our 3D micromaterial printer (see Figure 3).

The printer functions at the one micron resolution level, close to the limit of optical microscopy. It consists of a custom-designed optical microscope, with a 400mW ultraviolet sintering diode laser in-focus with the microscope's optical plane, and a Sutter Instruments nanomanipulator to pick-and-place starting materials from an "artist's palette" of non-close packed microspheres (see Figure 4). The microsphere mist deposition method is used to create this palette which contains widely spaced and easily located microspheres.

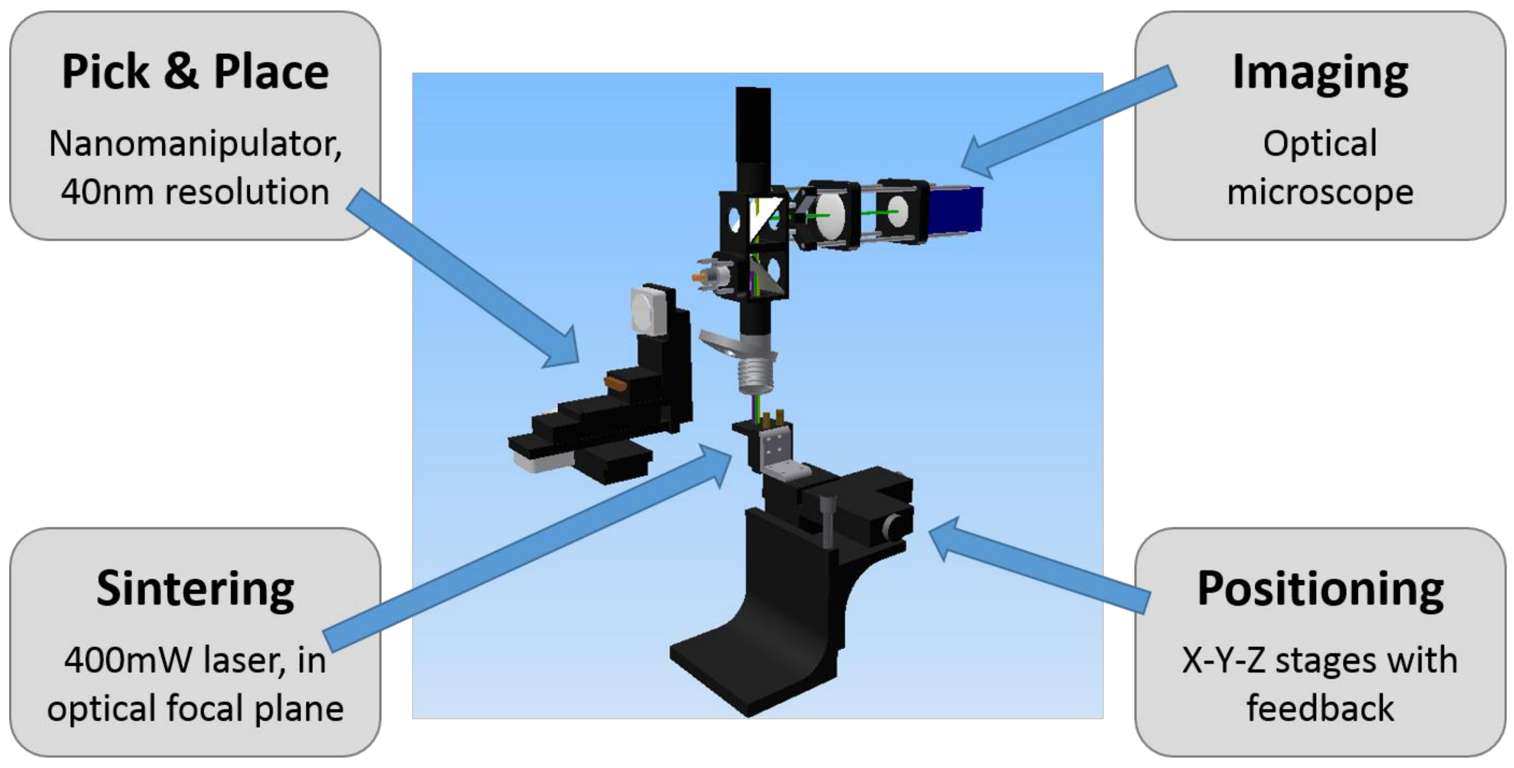

Figure 3 Schematic of the 3D Pick-and-Place Sintering Nanoprinter

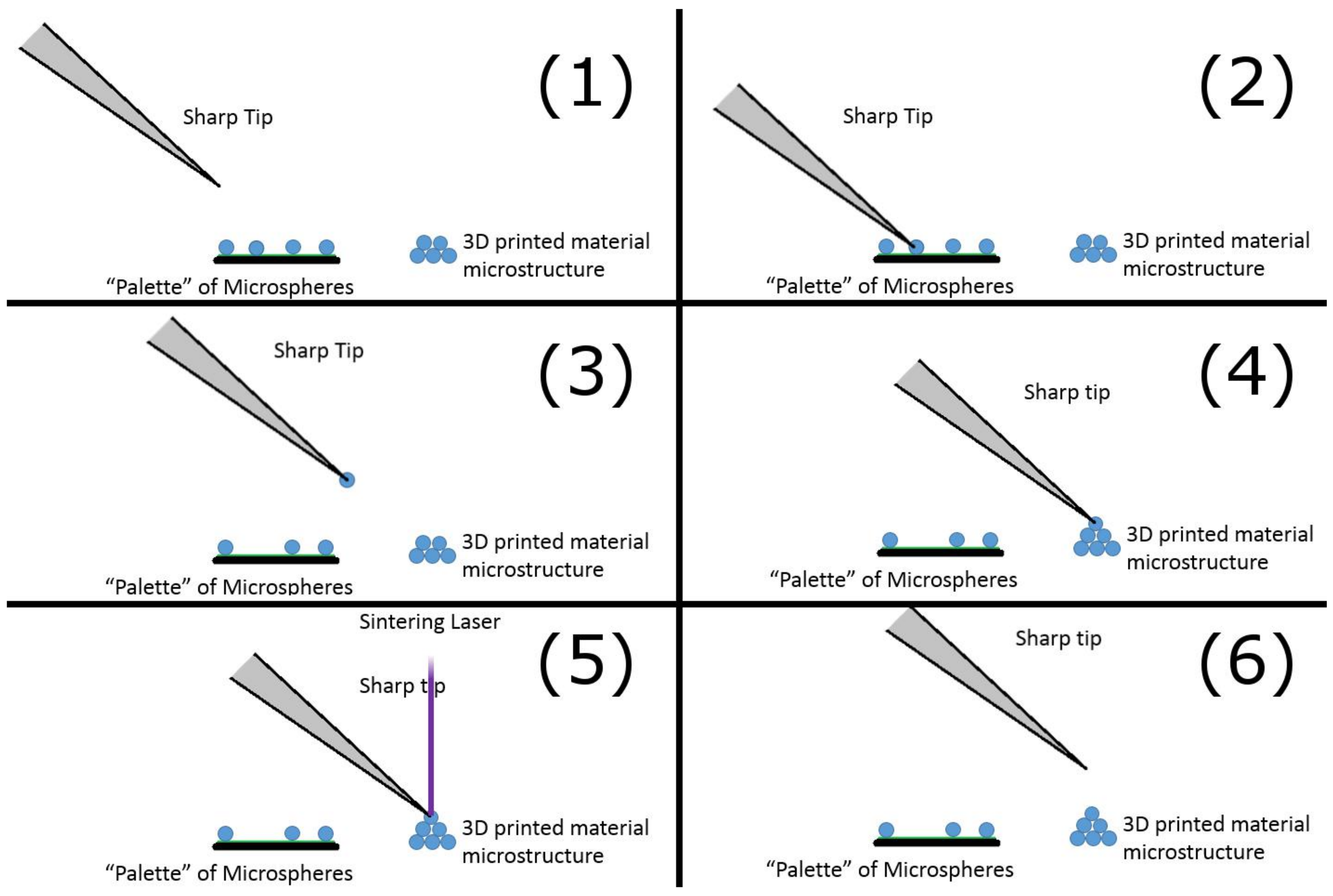

Figure 4 A diagram of the material printing process. (1-3) picking a single microsphere from a palette such as Fig. 1b. (4-6) placing and laser sintering the microsphere

References

[1] Cheng Li et al. Wet Chemical Approaches to Patterned Arrays of Well-Aligned ZnO Nanopillars Assisted by Monolayer Colloidal Crystals. Chemistry of Materials 21, 891-897 (2009).

[2] Yu Liu, Rong-Guo Xie, and Xiang-Yang Liu. Fine tuning of equilibrium distance of two-dimensional colloidal assembly under an alternating electric field. Applied Physics Letters 91, 063105 (2007).

Corresponding author: Prof. Michael Short, hereiam@mit.edu
Group website: http://web.mit.edu/shortlab/

The authors gratefully acknowledge IDC-SUTD support of this project.