

Parallel and Computer-Automated Optical Micro-Assembly

Jesper Glückstad, Ivan Perch-Nielsen, Carlo A. Alonzo, Jeppe S. Dam and Peter John Rodrigo

The parallel assembly of minute components with sizes in the range of 1-100 μm remains to be an exciting scientific challenge within micro-mechanics. Research into real-time, massively parallel and three-dimensional micro-assembly schemes may lead to revolutionary developments of new and reconfigurable micro-opto-electromechanical-systems.

In particular, micro-assembly done within a liquid environment seems attractive to pursue, due to the fact that the undesirable effects of van der Waals and surface interactions can be kept at a minimum. Most contemporary techniques for micro-integration of submerged components rely on self-assembly schemes. However, micro-scale self-assembly in liquid has some constraints, such as the trade-off between how accurate micro-elements can be positioned to receptor sites and the yield or efficiency of the overall process.

To overcome this, the sample must go through a few re-circulations, and the template may require some mechanical agitation. To improve positioning accuracy of micro-components on a template, one may apply suitable matching of the geometrical shapes of the building blocks with their receptor sites.

Real-time reconfigurable arrays of a plurality of interactive optical traps are perhaps a more attractive alternative that can enable precise assembly of freely suspended microstructures. Multiple optical traps are capable of holding, positioning and rotating a plurality of mesoscopic objects in 3D.¹ In the past year, we have demonstrated the first all-optical, directed micro-assembly scheme.² We did this by tiling a plurality of microscopic structural elements on a planar substrate using real-time reconfigurable optical traps from a variant of the parallel optical manipulation schemes on which we have previously reported.^{3,4}

The number of optical traps, their intensity profiles and spatial locations were all controlled either interactively or in an automated way using an advanced computer interface. Under computer-automated control, the system demonstrated the capability for fully autonomous search-and-collect routines without the need for any user-intervention.⁵

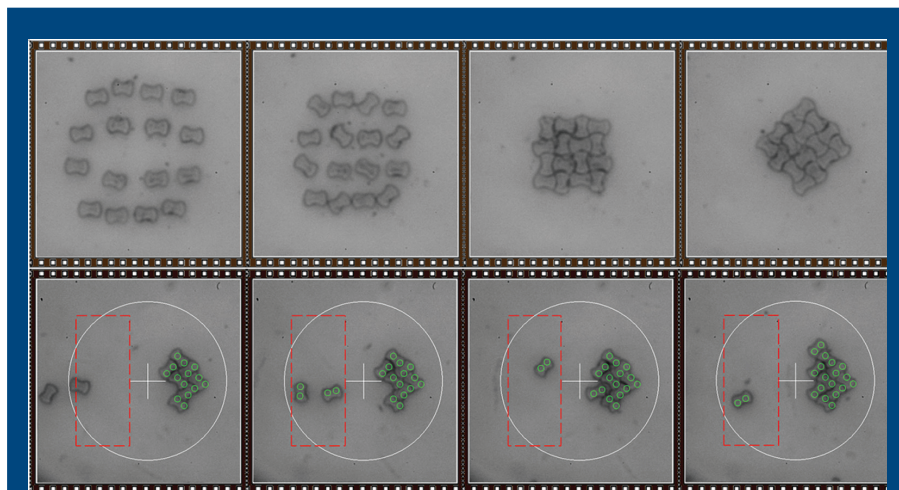
Our experimental demonstrations showed that optical traps of a few milli-watts can achieve good positional and rotational control of the assembled micro-structures. Efficient tiling also benefited from applying shape complementarity among the micro-puzzle pieces that have identical geometrical shapes and in-plane rotational symmetry. Finally, the puzzle pieces had an elongated aspect ratio so that the orientations were conveniently determined by an image analysis

subroutine; this made it easy to orient the projected elongated optical traps. The micro-fabrication of the puzzle pieces was achieved by a standard femtosecond laser two-photon polymerization technique. \blacktriangle

[Jesper Glückstad (jesper.gluckstad@risoe.dk), Ivan Perch-Nielsen, Carlo A. Alonzo, Jeppe S. Dam and Peter John Rodrigo are with the optics and plasma research department, Risø National Laboratory, Technical University of Denmark.]

References

1. Glückstad et al. "Optical 3D manipulation and observation in real-time (invited paper)," *J. Robotics Mechatronics* **18** (6), 692-7 (2006).
2. P. J. Rodrigo et al. "2D optical manipulation and assembly of shape-complementary planar microstructures," *Opt. Express* **15**, 9009-14 (2007).
3. P. J. Rodrigo et al. "GPC-based optical micromanipulation in 3D real-time using a single spatial light modulator," *Opt. Express* **14**, 13107-12 (2006).
4. P. J. Rodrigo et al. "Three-dimensional forces in GPC-based counterpropagating-beam traps," *Opt. Express* **14**, 5812-22 (2006).
5. I. Perch-Nielsen et al. "Autonomous and 3D real-time multi-beam manipulation in a microfluidic environment," *Opt. Express* **14**, 12199-205 (2006).



(Top) Micro-scale tessellation of 16 micro-puzzle pieces optically assembled in a parallel manner into a 4 x 4 tiling arrangement. Once assembled, all elements remain intact in the whole structure, which can also be displaced and rotated by the interactive group of optical traps. (Bottom) Computer-automated "hunt-and-collect" demonstration for joining micro-puzzle pieces. The dashed rectangle highlights the detection area, where incoming pieces from the left are automatically detected. Once detected, trapping beams with appropriate orientations and target trajectories are subsequently created.