DNA Origami-Gold Nanoparticle Constructs: Design for Nanomanufacturing

Seung Hyeon Ko,[a,b] Fernando Vargas-Lara,[d] Paul N. Patrone,[a,c] Samuel M. Stavis,[a] Jack F. Douglas,[d] J. Alexander Liddle[a]

[a]*Center for Nanoscale Science and Technology, National Institute of Standards and Technology, 100 Bureau Drive, Gaithersburg, MD 20899*
liddle@nist.gov
[b]*Maryland Nanocenter, University of Maryland, College Park, MD 20742*
[c]*Department of Physics, Institute for Research in Electronics and Applied Physics, and Condensed Matter Theory Center, University of Maryland, College Park, Maryland 20742-4111, United States*
[d]*Materials Science and Engineering Division, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, United States*

DNA origami[1] is a powerful platform for nanomanufacturing, but to simultaneously optimize functionality, purity and yield, a systems-engineering approach is required. DNA origami-gold nanoparticle constructs are a particularly important class of heterogeneous nanostructures with applications in single-molecule fluorescence enhancement,[2] nanoplasmonics and the formation of optically active materials.[3] We investigate the design for nanomanufacturing of such constructs. Gold nanoparticles are attached to DNA origami through the reaction of complementary DNA oligomers. Such reactions have yields of < 100 %, necessitating the development of methods to purify the target product. We demonstrate that bench-top centrifugation is a simple and efficient method of separating the reaction products, capable of achieving purities in excess of 90 %. The high density and plasmonic activity of gold nanoparticles enables them to perform a number of tasks in our systems-engineering approach, not only functioning as integral components of the purified products, but also as hydrodynamic separators and optical indicators of the reaction products during the purification process. We combine optical and hydrodynamic measurements and computations to study the performance of the centrifugation process. We find that the polydispersity in the size of gold nanoparticles and structural distortions of DNA origami caused by gold nanoparticles ultimately limit the separation resolution. We thus establish a methodology for determining the design rules for DNA origami-nanoparticle constructs. Our *design for nanomanufacturing* approach is broadly applicable and removes a major obstacle currently limiting the deployment of DNA nanotechnology. Further, the high yields of specific constructs that can be obtained with this method enables multi-step assembly processes, as opposed to the common one-pot methods currently employed.

---

[1] P. W. K. Rothemund, *Nature* **440** (2006) pp297-302
[2] G. P. Acuna et al., Science **338** (2012) pp506-510
[3] A. Kuzyk et al., *Nature* **483** (2012) pp311-314

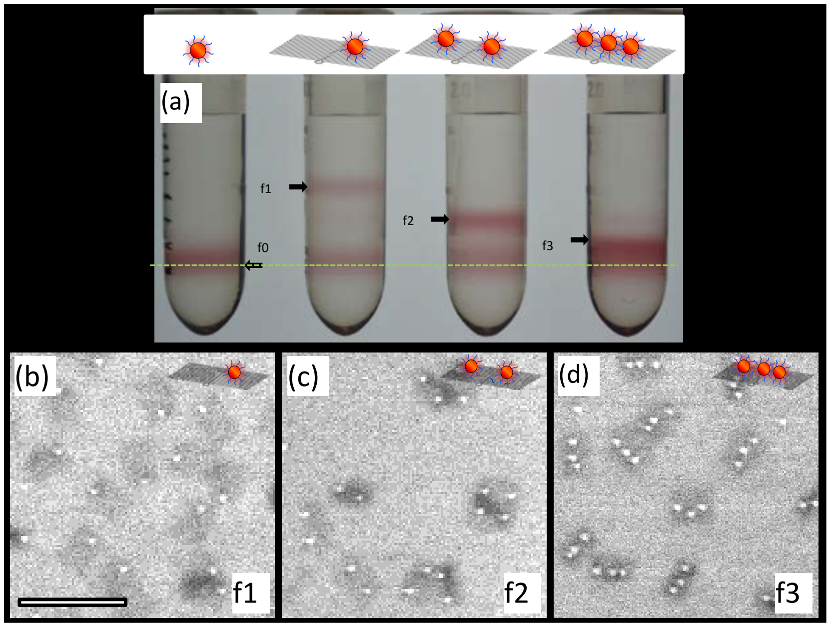

Figure 1. a) Representative images of the centrifugation of free gold nanoparticles and gold nanoparticle-origami constructs having (b) 1, (c) 2 and (d) 3 gold nanoparticles attached. SEM scale bar in b), c) and d) is 200 nm.

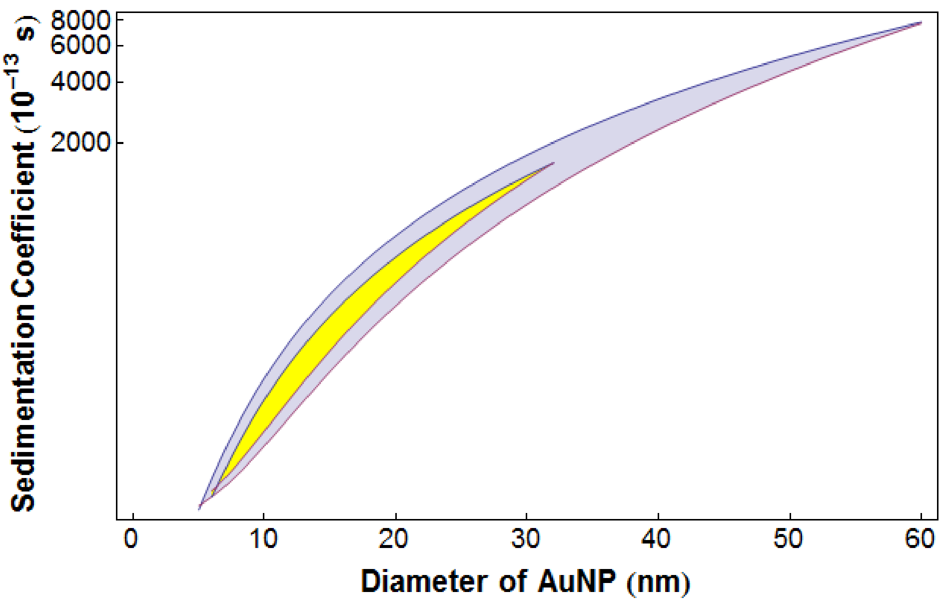

Figure 2. DNA origami-gold nanoparticle constructs must be designed within the parameters of the shaded regions for nanomanufacturing. The larger blue shaded region represents the range of parameters over which constructs consisting of a single gold nanoparticle bound to origami may be separated from free gold nanoparticles, assuming perfectly monodisperse gold nanoparticles. The smaller yellow shaded region represents the range of parameters over which separation may be achieved for typical (± 10 %) variations in particle diameter.