Nanostructured Origami

George Barbastathis,[1,2] Will Arora,[3] Nader S. Shaar,[1]
Se Young Yang,[1] Carol Livermore,[1] and H. I. Smith[1,4]
[1]MIT Mechanical Engineering Department; Cambridge, Massachusetts
[2]Singapore-MIT Alliance for Research and Technology (SMART) Centre; Singapore
[3]MC10, Inc.; Waltham, Massachusetts
[4]MIT Electrical Engr. and Comp. Sci. Department; Cambridge, Massachusetts

Nanostructured Origami™ is a three-dimensional (3D) fabrication and assembly method for 3D nanostructures using exclusively folded 2D substrates. The process consists of two steps: (1) nanopatterning of a substrate such as silicon nitride, silicon, or photocurable resist; and (2) folding the substrate along pre-defined creases and according to a compatible time sequence to result in the desired 3D shape. Step (1) includes the definition of the creases on a flexible substrate: for example, we have been able to fold ~150nm-thick silicon nitride cantilevers to radii of curvature as small as 2μm by He-ion implantation. Figure 1 shows an example of multiple folds, also on silicon nitride, initiated by bilayer stress due to a thin (~50nm) layer of Cr deposited on the cantilever. Note the term "nano" refers to the patterns on the folded substrates, and not the substrates themselves which are quite large (typically hundreds of microns in size.) It also constitutes the key innovation in Nanostructured Origami; folding of cantilevers to achieve arbitrarily oriented (but unpatterned) surfaces is an old concept, first proposed, to our knowledge, by Richard Syms in 1982. In the case of rigid substrates, we achieve folding by connecting the segments via flexible hinges, typically made of gold. Latches of male-female features connect in progressive (zipper-like) fashion as the structures fold to lock the moving parts in place. Magnetic actuation is used in the latter case to initiate the folding. Figure 2 is an example of a folded corner-cube with letters etched on the surfaces. In the presentation, we will describe the details of the kinematic and geometrical design of the structures and the latches, as well as quantitative results of latching and alignment achieved by the overall fabrication sequence. We will also present various applications and experimental prototypes of Nanostructured Origamis, encompassing nanophotonics (sub-wavelength modulated dielectric structures), electro-chemical energy storage devices (super-capacitors) and sensing of chemicals in selective fashion.

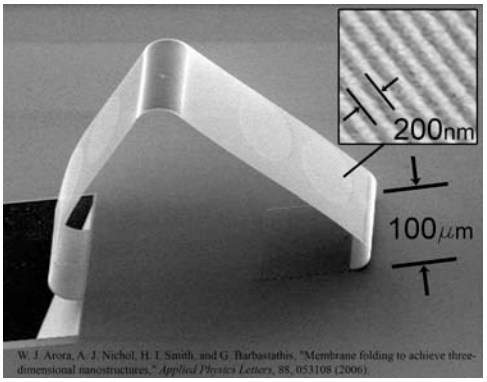

Figure 1 Experimental origami containing surface nanostructures on a folded strip of silicon nitride (after Arora *et al*, *Appl. Phys. Lett.* 88:053108, 2006.)

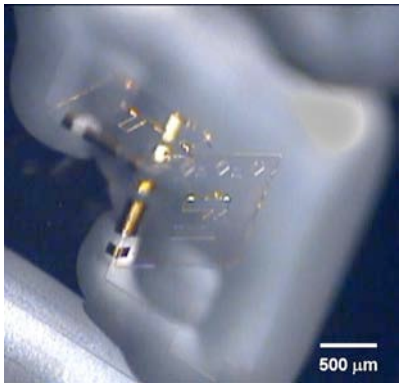

Figure 2 Experimental origami prototype of a folded and latched corner-cube made of SU-8 (a photocurable resist.) The letters "M" and "T" are visible on the surfaces while "I" is formed by the zipped latching features.