A New Technique for Creating Nanostructures on Tubular and Spherical Surfaces

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For so long nature has been sourceful and inspiring to fabrication and manufacturing community by presenting biological components with structures of incredible functions. While promising biologically inspired modern structure, generating these structures that match the criteria of their biological counterparts proves to be very challenging. One of the complexities includes creating tiny structures atop curved platforms. For instance, it is known that on the walls of blood vessels there are nanostructures which have close relation with the function of the immunological system, the same happens with the nanoridge feature atop compound eye of flies which provides them an exclusive vision of the surrounding world. What these two examples have in common is the tiny structure on curved surfaces. Patterning atop curved subjects, especially surfaces of hollow tubes or spheres, challenges a good number of lithography platforms. In photolithography, the issue relates to a complicated process in film coating and feature alignment; the difficulty in imprint-based technique lies on precise handling of the curved objects, as well as a good pattern coverage on the entire surface.

With our present technique we expect to show an alternative for creating patterns on non-flat surfaces (Figure 1). This protocol uses a soft poly(dimethylsiloxane) (PDMS) film which is deformed to have a strain in certain amount and orientation. Then, the film is coated with another layer of PDMS precursor. This new layer is imprinted to have nanostructures by using a rigid nanometer mold. Once the new layer is cured the initially strained film (substrate) is allowed to relax. Strong interface between both layers then ensures formation of a free-standing curved object, with nanostructures on surfaces.

Both experimental and schematic examples are shown in Figures 1-3. The first object is a hollow tube (Figure 1-1D object and Figure 3-left), where the substrate layer is axially stretched in 1-dimention. Patterns are applied before the strain is released and a tube in the lateral direction is resulted after strain release, with a diameter controlled by the amount of strain in the bottom film and a careful tuning of the thickness ratio (top/bottom) in the bi-layer structure. Generally, the film on top limits the relaxation of the bottom layer, thus generating a tube with curvature: larger strain on the bottom film results in a smaller tubular structure (Figure 2). Even more interestingly, the same concept can be applied to films strained in 2-dimention and this leads to formation of a spherical dome (Figure 1-2D object and Figure 3-right).

Since the nanostructures are constructed while the object is lying flat, we envision this new technique is compatible with a wide variety of lithographic platforms, in particular, imprint-based lithography and photolithography. Such compatibility ensures easy processing in both film coating and alignment steps. In addition, easy tunability of bi-layer film structure, plus strain and its orientation, could vary the shape and curvature of the non-flat object conveniently, making mimicking biological components and their functions feasible.

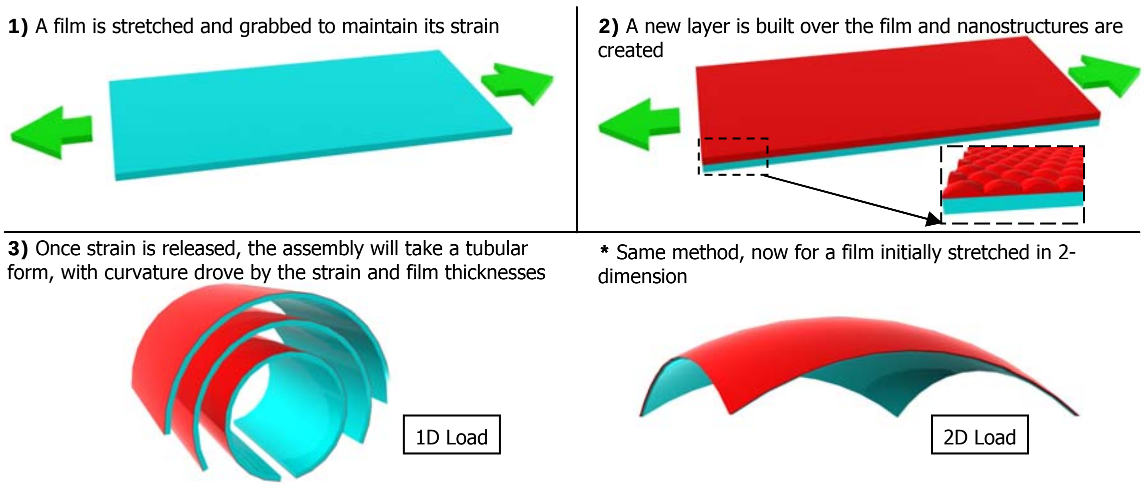

Figure 1: Process flow of forming tubular and spherical objects with patterned nanostructures.

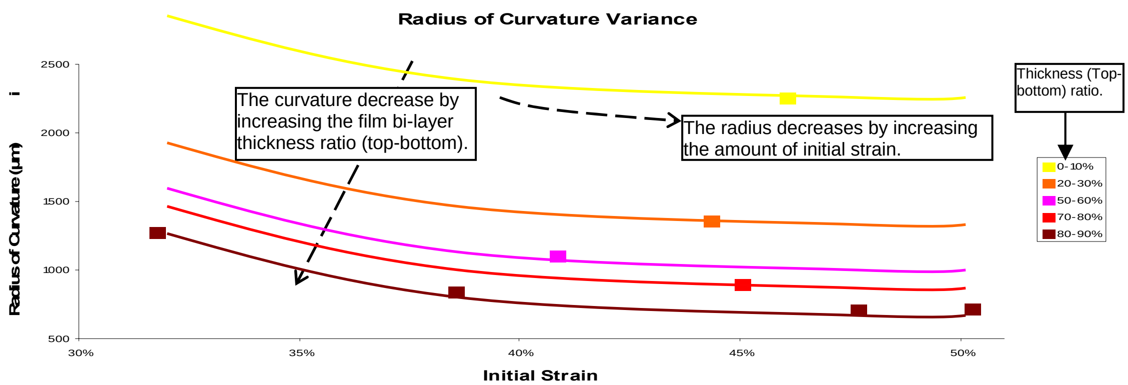

Figure 2: Relation between the film structure, strain and the final radius of curvature. An increase of bi-layer film thickness ratio (top vs. bottom) reduces the curvature of an object; and a decrease of initial strain in bottom film delivers a tubular or spherical object with much increased radius of curvature.

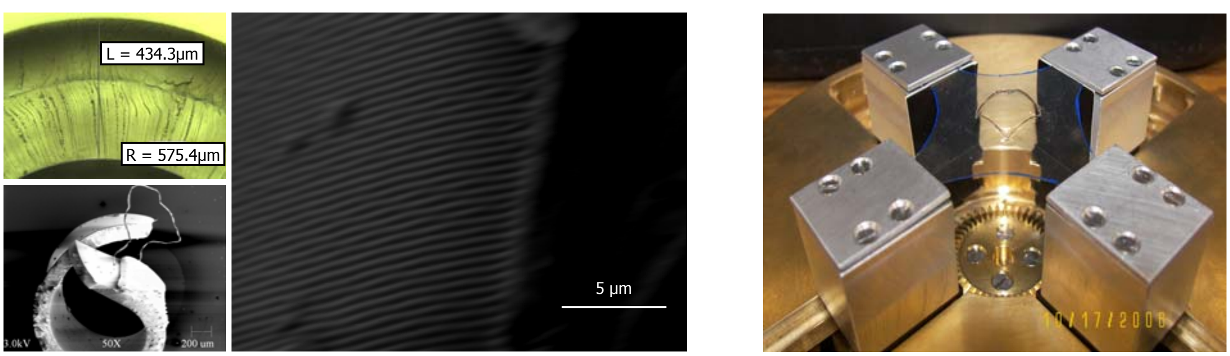

Figure 3: Top left – optical microscopic image with measurements of thickness and curvature; Bottom left – SEM image showing the tube and the distinct double-layer structure; middle – SEM image of the patterns on surface of the tube; and right – optical image of a spherical object.