Mechanics of wrinkled structures

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Surface wrinkling of thin films on compliant substrates is a common phenomenon and has been of interest to various fields ranging from flexible electronics to biomedical engineering[1, 2, 3]. Typical mechanisms that give rise to wrinkles are either external compression or differential growth or swelling[4, 5] between thin films and compliant substrates. While the formation of wrinkles is well understood, we know much less how wrinkled structures respond to additional external forces. This is the goal of my project.

Understanding the mechanics of wrinkled structures is important for practical applications, where wrinkled structures interact with environment. Lin et al.[6] demonstrated that wrinkled structures can be used to regulate the surface adhesion with external mechanical strain. Terwagne et al.[7] exploited the wrinkling instability on spherical surfaces to regulate aerodynamic drag by tuning the depth of dimples with internal pressure. Chung et al.[8] demonstrated that the effective wetting angle of liquid droplets on wrinkled structures can be tuned with external mechanical strain shown in the figure (1). If the wetting angle of the liquid droplet is small, then the system can also exhibit a remarkably different behavior, where the liquid from droplet starts penetrating wrinkled channels, which are subsequently squeezed into sharp folds by the capillary forces. Nagashima et al.[9] have exploited this phenomenon for producing DNA nanowires by placing a droplet of liquid solution containing DNA molecules on the wrinkled surface.

Experiments described above have successfully demonstrated proofs of principle, but theoretical models that would provide quantitative predictions are still lacking. Motivated by these applications, my goal is to analyze how wrinkled structures respond to external forces coming from the environment. It will be important to go beyond the linear elasticity and to properly

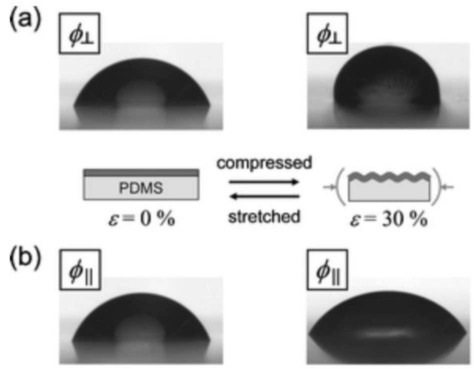

Figure 1: Water droplet on flat or wrinkled surface

take into account geometric nonlinearities associated with large deformations. While the linear elasticity can be used to predict critical strains and buckled modes at the onset of wrinkling instability, it cannot be used to analyze the post-wrinkling behavior. Wrinkled surfaces are extremely sensitive and even small forces can lead to large deformations, which have to be described with the nonlinear elasticity.

I intend to solve the corresponding nonlinear PDEs perturbatively, where the small parameter is the ratio between the magnitude of displacements (e.g. amplitude of wrinkles) with the wavelength of wrinkles (as determined from the linear elasticity). This will enable me to provide systematic estimates for the post-buckling response of wrinkled structures to external forces, such as a point indentation force or a point force directed in the plane of wrinkles. The accuracy of my analytical results will be tested against numerical finite element simulations. Once the postbuckling response of wrinkled structures to external point forces is properly understood, I will apply this formalism to analyze more complex interaction of the wrinkled structures with external environment, such as the effective wetting angle of liquid droplet on wrinkled surfaces.

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