Two-Dimensional Buckled Nanoscale Nanomembrane as Tunable Grating

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Abstract:

We have developed a tunable, optical two dimensional (2D) grating which can be used for measuring thermal-induced strain based on buckled thin film with periodic sinusoidal patterns on elastomeric substrates. One dimensional (1D) sinusoidal gratings and 2D herringbone gratings with a submicron scale have been fabricated with nanometer-thick gold (Au) film coated on uniaxial and biaxial pre-tensioned polydimethylsiloxane (PDMS) substrates, respectively. Due to the competition between the soft elastomeric substrates and relatively stiff Au films, uniform periodic wavy profiles are created upon releasing the pre-tension. The level of pre-strain, the mechanical properties of the PDMS and Au, and the thicknesses of Au films determine the amplitudes and wavelengths of wavy structures. The buckling profiles can be tuned mechanically by changing the level of pre-strain applied on the elastomeric substrate. Moreover, characteristics of the buckles vary based on the thickness of the stiff Au nanomembrane. Different methods of producing a stiff film on top of an elastomeric substrate have been established so far, while for this project, we focused on deposition of Au on PDMS by plasma sputter coating to create 2D herringbone buckles, which has the advantage of being low cost and extremely time efficient.

Introduction:

During the past few years the reliability of electronics packaging has received increasing attention, due to the soaring sales of iPhone and iPad. There are various electronic packaging failure modes like cracking, delamination and fatigue. Among them, the most well-known and often investigated mechanics issue for electronic packages is interface reliability. There is a great need for characterizing the deformations and strains in interfaces to the thermo-mechanical loadings caused by coefficient of thermal expansion (CTE) mismatches. Strain sensor using optical grating is a relatively new experimental mechanics method for measuring deformation and strain. Our method of making a buckled thin film on PDMS as a grating provides the capability of making uniform patterns at micro and submicron lever spontaneously without conventional photolithography techniques. More importantly, the wavelengths of buckling structure can be easily controlled by the thickness of Au film deposition at nanometer level which enables great tunability for optical grating.

Experimental Procedure:

The first part of our project was producing 1D ripples in Au nanomembrane stiff films. First, a thin slide of polydimethylsiloxane (PDMS) was prepared by mixing silicone elastomeric base and curing agent at the ratio of 10:1 by weight. After curing the PDMS at 80°C for three hours, we applied a desirable pre-strain on our substrate by mechanical stretcher only in one direction (x-direction). A thin layer of Au was coated on top of the pre-tensioned substrate by argon plasma-assisted sputter coating. Finally, releasing the pre-strain in the PDMS led to a compressive force in the Au film as the PDMS relaxed to zero strain, leading to periodic buckling.

In the second part of our research, we focused on 2D herringbone nanomembrane buckling. 2D samples were prepared with almost the same procedure as 1D, except that in the second step, we stretched our substrates in both X and Y directions sequentially (first in X and then in Y direction). Also, after coating the pre-stretched substrate with Au, the sample had to be released sequentially in both directions, but in reverse order (first in Y, then in X direction). This time, by releasing the sample 2D zigzag shape, buckling appeared in the nanomembrane.

Results:

Four 1D sample wavelengths and amplitudes of nanomembrane ripples were studied throughout the project. Figure 1 shows us the possible relationships [1] for amplitude and wavelength of the buckles based on thickness of the Au layer and level of pre-strain. The buckling period, amplitude, pre-strain and thickness of the Au film are characterized by "λ", "A", "ε_{pre}" and "h_f" respectively. Coating time determined the thickness of the Au nanomembrane linearly, and every thirty seconds corresponded to 5 nm.

Based on graphs in Figure 2, by increasing the coating times, both wavelength and amplitude of buckles became larger.

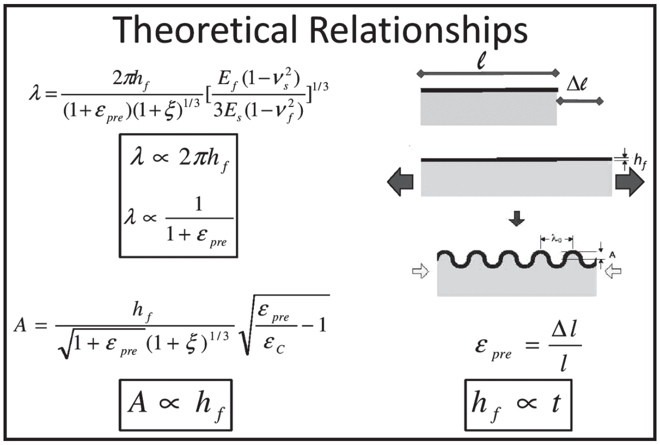

Figure 1: Theoretical relationships.

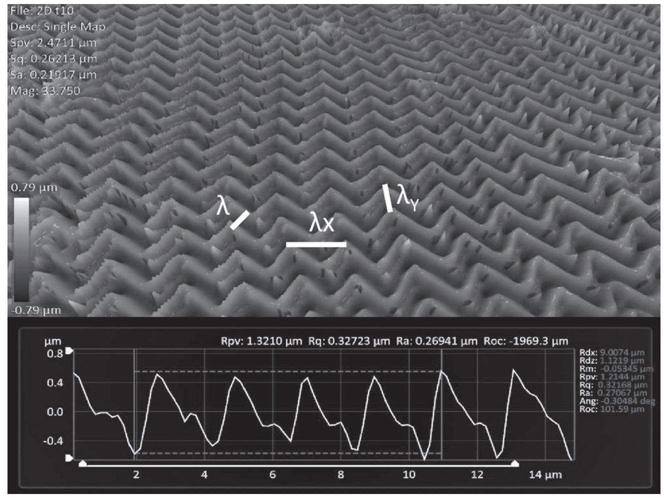

Figure 3: Optical profilometer image, 2D buckling, deposition time is 2.5 min, pre-strain of 15%.

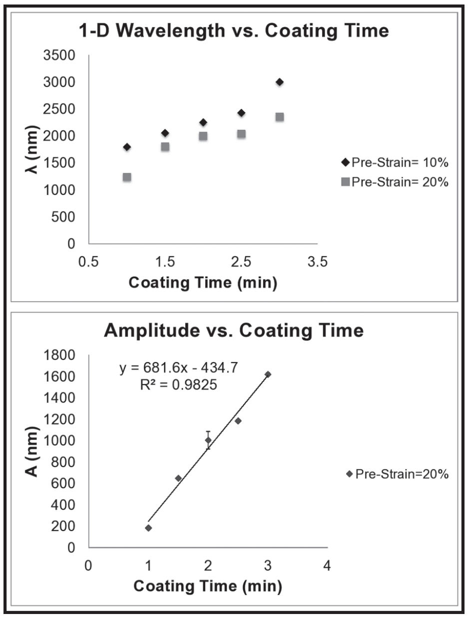

Figure 2: a) 1D wavelength vs. coating time graph, b) amplitude vs. coating time graph.

Also as pre-strain became larger the wavelength of the ripples decreased. These results supported our theoretical relationships.

Figure 3 is the 3D image of 2D buckles using optical profilometer. For each 2D buckle, three different wavelengths were measured, λ_x, λ_y and λ, in X, Y and normal to buckle direction, respectively. Figure 4 shows that all three types of wavelengths are in direct relationship to the coating time. Also amplitude of the wrinkling profile increases when coating time increases. These results also are a proof to our theoretical relationships.

Future Work:

In 2D buckles by increasing the pre-strain to even a greater level (25%-50%), the smallest wavelength (λ) was inversely proportional to the pre-strain, which means that as we stretched our samples to a greater extend, the wavelength of the buckles became smaller. Also if we can find a way to coat a thinner layer of gold, we might be able to produce gratings with wavelength closer to the wavelength of the natural light by even a smaller pre-strain. Moreover, we found out that creating a 2D herringbone structure in relatively stiff nanomembrane gold film on top of PDMS by argon plasma sputter coating is a low cost and time-efficient method.

Acknowledgements:

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References:

[1] Cunjiang, Y; "Forming wrinkled stiff films on polymeric substrates at room temperature for stretchable interconnects applications"; Thin Solid Films, 519, 819 (2010).

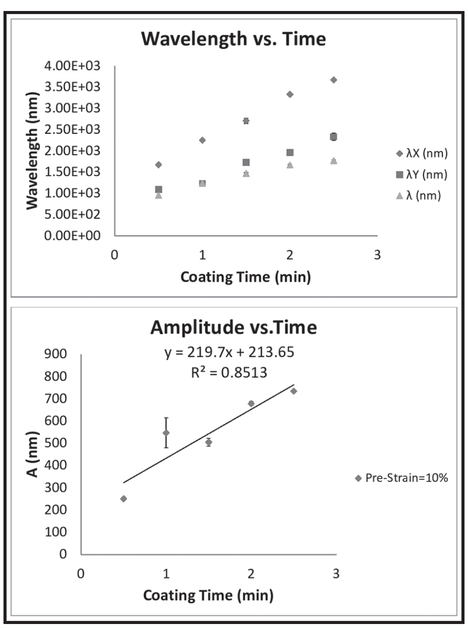

Figure 4, left: 2D wavelengths vs. coating time graph, b) amplitude vs. coating time graph.