# DETERMINISTICALLY ORDERED SURFACE WRINKLING MICROPATTERNS OF THIN POLYMERIC FILMS ON SOFT SUBSTRATE

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Summary A directed wrinkling strategy is developed to create a large area of deterministically ordered micropatterned surface topologies with specified long and short wavelengths with different jog angles. Modified herringbone patterns with jog angle of below $90^0$ are obtained for the first time through the directed wrinkling method. The multiple wavelengths and jog angles of buckling patterns are well predicted by analytical and computational modelling.

## INTRODUCTION

By harnessing the surface stability of stiff films on soft substrates, wrinkling have found broad applications in surface patterning [1], stretchable electronics [2], tunable surface mechanical properties such as adhesion and wettability [3], thin-film property measurements [4], fruit morphology and 3D microfabrications [5], among others. Upon isotropic thermal expansion or swelling, equi-biaxial compressive strain leads to the formation of an ideal 2D herringbone pattern with jog angle of $90^0$ with determined short wavelength, where the long wavelength is not deterministic and is experimentally found to exist over a wide range of value [6]. In addition, the ideal herringbone patterns occur only in small regions of the film, where the majority of the surface is experimentally observed to take a labyrinth pattern with randomly oriented wrinkles [7]. To quantitatively control the ordered wrinkling patterns, we carried out a combined experimental, analytical, and numerical investigation to create ordered and deterministic 2D patterned surface topologies of a relatively stiff thin polymeric film (ethyleneglycoldiacrylate (EGDA)) on soft PDMS substrates through a directed buckling strategy. Different from the common approaches employed to obtain stiff polymer coating on PDMS such as UV-curing, electron beam evaporation, and spin-coating, in this investigation, initiated chemical vapor deposition (iCVD) [8] is used for first time as the deposition technique to obtain wrinkles in a hierarchical pattern.

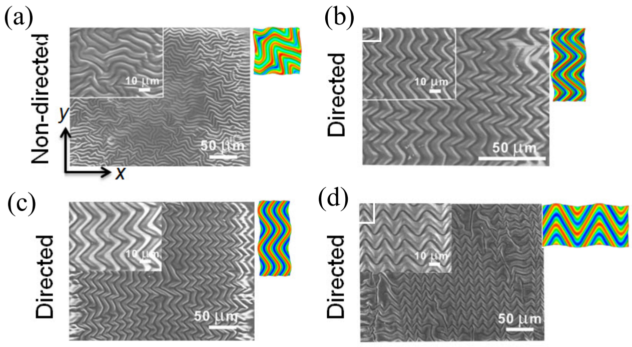


Figure 1 SEM images and FEM simulation (right top corner) of wrinkling patterns upon non-directed and directed wrinkling. (a) Labyrinth wrinkled patterns through undirected wrinkling (b)-(d) ordered wrinkled pattern through the directed wrinkling method: herringbone patterns with jog angle of $90^0$ (b), larger than $90^0$ (c), and smaller than $90^0$ (d)

## RESULTS AND DISCUSSIONS

Figure 1b shows scanning electron microscope (SEM) images of wrinkling patterns of EGDA coating on PDMS substrate through non-directed and directed wrinkling strategy. It shows that the non-directed wrinkling leads to a disordered labyrinth pattern (Figure 1a), whereas a large area of ordered herringbone patterns with jog angle of $90^0$ is observed through the directed wrinkling (Figure 1b). It is found that the long wavelength and short wavelength of such patterns remain robust over a large area, which shows the deterministic characteristics of the wrinkling patterns. The variety of wrinkling patterns are further explored with the directed wrinkling method, where a family of modified herringbone patterns with jog angle from larger than $90^0$ (Figure 1c) to smaller than $90^0$ (Figure 1d) are created. It

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should be noted that it is the first time that ordered herringbone patterns with jog angle smaller than $90^0$ are created in experiments, which may find potential applications in microfluid channels.

Finite element method (FEM) simulations are carried out to explore the more variety of wrinkling patterns. As shown in the right corner of Figure 1, the simulated wrinkling patterns are consistent with the experimental observations for both wrinkling methods.

## CONCLUSIONS

The directed wrinkling strategy opens a new avenue for creating highly ordered and deterministic wrinkled surface patterns, where the original disordered labyrinth patterns are transited into ordered and deterministic patterns with the help of directed wrinkling strategy. Such 2D deterministic wrinkling patterns provide the variation of surface morphology in two directions, which may find great potential applications in surface topology controlled phenomena such as controllable adhesion, wetting, and friction behaviors.

## References

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