SURFACE INSTABILITIES IN NON-LINEAR SOFT THIN FILMS

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by

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I would like to dedicate this thesis to my family.

CERTIFICATE

This is to certify that the work contained in the thesis entitled **"Surface instabilities in non-linear soft thin films"** by **Sunita,** in the Department of Chemical Engineering, Indian Institute of Technology Delhi, for the award of the degree of Doctor of Philosophy in Chemical Engineering is a record of original, bonafide research work carried out by her under my guidance and supervision. This research work has not been submitted elsewhere for the award of any other degree.

Prof. Jayati Sarkar

Professor

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Abstract

The work titled **'Surface instabilities in non-linear soft thin films'** studies the stability morphology and dynamics of a single soft, thin film on a substrate whose material properties (shear modulus) vary throughout the film thickness. Recently, we have focused on finding different techniques to miniaturize the patterns formed on such soft interfaces at smaller and smaller length scales to enhance surface properties like hydrophobicity, adhesiveness, optical and catalytic. Different techniques like patterned substrates and bilayers have been found to be fruitful where it was possible to decrease the lengthscale by about an order of magnitude than those formed in simple elastic thin films because of antagonistic energies (elastic and interaction) present. These techniques are also more cost-effective than the existing techniques of lithography, and suitable for hard materials. In the present work, we have found the smaller length scale features formed at the interface of these inhomogeneous elastic materials where the inhomogeneity exists only in the normal direction. The influence of the substrate geometry was also studied; as stated patterned substrates were already found to be effective in reducing lengthscales. Thus, it has been observed that the combined effect of patterned substrate and the inhomogeneity in the normal direction are worthwhile to influence further miniaturization. These studies involved numerical energy minimization techniques and finite element schemes to tackle non-linearities. Earlier works have shown that though it is easier to deform a compressible (Poisson's ratio $\vartheta \leq 0.25$) elastic film but the patterns formed were long waved and thus flat for most practical purposes. The current theoretical investigation carried out in thermally graded, soft, compressible and thin elastic film uncovers that combined destabilizing influences originating from van der Waals and tensile thermal stresses do engender smaller length scales in compressible elastic films. Though

some work has been presented in the literature for viscoelastic films, they are mostly from a viscous film perspective. In this thesis, for the first time, a three-parameter linear standard viscoelastic (solid) model has been developed to understand the adhesion debonding mechanism of such films. Also, a combined effect of charge leakage and the elastically graded nature of the film have been observed to be adequate to accelerate the growth rate of instabilities and alter the wavelength from short range to long range in elastic-viscous bilayers.

गैर-रैखिक नरम पतली फिल्मों में सतह की अस्थिरता

सार

"गैर-रेखीय नरम पतली फिल्मों में सतह अस्थिरता" शीर्षक वाला कार्य एक सब्सट्रेट पर एक एकल नरम पतली फिल्म की स्थिरता आकृति और गतिशीलता का अध्ययन करता है, जिसके भौतिक गुण (अपरुपड़ मापांक) पूरी फिल्म की मोटाई में भिन्न होते हैं। हाल के दिनों में हमने हाइड्रोफोबिसिटी, चिपकने वाले, ऑप्टिकल और कैटेलिटिक जैसे सतह गुणों को बढ़ाने के लिए छोटे और छोटी लंबाई के पैमाने पर ऐसे नरम इंटरफेस पर बने पैटर्न को छोटा करने के लिए विभिन्न तकनीकों को खोजने पर ध्यान केंद्रित किया है। पैटर्न वाले सब्सट्रेट्स और बाइलेयर जैसी विभिन्न तकनीकों को उपयोगी पाया गया है, जहां मौजूद विरोधी ऊर्जाओं (इलास्टिक और इंटरैक्शन) के कारण सरल लोचदार पतली फिल्मों में बनने वाली फिल्मों की तुलना में लंबाई के पैमाने को परिमाण के एक क्रम से कम करना संभव था। ये तकनीकें कठोर सामग्रियों के लिए उपयुक्त लिथोग्राफी की मौजूदा तकनीकों की तुलना में लागत प्रभावी भी हैं। वर्तमान कार्य में, हमने इन असमाँग लोचदार सामग्रियों के इंटरफेस पर गठित छोटी लंबाई के पैमाने की विशेषताएं पाई हैं जहां असमंगता केवल लंबवत्त दिशा में मौजूदहोती है। सब्सट्रेट ज्यामिति के प्रभाव का भी अध्ययन किया गया, क्योंकि बताए गए पैटर्न वाले सब्सट्रेट पहले से ही लंबाई के पैमाने को कम करने में प्रभावी पाए गए थे। इस प्रकार , यह देखा गया है कि पैटर्न वाले सब्सट्रेट और लंबवत्त दिशा में असमंगता का संयुक्त प्रभाव लघुकरण में आगे प्रभाव डालने के लिए उपयुक्त है। इन अध्ययनों में ऊर्जा न्यूनीकरण के लिए संख्यात्मक तकनीकें, और गैर-रैखिकताओं के लिए फ़ाइनायट एलेमेंट स्कीम (Finite element method) भी शामिल थीं। पहले के कार्यों से पता चला है कि यद्यपि एक संपीड़ित (Poisson ratio $\vartheta \leq 0.25$) इलास्टिक फिल्म को विकृत करना आसान है, लेकिन गठित पैटर्न लंबे समय तक तरंगित

थे और इस प्रकार अधिकांश व्यावहारिक उद्देश्यों के लिए सपाट थे। थर्मली ग्रेडेड, नरम, संपीड़ित और पतली इलास्टिक फिल्म में की गई वर्तमान सैद्धांतिक जांच से पता चलता है कि वैन डेर वाल्स और तन्य थर्मल तनाव से उत्पन्न होने वाले संयुक्त अस्थिर प्रभाव संपीड़ित इलास्टिक फिल्मों में छोटी लंबाई के पैमाने उत्पन्न करते हैं। यद्यपि साहित्य में विस्कोइलास्टिक फिल्मों के लिए कुछ कार्य प्रस्तुत किए गए हैं, लेकिन वे अधिकतर विस्कस फिल्म के संदर्भ में हैं। इस थीसिस में पहली बार ऐसी फिल्मों के आसंजन डिबॉन्डिंग तंत्र को समझने के लिए एक तीन-पैरामीटर रैखिक मानक विस्कोइलास्टिक (ठोस) मॉडल विकसित किया गया है। इसके अलावा चार्ज लीकेज और फिल्म की इलास्टिकली ग्रेडेड प्रकृति का संयुक्त प्रभाव अस्थिरता की वृद्धि दर में तेजी लाने और इलास्टिक-विस्कस बाई-लेअर में तरंग दैर्ध्य को छोटी दूरी से लंबी दूरी तक बदलने के लिए पर्याप्त पाया गया है।

सुनीता

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