

SURFACE INSTABILITIES IN NON-LINEAR SOFT THIN FILMS

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SURFACE INSTABILITIES IN NON-LINEAR SOFT THIN FILMS

by

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DEPARTMENT OF CHEMICAL ENGINEERING

Submitted

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to the



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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

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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 $\nu \leq 0.25$) 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 (अपरूपड़ मापांक) पूरी फिल्म की मोटाई में भिन्न होते हैं। हाल के दिनों में हमने हाइड्रोफोबिसिटी, चिपकने वाले, ऑप्टिकल और कैटेलेटिक 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 असमंग लोचदार सामग्रियों के इंटरफेस पर गठित छोटी लंबाई के पैमाने की विशेषताएं पाई हैं जहां असमंगता केवल लंबवत् दिशा में मौजूद होती 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 लंबवत् 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 फ़ाइन्याट एलेमेंट स्कीम (Finite element method) भी शामिल थीं। पहले के कार्यों से पता चला है कि यद्यपि एक संपीडित (Poisson ratio $\nu \leq 0.25$) 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 दैर्घ्य को छोटी दूरी से लंबी दूरी तक बदलने के लिए पर्याप्त पाया गया है।

सुनीता

Contents

CERTIFICATE	i
ACKNOWLEDGEMENTS.....	ii
ABSTRACT	iv
LIST OF FIGURES.....	xiii
1. Introduction	1
2. Miniaturized pattern formation in a soft elastically graded thin film in adhesive contact.....	5
2.1 Abstract	5
2.2 Introduction	6
2.3 Problem Formulation and Mathematical Modelling	9
2.3.1 Finite Difference Method.....	15
2.3.2 Energy Minimization (Weakly Non-Linear Analysis).....	18
2.3.3 3-D Analysis	18
2.4 Results and Discussion.....	20
2.5 Conclusions	32
Appendix A	34

3. Finite Element Approach: Adhesion- debonding in graded soft elastic film.....	37
3.1 Abstract	37
3.2 Introduction	37
3.3 Mathematical Modelling	38
3.4 Finite Element Method Analysis.....	40
3.4.1 Create Input File for 2-D Geometry of Thin Film in Python Script	41
3.4.2 Vdload Subroutine: Introduction of body force	44
3.4.3 Vumat Subroutine: Material Property Variation.....	45
3.5 Results and Discussion.....	45
3.6 Conclusions	54
 4. Further miniaturized pattern formation in inhomogeneous elastic film bonded on a patterned substrate	 55
4.1 Abstract	55
4.2 Introduction	56
4.3 Problem Formulation and Mathematical Modelling	57
4.3.1 Coordinate Transformation	61
4.3.2 Finite Difference Method.....	63
4.3 Results and Discussion.....	66
4.4 Conclusions	72

Appendix B	73
 5. Interfacial instabilities in the compressible soft, thin elastic film:	
Influence of thermal gradation – Linear Stability Analysis	79
5.1 Abstract	79
5.2 Introduction	79
5.3 Problem formulation	82
5.3.1 Temperature distribution inside a thin elastic film	83
5.4 Results and Discussion.....	91
5.4.1 Variation in Length Scale of Instability	91
5.4.2 Variation in Critical Stiffness Ratio Penalty	101
5.5 Conclusions	106
Appendix C	107
 6. Influence of stress relaxation behaviour of soft viscoelastic thin film on	
Adhesion–debonding: Three-element model.....	110
6.1 Abstract	110
6.2 Introduction	111
6.3 Problem Description and Mathematical Modelling	114
6.3.1 Linear stability analysis (LSA)	124
6.3.2 Weakly Non-Linear Analysis (Total Energy Minimization)	126
6.4 Results and discussion.....	127

6.4.1 Surface morphology: At the adhesion stage (when the contactor is at critical gap distance (dc)).....	129
6.4.1. (1A) Elastic behaviour of viscoelastic thin film with time:	129
6.4.1. (1B) Elastic-viscous-elastic behaviour of viscoelastic thin film with time:.....	132
6.4.1. (1C) Elastic-viscous behaviour of viscoelastic thin film with time:	135
6.4.1. (1D) Viscous behaviour of viscoelastic thin film with time:	137
6.4.1.(2A) Morphological changes in patterns with time during the adhesion stage: Variation in g_0 parameter:	140
6.4.1. (2B) Morphological changes in patterns with time during adhesion stage: Variation in g_1 parameter.....	142
6.4.1. (2C) Morphological changes in patterns with time during adhesion stage: Variation in stress relaxation time (τ).....	146
6.4.2 Surface morphology during debonding cycle	150
6.5 Conclusions	165

7. Charge-mediated instabilities in graded leaky dielectric elastic-viscous bilayer.....168

7.1 Abstract	168
7.2 Problem Formulation and mathematical modelling	168
7.2.1 Governing equations and boundary conditions for e-field.....	169
7.2.1.1 Base state and perturbed state governing equations and boundary conditions in bilayer for e-field	170
7.2.2 Governing equations and boundary conditions for fluid flow in bilayer	171

7.2.2.1 Base state and perturbed state forms of governing equations and boundary conditions in bilayer for fluid flow	173
7.3 Results and Discussion.....	176
7.4 Conclusions	184
8. Conclusions and future perspective	185
References	189
Publications.....	205
Conferences.....	205

List of figures

- 2.1 A 2-D schematic of a confined, incompressible, elastically graded soft thin film is rest over a flat substrate and under the influence of an external electrostatic field or van der Waals interactions from a top contactor kept at an initial gap distance of “d” from the mean surface of the film. The shear modulus $\mu(z)$ is a function of the depth. The dotted line is indicative of the deformation the film may undergo at a gap distance $< d_c$9
- 2.2 (A) Variation of shear modulus ratio with film thickness for distinct values of parameter M and $R > 1$, represented here by (a) square symbol line for parametric value of $(M = 16.0, R = 10^0)$ (b) delta symbol line for parametric value of $(M = 16.0, R = 10^2)$ (c) gradient symbol line for parametric value of $(M = 6.0, R = 10^2)$ (d) diamond symbol line for parametric value of $(M = 16.0, R = 10^5)$ (e) circle symbol line for data $(M = 50.0, R = 10^{10})$ respectively. Similarly the figure (B) shows the variation of shear modulus ratio with film thickness for different value of M and for $R < 1$ (a) square symbol line for parametric value of $(M = 2.0, R = 10^0)$ (b) delta symbol line for parametric value of $(M = 16.0, R = 10^{-2})$ (c) gradient symbol line for parametric value of $(M = 6.0, R = 10^{-2})$ (d) diamond symbol line for parametric value of $(M = 16.0, R = 10^{-5})$ (e) circle symbol line for data $(M = 30.0, R = 10^{-8})$ respectively. Figures (C) shows contour plot of the ratio of the slope of the shear modulus to the magnitude of the shear modulus for different parametric values of R and M12
- 2.3 “Instability regions” for different parametric values of parameters M and R . Coordinates of points $A(2.05, 8.79)$, $B(2.12, 6.22)$ and $C(2.75, 2.05)$ represent the critical values of wavenumbers and critical interaction stiffness to elastic stiffness ratios corresponding to curves a, b and c respectively.....21

2.4	A. Contours of ratio of critical length scale of instability for a general film to that of a homogeneous one λ_c/λ_c^h and B. Contour plot of critical stiffness ratio for a general film to that of a homogeneous one $(-hY_c/\mu_b)/(-hY_c/\mu_b)^h$ in the M-R parametric plane.....	23
2.5	A-D Contours of the ratio of the critical length scale of instability for a general film (non-homogeneous) to that of a homogeneous one λ_c/λ_c^h for various value of factor G and Fig 2.5 E-H Contours of critical stiffness ratio for a general film (non-homogeneous) to that of a homogeneous one $(-hY_c/\mu_b)/(-hY_c/\mu_b)^h$ for numerous value of factor G in the M-R parametric plane.....	24
2.6	2-D deformations at critical gap distance d_c exhibiting the number of columns formed on the film surface for elastic films having different R and M values λ_c Represents the dominant wavelength obtained via non-linear simulations, while λ_L represents the critical wavelength predicted by linear	26
2.7	Contour plots of 3-D morphologies formed in non-homogeneous elastic films kept at a fixed gap distance of 100nm having different parametric values of M, R and under the influence of an external e-field.....	31
2.8	Side-view of patterns formed under the influence of an electric field in films of thickness $h = 1\mu m$ when, the voltage difference between the two plates are kept at 156V. (A) Homogeneous film, (B) Less dense, lesser height patterns for films with $R < 1$. (C-D) High number density spiky patterns having high asperity ratios are formed in films with $R > 1$ and having moderate M values.....	32
3.1	A 2-D schematic view of a soft, incompressible (Poisson's ratio $\nu < 0.5$), inhomogeneous (thickness dependent shear modulus $\mu(z)$), thin film (thickness in nano/micro range) rigidly bonded with smooth substrate and vertically bounded with external contactor placed at a distance "d" from the free surface of the film. The dotted line in the blue domain demonstrates the deformation of thin elastic film when the external contactor is at a critical gap distance (d_c) between film-contactor. The dark colour arrow in the downward direction represents the	

	adhesion stage (external surface approaching the free surface of the thin film with defined adhesion velocity) and upward direction arrow is the debonding stage (contactor moving away from the free surface of the film with defined velocity called debonding velocity).	39
3.2	A 2-D cross-sectional view of undeformed finite element mesh in thin elastic film. A 4-node CPE4R (quadrilateral plain strain node) is used to divide the whole domain of the film. A denser mesh has been taken near the free surface to avoid any distortion due to external interaction in the presence of an external surface placed at a distance "d".....	42
3.3	Plots show the position of the contactor with time at various stages, like A-B path for adhesion stage (contactor is approaching the free surface from a distance d to d_c with velocity v_a nm/s condition for incipience of instability occurs), B-C path is the rest stages (where the instability occurs at d_c , has developed fully in the form of patterns) and C - D_1, D_2, D_3 path for debonding stage (once the pattern has fully developed, move the contactor away from the free surface of the film with different debonding velocities v_d	42
3.4	Contours of surface morphology at the free surface of the inhomogeneous thin film at different stages with the simultaneous movement of an external contactor with time. Figure 3.4(A) shows the surface profile of the elastic film when contactor is at $d > d_c$ and it remains flat. Figure 3.4(B) shows the emerged patterns when contactor at $d = d_c$ (condition for incipience of instability) Developed and elongated patterns morphology during debonding stage is shown in fig. 3.4(C-D) at different time stages.....	43
3.5	Displacement profile of corner most node at the top surface of a homogenous elastic film (constant shear modulus putting $M = 0$ or $R = 1$) and inhomogeneous elastic film ($M = 7, R = 10^3$) with time is shown by fig. 3.5(A) and (B) respectively. These plots also show an indication of incipience of surface morphology at higher critical gap distance (d_c).....	46

- 3.6 The plot of figure (A) depicts the displacement profile of the corner node (homogeneous thin film) at a particular time (nearby critical separation distance) for the different perturbed modes of the film. Figures 3.6(B) and 3.6(C) show the displacement profile of the corner node of the inhomogeneous film (inhomogeneous film, with increasing compliant behaviour of the film.....46
- 3.7 Comparison of critical length scale of instability (λ_c) in inhomogeneous thin elastic film bonded on a flat substrate with decreasing the shear modulus or increasing the compliancy at the top surface of the film using Linear Stability Analysis (solid line with circle symbol) and Finite element scheme (solid line with square symbol). The results obtained from finite element scheme are validated with the results obtained from LSA in an inhomogeneous elastic film.....47
- 3.8 Displacement and stress profile of normal component of displacement (u_{22}) and stress (s_{22}) at each node at the top surface of the inhomogeneous elastic film shown by blue and red solid respectively. Figure 3.8(A-D) shows the profiles at different positions of contactor or at the mentioned time in between the adhesion and debonding stages, for $M = 6, R = 10^2$ and corresponding critical length scale of instability is $\lambda_c = 8h/5 = 1.6h$ and debonding velocity is $v_d=0.25\text{nm/s}$49
- 3.9 Displacement and stress profile of normal component of displacement (u_{22}) and stress (s_{22}) at each node at the top surface of the inhomogeneous elastic film shown by blue and red solid respectively. Figure 3.9(A-D) shows the profiles at different positions of contactor or at the mentioned time in between the adhesion and debonding stages, for $M = 7, R = 10^3$ and corresponding critical length scale of instability is $\lambda_c = 8h/8 = 1.0h$ and debonding velocity is $v_d = 0.25\text{nm/s}$50
- 3.10 Displacement and stress profile of normal component of displacement (u_{22}) and stress (s_{22}) at each node at the top surface of the inhomogeneous elastic film shown by blue and red solid line respectively. Figure 3.10(A-D) shows the

- profiles at different position of contactor or at the mentioned time in between the adhesion and debonding stages, for $M = 9, R = 10^4$ and corresponding critical length scale of instability is $\lambda_c = 8h/10 = 0.8h$ and debonding velocity is $v_d=0.25\text{nm/s}$51
- 3.11 Variation in pull-off force per unit area at the debonding stage. The solid line depicts the case of homogeneous film, the dashed line for materialistic inhomogeneous film for a parameter ($M = 6, R = 10^2$) and dashed dot line for parametric range $M = 9, R = 10^4$. It can be seen from the figure, for greater unit value of parameter R depicts the snap-off at higher distance; thus, the obtained morphology could be sustained for a longer period of time.....52
- 3.12 Plots (A) and (B) shows the fractional contact area during the debonding cycle and the work of adhesion to detach the film from the contactor, respectively. The square symbol line(for homogeneous), gradient symbol line, and circle symbol lines are for inhomogeneous thin film in fig. 3.12(A) shows the fraction contact area of morphology during debonding stages for homogeneous and inhomogeneous thin film, respectively. The work of adhesion required to detach film surface by moving away the contactor with debonding velocity 0.25nm/s and 0.5nm/s, are shown by the square symbol line and circle symbol line, respectively.....53
- 4.1 Schematic view of a soft, incompressible (Poisson's ratio $\nu \sim 0.5$), inhomogeneous (thickness dependent shear modulus $\mu(z)$), thin film (thickness in nano/micro range) cast over a rough substrate of wavelength (λ_p) and amplitude (β_p) sinusoidal in shape and in close proximity of the external contactor placed at a distance "d" from the stress-free surface of the film. The dotted line in the blue domain demonstrates the deformation of the thin elastic film when the external contactor is at or below the critical gap distance (d_c).....57
- 4.2 “Instability zones” for different parametric values of parameters M, R and β . Co-ordinates of points A(9.57,6.86) ,B(5.17,4.11) and C(2.75,2.05) represent the

	critical values of wavenumbers and critical interaction stiffness to elastic stiffness ratios corresponding to curves a, b and c respectively.....	69
4.3	(A) Contours of critical stiffness ratio $-hY_c/\mu_b$ for inhomogeneous film cast over a patterned substrate (B) Contours of critical stiffness ratio for inhomogeneous film cast over a patterned substrate to the homogeneous film cast over a patterned substrate $(-hY/\mu_b)_{CP}^{lh}/(-hY/\mu_b)_{CP}^h$ and (C) contours of critical gap distance for the incipience of instability for an inhomogeneous film cast over a patterned substrate in the M-R- β parametric plane.....	69
4.4	(A) Contours of the critical length scale of instability λ_c/h and (B) Contours of ratio of critical length scale of instability for an inhomogeneous film cast over the patterned substrate to the homogeneous film cast over a patterned substrate $\lambda_{CP}^{lh}/\lambda_{CP}^h$, in the M-R- β parametric plane.....	72
5.1	2-D schematic of a confined, compressible ($\nu < 0.5$), thin elastic film ($\mu < 10$ MPa) bonded to a rigid flat substrate at temperature T_b and under the influence of van der Waals interactions from the heated contactor kept at an initial distance “d” from the un-deformed surface of the film. The dotted line represents the film's deformed shape once the gap distance becomes $d < d_c$	83
5.2	Represents the temperature profile of the thin film when the heat flux $q_0 (+ve)$ was dissipating from the system. For distinct parametric value of conductivity ratio K_0/K_{-1} , represented here by (a) Dashed line for the parametric value of $K_0/K_{-1} = 10^{-4}$ (b) DashDot line for parametric value of $K_0/K_{-1} = 10^{-2}$ (c) Solid line for parametric value of $K_0 = K_{-1} = K = 0.15$ (d) Dotted line for parametric value of $K_0/K_{-1} = 10^2$ (e) DashDD line for parametric value of $K_0/K_{-1} = 10^4$ respectively.....	86
5.3	Variation in normal stress component ($\sigma_{22} = \sigma_{22}/\cos(kx)$) with critical length scale of instability (λ_c/h) for equal conductivity ($K_0 = K_{-1}$) at the top and bottom interface of the thin film with the different parametric values of factor $U_f = \alpha_t h^2 q_0 / \alpha K_0$. Fig. 5.3(A) represents "instability region" for the	

homogeneous incompressible and compressible film. Here dotted line labelled curve for a compressible film of Poisson's ratio $\nu = 0.25$ and coordinates of minima(0.000682, 9204.5, 3), dashed dot line labelled curve for a compressible film of Poisson's ratio $\nu = 0.35$ and coordinates of minima(1.25, 5.04, 3.94), dashed line labelled curve for a compressible film of Poisson's ratio $\nu = 0.45$ and coordinates of minima (1.84, 3.42, 5.29) and solid line labelled curve for incompressible film $\nu = 0.499$ and coordinates of minima (2.11, 2.97, 6.20) . The coordinates of each minima represent the wavelength of instability and the minimum critical force required for the instability. In a similar way, the instability curve for a thermally graded compressible thin film is shown in 5.3(B), 5.3(C) and 5.3(D). Figure 5.3(B) for $(K_0 = K_1, U_f = 10^{-4})$ and coordinates of minima of dotted line (0.033954, 184.955, 3.00025) , dash dot line (1.24536, 5.042719, 3.94169) , dashed line (1.8378, 3.417129, 5.29394) and solid line(2.1139, 2.970812, 6.20216). Figure 5.3(C) for $(K_0 = K_1, U_f = 10^1)$ and coordinates of minima of dotted line(3.83909, 1.635804, 9.60206) , dash dot line (4.00743, 1.567089, 11.5155) , dashed line (4.18896, 1.499179, 14.1207) and Solid line (4.28795, 1.464569, 15.7801) are represents the minimum value of the normal stress component and critical length scale of instability, respectively. Figure 5.3(D) for $(K_0 = K_1, U_f = 10^4)$ and coordinates of minima of dotted line (111.803, 0.05617, 298.142), dash dot line (116.19, 0.054049, 357.506) , dashed line (120.416, 0.052153, 437.876) and solid line (122.434, 0.051293, 488.757) are represents the minimum value of normal stress component and critical length scale of instability, respectively.....93

5.4 2-D contour plot of the ratio of the critical wavelength of instability ratio $\lambda_{cCT}/\lambda_{cC}$ in 2-D plane (Poisson's ratio ν and $\log(U_f)$) for equal conductivity) and when heat flux q_0 is dissipating from the system.....95

5.5 Contour plots of the critical length scale of instability ratio $\lambda_{cCT}/\lambda_{cC}$ in 3-D (plane of conductivity ratio, Poisson's ratio and $\log(U_f)$) for different range of conductivity ratio, factors and when heat flux is dissipated from the system,

(A) $K_0/K_{-1} \leq 1, U_f \leq 1$; (B) $K_0/K_{-1} \geq 1, U_f \leq 1$; (C) $K_0/K_{-1} \leq 1, U_f \geq 1$; (D) $K_0/K_{-1} \geq 1, U_f \geq 1$98

5.6 Variation of the normal stress component $\sigma_{22} = \sigma_{22}/\cos(kx)$ with critical length scale of instability (λ_c/h) in four different regions based on parametric range of K_0/K_{-1} and U_f given in figure 5A, 5B, 5C and 5D. Fig. 5.6(A) Depicts region I where parameters have the following range ($K_0/K_{-1} = 10^{-4}, U_f = 10^{-4}$), here dotted line for, $\vartheta = 0.25$ and coordinates of minima point ($kh=0.003, \lambda_c/h = 2093.33, -hY_c/\mu_b = 3.0001$) gives critical value of length scale and normal stress component. Similarly dashed dot line for $\vartheta = 0.35$, coordinates of minima point (1.245, 5.044 and 3.9415), dashed line for $\vartheta = 0.45$ and coordinates of minima point (1.8377, 3.417 and 5.2937) and solid line for $\vartheta = 0.499$ and coordinates of minima point (2.1138, 2.970911, 6.202). Fig. 5.6(B) for region II and the range of parameters are given as ($K_0/K_{-1} = 10^4, U_f = 10^{-4}$), dotted line line for, $\vartheta = 0.25$ and coordinates of minima point (0.5574, 11.2665, 3.01911) give critical values of length scale and normal stress component. Similarly dashed dot line for $\vartheta = 0.35$, coordinates of minima point (1.25305, 5.0117, 3.94466), dashed line for $\vartheta = 0.45$, coordinates of point (1.83954, 3.4138, 5.29557) and Solid line for $\vartheta = 0.499$, coordinates of minima (2.11496, 2.969323, 6.20352). The following parameter range of ($K_0/K_{-1} = 10^{-4}, U_f = 10^4$) represents the region III in Fig. 5.6(C), and we obtained two minima for this range of the parameter, here dotted line for, $\vartheta = 0.25$ and coordinates of two minima are (0.6409, 9.7987, 583.634) and (104.497, 0.06, 288.588) gives critical values of length scale and normal stress component. Similarly dashed dot line for, $\vartheta = 0.35$ and coordinates of two minima are (1.3456, 4.667, 827.281) and (108.9, 0.05766, 346.498), the dashed line for, $\vartheta = 0.45$ and the coordinates are C31(1.86234, 3.372, 1152.28) and C32(113.141, 0.055, 424.884) and solid line for $\vartheta = 0.499$ and the coordinates are (2.1241, 2.956602, 1361.83) and (115.17, 0.05453, 474.503) respectively. In a similar way Fig. 5.6(D) represents region IV, where the range of the parameter are ($K_0/K_{-1} = 10^4, U_f = 10^4$), dotted line for, $\vartheta = 0.25$ and coordinates of minima (118.388, 0.053, 307.059) depicts the critical value of length scale and normal stress

	component. Similarly dashed dot line for $\vartheta = 0.35$ and coordinates of minima point are (122.786, 0.051, 367.806), the dashed line for $\vartheta = 0.45$ and coordinates of minima point (127.022, 0.049, 450.062) and solid line for $\vartheta = 0.499$ and coordinates of minima point (129.044, 0.048666, 502.141), respectively.....	99
5.7	Contour plot of the critical stiffness ratio $((-hY_c/\mu_b)_{CT}/(-hY_c/\mu_b)_C)$ of thermally graded compressible thin elastic film to the compressible thin elastic film in a 3-D plane (plane of conductivity ratio, Poisson's ratio and $\log(U_f)$). For isothermal case parametric value of conductivity ratio ($K_0 = K_{-1} = 0.15W/mK$), factor $U_f(\alpha_t h^2 q_0/\alpha K_0)$, when heat flux q_0 dissipating from the system.....	103
5.8	Contour plots of the critical stiffness ratio $((-hY_c/\mu_b)_{CT}/(-hY_c/\mu_b)_C)$ of instability in 3-D (plane of conductivity ratio, Poisson's ratio and $\log(U)$) for different range of conductivity ratio K_0/K_{-1} , factor $U_f(\alpha_t h^2 q_0/\alpha K_0)$ and when heat flux q_0 dissipated from the system, (A) $K_0/K_{-1} \leq 1, U_f \leq 1$; (B) $K_0/K_{-1} \geq 1, U_f \leq 1$; (C) $K_0/K_{-1} \leq 1, U_f \geq 1$ (D) $K_0/K_{-1} \geq 1, U_f \geq 1$	105
6.1	A 2-D sketch of a confined thin, soft and incompressible viscoelastic film of length L , cast over a flat substrate and under the influence of van der Waals interaction from transversely confined by a flat external surface (called a contactor) placed at separation distance d . The dotted line shows the unstable state of the film when the contactor is at less than the critical gap distance. The shear modulus of the film $\mu(t)$ is a function of time.....	114
6.2	Schematic representation of Maxwell form of the standard linear solid model (Three parameter model).....	116
6.3	Variation of shear modulus $\mu(t)$ with time (t) under constant strain for parametric values of g_0, g_1 and τ	117

- 6.4 “Instability zones” represent the critical value of wavenumber and critical interaction stiffness to elastic stiffness ratio corresponding to the curve are (2.12,6.22).....125
- 6.5 Surface profile of the viscoelastic thin film when the contactor is at $d_c = 3.04$, shows the columnar structure at the film surface with time. The parameters used in this case are $G = g_0/g_1 = 3000$, $g_0 = 3.0$, $g_1 = 0.001$ and $\tau = 0.203$. Fig. 6.5(A) presents the surface morphology when the contactor reaches the critical gap distance from the film surface at constant strain at $t=0.0$, and the changeover in surface profile with time when the contactor is still at the critical gap distance is shown in fig. 6.5(C). The stresses that develop at the film surface when the contactor is at d_c with time are shown in figure 6.5(B and D).....130
- 6.6 (A) depicts the fractional contact area of patterns formed at the free surface (parametric range of $G = g_0/g_1 = 3000$, $g_0 = 3.0$, $g_1 = 0.001$ and $\tau = 0.203$) with time shown by the red square symbol line, and the red square symbol line in fig 6.6(B) shows the number of columns formed at the free surface with time. The summation of normal stresses per unit area (represents the adhesive force) and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.6(C) and (D), respectively. The interaction potential energy and stored energy with time are represented by the red square symbol line and the blue circle symbol line of fig. 6.6(E), respectively. The elastic part and viscous part of total stored energy in the film with time is shown by the red square symbol line and blue circle symbol line in fig. 6.6(F).....131
- 6.7 Surface profile of the viscoelastic thin film when the contactor is at $d_c = 3.04$, shows the changeover in structure at the film surface with time. The parameters are in the range of $G = g_0/g_1 = 600$, $g_0 = 3.0$, $g_1 = 0.005$ and $\tau = 0.203$. Figure 6.7(A, C, E and G) shows the changeover in surface morphology with time and figure 6.7(B, D, E and H) shows the stresses developed at the film surface when the contactor is placed at the minimum gap distance from the film surface with time.....133

- 6.8 (A) depicts the fractional contact area of column patterns formed at the free surface (parametric range of $G = g_0/g_1 = 600$, $g_0 = 3.0$, $g_1 = 0.005$ and $\tau = 0.203$) with time shown by the red square symbol line, and the red square symbol line in fig 6.8(B) shows the number of columns formed at the free surface with time. The summation of normal stresses per unit area (represents the adhesive force) and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.8(C) and (D), respectively. Variations of interaction potential energy and stored energy in a viscoelastic film with time are represented by the red square symbol line and the blue circle symbol line in fig. 6.8(E) respectively. The elastic part and viscous part of total stored energy in the film with time are shown by the red square symbol line and blue circle symbol line in fig. 6.8(F).....134
- 6.9 Surface profile of viscoelastic thin film surface when the contactor is at $d_c = 3.36$, shows the changeover in structure at the film surface with time. The parameters are in the range of $G = g_0/g_1 = 200$, $g_0 = 2.0$, $g_1 = 0.01$ and $\tau = 0.203$. Figure 6.9(A, C, E and G) shows the changeover in surface morphology with time and figure 6.9(B, D, F and H) shows the stresses developed at the film surface when the contactor is placed at the minimum gap distance from the film surface with time.....135
- 6.10 (A) depicts the fractional contact area of column patterns formed at the free surface (parametric range of $G = g_0/g_1 = 200$, $g_0 = 2.0$, $g_1 = 0.01$ and $\tau = 0.203$) with time shown by the red square symbol line, and the red square symbol line in fig 6.10(B) shows the number of columns formed at the free surface with time. The summation of normal stresses per unit area (represents the adhesive force) and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.10(C) and (D), respectively. Variations of interaction potential energy and stored energy in a viscoelastic film with time are represented by the red square symbol line and blue circle symbol line in fig. 6.10(E) respectively. The elastic part and viscous part of total stored energy in the film

- with time are shown by the red square symbol line and blue circle symbol line in fig. 6.10(F).....136
- 6.11 Surface profile of viscoelastic thin film when the contactor is at $d_c = 3.82$, shows the changeover in structure at the film surface with time. The parameters are in the range of $G = g_0/g_1 = 5$, $g_0 = 1.0$, $g_1 = 0.2$ and $\tau = 0.203$. Figure 6.11(A and C) show the changeover in surface morphology with time and figure 6.11(B and D) shows the stresses developed at the film surface when the contactor is placed at the minimum gap distance from the film surface with time.....138
- 6.12 (A) depicts the fractional contact area of column patterns formed at the free surface (parametric range of $G = g_0/g_1 = 5$, $g_0 = 1.0$, $g_1 = 0.2$ and $\tau = 0.203$) with time shown by the red square symbol line, and the red square symbol line in fig 6.12(B) shows the number of columns formed at the free surface with time. The summation of normal stresses per unit area (represents the adhesive force) and total energy variation with time in the film is shown in fig 6.12(C) and (D), respectively. The red square symbol line and the blue circle symbol line in fig 6.12(E) represent the interaction potential energy and stored energy in a viscoelastic film with time. The elastic part and viscous part of total stored energy in the film with time are shown by the red square symbol line and blue circle symbol line in fig. 6.12(F).139
- 6.13 Changeover in surface morphology in a thin viscoelastic film with time and with the variation in parameter g_0 , when the contactor is at critical gap distance. The parameters used for the surface profile shown in column (A) are $g_0 = 0.5$, $g_1 = 0.005$ and $\tau = 0.203$, surface profile shown in column (B) are $g_0 = 1.0$, $g_1 = 0.005$ and $\tau = 0.203$ and surface profile shown in column (C) are $g_0 = 3.0$, $g_1 = 0.005$ and $\tau = 0.203$ respectively.....140
- 6.14 (A) depicts the variation in the fractional contact area of patterns formed at the free surface with time with variation in parameter $g_0 = 0.5, 1.0$ and 3.0 (when

parameter $g_1 = 0.005$ and $\tau = 0.203$ are constant) shown by a red square, green triangle and blue circle symbol lines and similarly, figure 6.14(B) shows the number of columns formed at the free surface with time respectively. The summation of normal stresses per unit area represents the adhesive force and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.14(C) and (D) with the variation in parameter g_0 (represented by respective symbol line, shown in the legend) respectively. The variation in interaction potential energy and stored energy in the viscoelastic film with time are represented by the filled symbol line and hollow symbol line in fig. 6.14(E) respectively. Similarly, fig 6.14(F) shows the elastic part and viscous part of total stored energy in the film with time shown by respective filled symbol line and hollow symbol line (shows variation in g_0 parameter).141

6.15 Changeover in surface morphology in a thin viscoelastic film with time and with the variation in parameter g_1 , and parameter g_0 and τ kept constant when the contactor is at a critical gap distance. The parameters used for the surface profile shown in column (A) are, $g_0 = 1.0$, $g_1 = 0.001$ and $\tau = 0.203$, column (B) are $g_0 = 1.0$, $g_1 = 0.005$ and $\tau = 0.203$, column (C) are $g_0 = 1.0$, $g_1 = 0.05$ and $\tau = 0.203$, and column (D) are $g_0 = 1.0$, $g_1 = 0.5$ and $\tau = 0.203$ with time, respectively. 143

6.16 (A) depicts the variation in the fractional contact area of patterns formed at the free surface with time with variation in parameter $g_1 = 0.001, 0.005, 0.05$ and 0.5 (when the parameter $g_0 = 1.0$ and $\tau = 0.203$ are constant) shown by a red square, green triangle and blue circle symbol lines and similarly, figure 6.16(B) shows the number of columns formed at the free surface with time respectively. The summation of normal stresses per unit area represents the adhesive force and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.16(C) and (D) with the variation in parameter g_0 (represented by respective symbol line, shown in the legend) respectively. The variation in interaction potential energy and stored energy in the viscoelastic film with time are represented by the filled symbol line and hollow symbol line in fig. 6.16(E) respectively. Similarly, fig 6.16(F) shows the elastic

	part and viscous part of total stored energy in the film with time shown by respective filled symbol line and hollow symbol line (shows variation in g_0 parameter).....	144
6.17	Shear modulus variation or stress relaxation in the film with the time with the variation in stress relaxation time τ represents by the square symbol line ($\tau = 0.0203$), triangle symbol line ($\tau = 0.203$), and circle symbol line ($\tau = 2.03$) respectively at a constant value of $g_0 = 1.0$ and $g_1 = 0.005$ shown in figure 6.17(A). Figure 6.17(B) depicts the variation in time (time taken by a viscoelastic film to come in full contact with a contactor) with stress relaxation time.....	146
6.18	Changeover in surface morphology in the thin viscoelastic film with time and with the variation in stress relaxation parameter (τ) and parameter g_0 and g_1 are constant when the contactor is at a critical gap distance. The stress relaxation times used for the surface profile shown in columns (A), (B) and (C) are $\tau = 0.0203, 0.203$ and 2.03 , respectively.	147
6.19	(A) depicts the variation in the fractional contact area of patterns formed at the free surface with time with variation in stress relaxation time parameter $\tau = 0.0203, 0.203$ and 2.03 (when the parameter $g_1 = 1.0$ and $g_1 = 0.005$ are constant) shown by a red square, green triangle and blue circle symbol lines and similarly, figure 6.19(B) shows the number of columns formed at the free surface with time respectively. The summation of normal stresses per unit area represents the adhesive force and total energy variation with time in the film when the contactor is at the d_c is shown in fig 6.19(C) and (D) with the variation in parameter g_0 (represented by respective symbol line, shown in the legend) respectively. The variation in interaction potential energy and stored energy in the viscoelastic film with time are represented by the filled symbol line and hollow symbol line in fig. 6.19(E) respectively. Similarly, fig 6.19(F) shows the elastic part and viscous part of total stored energy in the film with time shown by respective filled symbol line and hollow symbol line (shows variation in g_0 parameter)...	148

- 6.20 2-D simulation results predict different modes of surface morphology in viscoelastic thin film with time at critical gap distance and with the variation in parameter g_0 , g_1 and τ at constant stress relaxation time. Contour represents the magnitude of $G = g_0/g_1$ in g_0 - g_1 plane.....150
- 6.21 Depicts the surface morphology developed and varies with time at the viscoelastic film surface when the contactor is at debonding stage (moving away from the film surface with debonding velocity). Column (A) represents the changeover in surface morphology with time during debonding stages for parameters for $g_0 = 3.0$, $g_1 = 0.001$, $\tau = 0.203s$ and 0.0 nm/s debonding velocity. Similarly, column (B) and (C) represents the morphology having the same parametric value but with different debonding velocities of 0.1 nm/s and 1.0 nm/s, respectively.152
- 6.22 Plot (A) depicts the fractional contact area of patterns formed at the film surface with gap distance during debonding cycle having fixed parametric value $g_0 = 3.0$, $g_1 = 0.001$ and $\tau = 0.203$. The green triangle symbol line and blue circle symbol lines present the corresponding data in plots for debonding velocity $v_d = 0.1$ nm/s, 1.0 nm/s respectively. The number of columns formed at the free surface with gap distance is shown in plot (B) at respective withdrawal velocities (given in the legend) of the contactor. The summation of normal stresses per unit area represents the adhesive force (F) and total energy (Π) variation with separation distance in the film when the contactor is moving with respective velocities (0.1 nm/s and 1.0 nm/s). Variations in interaction potential energy and stored energy with gap distance are represented by the filled symbol line and hollow symbol line in plot (E), respectively. Similarly, plot(F) shows the variation of elastic compliance and viscous compliance of total stored energy in the film with gap distance shown by respective filled symbol line and hollow symbol line (Here, green triangle and blue circle symbol lines represent withdrawal velocities 0.1 nm/s and 1.0 nm/s respectively).153

- 6.23 Depicts the surface morphology developed and varies with time at the viscoelastic film surface when the contactor is at debonding stage (moving away from the film surface with debonding velocity). Column (A) represents the changeover in surface morphology with time during debonding stages for parameters for $g_0 = 1.0$, $g_1 = 0.001$, $\tau = 0.203s$ and 0.0 nm/s debonding velocity. Similarly, column (B) and (C) represents the morphology having the same parametric value with different debonding velocities of 0.1 nm/s and 1.0 nm/s, respectively.155
- 6.24 Plot (A) depicts the fractional contact area of patterns formed at the film surface with gap distance during debonding cycle having fixed parametric value $g_0 = 1.0$, $g_1 = 0.001$ and $\tau = 0.203$. The green triangle symbol line and blue circle symbol lines present the corresponding data in plots for debonding velocity $v_d = 0.1$ nm/s, 1.0 nm/s respectively. The number of columns formed at the free surface with gap distance is shown in plot (B) for respective withdrawal velocities (given in the legend) of the contactor. The summation of normal stresses per unit area represents the adhesive force (F) and total energy (Π) variation with separation distance in the film when the contactor is moving with respective velocities (0.1 nm/s and 1.0 nm/s). Variations in interaction potential energy and stored energy with gap distance are represented by the filled symbol line and hollow symbol line in plot (E), respectively. Similarly, plot(F) shows the variation of elastic compliance and viscous compliance of total stored energy in the film with gap distance shown by respective filled symbol line and hollow symbol line (Here green triangle, and blue circle symbol lines represents withdrawal velocities 0.1 nm/s and 1.0 nm/s respectively).157
- 6.25 Depicts the surface morphology developed and varies with time at the viscoelastic film surface when the contactor is at debonding stage (moving away from the film surface with debonding velocity). Column (A) represents the changeover in surface morphology with time during debonding stages for parameters for $g_0 = 1.0$, $g_1 = 0.005$, $\tau = 0.203s$ and 0.0 nm/s debonding velocity. Similarly, column (B) and (C) represents the morphology having the

- same parametric value with different debonding velocities of 0.1 nm/s and 1.0 nm/s, respectively.159
- 6.26 Plot (A) depicts the fractional contact area of patterns formed at the film surface with gap distance during debonding cycle having fixed parametric value $g_0 = 1.0$, $g_1 = 0.005$ and $\tau = 0.203$. The green triangle symbol line and blue circle symbol lines presents the corresponding data in plots for debonding velocity $v_d = 0.1$ nm/s, 1.0 nm/s respectively. The number of columns formed at the free surface with gap distance is shown in plot (B) for respective withdrawal velocities (given in the legend) of contactor. The summation of normal stresses per unit area represents the adhesive force (F) and total energy (Π) variation with separation distance in the film when the contactor is moving with respective velocities (0.1 nm/s and 1.0 nm/s). Variations in interaction potential energy and stored energy with gap distance are represented by the filled symbol line and hollow symbol line in plot (E), respectively. Similarly, plot(F) shows the variation of elastic compliance and viscous compliance of total stored energy in the film with gap distance shown by respective filled symbol line and hollow symbol line (Here, green triangle and blue circle symbol lines represent withdrawal velocities 0.1 nm/s and 1.0 nm/s respectively).160
- 6.27 Depicts the surface morphology developed and varies with time at the viscoelastic film surface when the contactor is at debonding stage (moving away from the film surface with debonding velocity). Column (A) represents the changeover in surface morphology with time during debonding stages for parameters for $g_0 = 0.5$, $g_1 = 0.005$, $\tau = 0.203$ s and 0.0 nm/s debonding velocity. Similarly, column (B) and (C) represents the morphology having the same parametric value with different debonding velocities of 0.1 nm/s and 1.0 nm/s, respectively.162
- 6.28 Plot (A) depicts the fractional contact area of patterns formed at the film surface with gap distance during debonding cycle having fixed parametric value $g_0 = 0.5$, $g_1 = 0.005$ and $\tau = 0.203$. The green triangle symbol line and blue circle symbol lines present the corresponding data in plots for debonding velocity $v_d =$

	0.1 <i>nm/s</i> , 1.0 <i>nm/s</i> respectively. The number of columns formed at the free surface with gap distance is shown in plot (B) for respective withdrawal velocities (given in the legend) of the contactor. The summation of normal stresses per unit area represents the adhesive force (F) and total energy (Π) variation with separation distance in the film when the contactor is moving with respective velocities (0.1 <i>nm/s</i> and 1.0 <i>nm/s</i>). Variations in interaction potential energy and stored energy with gap distance are represented by the filled symbol line and hollow symbol line in the plot(E), respectively. Similarly, plot(F) shows the variation of elastic compliance and viscous compliance of total stored energy in the film with gap distance shown by respective filled symbol line and hollow symbol line (Here, green triangle, and blue circle symbol lines represent withdrawal velocities 0.1 <i>nm/s</i> and 1.0 <i>nm/s</i> respectively).	163
6.29	2-D simulation results predict different mode of surface morphology in viscoelastic thin film with time, when contactor is moving away (debonding process) and with the variation in parameter g_0 , g_1 and τ at constant stress relaxation time. Contour represents the magnitude of $G = g_0/g_1$ in g_0 - g_1 plane.	165
7.1	Schematic figure of an inhomogeneous leaky bilayer configuration, externally applied an E-field of potential ψ and confined between two electrodes, placed at a gap distance "d". Both elastic and viscous films have thickness-dependent material properties like shear modulus $G(z)$ and viscosity μ . The dotted line represents the undeformed interface of the bilayer configuration.	169
7.2	Shear modulus variation in the elastic film with film thickness. For the negative value of α , the film is softer at the base state, for positive values of α film is softer at the top compared to base state and at $\alpha = 0$, film has constant shear modulus throughout.	176
7.3	Plot (A) shows the validated LSA results of growth rate of instability vs wave number. The solid black line corresponds to the inhomogeneous thin film, and the solid line with square symbol for the homogeneous thin bilayer. Plot (B) shows	

	the growth rate of instability curve for homogeneous bilayer film ($\alpha = 1$) and inhomogeneous bilayer (softer interface (α positive) and with stiffer interface (α negative)).	177
7.4	Plot of figure 7.4(A) for the dominant wavelength of instability with the variation of α (range from positive to negative), the plot of fig. 7.4(B) depicts the dominant growth rate of the coefficient with the variation of α .	177
7.5	Plot (A1-A3 and B1-B3) shows the growth rate of instability and wavenumber for both homogenous leaky dielectric bilayer. Plot (A1-A3) shows the data when elastic layer is leakier while plot (B1-B3) shows the data when viscous layer is leakier.	178
7.6	Plot (A1-A3 and B1-B3) shows the growth rate of instability and wavenumber for both homogenous and one of the leaky dielectric layers in bilayer. Plot (A1-A3) shows the data when elastic layer is leakier while plot (B1-B3) shows the data when viscous layer is leakier.	179
7.7	Plot (A1-A3) shows the growth rate of instability and wavenumber, when leaky, graded elastic layer is confined with leaky viscous layer. Plot (A1-A3) shows the data when graded elastic layer is more leaky than viscous, while plot (B1-B3) shows the data when viscous layer is leakier than viscous layer.	181
7.8	Plot (A1-A3) shows the growth rate of instability and wavenumber, when leaky, graded elastic layer is confined with leaky viscous layer. Plot (A1-A3) shows the data when graded elastic layer is leaky and confined dielectric viscous, while plot (B1-B3) shows the data when viscous layer is leakier and confined with graded elastic layer.	183