Evolution of Surface Undulations in Polymer Composite Films with Immobilized Film Spanning Nanoparticles

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The evolution of surface undulations in polymer films under thermal stress in the presence of immobilized film spanning nanoparticles is investigated. The elastic stresses in the plane of the polymer thin films is induced by fixed lateral constraints within the film that resist in-plane film thermal expansion as the temperature increases. Surface undulations arising from stress relaxation are observed as the thin-film systems are heated to a temperature above the glass-transition temperature. Our studies reveal a three-stage evolution of wavelike undulations on the film surface: early stage, intermediate stage and late stage. Although the origin is different, the dynamic evolution of these wavelike undulations is strikingly similar in characteristics to spinodal decomposition. We also find that the evolution of the wavelike undulations in NP-filled polymer films is greatly influenced by the annealing temperature, molecular mass, film thickness and solvent annealing process.