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# In situ GISAXS investigation of ternary hybrid diblock copolymer thin films containing two types of magnetic nanoparticles

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The fabrication of hybrid thin films can be realized utilizing diblock copolymers (DBCs) that form periodic, ordered nanostructures and inorganic nanoparticles (NPs). While binary hybrid films have been the focus of much research, ternary hybrid films containing two types of NPs expand the possible functionalities of such films. In this work, polystyrene-block-poly(methyl methacrylate) (PS-b-PMMA) thin films containing iron oxide and nickel oxide nanoparticles are fabricated in a one-step slot die-coating process. The morphology evolution of the hybrid thin films is tracked in situ utilizing grazing-incidence small-angle X-ray scattering (GISAXS). Film formation can be characterized by three stages, clearly observed in the scattering data. The first stage is the wet film, where, after deposition, the scattering from the deposited solution dominates. In the second stage, a rapid coalescence and microphase separation are observed which is unperturbed by the presence of the NPs. Finally, the third stage is attributed to the stable dry film where no further changes in scattering intensity or film morphology occur. The magnetic properties of the hybrid thin films are investigated utilizing a superconducting quantum interference device. With increasing nickel oxide NP content, while maintaining the iron oxide NP content, the saturation magnetization, remanence, and coercivity of the hybrid films are improved. These hybrid films demonstrate the potential for ternary composites to exert a greater degree of control on the resulting magnetic properties.

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