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Direct measurement of the role of confinement and chemistry on local physical and mechanical properties of polymers

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ABSTRACT

It has been demonstrated that the physical properties of the interfacial regime near the interfaces of polymers and inorganic inclusions can be significantly altered because of the geometric and chemical interactions between the two constituents and the subsequent communication of those interactions through the macromolecular polymer network. The mechanical properties are expected to deviate from those of the bulk polymer because of the altered polymer chain mobility in the interfacial regime. However, the physical mechanism of the structural alternation is still poorly understood and thus quantitative prediction of the property change is still lacking. Thus, state-of-art experimental techniques applied to provide understanding and characterization of the local modulus are needed. In our study, Quantitative Nanomechanical Property Mapping (QNM) mode in Atomic Force Microscopy (AFM) is utilized to measure both the topology and the mechanical property in the interfacial regime of polymer thin film/substrate systems directly by performing high frequency nanoindentation test on the lateral surface of the sample with a very sharp tip (radius ~10 nm). In addition, a 3D finite element model featuring explicitly simulated cantilever and tip geometry and beam vibration is built such that the measured local modulus results are calibrated. In addition, a noncontact based technique (Fluorescence probing) for local stiffness measurement, are also performed on the same samples. Comparison and correlation between the results from direct AFM measurement and those from Fluorescence Probing provide validation of both methods and insight into mechanisms. Using both approaches, several different polymer/substrate systems are tested. The AFM results after calibration show that distinct modulus increase has been found in the first ~100nm region starting from the boundary between the substrate and polymer. The local stiffening effect in the same region is also captured via Fluorescence Probing. Moreover, the stiffening effects are observed to be substantially weaker as the distance increases from the substrate for both techniques. The results not only indicate the existence of the interfacial regime with altered properties, but also provide an estimate on the quantity of such property change, which provides helpful information for understanding the microscale mechanism of formation of such regime and the interaction between the polymer and substrate.