Quantifying Liquid Transport and Patterning using Atomic Force Microscopy

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Atomic force microscopy (AFM) provides unique insight into the nanoscale properties of materials through its ability to image and pattern materials at these scales. It has been challenging, however, to use AFM to study soft materials such as liquids or gels because of their tendency to flow in response to stress, which means that they cannot be simply imaged. Here, we propose an AFM-based technique for quantitatively analyzing the transport of soft materials from an AFM probe to a surface.[1] Specifically, we present a method for loading an AFM probe with a single 0.3 to 30 pL droplet of liquid, and subsequently measuring the mass of this liquid by observing the change in the vibrational resonance frequency of the cantilever. Using this approach, the mass of this liquid was detected with pg-scale precision using a commercial AFM system. Additionally, sub-fL droplets of liquid were transferred from the probe to a surface with agreement found between the real-time change in mass of the liquid-loaded probe and the volume of the feature written on the surface. To demonstrate the utility of this approach in studying nanoscale capillary and transport phenomena, we experimentally determine that the quantity of liquid transported from the tip to a surface in a given patterning operation scales as the mass of liquid on the probe to the 1.35 power. In addition to providing new avenues for studying the dynamics of soft materials on the nanoscale, this method can improve nanopatterning of soft materials through *in situ* feedback. Thus, we conclude by exploring the implications of this approach for scanning probe lithography and discuss ongoing efforts to realizing closed-looped nanofabrication.

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[1]N. Farmakidis, K. A. Brown *Langmuir* **33**, 5173 (2017).