Coffee rings for microscale biomolecular processing

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Understanding biological-fluid evaporation on small scales facilitates development of advanced biomolecular-processing techniques for a broad range of biomedical applications.

Biological fluids (such as blood, saliva, and urine) contain a large amount of information that can be used for medical diagnostic purposes. This information is encoded within biological molecules (i.e., proteins and DNA) and cells with sizes ranging from a few nanometers to \( \mu m \). Precise extraction and timely processing of this information can ensure efficient medical diagnosis. Traditionally, analysis of biological fluids is carried out in specialized laboratories that require highly trained personnel and access to sophisticated instruments. However, such facilities are not always available in remote areas or underdeveloped countries. Therefore, development of simple and efficient devices is needed for fundamental processing of biological fluids for medical diagnosis.

Many diseases and illnesses are characterized by abnormal variations in the amounts of molecules and cells in biological fluids. Detecting these small variations, especially during the early stages of disease progression, can be achieved by ultra-highly sensitive optical or electrochemical detection methods. Alternatively, less sensitive devices can be used if these biological molecules are transported and concentrated in a confined region within the fluid sample. We (as well as other colleagues) previously developed a variety of microsystems for transportation and concentration of biological molecules for disease detection. Despite the versatility of these microsystems, external power sources are required for their operation, which increases the size and weight of such systems and may limit their applicability in remote areas.

The coffee-ring phenomenon offers a novel avenue for transportation and concentration of molecules without requiring external power sources. A coffee ring forms when a liquid droplet containing suspended particles evaporates. These particles are transported to the droplet’s edge by the evaporation-induced capillary flow. Once all liquid has

Figure 1. Microscale coffee ring.

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We showed that droplets containing 100nm-sized particles can produce well-defined coffee rings down to 10\,\mu m in circumference, which is 10 times smaller than the width of a single human hair. For smaller droplets, water evaporates faster than the particles can move: rather than forming a ring pattern, the particles will be dispersed uniformly within the droplet region, since they do not have enough time to move to the droplet’s edges. Physical understanding of coffee-ring formation on small scales will guide us to design engineering devices for effective biomolecular transportation and concentration.

Thus far, we have shown that the coffee-ring phenomenon can be used as a simple yet effective mechanism for particle transportation and concentration on small scales. Now that we better understand the definitive size limit of coffee-ring formation, we are exploring the capabilities of these microscale coffee rings for novel biomolecular-processing devices. We believe that coffee-ring-based bioprocessing techniques, when integrated with suitable protocols for detection of disease-specific biological markers, can offer a novel, simple, and low-cost solution for biodetection and diagnostic testing in remote areas and underdeveloped countries.

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References