Microfluidics, Chromatography, and Atomic-Force Microscopy

Capillary and shear effects are exploited to transport small quantities of liquids.

NASA's Jet Propulsion Laboratory, Pasadena, California

A Raman-and-atomic-force microscope (RAFM) has been shown to be capable of performing several liquid-transfer and sensory functions essential for the operation of a microfluidic "laboratory on a chip" that would be used to perform rapid, sensitive chromatographic and spectro-chemical analyses of unprecedentedly small quantities of liquids. The most novel aspect of this development lies in the exploitation of capillary and shear effects at the atomic-force-microscope (AFM) tip to produce shear-driven flow of liquids along open microchannels of a microfluidic device. The RAFM can also be used to perform such functions as imaging liquids in microchannels; removing liquid samples from channels for very sensitive, tip-localized spectrochemical analyses; measuring a quantity of liquid adhering to the tip; and dip-pen deposition from a chromatographic device.

A commercial Raman-spectroscopy system and a commercial AFM were integrated to make the RAFM so as to be able to perform simultaneous topographical AFM imaging and surface-enhanced Raman spectroscopy (SERS) at the AFM tip. The Raman-spectroscopy system includes a Raman microprobe attached to an optical microscope, the translation stage of which is modified to accommodate the AFM head. The Raman laser excitation beam, which is aimed at the AFM tip, has a wavelength of 785 nm and a diameter of about 5 μm, and its power is adjustable up to 10 mW. The AFM is coated with gold to enable tip-localized SERS.

Heretofore, the use of microfluidic devices for "laboratory on a chip" applications has been inhibited by the need for very high pressures to pump fluids through capillary channels at sufficient rates. Shear-driven flow offers an alternative by eliminating the need for pressure. In the basic form of shear-driven pumping, illustrated at the top of Figure 1, two parallel plates with a liquid between them are driven laterally with respect to each other, causing the liquid to be pumped between the plates. Shear-driven pumping makes it possible to produce very rapid flows along very narrow channels aligned along the sliding direction. The basic form of shear-driven pumping is used in shear-driven chromatography (SDC), in which the stationary plate is functionalized to effect chromatographic separation. In the present approach to shear-driven pumping, illustrated at the middle and bottom of Figure 1, liquid adhering to the RAFM tip and cantilever (or to the tip only) is simply dragged along a microchannel by moving the tip as in normal AFM operation.

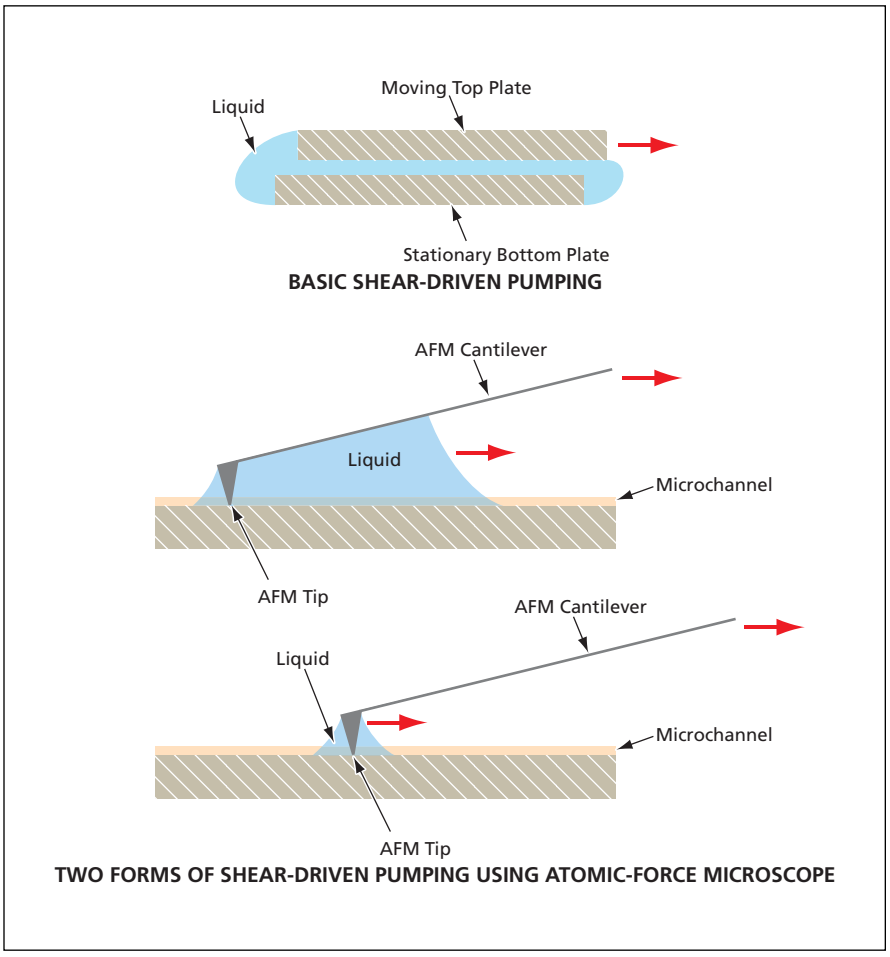

Figure 1. **Shear-Driven Pumping** is a viable technique for moving small quantities of liquid rapidly along a microchannel.

In addition to moving a sample of liquid along a microchannel, the RAFM could be used to perform several other operations:

- A sample of liquid could be removed from a microchannel and placed in another microchannel.
- A sample of liquid clinging to the RAFM tip after removal from a microchannel could be subjected to SERS to determine its chemical composition.
- The RAFM could be operated as a conventional AFM in a tapping mode to topographically map the surface of a liquid in a microchannel.
- The change in frequency of vibration of the cantilever-and-tip structure could be measured to determine the mass of liquid clinging to the tip.
- In a generalization from the concept of dip-pen nanolithography, one could perform dip-pen microchromatography, in which a chromatographic liquid would be discharged from a microchromatographic column at the base of the cantilever as the AFM tip was moved along a microchannel (see Figure 2). The liquid would flow along the cantilever onto the tip and would be deposited in the microchannel. After evaporation of the eluent (solvent), the resulting deposits of analytes along the channel could be analyzed

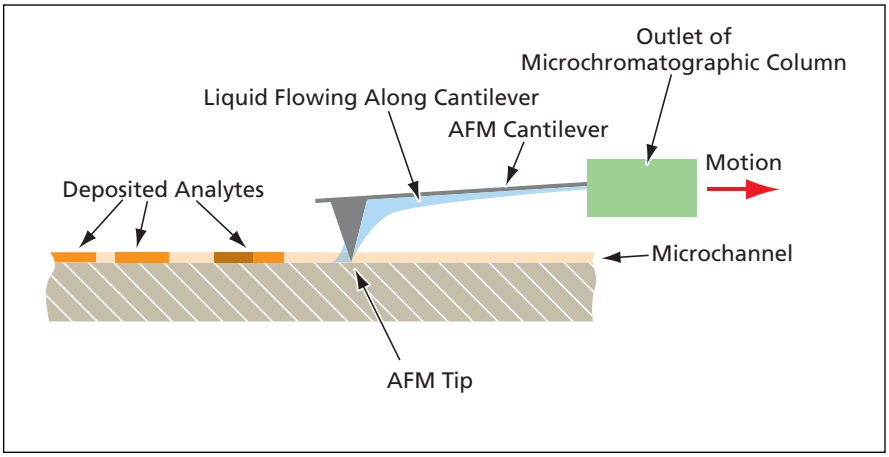

Figure 2. The **Moving AFM Tip** would deposit the outflow of a microchromatography column along a microchannel. After subsequent evaporation of the solvent, the AFM could be used to profile the deposited analytes.

by conventional AFM profiling.

This work was done by Mark Anderson of Caltech for NASA's Jet Propulsion Laboratory.

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Model of Image Artifacts From Dust Particles

This first-order geometric-optics-based model yields realistic predictions.

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A mathematical model of image artifacts produced by dust particles on lenses has been derived. Machine-vision systems often have to work with camera lenses that become dusty during use. Dust particles on the front surface of a lens produce image artifacts that can potentially affect the performance of a machine-vision algorithm. The present model satisfies a need for a means of synthesizing dust image artifacts for testing machine-vision algorithms for robustness (or the lack thereof) in the presence of dust on lenses.

A dust particle can absorb light or scatter light out of some pixels, thereby giving rise to a dark dust artifact. It can also scatter light into other pixels, thereby giving rise to a bright dust artifact. For the sake of simplicity, this model deals only with dark dust artifacts. The model effectively represents dark dust artifacts as an attenuation image consisting of an array of diffuse darkened spots centered at image locations corresponding to the locations of dust particles. The dust artifacts are computa-

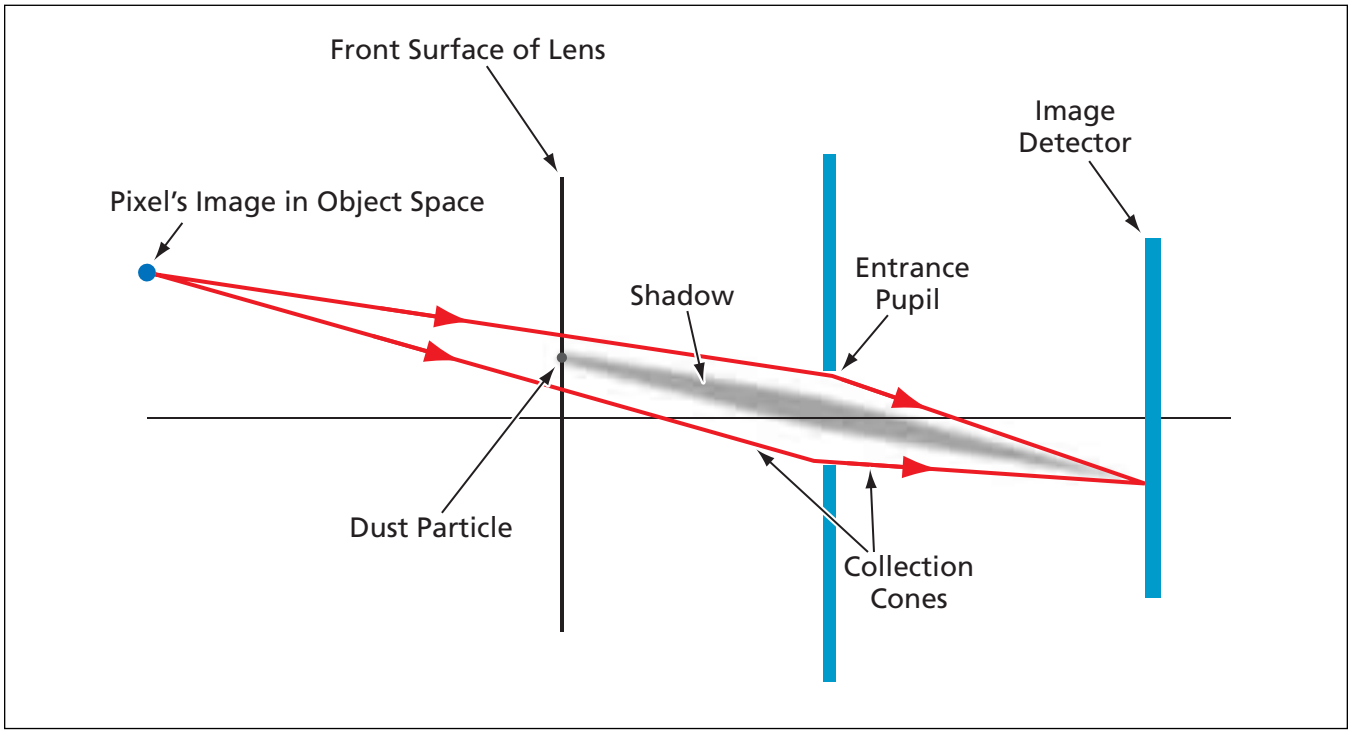

Figure 1. A **Geometric-Optics Model** of shadowing is used to compute the effects of dust particles on an image.