HYDRODYNAMIC LEVITATION OF A MICROFLUIDIC PROBE FOR SAMPLE-HEAD DISTANCE CONTROL

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ABSTRACT

We report on a self-regulating, simple and precise approach to control the distance between a scanning microfluidic probe and a surface. The approach is based on hydrodynamic levitation of the probe over a surface. We demonstrate this distance control in the context of life-sciences, where the surfaces are most often immersed in liquid, and typical variations of the surface topography are in the tens to hundreds of micrometers.

KEYWORDS

microfluidic probe, open microfluidics, surface processing, hydrodynamics.

INTRODUCTION

Microscale patterning of curved and corrugated surfaces using scanning probe devices remains challenging, in particular for biological surfaces where contact between the probe and the sample must be avoided. Distance control is central to probes such as nanopipettes, microfluidic probes (MFPs) and atomic force microscopes.[1] Generally, force, current [2], voltage or optical signals are used as feedback for distance control. These signals and feedback approaches are suitable for the μm range but not for operation within tens of micrometers and in liquid environments. One recent demonstration of locally processing surfaces on liquid environment is the cantilever-based approach, e.g. the FluidFM.[3] In such systems, it is difficult to focus the laser in a liquid environment, and with multiple interfaces (air-liquid). This results in low Q-factor, and air bubbles tend to change refractive index, in turn disturbing the laser reflection. There is a critical need to develop strategies for regulating the distance between a scanning probe and a biological surface. We here report a simple and efficient distance control principle for the MFP.

The MFP is a scanning microfluidic technology, which hydrodynamically confines picoliters of a processing liquid on substrates immersed in liquid. It operates 10-50 μm above the surface.[4] The MFP has been applied to flat substrates with roughnesses smaller than 5 μm to pattern proteins, stain tissues and cells.[4][5] The main component of the MFP is a rhombus-shaped head made of Si and glass comprising microchannels terminating at an apex, Fig. 1. So far, the sample-head distance was set manually based on a sample-head contact observed using an inverted microscope. This required transparency of the sample and its carrier (e.g. glass slide) and corrugated and curved surfaces could not be processed without human interaction. The head was leveled relative to the glass slide comprising a biological sample (e.g. tissue section) and the zero position established. Another approach was the *a priori* calibration to specific topographies of the surfaces. This was time consuming, and some liquid-surface interactions were not easy or possible to visualize and often dust particles resulted in problems.

PRINCIPLE

Here, we use hydrodynamic levitation for automated distance control. This requires only an additional pump and extra channels within the MFP head. A liquid flowing through levitation apertures generates a pressure underneath the head, thereby lifting it. At steady state, the lifting height (d) of the head depends on the weight (F_{weight}) as set with a balanced rocker arm, the flow rate (D) through the levitation apertures, and the area of the apex. When the MFP head encounters a topographical variation, the distance is self-corrected due to the dependence of the lifting height (d) on the lifting force (F_{lift}) altering the hydraulic resistance ($R(d)$). The placement of the apertures on the apex is critical. Placing them near the injection/aspiration apertures perturbs the confined processing liquid whereas close placement to the periphery of the apex reduces F_{lift}. Design rules have been established for optimal apex size, aperture placement and flow confinement, and the head can easily be redesigned accordingly.[6]

978-0-9798064-5-2/μTAS 2012/$20©12CBMS-0001

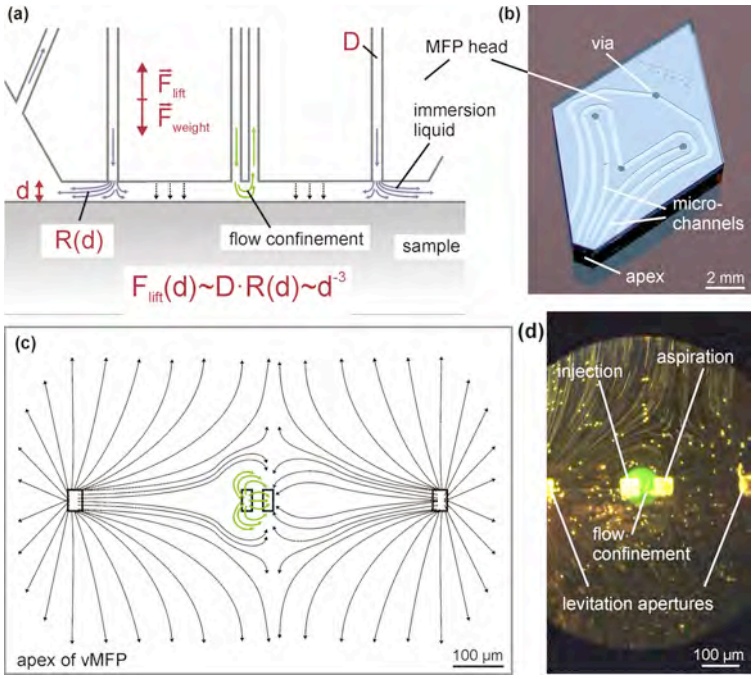

Figure 1. *Principle of the hydrodynamically levitated MFP.* ***(a)*** *A lifting force (F_{lift}) acts on the MFP head due to a liquid flow (D) through the levitation apertures, resulting in a lifting height (d).* ***(b)*** *Photograph of a MFP head comprising apertures for levitation, flow confinement and aspiration of immersion liquid.* ***(c)*** *Representation of flow lines between the apertures. The green arrows show the confinement of processing liquid and the black arrows represent the liquid injected through the levitation apertures.* ***(d)*** *Microscope image showing the confinement of a fluorescein solution and the injection of a suspension, containing 1 µm fluorescent beads, through the levitation apertures.*

vMFP HEAD FABRICATION AND PLATFORM

The vMFP head is a two layer (Si/glass) microfluidic device comprising microchannels, vias for fluidic connection and a polished edge (apex) where the microchannels exit into open space (apertures). The apex physically supports the flow confinement, and has an area of approximately 1 mm^2. The microchannels are typically 50 µm deep and taper from 200 µm width (starting from a via) to 50 µm (at the apertures). This design can easily be changed as needed and several variants of heads are described in [3].

Fabrication of vMFP heads was done using standard microfabrication techniques such as photolithography, deep reactive ion etching and anodic bonding. The microchannels and vias were etched in a 500-µm-thick 4 inch Si wafer (Siltronix, Geneva, Switzerland). The microstructured Si wafer, with 33 vMFP heads was then anodically bonded to a 500-µm-thick glass wafer (Borofloat® 33, SCHOTT AG, Germany). The microstructures were filled with 80 °C molten wax (OCON 199, Logitech GmbH, Germany) for protection during dicing and polishing of the heads. Heptane was subsequently used to remove the wax from the microstructures of the polished heads.

The vMFP head was mounted in a custom aluminum holder prior to performing an experiment. The syringe pumps (not shown) were connected to the holder through capillary tubing. O-rings were used to seal the connection between the vias of the vMFP head and the ports in the holder.

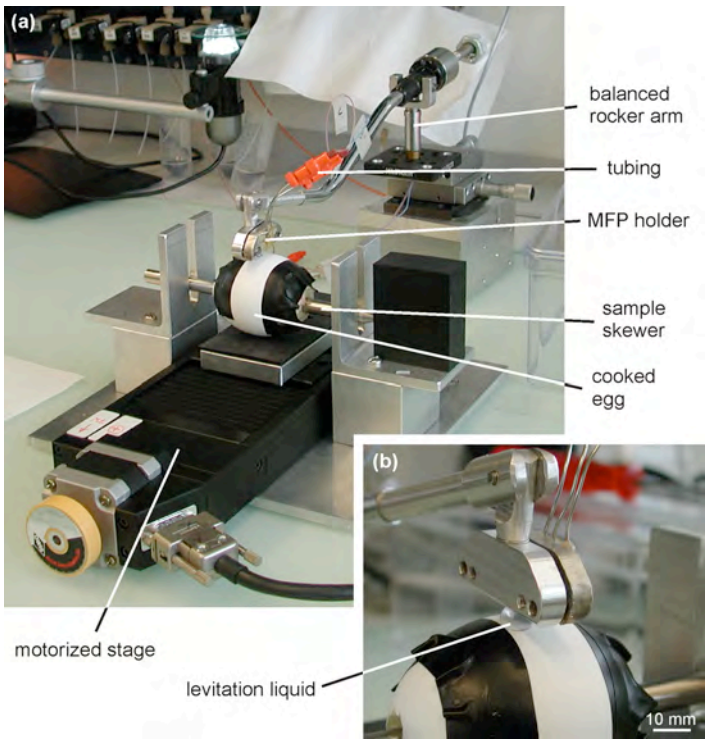

Figure 2*. Setup for local staining of an egg shell using a levitating MFP. (a) The setup consists of a motorized stage, a MFP head clamped in a holder, which was mounted on a record player arm to balance the weight. (b) Close-up of the holder with the levitating MFP head interacting with the egg shell.*

EXPERIMENTAL SECTION

We used the levitating MFP to pattern "challenging" surfaces, for example, a 35-µm-thick Cu substrate used for circuit boards and the shell of an egg. Etching Cu was performed using a $Na_2S_2O_8$ solution (20% w/v), while logwood brew (used to color Easter eggs) was applied to stain the egg shell. Rotating the egg around its axis resulted in 75 to 100 µm-wide stained lines, Fig. 2 and 3.

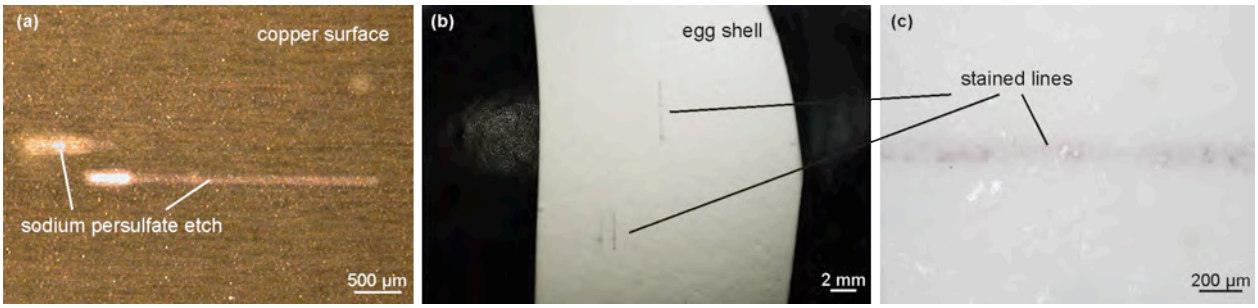

***Figure 3**. Local processing of "challenging" surfaces. (a) A 35-µm-thick Cu surface was locally etched using a confined $Na_2S_2O_8$ solution (20% w/v). (b) and (c) Lines of 75 to 100 µm width stained with logwood brew on the shell of an egg using the levitating MFP.*

OUTLOOK

Using hydrodynamic levitation, a MFP can now easily process a large range of surfaces and not only biological specimens on glass slides. In addition, the MFP is now compatible with opaque surfaces and does not need complex sensing and actuation systems in the z-axis. This new distance control principle may spur the use of MFPs for microscale processing of surfaces in many fields. This approach is not limited to the MFP, but could broadly be used for other scanning probe approaches.

ACKNOWLEDGEMENT

The authors thank U. Drechsler for assistance in microfabrication and M. Hitzbleck for discussions. V. Vogel (ETH Zurich), M. Despont and W. Riess are acknowledged for their continuous support.

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