Lab on a Chip

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HIGHLIGHT

# Research highlights

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## Lab-on-a-yarn

Research in the field of microfluidics is progressing in two diametrically opposed directions: highly complex integrated lab-on-a-chip devices on one hand and simple devices for rapid and reliable point-of-care applications on the other hand.[1] In the latter group, researchers are studying shrink-films, paper, and now yarn as model materials. Juncker and co-workers, for example, are studying the properties of cotton yarn as a wicking medium and of knots as elements for making passive microfluidic circuits.

In a recent article, Safavieh *et al.*[2] have detailed their studies of flow resistance and surface drying of cotton yarn. The yarn, 500 μm in diameter, is usually coated with wax, and consists of 70% fibers and 30% gaps. The yarn was first dried in an oven and then rendered hydrophilic using air plasma. The resulting yarn was held horizontally on a PTFE sheet in all experiments in order to prevent gravitational and interfacial effects on the wicking process. When dye was applied to one end of the fibers, it was wicked spontaneously, such that the wetted length increased as a square root of time, as predicted by the Washburn equation. The gaps between fibers, of the order of 15 μm, give rise to a Reynolds number of $Re = 0.03$. The relationship between wetted length and time, however, was linear in hydrophobic fibers. It was determined from the calculation of the evaporation rate of water at the yarn surface that a maximal wetted length at 30% humidity was 90 mm. At the arbitrary evaporation to capillary flow ratio of 1 : 3, this length is shortened to 30 mm, and is reached after roughly 38 s. The flow resistance of the yarn was determined to be in the order of $10^{16}$ Pa s m$^{-3}$, based on the capillary pressure of the yarn and the flow rate.

Even more interestingly, the authors showed that knots can serve as flow dividers and mixers and thus mimic complex microfluidic circuitry (Fig. 1). Two yarns were wetted with yellow and blue dyes, respectively, and upon joining at the knot, the two dyes mixed to form a green fluid, which then continued to wet the remaining parts of the yarns. The mixing ratio and thus the intensity of the green fluid were dependent on the knot topology and could be adjusted between complete mixing and almost no mixing, depending on the configuration. These findings were exploited in the design of a knotted web, which using electrical circuit analysis, was predicted to produce a serial diluter such as the ones used for generating microfluidic gradients. The prediction was then validated.

The flow properties of cotton yarn explored in this article complement current research on functional textiles, which commonly includes electro- and temperature sensitive materials. It also highlights the potential to apply an inexpensive and widely available material such as cotton in low-cost lab-on-a-chip applications.

## Watching biomolecules—with the naked eye

Early diagnosis of various diseases has been correlated with improved survival and recovery chances of patients. Generally, diagnostic tools that offer the required high levels of accuracy and precision are expensive and moderately difficult to operate, and are therefore limited to hospital use. This makes them incompatible with point-of-care applications, which require inexpensive, simple-to-use, but at the same time highly accurate devices.[3] In their efforts to develop such a diagnostic device, Altug and colleagues have recently published an article in which they describe a process that allows users to visually observe biomolecules and chemical reactions. The suggested approach enables the user to visualize molecules with the naked eye without the need for fluorescent labeling or enzymatic reactions.

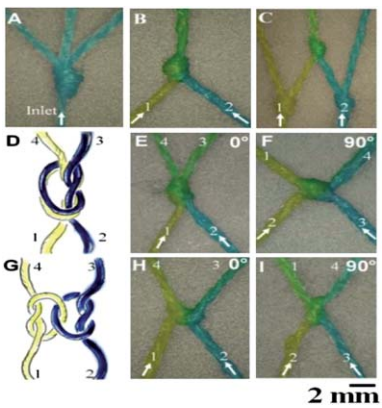


**Fig. 1** Various knots with different topologies used to mix yellow and blue dyes in cotton yarn. Figure reprinted with permission of the Royal Society of Chemistry from Safavieh *et al.*[2]

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In their paper, Yanik *et al.*[4] utilized highly dispersive Fano resonances in plasmonic nanohole devices for direct detection of biomolecules. The nanohole array (90 μm × 90 μm) was fabricated using standard methods of electron-beam and interference nanolithography. Fano resonance is observed when two alternative light pathways interfere, enabled through direct transmission by a broad plasmonic resonance and resonant transmission by a discrete plasmonic resonance. Depending on the phase difference between these alternative pathways, a resonance profile that looks like an asymmetric Greek letter "Λ" arises. Since the phase changes rapidly from destructive to constructive, the resulting resonance dispersion is extremely steep - something that leads to strong modulation of the transmitted light intensities in a narrow wavelength interval. The Fano effect was utilized by the authors for label free sensing of biomolecules, as the strongly dispersive Fano resonances produce large changes in light intensity when an object, *e.g.* a biomolecule, is encountered.

The exploitation of surface plasmon polaritons (SPPs), coupled states between plasmons and photons, on a nanohole array allows for micro- and nanoscale device development as well as system integration. When coupled with the subradiant dark resonances, however, an additional advantage was revealed in that the sensitivity of the SPPs was boosted by the optical line-widths of down to 4 nm, which is one to two orders of magnitude better than surface plasmon resonators and metamaterials. This is noteworthy, as smaller line-widths enable detection of very small molecule concentrations. Finally, this observation method was shown to be compatible with high numerical aperture imaging, which enables large area multiplexing compatible with microfluidics.

The capabilities of this device were demonstrated when mouse IgG immunoglobulins were deposited onto the nanohole array and bound to the surface with protein A/G. The formed immunoglobulin monolayer strongly absorbed the incident light. This resulting variation in transmitted light intensity was readily observed by eye without optical isolation from the environment (Fig. 2).

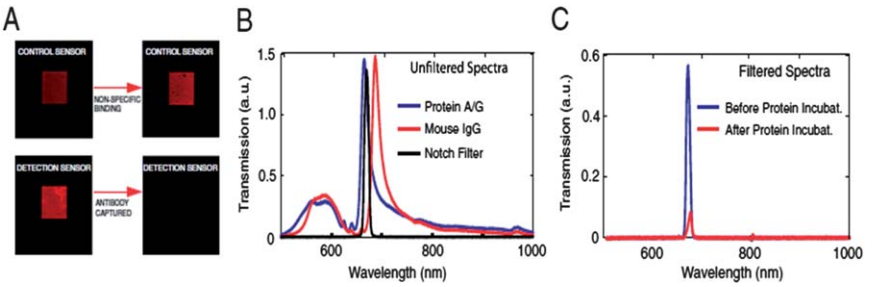


**Fig. 2** (a) Optical images of nanohole arrays functioning as control and detection sensors. The detection sensor appears visibly darker when a monolayer of biomolecules is formed on its surface. (b) Transmission spectra of a notch filter and before (protein AG) and after (mouse IgG) specific binding of mouse IgG antibodies. (c) Same spectra as in (b), but with the notch filter in place. Figure reprinted with permission from the National Academy of Sciences.[4]

The small size of the device in addition to the ease of use and lack of supporting equipment such as expensive optical imaging systems, fluorescence filters and electronic signal converters, and most of all the extremely high signal accuracy and sensitivity make this device a promising candidate for future applications in portable point-of-care devices.

## Laser scanning lithography for microfabrication

Engineered surfaces that can be used for microscale patterning of a single type of ligand are now routinely fabricated.[5] It is still challenging, however, to build similar devices that enable simultaneous patterning of two or more ligand types on the same surface. A novel strategy has recently been offered by West and colleagues. In their paper, Slater *et al.*[6] introduced the use of laser scanning lithography for fabrication of such multifaceted and micropatterned surfaces.

In this method, a gold coated glass substrate was first functionalized with a self-assembled molecular monolayer (SAM) and then exposed to a raster-scanning laser (532 nm) along desired patterns to thermally remove certain parts of the SAM. Then, a second SAM was deposited on the clean gold surface and further patterned with the laser and so on. This approach yielded multiple functionalized microscale patterns (1 μm and larger) on the glass substrate. The pattern size increased linearly with the laser fluence and non-linearly up to a maximum size with the number of iterations. An increase in the thickness of the gold layer from 6 nm to 10 nm, and therefore the conductivity, also aided in forming larger features, due to the stronger heating and desorption of the SAM. For example, thinner gold films were helpful in fabricating raised features, while thicker films were more useful in forming indented patterns. The utility of this method for biological applications was displayed by studying human umbilical vein endothelial cells. When seeded on a multifaceted pattern containing two different ligands, the cells were observed to rely on both molecules in migration and formation of lamellae.

The laser scanning patterning method presented in the paper is mask-less, it can be used to produce multifaceted nano- and microscale patterns for imaging of several ligands, and it enables display of both discrete and continuous ligand gradients. Specifically the dimensional and topographic variations in the patterns are suitable for studying the effects of several experimental conditions on biological samples simultaneously. These characteristics make the engineered surfaced useful for multi-parameter studies of cellular microenvironmental factors.

## References


1 G. M. Whitesides, The origins and the future of microfluidics, *Nature*, 2006, **442**(7101), 368–73.
2 R. Safavieh, G. Z. Zhou and D. Juncker, Microfluidics made of yarns and knots: from fundamental properties to simple networks and operations, *Lab Chip*, 2011, **11**, 2618–2624.
3 C. A. Holland and F. L. Kiechle, Point-of-care molecular diagnostic systems - past, present and future, *Curr. Opin. Microbiol.*, 2005, **8**(5), 504–509.

4 A. A. Yanik, *et al.*, Seeing protein monolayers with naked eye through plasmonic Fano resonances, *Proc. Natl. Acad. Sci. U. S. A.*, 2011, **108**(29), 11784–11789.

5 A. L. Hook, N. H. Voelker and H. Thissen, Patterned and switchable surfaces for biomolecular manipulation, *Acta Biomater.*, 2009, **5**, 2350–2370.

6 J. H. Slater, *et al.*, Fabrication of Multifaceted Micropatterned Surfaces with Laser Scanning Lithography, *Advanced Functional Materials*, 2011, **21**(15), 2876–2888.

 