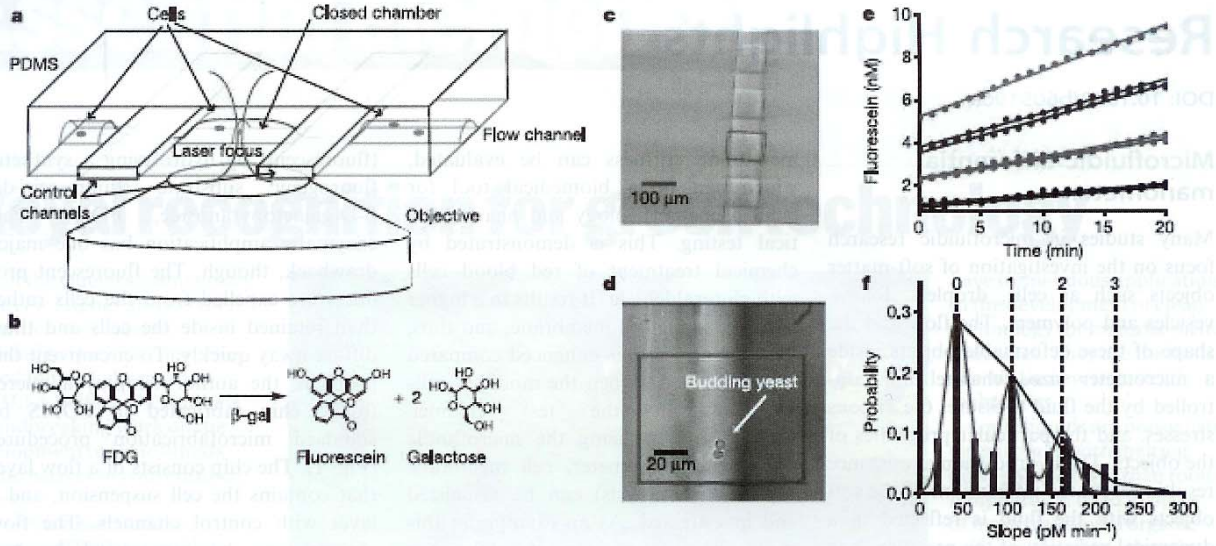

Fig. 1 Single-cell analysis on a microchip: (a) The microchip consists of two layers. A microchamber is formed in the flow channel by actuating the control channels. (b) Enzymatic amplification: hydrolysis of the synthetic substrate FDG by the enzyme β-gal yields the fluorescent product (fluorescein). (c) and (d) are DIC images of the microchambers, and budding yeast cells entrapped in a microchamber, respectively. (e) Hydrolysis of FDG by purified β-gal in a microchamber. The concentration of fluorescein increases with time. The different slopes are reflecting different numbers of the enzyme β-gal. (f) A histogram derived from the slopes in (e). The peaks can be assigned to discrete numbers of the enzyme. (Adapted by permission from Macmillan Publishers Ltd: Nature,[2] copyright 2006.)

cells at a particular time is observed. The authors create a model to explain their observations and suggest two different regimes of stochasticity in protein expression.

The microfluidic single-cell assay is applicable to different prokaryotic and eukaryotic cell types expressing β-gal as a reporter. It opens up possibilities for system-wide characterization of the expression of these low copy number proteins. Moreover, the simple microchip design allows a dense package of the microchambers on a chip and thereby high parallelization of single-cell observation.

Patterning of carbon nanotubes

Single-walled carbon nanotubes (SWNTs) exhibit remarkable electrical, mechanical, and chemical properties, which makes them potentially useful as semiconducting or conducting elements in sensors, transistors, and other electronic systems. The integration of SWNTs into electronic circuits, however, is challenging, and requires techniques for depositing and patterning of individual SWNTs, or SWNT aggregates, from solutions onto substrates.

Park *et al.* have addressed this problem by exploiting the laminar flow inside a microfluidic device for controlled patterning and flocculation of SWNTs onto a wide range of substrates, including plastics, without the need to functionalize the substrates or the tubes with chemistries designed to create strong interactions.[3] In this approach, two streams—methanol and an aqueous suspension of surfactant-stabilized SWNTs—are joined at a microfluidic Y-junction (Fig. 2). Methanol exhibits a strong affinity for the surfactant and hence, the concentration of the surfactant in the aqueous stream is lowered. Since the flow is laminar, only diffusive mixing occurs near the liquid–liquid interface. When the concentration of surfactant available to interact with the SWNTs is reduced to values below the critical micellar concentration, the tubes are no longer well suspended. Interactions between SWNTs can now result in formation of bundles, and interactions of SWNTs to surfaces can lead to coating of these surfaces. The flow duration determines the coverage of the deposited SWNTs, which is determined by AFM. High shear forces generated by high flow rates improve the degree of alignment of the nanotubes. Dynamical changes of flow rates during the deposition sweep the interface of the methanol and water streams across the channel to generate wide SWNT stripes or multiple, parallel narrow stripes. Since the microfluidic channels are fabricated in flexible PDMS, curved and uneven surfaces, *e.g.* the surface of spherical lenses, can be coated with this technique.

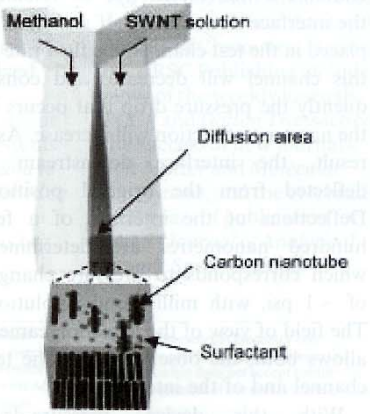

Fig. 2 A microfluidic Y-junction for patterning of single-walled carbon nanotubes by multiphase laminar flow and controlled flocculation. (Adapted with permission. Copyright 2006, Wiley-VCH.)

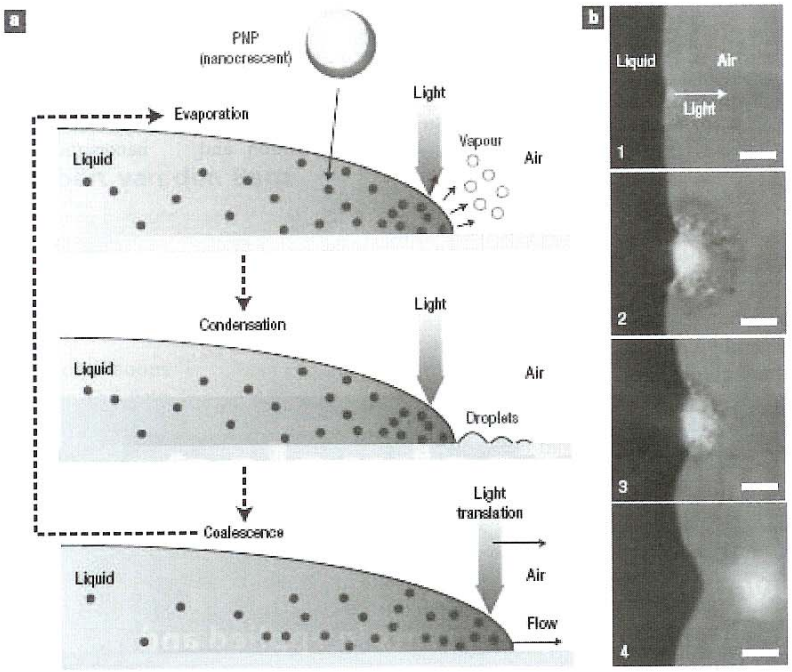

Fig. 3 (a) The principle of optofluidic control using photothermal nanoparticles (PNPs, for explanation: see text). (b) Video prints showing the light-driven advance of the liquid–air interface of a 1 nM PNP water solution on a glass surface. (Adapted by permission from Macmillan Publishers Ltd: Nature Materials,[4] copyright 2006.)

To demonstrate the ability to build electronic devices with patterned SWNTs, organic thin film transistors are fabricated, in which SWNT networks serve as source/drain electrodes. The electrical behaviour ranges from insulating for low SWNT coverage, to semiconducting for medium SWNT coverage, and to metallic for high coverage, and is modulated by controlling the flow duration.

Optofluidic control in microchannels

The control of liquid transport, *i.e.* pumping and guiding of fluids, is obviously crucial in microfluidic systems. In most applications, the driving force for liquid flow is a pressure gradient or an electrical field, which is typically realized by use of syringe pumps and valves, or by integration of electrodes, respectively.

Luke Lee and co-workers at the University of California at Berkeley have recently presented a novel method to drive and guide liquids, which is based on a direct optical-to-hydrodynamic energy conversion utilizing photothermal particles and laser light.[4] The all optical-control of fluid movement does not require any additional functionality such as mechanical valves or external pumping devices.

The principle is shown in Fig. 3. Gold nanocrescent particles with a strong absorption band around 780 nm were introduced to an aqueous solution in a concentration of $\sim 10^{14}$ particles l^{-1} (~ 1 nM). The nanoparticles absorb light that is focussed in proximity of the liquid–air interface. The subsequent temperature increase around the nanoparticles results in evaporation of the water at the liquid–air interface. The vapour condenses into droplets in front of the interface. The droplets coalesce with the original bulk liquid, and the liquid–air interface advances. Continuous fluid movement is facilitated if the processes are repeated as the laser light is translated. The flow speed in a linear microchannel achieved by this technique depends on the power (here up to 20 mW) of the focused laser light as well as on the concentration of the nanoparticles. A velocity of 500μm s^{-1} is experimentally realized in a 10 μm wide channel. The maximum speed, however, is limited due to time that is needed for droplet formation, growth and coalescence with the bulk liquid, and a theoretical value of ~ 1 mm s^{-1} is evaluated by the authors. They also demonstrate optofluidic control in more complex systems. The guidance of liquids at two adjacent T-shaped channel junction is presented, as well as mixing of three separate liquid streams into one. The simultaneous movement of fluids in parallel microchannels is feasible by use of a focused laser line that exposes each microchannel with a small portion of light (here smaller than 1 mW per microchannel). The rise of temperature up to 70 °C is highly localized to the illuminated spot, which is confirmed by thermo-fluorescence microscopy and thermochromic microcapsules. Hence, biomolecules or living cells suspended in the aqueous buffer solution are not affected.

Beside the use of optofluidic control in complex microsystems for biomolecular and cellular medicine, the authors expect applicability of the technique for optically powered machines, such as microscale power systems or solar heating systems.

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