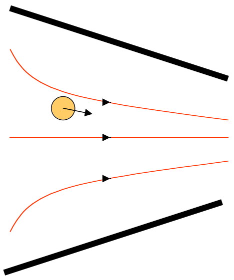
Dielectrophoresis

Inhomogeneous a.c. field

→ dielectric particles move along the field gradient



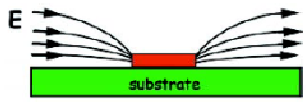
$$\tilde{F} = \nabla \tilde{p}.\tilde{E}$$

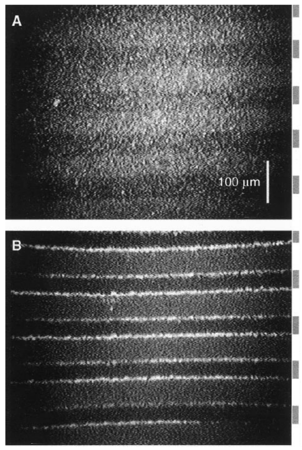
$$F_x = \alpha \frac{d}{dx}|E^2|$$

polarizability depends on size & frequency

Dielectrophoretic trapping

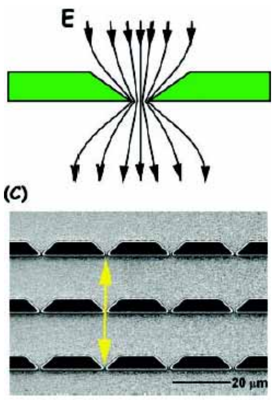
Asbury & van den Engh '98

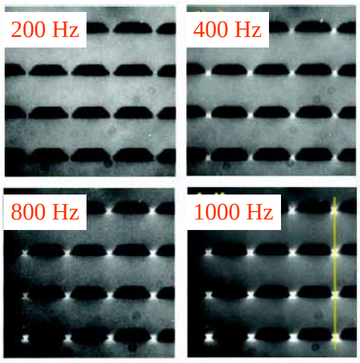




Electrodeless dielectrophoretic trapping

Chou et al. '02

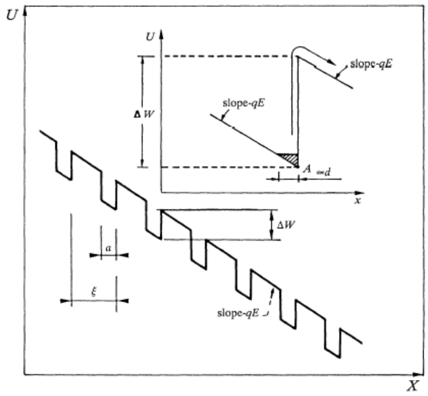




368 bp DNA

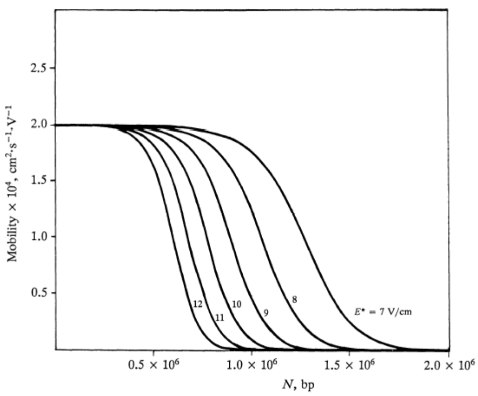
Free-flow electrophoresis with dielectric trapping

Ajdari & Prost '91



Free-flow electrophoresis with dielectric trapping

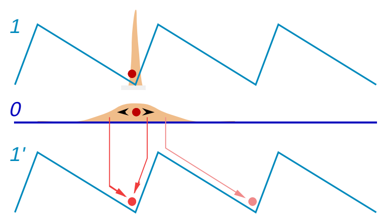
Ajdari & Prost '91



Brownian ratchet

Ajdari & Prost '92

Brownian particle in an asymmetric, periodic potential



- switch potential on and off periodically

→ particle drifts to the right, on average

Rectifed Brownian motion → movement without an applied force

Brownian ratchet
drift velocity

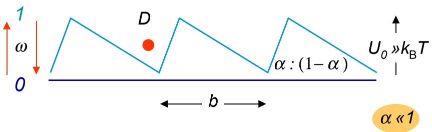
$$p_+ = \frac{1}{2}\mathrm{erfc}\left(\frac{\alpha b}{2}\sqrt{\frac{\omega}{D}}\right)$$

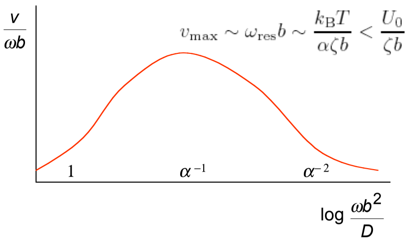
$$p_- = \frac{1}{2}\mathrm{erfc}\left(\frac{b}{2}\sqrt{\frac{\omega}{D}}\right)$$

$$v = \omega b\,(p_+ - p_-)$$

flux when $\boxed{\alpha^2 < \frac{D}{\omega b^2} < 1}$

and $\boxed{U_0 > \frac{k_B T}{\alpha}}$

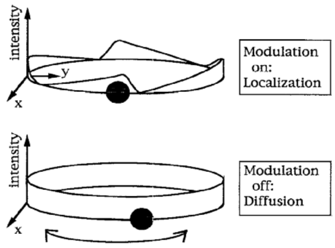


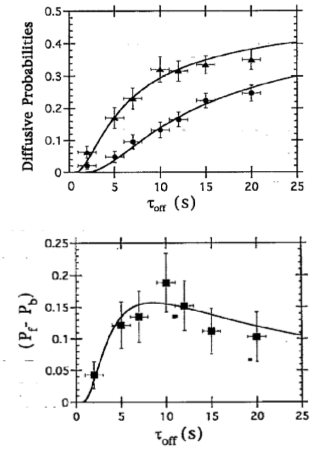


Brownian ratchet
experimental demonstration

Faucheux et al. '95

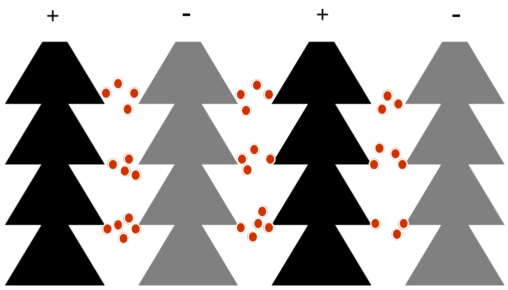
Optical ratchet





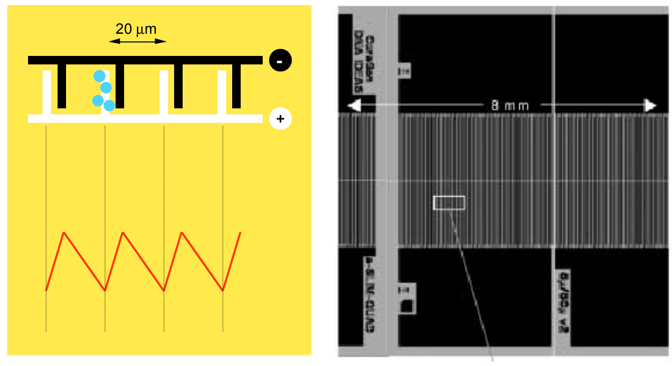
Dielectrophoretic ratchet

Rousselet et al. '94



Electrophoretic ratchet

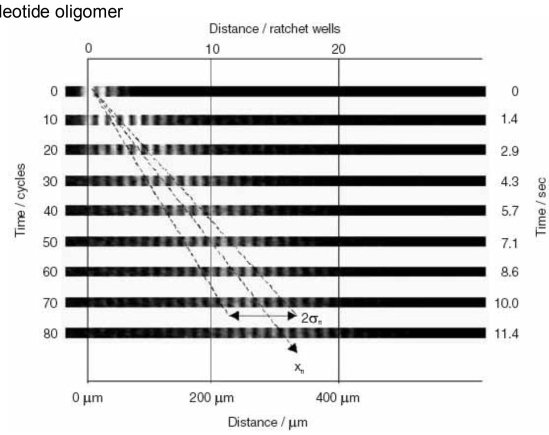
Bader et al. '02



Brownian ratchet

Bader et al. '02

50 nucleotide oligomer

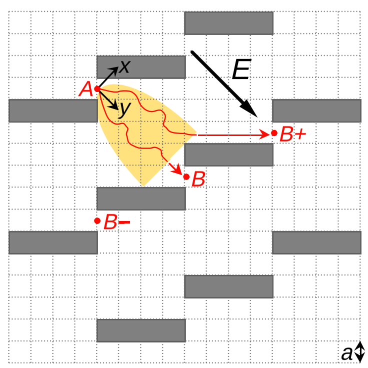


Brownian dynamics in a 2d asymmetric environment

Duke & Austin '98

Oblong obstacles deflect particles away from the field direction

- angle of deflection depends on diffusion coefficient

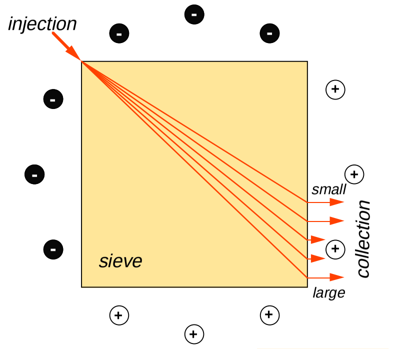


Microfabricated sieve
continuous sorting

Duke & Austin '98

Molecules of different size
follow different trajectories

Permits continuous sorting



Ready automation and integration with analytical steps → Lab-on-a-chip

Microfabricated sieve
predicted separation

Duke & Austin '98

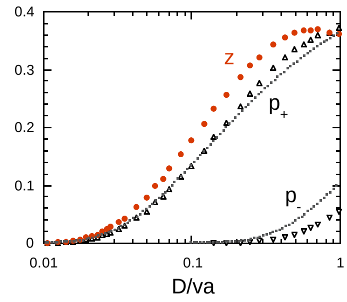
Transition probabilities: p_+ A → B+

p_- A → B-

$$p_\pm = \frac{1}{2}\mathrm{erfc}\left(c_\pm\sqrt{\frac{va}{D}}\right)$$

$$c_+ = 0.35$$

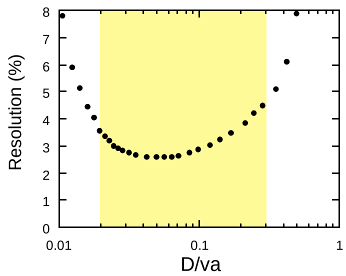
$$c_- = 1.26$$



Microfabricated sieve
predicted separation

Duke & Austin '98

Good resolution in range $0.02 < \frac{D}{va} < 0.3$

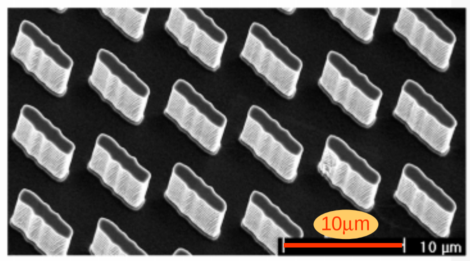


- for DNA 100-10,000 bp

$$a = 1\,\mu\mathrm{m}$$
$$v = 50\,\mu\mathrm{m/s}$$

Microfabricated sieve

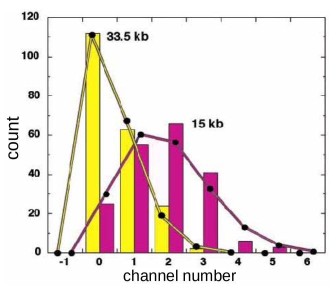
Chou et al. '99

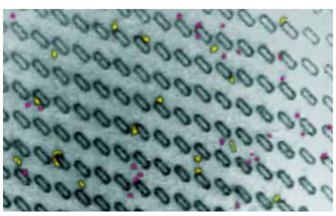


Microfabricated sieve
performance

Chou et al. '99

Separation of 15 kb and 34 kb DNA



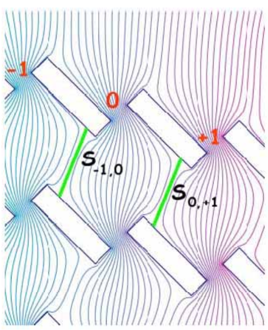


Microfabricated sieve
practical considerations

Huang et al. '02

Insulating obstacle distort the field

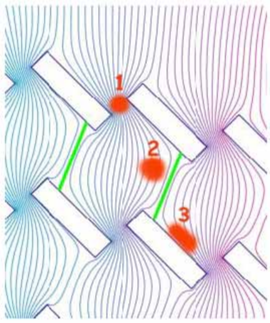
→ theoretically, no separation of point particles

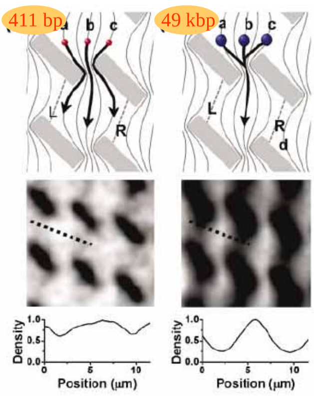


Microfabricated sieve
practical considerations

Huang et al. '02

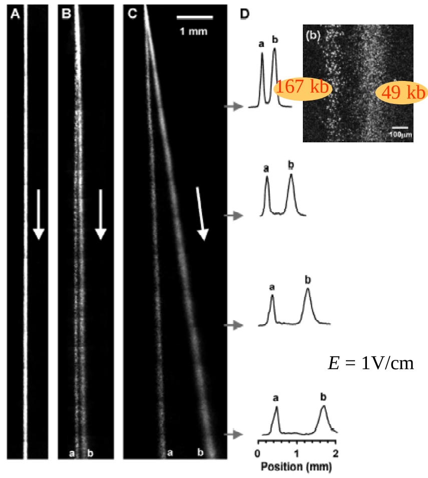
In practice, molecules are sorted by size, due to excluded volume





Microfabricated sieve
continuous separation

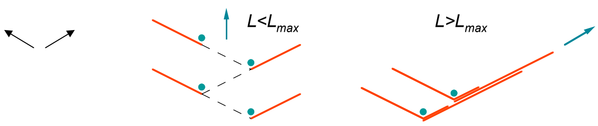
Huang et al. '02



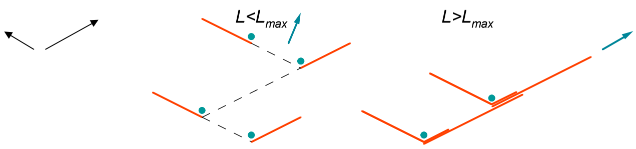
E = 1V/cm

Pulsed-field hex arrays
broken symmetry

- in pulsed-field hex arrays, long molecules migrate along one of the field directions



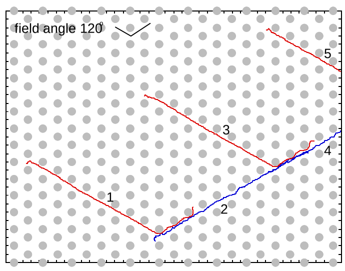
- break symmetry deliberately by pulsing for longer along one field direction

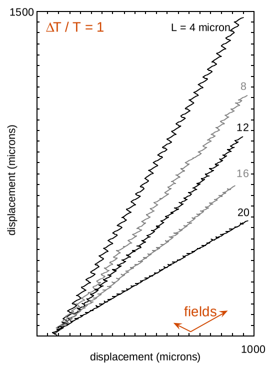


molecules move at an angle which depends on their length

Asymmetric pulsed-field hex arrays

It is essential to align the flow with the axes of the array

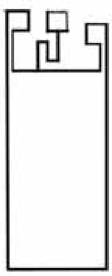


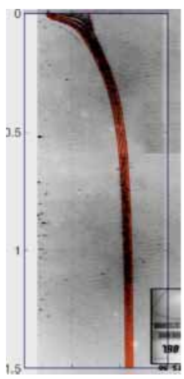


Jet injection

Darnton et al. '01

How to maintain a steady flow across an open area at low Reynolds number?

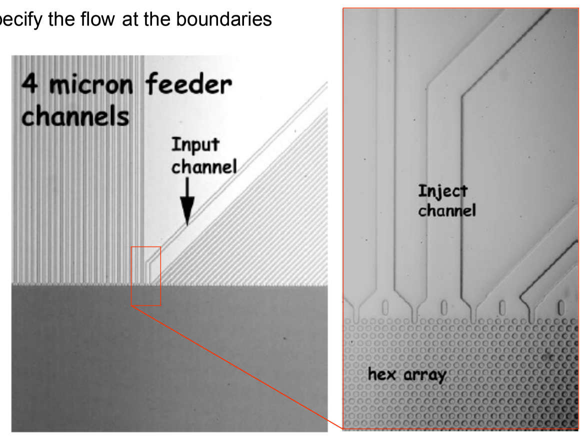




Microfluidic control of flow field

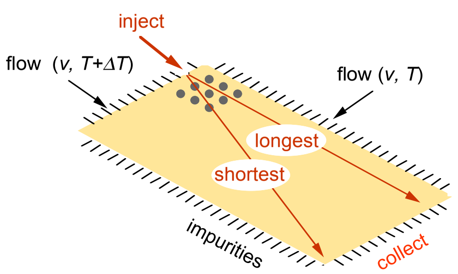
Darnton et al. '01

Need to specify the flow at the boundaries



DNA prism

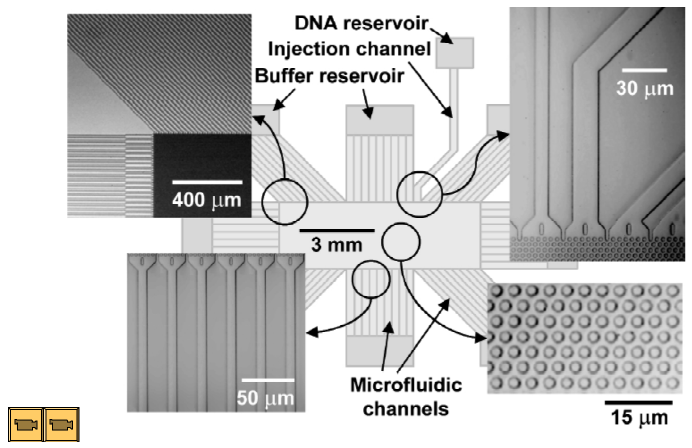
Inject flow along the sides of a 120° parallelogram



o

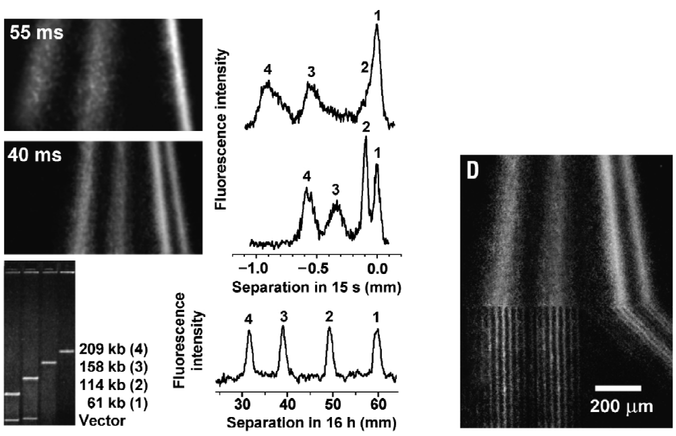
DNA prism

Huang et al. '02



DNA prism

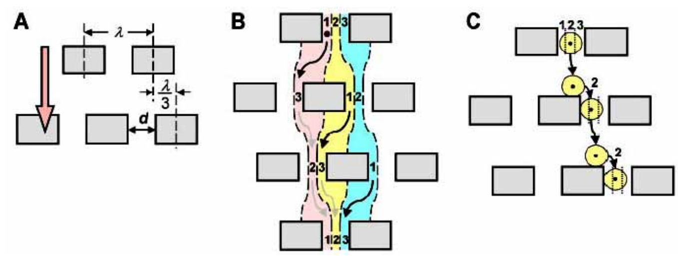
Huang et al. '02



Divided flow sorter

Huang et al. '04

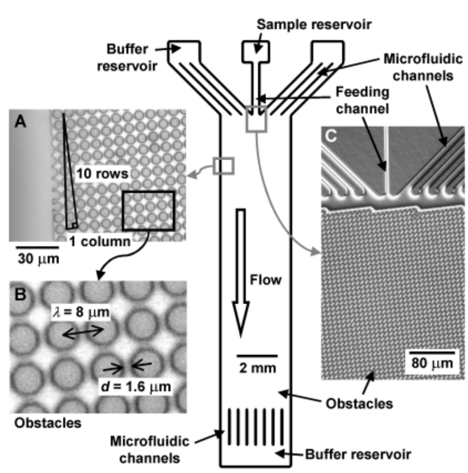
Asymmetrically placed obstacles divide flow



- high Peclet number → separation based on excluded volume

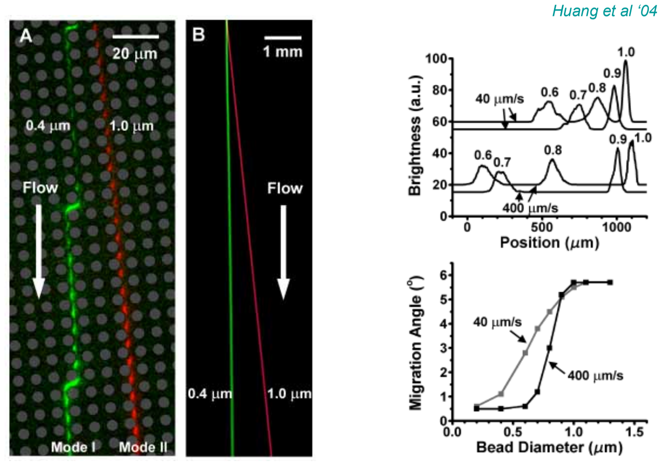
Divided flow sorter

Huang et al '04



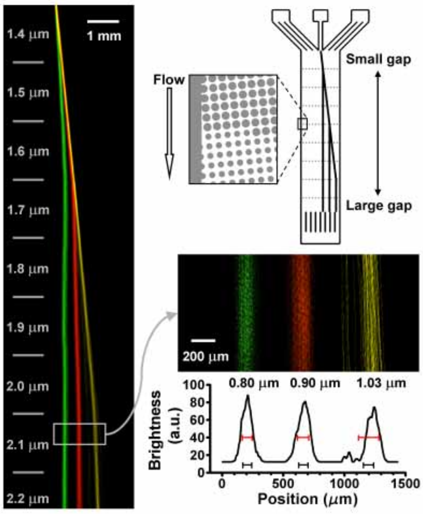
Divided flow sorter

Huang et al '04



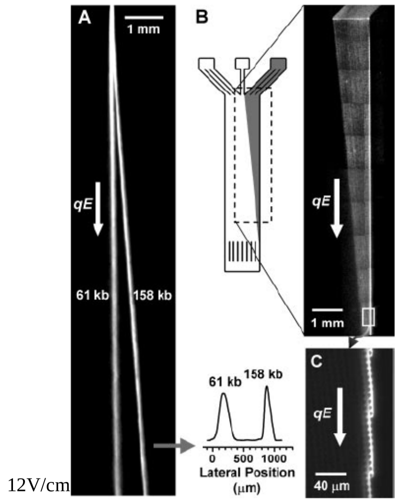
Divided flow sorter
graded array

Huang et al '04



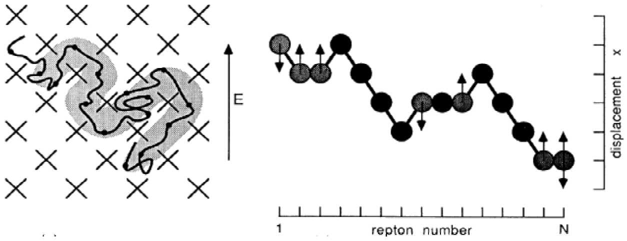
Divided flow sorter
separation of BACs

Huang et al '04



Open problems

Biased reptation / repton model

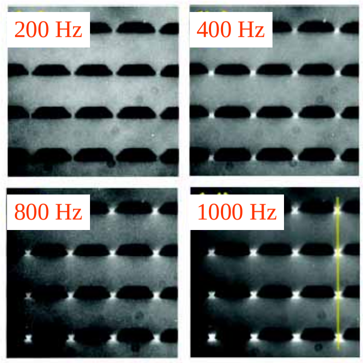


- rigorously prove $v \sim |E|E$ for long chains

Open problems

Dielectrophoresis

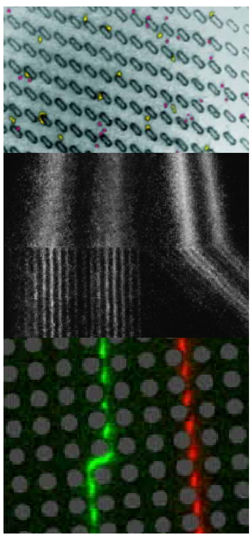
- theory of dielectric response of DNA molecules



Open problems

Continuous sorters / lab-on-a-chip

- optimized design
- microfluidic control
- interfacing



Killer app.

?