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Nanofluidic gates for diffusion-free controlled release from microfluidic devices

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Chemical transport and release in micro- or nanofluidic systems can be achieved by pressure, electrokinetic or hydrophobic effects. However, control of chemical release must always consider diffusion, which ensures that finite transport of solutes will occur along any solvent path. For some applications this leakage may be sufficiently managed. Other applications, such as *in vitro* studies of drug toxicology or *in vivo* neurostimulation, require absolute shut-off. Various efforts have attempted such absolute control of chemical release with limited results. For example, neurostimulation through microfluidic apertures was attempted but resulted in high diffusive losses [1]. Other approaches produced diffusion-free barriers, but are limited to single-use with no reversibility [2]. Robust control of chemical release requires a reversible method to realize discrete disruption of solvent paths.

Previous work has successfully demonstrated diffusion-free *in vitro* release of a chemical neurotransmitter, by releasing small droplets across air gaps [3–5] but new concepts are required to improve resolution, dosage limits, and suitability for implantation. Inspiration is drawn from biological cell membrane pores, which exploit mechanisms including electrostatic and hydrophobic effects to achieve extraordinary control of non-linear transport properties, including high rectification, on/off ratios, and permselectivity [6]. The ability to form nanoscale vapour barriers in synthetic nanopores is supported by molecular dynamics simulations [7] and recent experimental work [8,9].

Therefore, we aim to develop a nanofluidic switch that enables tuneable and reversible chemical release and achieves complete elimination of diffusive leakage during shut-off. Our goal includes the ability for integration in standard microfabrication processes. The proposed mechanism for this chemical switch is an electrically-actuated nanoscale vapour barrier.

Towards this goal, we have fabricated nanopores by irradiating 10-µm thick polymer foils with individual GeV heavy ion projectiles at the GSI accelerator facility (Darmstadt). Subsequent chemical etching of the ion tracks produces channels of defined diameter in the sub-20-nm range [10]. Fig. 1 shows the electrolytic cell used for controlled track etching as well as for transport measurements. Modification of pore dimensions and surface properties enables fine tuning of novel transport characteristics, such as diode-like rectification (Fig. 2). Reversible switching between open and closed states has also been demonstrated (Fig. 3). Further development is on-going.

Wortzahl: 358

Förderung
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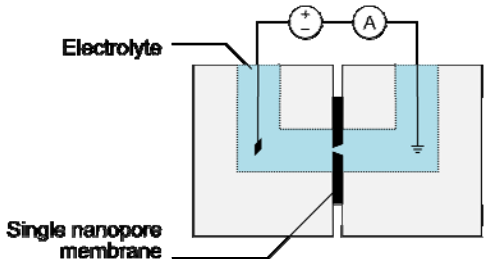

Figure 1. Schematic of cell for measurement of nanopore current–voltage characteristics.

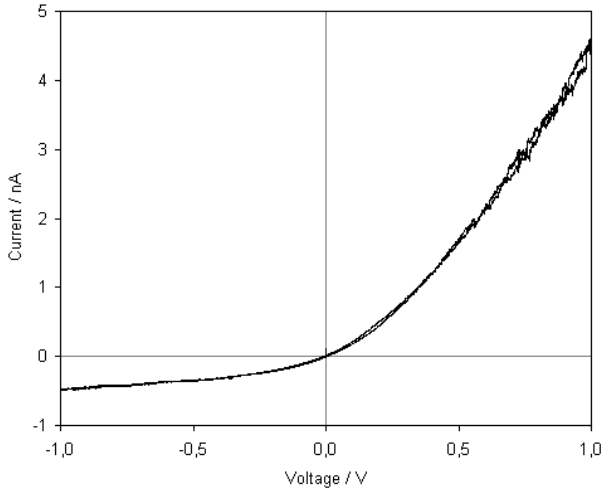

Figure 2. Rectification of current through a nanopore. Current is the average of five voltage scans over ±1 V.

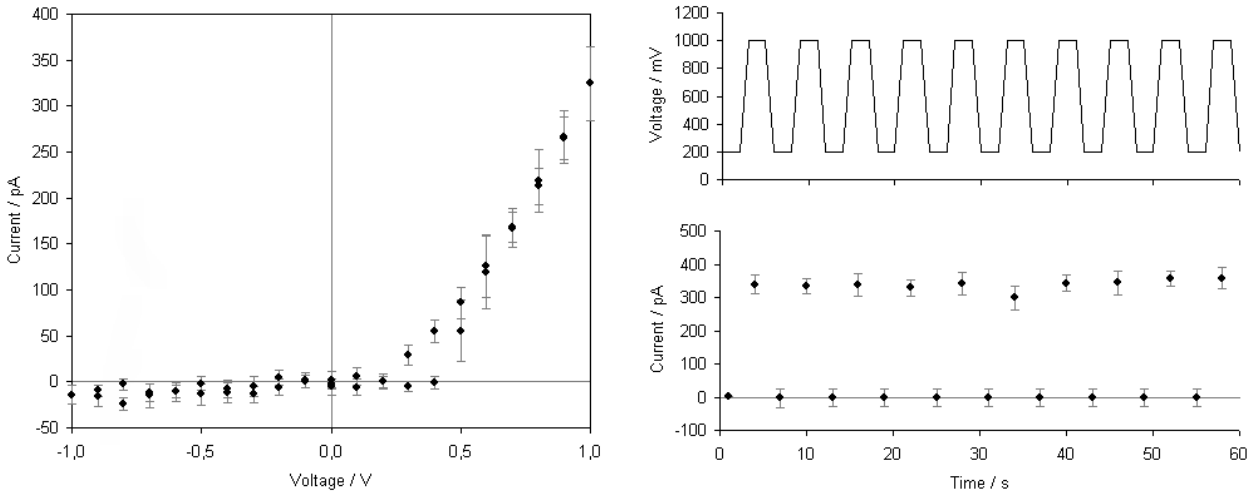

Figure 3. Switching characteristics of a nanopore. **Left:** Current measured at various voltages. Each point is the average of a two-minute recording. Below a threshold voltage, no measureable current is observed. **Right:** Gating behaviour, exhibiting no current below a threshold. Above the threshold, the pore opens to current transport. Switching is shown between a zero-current off-state ($I = 0 \pm 4$ pA at $V = 200$ mV) and an on-state ($I = 337 \pm 27$ pA at $V = 1000$ mV). Current points show average current over two-second scans.