EDITORIAL

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Editorial

Ion age transport: developing devices beyond electronics

Anna Demming

There is more to current devices than conventional electronics. Increasingly research into the controlled movement of ions and molecules is enabling a range of new technologies. For example, as Weihua Guan, Sylvia Xin Li and Mark Reed at Yale University explain, ‘It offers a unique opportunity to integrate wet ionics with dry electronics seamlessly’. In this issue they provide an overview of voltage-gated ion and molecule transport in engineered nanochannels. They cover the theory governing these systems and fabrication techniques, as well as applications, including biological and chemical analysis, and energy conversion [1].

Studying the movement of particles in nanochannels is not new. The transport of materials in rock pores led Klinkenberg to describe an analogy between diffusion and electrical conductivity in porous rocks back in 1951 [2]. And already in 1940, Harold Abramson and Manuel Gorin noted that ‘When an electric current is applied across the living human skin, the skin may be considered to act like a system of pores through which transfer of substances like ragweed pollen extract may be achieved both by electrophoretic and by diffusion phenomena’ [3].

Transport in living systems through pore structures on a much smaller scale has attracted a great deal of research in recent years as well. The selective transport of ions and small organic molecules across the cell membrane facilitates a number of functions including communication between cells, nerve conduction and signal transmission. Understanding these processes may benefit a wide range of potential applications such as selective separation, biochemical sensing, and controlled release and drug delivery processes. In Germany researchers have successfully demonstrated controlled ionic transport through nanopores functionalized with amine-terminated polymer brushes [4]. The polymer nanobrushes swell and shrink in response to changes in temperature, thus opening and closing the nanopore passage to ionic molecules. ‘This process should permit the thermal gating and controlled release of ionic drug molecules through the nanopores modified with thermoresponsive polymer chains across the membrane,’ they explain.

With their intrinsic nanoscale features, carbon nanomaterials often feature as possible nanochannel systems. The intrinsic two-dimensional nanochannel structures formed by carbon nanotubes led Jae Hyun Park, Susan Sinnott and Narayana Aluru to pursue molecular dynamics simulations of Y-junction carbon nanotubes. Their results suggest that when the nanotubes of the different arms of the Y have different diameters they could be used in a type of permselectivity to separate K+ and Cl− ions from a KCl solution [5]. Guohui Hu, Mao Mao and Sandip Ghosal in China and the US also used molecular dynamics simulations to investigate the mechanisms at play in the ionic transport of NaCl in solution through a graphene nanopore under an applied electric field. Their results confirm that the electric conductance is proportional to the nanopore [6], and help to understand how these structures can be exploited in applications. In fact
nanopores were among the early suggestions for fast DNA sequencing as Massimiliano Di Ventra points out in his perspective [7]. If the pore is large enough to allow DNA bases through but small enough to allow only one to pass at a time, current values can be assigned to each base and the DNA sequenced by measuring the ionic currents.

It is clear that at these scales the characteristics of transport phenomena can be hugely valuable for developing new technologies. In this issue Weihua Guan, Sylvia Xin Li and Mark Reed provide an overview of voltage-gated nanochannels in systems that have three or more terminals, similar to metal-oxide-semiconductor field-effect transistors [1]. They describe the potential profiles in the nanochannels and the theory behind some of the effects that originate from the nanoscale feature sizes such as ion permselectivity. They also describe bottom-up and top-down approaches to fabricating nanochannels in different dimensions—nanopores, nanotubes and nanoslits—and their applications.

Fifty years ago a visit to the 1964 New York World’s Fair inspired Isaac Asimov to postulate on the exhibits of the World’s Fair of 2014, and he did so with an eerie accuracy [8]. As well as ready meals and skype type video communications, his projections correctly forecast a prevalence of electronic devices—and cordless devices too. But perhaps even one of the world’s most celebrated science fiction writers did not foresee that the current in a lot of next-generation devices might be in some ways ‘electronic-less’ as well.

References

[1] Guan Weihua, Li Sylvia Xin and Reed Mark A 2014 Voltage gated ion and molecule transport in engineered nanochannels: theory, fabrication and applications Nanotechnology 25 122001


[7] Di Ventra M 2013 Fast DNA sequencing by electrical means inches closer Nanotechnology 24 342501