The engineered virus was then bound to the AFM tip at low concentration to enable single-virus to cell interaction measurements. Together this makes an excellent experimental platform to test the performance of the new correlative light microscopy force mapping system.

Adherent MDCK cells expressing TVA fused to the fluorescent protein mCherry were co-cultured with control cells without TVA and imaged simultaneously using confocal microscopy and AFM-based force mapping. The authors retrieve the AFM-typical topographs along with a fluorescent micrograph and show that their system is indeed sensitive enough to detect specific EnvA-receptor contacts. While no interaction could be detected on control cells, those expressing TVA–mCherry show specific adhesion events at the estimated distance with the binding probability correlated to the expression level of TVA–mCherry. Investigation of the rupture force distribution revealed that the single EnvA–TVA interaction is weak but the viruses rapidly form multiple attachments. The high axial AFM resolution allows the detection of those multiple binding events that can be ruptured simultaneously or serially. The authors conclude that the formation of multiple interactions must occur within the lifetime of the initial contact, on the order of a few milliseconds. The virus probes a specific cell or its surface region to form a stable multivalent attachment. If the receptor density were too low, it would rapidly detach or surf across the cell surface to search for a more suitable attachment spot or for another cell. Finally, a multivalent binding model implicates that receptor binding of the trimeric EnvA occurs in a cooperative manner, indicating a conformational change of the protein.

Alsteens and co-workers describe in detail how much their technique can reveal about ligand–receptor interactions. The developed system enables simultaneous force mapping and confocal microscopy using live cell culture. This innovation marks an important step towards a quantitative understanding of virus–receptor and other ligand–receptor interactions in general. Mapping molecular interactions will help uncover regulatory processes undetectable in fluorescence micrographs. Cell-to-cell variability of protein expression levels related to the molecule conformational or activational state could be mapped with high resolution (<50 nm) using this system. The spatial arrangement of active receptors can be studied in great detail, although this will remain challenging in a live cell context due to the dynamic nature of the plasma membrane. Nevertheless, a combination with single molecule tracking or super-resolution microscopy seems tempting especially when investigating single molecule interactions within the virus–cell interface. Future studies should address the effect of a higher order lateral organization of cellular receptors such as clustering on virus binding and whether additional receptors are recruited to the initial binding site. Finally, a quantitative description of multivalency in virus binding is important for guiding the design of synthetic nanoparticles decorated with cell (-like) receptors to prevent infection by interfering with virus binding to the cell surface[5,6]. ❐

Christian Sieben is in the Laboratory of Experimental Biophysics, École Polytechnique Fédérale de Lausanne (EPFL), Rte de la Sorge, 1015 Lausanne, Switzerland. Andreas Herrmann is at Humboldt Universität zu Berlin, Institute for Biology, Molecular Biophysics, Invalidenstr. 42, 10115 Berlin, Germany.
e-mail: christian.sieben@epfl.ch; andreas.herrmann@rz.hu-berlin.de

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SPINTRONICS

Electric control of skyrmions

The creation and destruction of magnetic whirls by the application of an electric field may be the basis for novel memory technologies.

Achim Rosch

Magnetic skyrmions are tiny whirls that can be stabilized in certain magnets and magnetic layers by subtle relativistic effects[1,2]. They can be as small as a nanometre[2,3] and are stable at room temperature in magnetic films consisting of multiple layers[4]. The microscopic magnetic moments composing skyrmions are arranged in such a way that they adopt all possible spatial orientations, as depicted schematically in Fig. 1a. Their peculiar topology, stability and high mobility make them very interesting candidates for technological applications. In particular, several proposals have been put forward in order to exploit the guided motion of skyrmions in racetrack geometries for novel memory devices[5,6]. Accordingly, the deterministic generation, manipulation and destruction of skyrmions is a crucial goal for researchers both in fundamental and applied physics.

Previous pioneering work has shown that skyrmions can be created and destroyed by the fluctuations arising from electrons impinging from the tip of a scanning tunnelling microscope[3] or by current pulses[4]. While the first approach is probabilistic in nature, the second has the disadvantage of requiring substantial amounts of energy. Writing in Nature *Nanotechnology*, Pin-Jui Hsu and collaborators now demonstrate that an electric field can create and destroy skyrmions in a controlled and energy-efficient way[7].

Hsu and colleagues study a thin film consisting of three atomic layers of iron grown on an iridium surface. A magnetic scanning tunnelling microscope is used both to image and manipulate the magnetic configuration. Applying a moderate voltage of ±3 V to the microscope tip generates an electric field close to the magnetic surface. As a result, a negative voltage leads to the creation of a skyrmion and a positive voltage erases it (Fig. 1a). Both states of the system, with and without a skyrmion, are stable and therefore voltage pulses are sufficient to switch between them (Fig. 1b).

These findings are of great interest for potential memory technologies. In this respect, a decisive factor to be considered

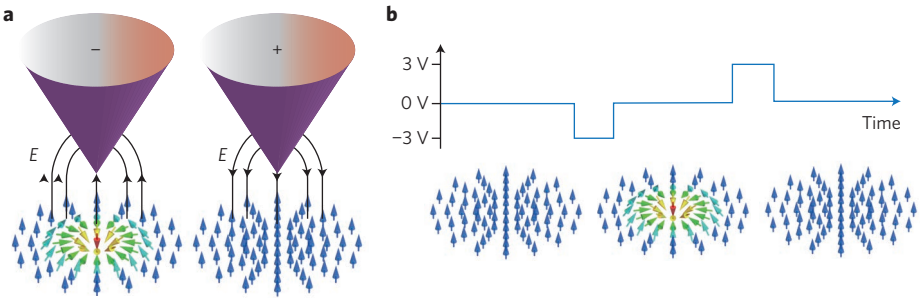

Figure 1 | Changing the voltage of the tip of a scanning tunnelling microscope allows creation and destruction of magnetic whirls in a controlled way. **a**, With negative or positive voltage it is possible to stabilize either a magnetic whirl (skyrmion) or the ferromagnetic state, respectively. **b**, Voltage pulses allow switching between the ferromagnetic and skyrmion state in a deterministic way.

is the power consumption required by the switching process. Standard random-access memory (RAM) used in present-day computers is volatile and consumes energy even if the memory is not accessed. In non-volatile (for example, flash) memories, energy is only needed for writing and reading of the information, but the writing processes typically require a substantial amount. In this respect, a highly advanced technology — soon to hit the consumer market — is magnetoresistive RAM (MRAM). Here, spin-transfer torques arising from magnetically polarized electric currents are used to switch magnetic domains, and recent reports have shown record low switching energies below 100 fJ (ref. 8). However, this tiny energy is still ~10^5 times larger than the height of the energy barrier separating the two magnetic states. The ultimate reason is that a sizable number of electrons (~10^5–10^6) have to move through the device to realize the switching.

The experimental setup used by Hsu and collaborators does not allow them to directly measure the energy needed to create or destroy a skyrmion. Nonetheless, their method does not rely on the motion of many electrons but instead only on tiny rearrangements of charges, which apparently trigger changes in the magnetic configuration. Therefore, it is reasonable to expect that the energy consumption used to change a bit is several orders of magnitude smaller than, for example, with MRAM.

Two future experimental challenges will be to replace the tip of the scanning tunnelling microscope with a nanostructured gate electrode and to demonstrate electric-field switching at room temperature. This could make it possible to go beyond the racetrack concept[5,6] towards devices that do not rely on the motion of skyrmions but rather address them electrically. At the same time, it will be important to identify why and how an electric field triggers the twisting of the magnetic structure. Theoretically, it has been shown that electric fields of similar magnitude as used by Hsu and collaborators can create skyrmions in insulating compounds by using the electric polarization induced by the magnetic structure[9]. However, this theory cannot be applied directly to the conducting magnetic layers investigated by Hsu and colleagues. It has also been demonstrated that certain quantum mechanical effects (Berry phases in phase space) naturally lead to the accumulation of charge in skyrmions which directly couples to electric fields[10]. Also, changes of the magnetic couplings triggered by distortions of the electronic structure could be sufficient to explain the observed effect.

The building blocks of any promising memory technology have to be small, fast, reliable, operate at room temperature, and consume as little power as possible. The new way to write information on a magnetic layer by creating and erasing tiny magnetic skyrmions is highly promising to achieve these goals. ❐

Achim Rosch is at the Institute for Theoretical Physics, University of Cologne, D-50937 Cologne, Germany.
e-mail: rosch@thp.uni-koeln.de

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