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Tip-Top Imaging [Microscopy]

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News & Views

MICROSCOPY

Tip-Top Imaging

Herman Batelaan and Kees Uiterwaal

Images of nanoscale structures can be constructed using the flow of electrons ejected from a metal probe tip by a fast laser pulse. The technique adds new dimensions to established methods of microscopy.

How can we see without eyes? One way is with electric fields. Fishes do this all the time: sharks, for instance, use electroreceptors to 'see' distortions of fields caused by nearby objects, and thus locate their prey. The builder's tool known as a stud finder works in a similar way, using electric fields to locate the load-bearing members inside a wall. Writing in *Physical Review Letters*, Ropers et al.[1] demonstrate a way to downscale this kind of depth-imaging capability to nanometer sizes.

Technologies for seeing objects too small for the naked eye have a long history. The Dutchman Antonie van Leeuwenhoek reported "with great wonder" the sight of microorganisms through one of his newly developed optical microscopes more than three centuries ago. Optical microscopy has been an important imaging tool ever since, despite an obvious limitation — it cannot be used to see structures smaller than the wavelength of visible light, roughly a micrometer. This shortcoming was bypassed in the 1930s in Germany, when the first microscope was built that exploited the fact that the electron, as a quantum-mechanical particle, is also a wave. An electron's wavelength becomes shorter the faster it moves: modern, fast electron microscopes can therefore spy out objects 10,000 times smaller than the smallest structures visible with an optical microscope.

But, as physicist Richard Feynman remarked in 1959, in a talk[2] often considered to mark the birth of nanotechnology, "there is plenty of room at the bottom". Scanning tunnelling microscopy (STM), invented in the 1980s, was the first of a series of revolutionary imaging techniques that can be used to probe surfaces down to their atomic structure. STM reveals a surface's structure by passing a very sharp needle over the surface, rather as the needle of an old-fashioned record player is dragged over a structured surface to reproduce the sounds imprinted on it. The shape of an STM tip distorts the electric field around it, causing a tunnelling current to flow to a nearby surface. In much the same way, a metal lightning rod on a tower distorts Earth's electric field, allowing a current of electrons stored in the clouds above to flow to Earth (Figure 1).

Figure 1. Tip and flow. The discharge of current in a lightning strike bears similarities to the electron-imaging technique developed by Ropers and colleagues[1].

The magnitude of the charge flow in STM depends on the distance between the probe and the surface, so an atomic-scale, contoured

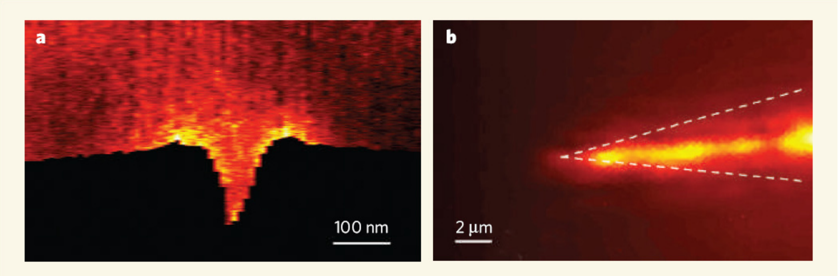

Figure 2. Into the groove. **a**, Ropers and colleagues' 'tip-enhanced electron emission microscopy'[1] provides a picture of a nanoscale groove in a gold surface. **b**, The laser-illuminated probe tip.

'map' of the surface can be made. What STM cannot easily give us, however, is information on what happens in the third dimension above the surface. Step forward Ropers et al.[1], with their 'tip-enhanced electron emission microscopy'. Like STM, the authors' technique involves measuring the effect of a sample surface on the electrical current flowing through a probe tip. So far, so conventional. But the real beauty of the technique is how that current is generated: it is stimulated by a pulsed laser beam focused on the tip. Because this laser field is affected by any kind of sample that is introduced near to the probe, the device can act in three dimensions. Furthermore, the current flow scales highly nonlinearly with changes in the laser field, making the imaging extremely sensitive to whatever is put near the probe tip.

So what sorts of things could the technique be used to look at? Ropers et al. use it to image a nanometer-scale groove on a gold surface (Figure 2). But anything down to a single metal atom is theoretically possible: the spatial resolution of the authors' technique is given by the size of the metal tip, 20 nanometers, which is certainly scalable to atomic size. Questions such as the distance from which atomic-scale objects would be visible, and whether the technique could also be used for non-conducting nano structures, will no doubt be addressed soon.

A further dimension is added to Roper and colleagues' technique through its time resolution. The laser pulses that dictate the electron emission are exceedingly short (7 femtoseconds, or 7×10^{-15} s) and have a frequency of 80 megahertz. This admits the exciting prospect of tracking atomic-scale dynamics in real time. For example, the authors suggest[1] that the dynamics of surface polaritons — discrete packets of energy that result from the interaction of an electric field and the vibrations of a material — could be studied using pairs of time-delayed pulses. Surface polaritons have been credited with wide-ranging potential for 'optical' devices that do not suffer the wavelength limitations associated with devices using light propagation. Another recent study[3] has achieved an electron pulse resolution of below 100 femtoseconds using an identical source, and there is promise for entering the attosecond (10^{-18} s) domain[3]. Ahmed Zewail, who won the 1999 Nobel Prize in Chemistry for his studies of reaction dynamics using femtosecond spectroscopy, recently observed[4] that "Ultrafast electron microscopy should have an impact on all areas of microscopy, including biological imaging." Following Zewail's vision, Ropers et al. have made exciting progress in an area that might be called ultrafast near-field microscopy.

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