Single spin detection by magnetic resonance force microscopy,

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Recommended with a Commentary by Teun Klapwijk, Delft University

Some experiments do not come easy, but are ultimately realized by determination and care. In 1991 John A. Sidles, a physicist working at the School of Medicine, at the University of Washington, Seattle, argued in Appl. Phys. Letters **58**, 2854 (1991) (see also, Phys. Rev. Letters **68**, 1124 (1992) by the same author) that it ought to be possible to detect a single-proton by inductively coupling the nuclear spin to the motion of a mechanical oscillator. A first experiment, published by Rugar, Yannoni and Sidles (Nature **360**, 563 (1992)), demonstrated, what they called, the mechanical detection of magnetic resonance. In the present paper, published in Nature, a 10^7 times improvement has been realized and the authors argue convincingly that indeed the signal is due to a single spin.

In Sidles' 1991APL he stated: *It is therefore clear that developing a practical molecular imager would require a substantial effort by many scientists, and that their would be no absolute assurance of success. Nonetheless, present and projected medical needs might justify such an effort. Of the proteins encoded by the AIDS genome, only HIV-1 protease has a known three-dimensional structure. Recently, a partial structure for HIV-1 reverse transcriptase has also been obtained. The remainder proteins have so far proven refractory to x-ray crystallography. The missing structural information is a significant obstacle to rational design of drugs and vaccines.*

Biological researchers were seeking a molecular imaging technique, which would be non-destructive, three-dimensional, Angstrom scale resolution, and able to image individual biological molecule *in situ*. It is obvious that STM and AFM are predominantly surface-techniques. Electron microscopy is a destructive technique. Optical techniques are limited by the wavelength, although some techniques exist to overcome this barrier. Magnetic resonance force microscopy (MRFM) has been introduced as a means to achieve this goal. It uses an inductive coil to excite the spin according to protocols develop for magnetic resonance techniques. A cantilever is used on which a small magnet (SmCo) is mounted, a magnetic tip, providing an inhomogeneous magnetic field, which penetrates a sample close to the tip. The position of the cantilever is read out optically, a well-known technique in AFM's. The position of

the cantilever is a measure of the force from the electron spin. The permanent magnet creates an inhomogeneous field and it therefore creates inside the sample a sphere in which the conditions for magnetic resonance is satisfied, providing the depth resolution. As a sample vitreous silica is used which by implantation contains a low density of dangling bonds, so-called E' centres. By scanning the tip over the sample a local magnetic resonance force is detected, which corresponds with a spatial resolution of about 25 nm. This spatial isolation of the signal is also the main argument that a single spin is being detected. For an animation of the experiment see:

http://www.almaden.ibm.com/st/nanoscale_science/asms/mrfm/

Obviously, this is a major step forward, which brings MRFM at the verge of being usable for biological and medical research. It allows spatial resolution of dopants in small semiconductor devices and it might be applicable for spin-based computation. The authors argue that more needs to be done but 'show-stoppers', overlooked in the original proposal (See for details Sidles et al, Reviews of Modern Physics, 67, 249 91995), have not been identified.