polarization of the electrons in silicon from its light-emitting behaviour. Yet, Jonker *et al.*[4] show that both these problems can be overcome.

First, they show that despite silicon's indirect bandgap, the current passing from an Fe contact via an Al_2O_3 tunnel barrier into a silicon p–i–n diode structure is sufficient to produce enough polarized light emission (at temperatures below 80 K) to demonstrate the successful injection of spin-polarized electrons (Fig. 1a). This in itself is an important achievement. Yet it demonstrates that spin has been injected, but not precisely how much. To show this, the researchers grow their Fe/Al_2O_3/Si structure on top of a GaAs light-emitting diode (LED) structure. Analysis of the emission generated by the current passing from Fe through Si into the GaAs enables the authors to determine the lower bound of the polarization ratio of the spins injected into the Si, which they find to be 10% (Fig. 1b). The size of this ratio not only demonstrates the effectiveness of the Fe/Al_2O_3/Si contacts, but more surprisingly the robustness of the spins as they pass across the inevitably rough and potentially detrimental interface between the Si and the GaAs.

Now that we can confidently inject spin-polarized currents into silicon, the next step will be to make functioning silicon-based spintronic devices. From a technological point of view, the Fe tunnel contacts are simple and efficient. They do not suffer from the low current levels associated with a recently reported approach[7] in which hot electrons are driven across complicated multi-terminal device structures, only a small fraction of which are injected into the semiconductor. And although it is expected that electron spins in silicon should survive long enough to perform useful spin functions, data on how far they can travel is scarce. Building on the present work of Jonker *et al.*[4] — by simply fabricating several Si-on-GaAs LED devices with silicon layers of varying thickness, for example — should fill in the gaps in this knowledge.

Perhaps the most intriguing device possibility enabled by the present work is the silicon spin-FET — a field-effect transistor with ferromagnetic source and drain contacts, the relative magnetization of which determines the transistor's channel conductance. It should be noted that the requirements for the source and drain contact of a spin-FET differ from that of optical detection — their resistance should not be too high[8]. For the source of such a device, this is vital to being able to supply spins into the channel at sufficiently high rate. And for the drain, if the probability of spin-polarized electrons transiting across the interface of such a contact is too low, the electrons could be forced to dwell too long within the channel and lose their polarization. The resistance of the Fe/Al_2O_3 contacts thus needs careful consideration. Thankfully, an approach to forming spin-tunnel contacts to silicon with low and tunable resistance has also been reported[9]. Together with the spin-injection contacts of Jonker *et al.*[4] everything is now in place to design novel silicon electronic devices based on spin, and explore the possibilities (and limitations) of such devices and systems. An exciting new era of silicon spintronics could thus soon be upon us.

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SINGLE-MOLECULE DETECTION

Identification without labels

GETTY

The properties of molecules are traditionally inferred from bulk measurements. But, some 20 years ago, fluorescence spectroscopy made it possible to look at the behaviour of single molecules, and thus investigate properties that are averaged out in bulk studies. In these experiments, however, a fluorescent label must be attached to the target molecule, which limits the scope of the approach. Andrea Armani and colleagues report that single molecules can now be detected without fancy labels (*Science* doi: 10.1126/science.1145002; 2007).

The alternative to amplifying the signal of a single molecule by attaching a label — as required in fluorescence spectroscopy — is to sample the unmodified molecule many times over. This can be done using a high-quality optical microcavity — a device in which light is confined and circles at discrete frequencies. Armani *et al.* use silica toroids of about 80 μm diameter; light circulating in such a structure passes a molecule sitting on its surface more than 100,000 times, enough for even a single molecule to leave a signature.

The microtoroid sensor exploits the time that the light spends in the cavity in two ways. On the one hand, the long confinement time results in narrow resonance lines, and therefore good resolving power for small shifts in the resonant wavelength (which occur because the presence of the molecule increases the path length of the light). On the other hand, the molecule is heated by the high-intensity light inside the cavity; the molecule, in turn, heats up the cavity, leading to a more pronounced shift.

As well as achieving single-molecule sensitivity, Armani and co-workers can make their technique selective to specific molecules by sensitizing the resonator surface — for example, by coating it with antibodies. Such specificity, together with the possibility of operating the device in an aqueous environment, opens the door to biological applications, in which the sensor could be used to sensitively determine concentrations of marker molecules. Using the biomolecule interleukin-2 as an example, the authors show that concentrations from micromolar to attomolar — an impressive twelve orders of magnitude — could be detected.

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