QUANTUM INFORMATION

Long live the spin

The long spin-coherence time of electrons in semiconductor quantum dots has strong potential for quantum information processing. A new study shows a way to further enhance it by controlling the interaction of electrons with light.

DAVID GERSHONI

is in the Physics Department and the Solid State Institute, Technion–Israel Institute of Technology, Haifa 32000, Israel.

e-mail: dg@physics.technion.ac.il

Semiconductor materials form the basis of the modern electronics, communication, data storage and computing technologies that shape our civilization. Two conditions lie at the basis of these technologies: precise control and manipulation of electric charge transport in semiconductors, and the ability to use these materials for efficient generation and detection of light. One of today's challenges for the development of future technologies is the realization of devices that control not only the electron charge, as in present electronics, but also its spin, setting the basis for future spintronics. Control over the electronic spin, which semiclassically can be viewed as its rotation (either clockwise or counter-clockwise) about a given axis, open up novel technological horizons, as it largely increases the information that the electron carries. The electron spin is far less disturbed by the semiconductor environment than its other physical properties, such as the velocity and spatial position of the carriers. The spin-coherence time, that is, the time in which the spin loses its phase information, is therefore relatively long. This is particularly important for future devices that will be based on the quantum properties of the matter. Writing in this issue, Ghosh and colleagues[1] show that it is possible to further enhance the spin-coherence time by a proper design of the semiconductor structure in which the electron lives. In particular, they have focused on optically excited electrons in quantum dots (QDs) — semiconductor regions in which the electron motion is confined in all dimensions[2,3].

Absorption or emission of light in semiconductors is associated with transitions of electrons between their energy levels. The law of energy conservation implies that the amount of energy that an electron gains or loses in its transition exactly matches the energy of the absorbed or emitted photon (the quantum of light), respectively. In a similar manner, the law of angular momentum conservation implies that the photon polarization — the direction of the electric fields that the photon carries — is determined by the electron spin. According to the laws of quantum mechanics, because the QD size is a few nanometres, only a finite number of electrons, having a discrete energy spectrum, can be accommodated in it. This translates into a discrete optical spectrum, as in atomic physics.

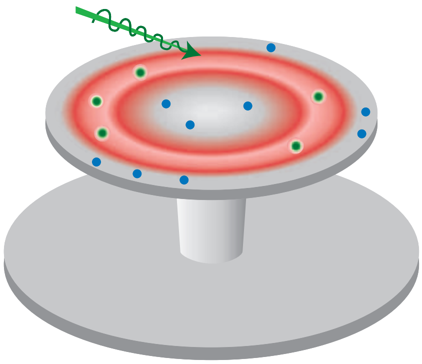

Figure 1 Semiconductor quantum dots in a disk microcavity. The photonic modes of the cavity (red) are concentrated in proximity of the disk circumference. Those quantum dots (green) located within the cavity modes can be 'written' or 'read' by photons.

Ghosh and colleagues have incorporated their QDs into what can be considered an artificial atom for photons, a semiconductor microcavity. This is a semiconductor structure with dimensions typically comparable to the wavelength of light, in which the interfaces are designed to be highly reflective. Photons of a specific (resonant) wavelength only, which exactly matches the size of the cavity, are trapped inside. An ideal cavity would confine photons indefinitely. Deviation from this ideal condition is described by the cavity *Q* factor. In high-*Q* cavities, when the probability of generating a cavity photon by external excitation is larger than the probability of losing one, lasing may occur. The cavity used by Gosh *et al.* is a disk microcavity, in which the photon modes are located around the disk perimeters[1]. They have measured the time evolution of the electron spin following laser excitation, and found that at lasing conditions, the spin lifetime is enhanced.

The results obtained by Ghosh and colleagues may be particularly relevant for the development of logic devices that make use of the electron spin as the variable. Unlike conventional logic, which is based on classical bits of information (either 0 or 1, for example), the electron spin state also carries with it information about its relative quantum mechanical phase. Such quantum bits of information are known as qubits, and they form the building blocks of the emerging field of quantum information processing[4]. To understand the potential of the results, we have to keep in mind that the size, shape and composition of the microcavities can be engineered for allowing tailoring of the photon–spin interaction to specific quantum dots[5]. Let us now imagine, for example, an ultimate future device using electron–photon interaction to prepare ('write') the spin states of the electrons in the quantum dots. Once the spin state is prepared, it will evolve owing to the electronic interaction with the spin of electrons in neighbouring QDs. Eventually, electron–photon interaction will be used again for 'reading' out the resulting new electron spin state[6,7]. In such a device, the capability of controlling the photon–spin coupling is essential for the input–output operations. Successful implementation of qubit logic, based on semiconductor quantum dots embedded in microcavities, will therefore result in an enormous impact on the path of future technology.

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MATERIAL WITNESS

Sonic sense

In ancient China, one of the most acoustically sensitive of world cultures, materials such as metal, wood and stone were classified by what they sounded like. The Chinese recognized that metal creates a very different sound from wood, just as the timbres of the brass and woodwind sections in today's orchestras fulfil very specific roles in painting images with sound.

But the acoustic fingerprints of materials remain underexplored. It is straightforward to measure the acoustic signals produced by, say, striking an object; but how this translates into a perception of timbre and then` into an interpretation of the source is poorly understood. A listener's ability to distinguish the same pitch played on a trumpet and a clarinet obviously has something to do with both the harmonic content of the sound and its time variation. Yet our acoustic 'material sense' seems to be considerably more fine-tuned than that.

For instance, people have been shown to estimate accurately the elasticity of bouncing balls merely by hearing the sound of a single bounce. Some sounds with extremely complex time–frequency signals are experienced as single, clearly identifiable events, such as the smashing of glass. There seem to be particular acoustic signatures of 'glass-ness' and 'wood-ness' that create a perceptual link between very different sounds.

At the same time, our auditory sense of material can be fooled by context. Movie makers rely on this, which is why we wince at the sound of a cabbage being split in half when in a movie it accompanies an image of bones breaking. It's an example of so-called Foley sound, named after the 1950s pioneer of film sound Jack Foley, in which sounds made artificially by simple mechanical means 'stand in' for those associated with images in the film. Footsteps, rustling, jangling keys and creaking doors are reproduced live in a studio by 'Foley artists' as they watch the footage on a screen.

Clearly, the sound of jangling keys can be made by metal objects that are not real keys, but not by plastic ones. What are the limits of this mimicry? Bruno Giordano and Stephen McAdams have recently tried to map out the boundaries of our acoustic identification of materials by measuring the ability of a group of listeners to recognize sheets of plastic (plexiglass), steel, glass and wood from the sound when sheets of different sizes are struck (*J. Acoust. Soc. Am.* 119, 1171–1181; 2006). Steel and glass could readily be distinguished from wood and plastic, but it was harder to differentiate within each pair.

Giordano and McAdams suggest that our recognition is based not so much on pure acoustic differences but on environmental 'training': for example, we tend to hear impacts on smaller objects of glass (such as tumblers) than of metal (pots and pans), and for thicker objects of wood than of plastic. This learning generally serves us well, but it means we can be fooled by sound when the material sources come in unfamiliar shapes and sizes.

Philip Ball