Plenty of nothing: A hole new quantum spin

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Electronic devices are always shrinking in size but it's hard to imagine anything beating what researchers at the University of New South Wales have created: a tiny wire that doesn't even use electrons to carry a current.

Known as a hole quantum wire, it exploits gaps – or holes - between electrons. The relationship between electrons and holes is like that between electrons and anti-electrons, or matter and anti-matter.

The holes can be thought of as real quantum particles that have an electrical charge and a spin. They exhibit remarkable quantum properties and could lead to a new world of super-fast, low-powered transistors and powerful quantum computers.

Associate Professor Alex Hamilton and Dr Adam Micolich, who lead the UNSW Quantum Electronic Devices group in Sydney, Australia, say the discovery that the holes can carry an electrical current puts the team at the front of its field in the quantum electronics revolution.

"Research groups around the world have been trying to make these devices for more than a decade and we're the first to do so successfully," Professor Hamilton says. "We really do have a big lead now."

Quantum wires are microscopically small, in this case about 100 times narrower than a human hair. They are so narrow that electrons can only pass along them in single file.

Manufacturers are keenly interested in them because they hold the potential for new high-speed electronics applications, known as spintronics, where semiconductor devices have both electric and magnetic properties.

Electrons have both electric (charge) and magnetic (spin) properties but today's micro-chips use only the charge properties of electrons.

"To move ahead with spintronics, we need to be able to control the magnetic properties with electronics," says Professor Hamilton.

"However, in most semiconductors the electron's charge and spin are independent of each other, so we can't control the magnetic properties with electrical impulses."

Quantum wires made it possible to isolate and exercise some control over single electrons. But the UNSW team - working with researchers in Britain, Japan and New Zealand - has gone a step further to develop super-clean gallium arsenide quantum wires that use holes, instead of electrons, to carry the current.

"The idea that a hole can have such dynamic properties is a hard concept to grasp," says Hamilton. "It's a bit like when you tilt a builder's spirit level: you can either think of the liquid sinking downwards, or the bubble - an absence of liquid - rising upwards."

"Quantum holes also have spin, and this can be strongly affected by electric impulses. So semiconductors that use holes, rather than electrons, would be good for spintronics and quantum information technologies that use spin to store and process data."

"The problem is that until now it has not been possible to make high-quality hole nanostructures. What we've done is to make highly stable hole quantum wires, where the holes can travel without hitting anything else.

"As the holes pass along the wire, they line up like soldiers marching in single file and our experiments show that their magnetic dipoles (their little bar magnets) all want to point along the wire. Electrons don't do this.

"This means that we can manipulate the spin properties of the holes by forcing them into these narrow quantum wires, which is one of the pre-conditions for making spin-based transistors."

These findings will be presented by UNSW researchers at the forthcoming 26th international conference on the Physics of Semiconductors, in Vienna, with two talks by PhD student Mr Oleh Klochan and Australian Research Council postdoctoral fellow Dr Romain Danneau.

Citation: Full details of these advances have been reported in the top-ranked physics journal *Physical Review Letters* (Danneau et al, *Physical Review Letters*, 97 026403 (2006), dx.doi.org/10.1063/1.2161814), with two additional papers appearing in *Applied Physics Letters* (Danneau et al, *Applied Physics Letters* 88, 012107 (2006) (dx.doi.org/10.1063/1.2161814), Klochan et al, *Applied Physics Letters*, in press (arxiv.org/abs/cond-mat/0607509))

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