Superconducting spintronics pave way for next-generation computing

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Data storage at CERN, Geneva. Superconducting spintronics could enable such facilities to process unprecedented amounts of data with a high level of energy-efficiency. Credit: Gruntzooki, via Flickr

A breakthrough for the field of Spintronics, a new type of technology which it is widely believed could be the basis of a future revolution in computing, has been announced by scientists in Cambridge.

The research, reported in *Nature Communications*, provides the first evidence that superconductors could be used as an energy-efficient source for so-called "spin-based" devices, which are already starting to appear in microelectronic circuits.

Beyond these early developments, spin-based electronics (or "spintronics") promises the potential to create a new generation of super-fast computers, capable of processing vast amounts of data in an energy-efficient way.

Unlike conventional electronic devices, which transmit information via the charge carried by an electron, spintronics exploits another fundamental property of that electron, called "spin". In simple terms, spin refers to the intrinsic angular momentum of the electron, and makes it behave like a tiny magnet. Spintronics involves manipulating this to perform logic operations in devices.

There is, however, a catch: Any such device requires a large spin current to operate, which in itself requires the input of a large electrical charge. Since the spin currents are dissipative, a large fraction of the input energy is wasted as heat.

Superconductors – materials which, when cooled below a certain temperature, can carry a current without losing energy – provide one potential solution to this. If these materials could be harnessed in spin-based devices, an energy-efficient source for the charge required to create spin currents could be provided.

Until relatively recently, scientists believed that superconductors and spintronics were incompatible. The new study breaks new ground by showing, for the first time, that the natural spin of electrons can be manipulated, and more importantly detected, within the current flowing from a superconductor. The results could pave the way for the use of superconductors in spintronics, making these devices more energy-efficient.

The research was led by Dr Jason Robinson, a materials scientist and Fellow of St John's College, Cambridge. "At the moment, highperformance computers like those used in large-scale data handling facilities such as e-data centres waste huge amounts of energy," Robinson said. "In Europe, about three per cent of the energy that we generate is consumed by them."

"If we could combine spintronics with superconductivity, we would be able to take advantage of the benefits that both areas offer to reduce this. We could create circuits that are highly complex and extremely powerful on the one hand, but very low in terms of their energy demands on the other."

The spin of electrons can point either "up" or "down". In spintronic devices, researchers manipulate this to make the direction essentially correspond to the 0s and 1s used in standard binary code. Potentially, this technique could then be used to transmit or store data on an unprecedented scale.

Supplying the charge current from a superconductor offers the tantalising prospect of zero electrical resistance (and therefore 100% energy efficiency). It is also deeply problematic, however, because of the way in which electron spins behave in superconducting materials.

The problem arises from the fact that researchers use magnetic materials, such as iron or cobalt, which have an inherent spin bias, towards "up" or "down". In general, spintronic devices contain multiple magnetic and non-magnetic layers. If a charge current passes through them, the spin carried by the electrons is polarised by the magnets, thus creating a bias towards either up- or down-spins.

Unfortunately, the zero-resistance in superconductors is normally possible since the electrons are paired up into what are called "Cooper Pairs". In these pairs, one electron must have its spin up and the other must be down. The net spin of a Cooper is thus zero.

Because this pairing must be retained in order for electrical currents to superconduct, the energy-efficiency of superconductors has traditionally been seen as incompatible with spintronics: Pass a Cooper pair through a magnet, and one electron will "flip", leading to energy loss.

In the new study, the research team resolve that stalemate, making both superconductivity and spin possible simultaneously. This was achieved by adding an intervening magnetic layer – the rare earth element holmium. Within this layer the magnetism rotates and forms a non-collinear interface with the magnetic layers (of permalloy) which were being used to manipulate the spin.

As the Cooper pairs passed through this rotating magnetic layer, the pairing was preserved despite the fact that one electron had effectively "flipped" to create parallel aligned spins. The researchers' experiment successfully detected these parallel spin Cooper pairs, thus confirming their existence. In short, a spin bias was created, but superconductivity was retained.

Team member Dr Niladri Banerjee from the Materials Science Department at the University of Cambridge, said: "What's never been directly demonstrated until now is that Cooper pairs can serve as transmitters of spin. That's an important step forward since now it is clear that superconductivity can play a key role in spintronics."

The next stage of the team's research will be to create a prototype memory element based on superconducting spin currents, and look for new material combinations which would increase the effectiveness of their method.

"We've essentially created a marriage that opens up an emerging field called superconducting spintronics," Robinson added. "Much fundamental research is now required in order to understand the science of this new field, but the results offer a glimpse into a future in which super-computing could be far more energy-efficient."

Provided by University of Cambridge

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