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The rise of semiconductor spintronics

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Most of the electronic devices that we use in everyday life exploit the intrinsic electronic structure of semiconductors, by using electric fields to control charge transport and optical emission. Adding control of the spin degree of freedom of electrons is a natural route forwards, leading to the integration of current technology with spintronics devices. A series of breakthroughs has brought semiconductors on a par with metals (Milestone 18) in the race towards spintronics applications.

Following early work on spin effects in semiconductors — in which the groups around Ionel Solomon in Paris and Boris Zakharchenya in Saint Petersburg were prime movers — it was David Awschalom and colleagues who put non-magnetic semiconductors on the map in spintronics research. In 1997, they discovered coherence times for spin states of up to 1 ns in a II–VI compound — proving that the spin state can live for long enough, in principle, to allow external manipulation, which is an essential requirement for any spintronics device. Two years later, the same group also measured coherence times exceeding 100 ns in III–V compounds, and showed that, under the influence of an electric field, charges can diffuse over distances greater than 100 μm without changing their spin state.

To make full use of these developments, the spins must be prepared in a well-defined state at the outset; with an eye on practical application, this should ideally happen by electrical means. In 1976, Arkady Aronov and Gregory Pikus had shown that it should be possible theoretically to inject spins with a defined orientation from external electrodes into a semiconductor. Following on from initial experimental studies in 1999 from groups led by Laurens Molenkamp and Awschalom, both of which used a light-emitting diode to demonstrate spin injection into a gallium-arsenide layer, a wide range of work has established spin injection into semiconductors.

Spin polarization can also be created and manipulated without ferromagnetic contacts or external magnetic fields. In 2004, Yuichiro Kato *et al.* demonstrated, in a gallium-arsenide layer, that an electrical current generates polarized electron spins, along with a transverse spin current, leading to spin polarization at the edges of the conducting channel. The phenomenon is known as the spin Hall effect — predicted in 1971 by Mikhail Dyakonov and Vladimir Perel — and following the first observation by Kato, it has been seen in a wide range of other materials, including metallic structures.

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