

# A new, tunable device for spintronics

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Recently, the research group of Professor Jairo Sinova from the Institute of Physics at Johannes Gutenberg University Mainz in collaboration with researchers from the UK, Prague, and Japan, has for the first time realised a new, efficient spin-charge converter based on the common semiconductor material GaAs. These results have recently been published in the journal *Nature Materials*.

Spin-charge converters are important devices in spintronics, an electronic which is not only based on the charge of electrons but also on their spin and the spin-related magnetism. Spin-charge converters enable the transformation of electric into magnetic signals and vice versa. Recently, the research group of Professor Jairo Sinova from the Institute of Physics at Johannes Gutenberg University Mainz in collaboration with researchers from the UK, Prague, and Japan, has for the first time realised a new, efficient spin-charge converter based on the common semiconductor material GaAs.

Comparable efficiencies had so far only been observed in platinum, a heavy metal. In addition, the physicists demonstrated that the creation or detection efficiency of [spin currents](#) is electrically tunable in a certain regime. This is important when it comes to real devices. The underlying mechanism, that was revealed by theoretical works of the Sinova group, opens up a new approach in searching and engineering spintronic materials. These results have recently been published in the journal *Nature Materials*.

Spintronics does not only make use of the electron's charge to transmit

and store information but it takes also advantage of the electron's spin. The spin can be regarded as a rotation of the electron around its own axis, and generates a magnetic field like a small magnet. In some materials, electron spins spontaneously align their direction, leading to the phenomenon of ferromagnetism which is well known e.g. in iron. Additionally, "spin-up" or "spin-down" directions can be used to represent two easily distinguishable states – 0 and 1 – used in information technology. This is already used for memory applications such as computer hard discs.

Making use of electron spin for information transmission and storage, enables the development of electronic devices with new functionalities and higher efficiency. To make real use of the [electron spin](#), it has to be manipulated precisely: it has to be aligned, transmitted and detected. The work of Sinova and his colleagues shows, that it is possible to do so using electric fields rather than magnetic ones. Thus, the very efficient, simple and precise mechanisms of charge manipulation well established in semiconductor electronics can be transferred to the world of spintronic and thereby combine semiconductor physics with magnetism.

Spin-charge converters are essential tools for that. They can transform charge currents into spin currents, and vice versa. The main principle behind these converters is the so called spin-Hall effect. Jairo Sinova had already been involved in the prediction and discovery of this relativistic phenomenon in 2004.

The spin-Hall effect appears when an electric field drives electrons through a (semi-) conductor plate. Taking a look at the classical Hall effect that is known from undergraduate physics, the interaction of moving electrons and an external magnetic field forces the electrons to move to one side of the plate, perpendicular to their original direction. This leads to the so called Hall voltage between both sides of the plate. For the spin-Hall effect electron-spins are generated by irradiating the

sample with circularly polarised light. The electron spins are then parallel or antiparallel, and their direction is perpendicular to the plate and the direction of movement. The moving electron spins are now forced to one or the other side of the plate, depending on the spin orientation. The driving force behind this is the so called spin-orbit coupling, a relativistic electromagnetic effect which influences moving electron spins. This leads to the separation of both spin orientations.

To make practical use of this effect, it is essential to get a highly efficient spin separation. Up to now, platinum has been the most efficient spin-charge converter material, as it is a heavy metal, and the spin-orbit coupling of heavy metals is known to be especially strong due to the large amount of protons (positive charge) in their core.

Now, Sinova and his colleagues have shown that gallium-arsenide (GaAs), a very common and widely used semiconductor material, can be as efficient spin-charge converter as platinum, even at room temperature, which is important for practical applications. Moreover, the physicists have demonstrated for the first time that the efficiency can be tuned continuously by varying the electric field that drives the electrons.

The reason for this – as theoretical calculations of the Sinova group have shown – lies in the existence of certain valleys in the [conduction band](#) of the [semiconductor material](#). One can think of the conduction band and its valleys as of a motor highway with different lanes, each one requiring a certain minimum velocity. Applying a higher electric field enables a transition from one lane to the other.

Since the spin-orbit coupling is different in each lane, a transition also affects the strength of the [spin-hall effect](#). By varying the [electric field](#), the scientists can distribute the electron spins on the different lanes, thus varying the efficiency of their spin-charge converter.

By taking into account the valleys in the conduction band, Sinova and his colleagues open up new ways to find and engineer highly efficient materials for spintronics. Especially, since current [semiconductor](#) growth technologies are capable of engineering the energy levels of the valleys and the strength of spin-orbit coupling, e.g. by substituting Ga or As with other materials like Aluminum.

**More information:** N. Okamoto, H. Kurebayashi, T. Trypiniotis, I. Farrer, D. A. Ritchie, E. Saitoh, J. Sinova, J. Mašek, T. Jungwirth & C. H. W. Barnes, Electric control of the spin Hall effect by intervalley transitions, *Nature Materials*, August 2014, [DOI: 10.1038/nmat4059](https://doi.org/10.1038/nmat4059)

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