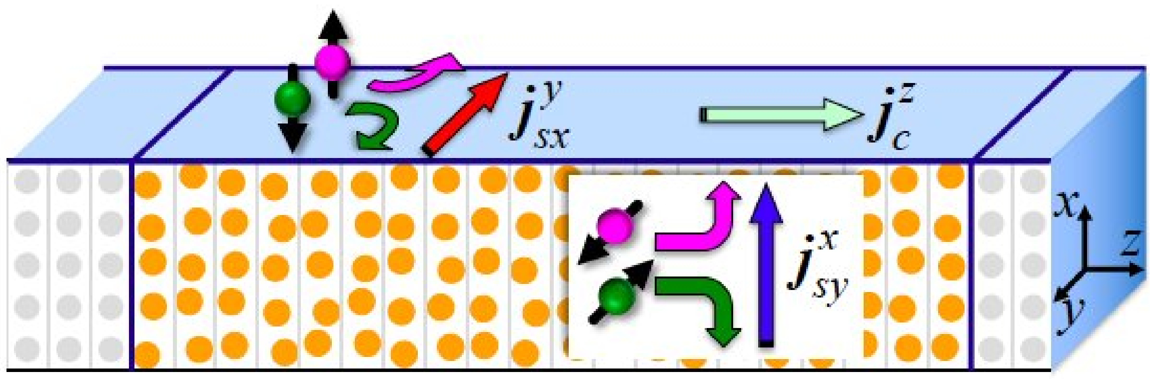
# Study unveils dependence of spin memory loss in a variety of interfaces

March 24 2020, by Ingrid Fadelli




Credit: Gupta et al.

Researchers at the University of Twente and Beijing Normal University have recently conducted a study investigating the parameter known as spin memory loss (SML) for a variety of different interfaces, using a combination of theoretical and computational methods. Their paper, published in *Physical Review Letters*, offers valuable new insights that could inform the design of more efficient interfaces.

"The holy grail in our field of study is a new concept in magnetic memory storage that would be 100% electronic; i.e. potentially faster, denser and more reliable than present day hard disk drives (HDD) that form the backbone of the internet (e.g., data farms) and that are based upon a mechanically spinning magnetic disk where data is accessed by a read/write head floating only nanometers above the rapidly spinning hard disk," Paul Kelly, one of the researchers who carried out the study, told Phys.org. "The new concept is based on something called the spin Hall effect (SHE), which was theoretically predicted 50 years ago, but first observed in semiconductors in 2004 and two years later in metals."

In addition to having a charge, electrons have a spin, which means that they can act as 'spinning tops.' Associated with this spin is a magnetic moment. The SHE is a direct consequence of the relativistic effect called spin-orbit coupling (SOC), which 'couples' how electrons are spinning (clockwise or anticlockwise) with how they are moving around atoms.

As a result of this effect, when a current of charge passes through a slab of a heavy metal like platinum, it excites a current of spin at right angles to the charge current. If the platinum is in contact with a magnetic material like iron, nickel or permalloy, a FeNi alloy, the 'spin current' is driven into this neighboring magnetic material.

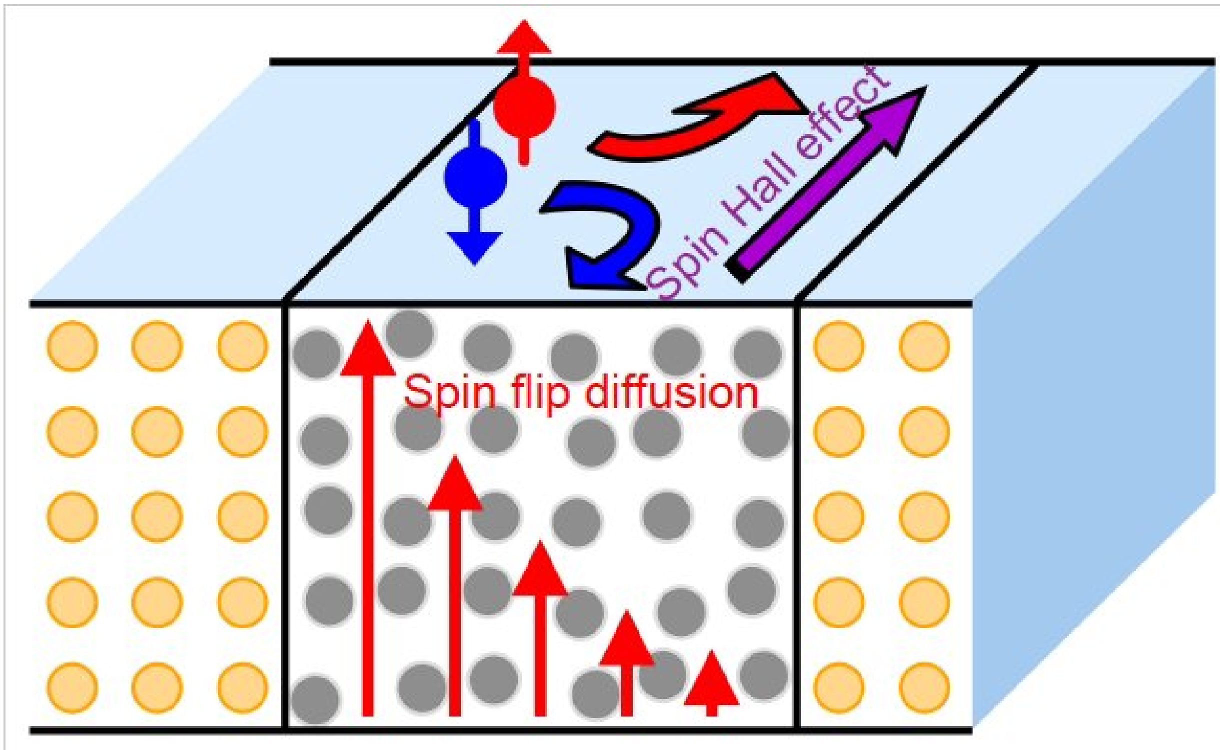


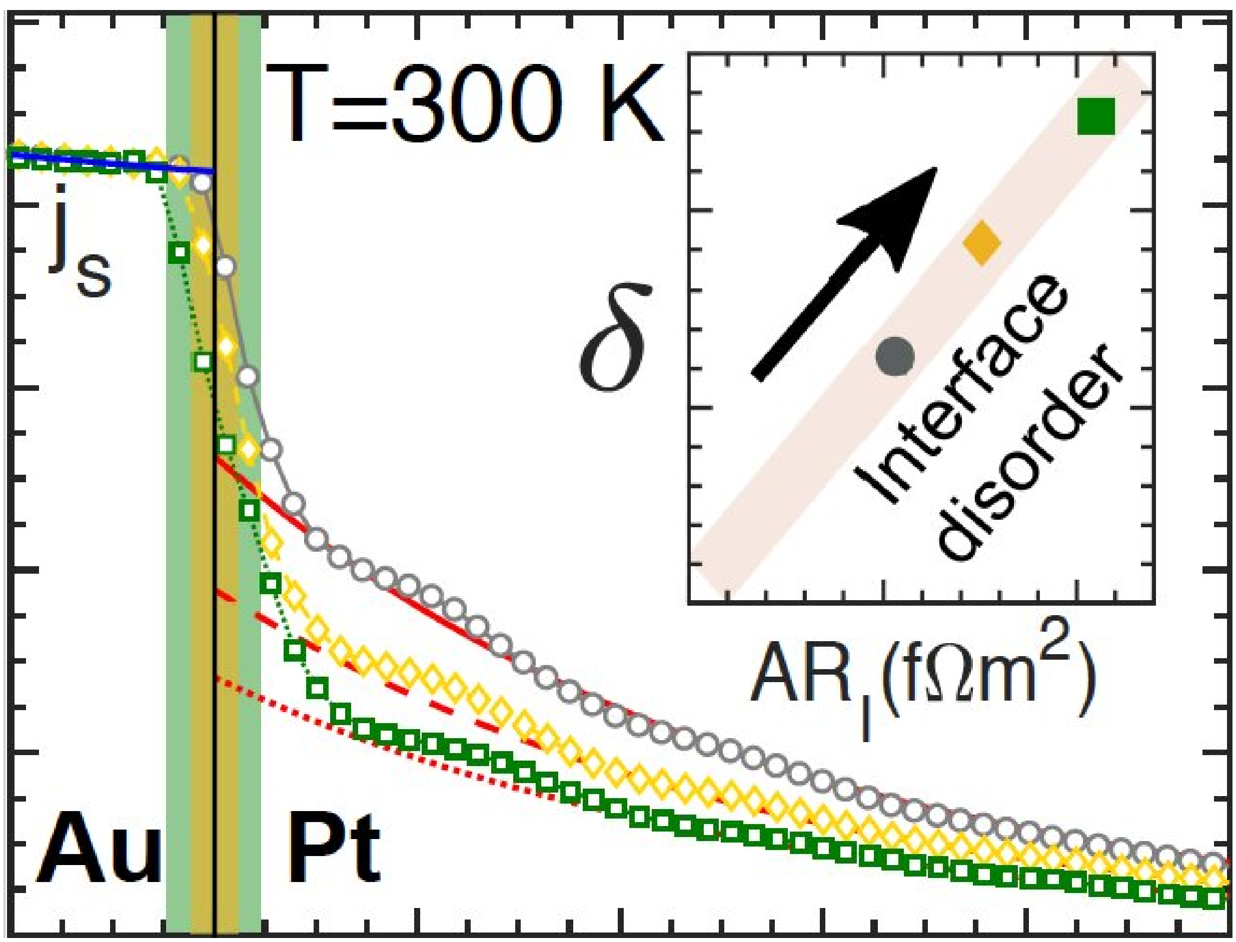

Figure explaining the Spin Hall Effect. Credit: Gupta et al.

"Under the right circumstances, this spin current can reorient the direction in which the magnetic moment points: up is '1', down is '0'; and we have the basis of a new type of magnetic memory," Kelly explained. "This is where we come in."

As Kelly goes on to explain, the spin current typically gets degraded when it passes from the Pt wire into the magnetic material, which often happens at interfaces between two different materials. This degradation in current, known as 'spin memory loss' (SML), has been the focus of many studies, including the one carried out by Kelly's team, and yet currently very little is known about it.

"What is known so far about SML has been gleaned from low temperature experiments, whereas 99% of interest is in what happens at room temperature, the temperature of importance for numerous applications," Kelly said. "Our research has been geared to be able to study properties such as this."

The main objective behind the study carried out by Kelly and his colleagues was to study SML and its behavior at different interfaces and at finite temperatures (where temperature-induced atomic vibrations and fluctuations in magnetic moments are unavoidable). The researchers focused on four combinations of materials that are typically used when trying to develop a magnetic memory storage that is entirely electronic.



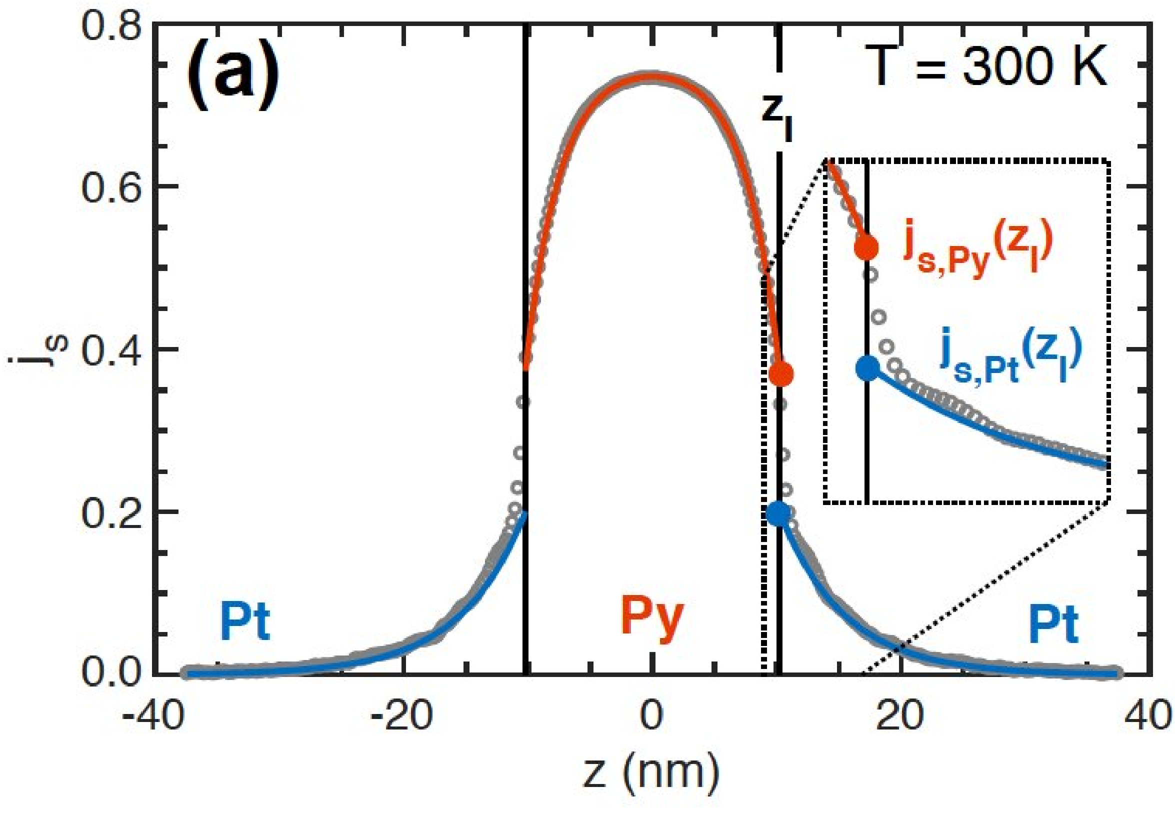
A fully polarized spin current is injected into a Au / Pt bilayer with a sharp interface (vertical black line), two layers of Au50Pt50 interface (yellow shaded region), and four layers of Au50Pt50 interface (green shaded region) between them. The calculated spin currents for the three cases are shown as grey circles, yellow diamonds, and green squares, respectively. The solid blue line indicates a fit to the VF equation in Au. The solid, dashed, and dotted red lines indicate fits to the VF equation in Pt for Au / Pt, Au/Au50Pt50(2)Pt, and Au/Au50Pt50(4)jPt, respectively. (Inset) δ vs ARI for N ¼ 0, 2, and 4 interface layers of mixed Au50Pt50. Credit: Gupta et al.

Over the past 20 years, Kelly and his colleagues have developed computer codes that can be used to study the transport of electrons and spins (i.e., spin transport) in complex materials. These codes are based on solving the 'Schrödinger equation' of quantum mechanics in a form called "scattering theory" which means that the behavior of the electrons is in terms of matter waves.

"Two important steps in the development of these codes were the inclusion of relativistic effects, namely SOC and temperature in the form of temperature-induced lattice and spin disorder," Kelly said. "As the temperature of a material is increased, the atoms of which the material is composed vibrate more and more; this is called lattice disorder. If the material is ferromagnetic, then the magnetic moments on the atoms rotate away from their original, uniform orientation."

As a final step in the development of code for studying spin transport through interfaces, Kelly and his colleagues used the results of their quantum mechanical 'scattering' calculations to compute the charge and spin currents observed by experimentalists. This process ultimately allowed them to study the SHE at interfaces, as well as the degradation of spin currents as they pass from one material to another (i.e., SML).

"The key difference between our study and those conducted by other research teams is that we long ago identified interfaces as a key target and focused our code development on being able to study interfaces between materials that have very different sizes (i.e., lattice constants)." Kelly said. "This involved making extensive use of 'sparse matrix methods' to be able to handle the huge numerical arrays that result from describing interfaces realistically."




Open circles: spin current jS(z) through a Pt Py Pt trilayer calculated for T ¼ 300 K. The solid blue (orange) curve is a fit to the VF equations in bulk Pt (Py). These fits are extrapolated to the interface zI to obtain the values js,Pt (ZI) and Js,Py (ZI)shown in detail in the right inset. (Left inset) The spin current with (red) and without (blue) proximity-induced moments in Pt. Credit: Gupta et al.

Kelly and his colleagues were the first to study spin transport as a function of temperature through realistic interfaces. In addition to introducing numerical values for parameters describing this transport, they gathered valuable insight into how these parameters vary across different interfaces, as well as their dependence on the types of disorder they are affected by.

In particular, the researchers observed that nonmagnetic interfaces have a minimal temperature dependence, while interfaces containing ferromagnets strongly depend on temperature. They also found that the SML was greater for certain interfaces, especially when the passage between the different materials is more abrupt (e.g. Co/Pt interfaces).

Finally, Kelly and his colleagues found that SML can be significantly enhanced by lattice mismatch and interface alloying. In the future, the observations and insights they gathered will guide the design of more effective interfaces with various possible applications.

"As a next step, we want to directly study the process whereby a spin current generated by the SHE in a heavy metal is injected into various other materials, nonmagnetic as well as magnetic, to make closer contact with magnetic memory and related nanodevices," Kelly said. "We will also study properties of the new two-dimensional van der Waals ferromagnetic materials, which may have distinct charge and spin transport properties and whose 'interfaces' are supposed to play a key role in determining their magnetic properties."

**More information:** Kriti Gupta et al. Disorder Dependence of Interface Spin Memory Loss, *Physical Review Letters* (2020). DOI: 10.1103/PhysRevLett.124.087702

Yi Liu et al. Interface Enhancement of Gilbert Damping from First Principles, *Physical Review Letters* (2014). DOI:

10.1103/PhysRevLett.113.207202

Yi Liu et al. Direct method for calculating temperature-dependent transport properties, *Physical Review B* (2015). DOI: 10.1103/PhysRevB.91.220405

R. J. H. Wesselink et al. Calculating spin transport properties from first principles: Spin currents, *Physical Review B* (2019). DOI: 10.1103/PhysRevB.99.144409