2015

COHERENT SPIN TRANSPORT IN NANOWIRE SPIN VALVES AND NOVEL SPINTRONIC DEVICE POSSIBILITIES

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COHERENT SPIN TRANSPORT IN NANOWIRE SPIN VALVES AND NOVEL SPINTRONIC DEVICE POSSIBILITIES

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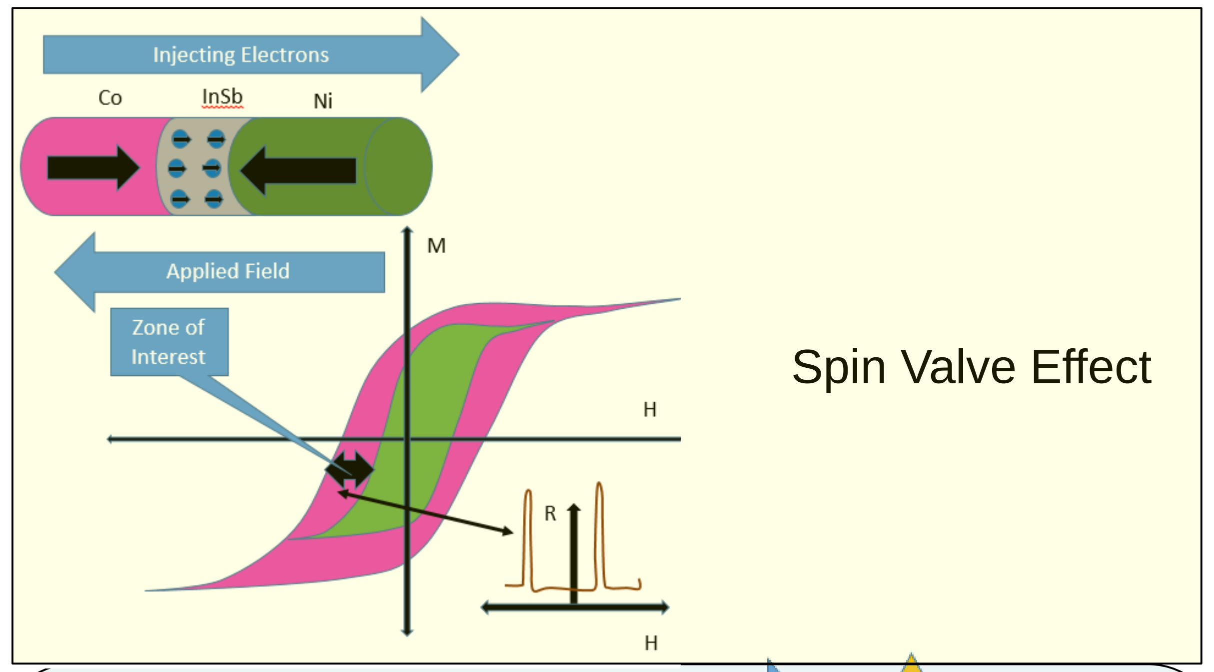
Objective

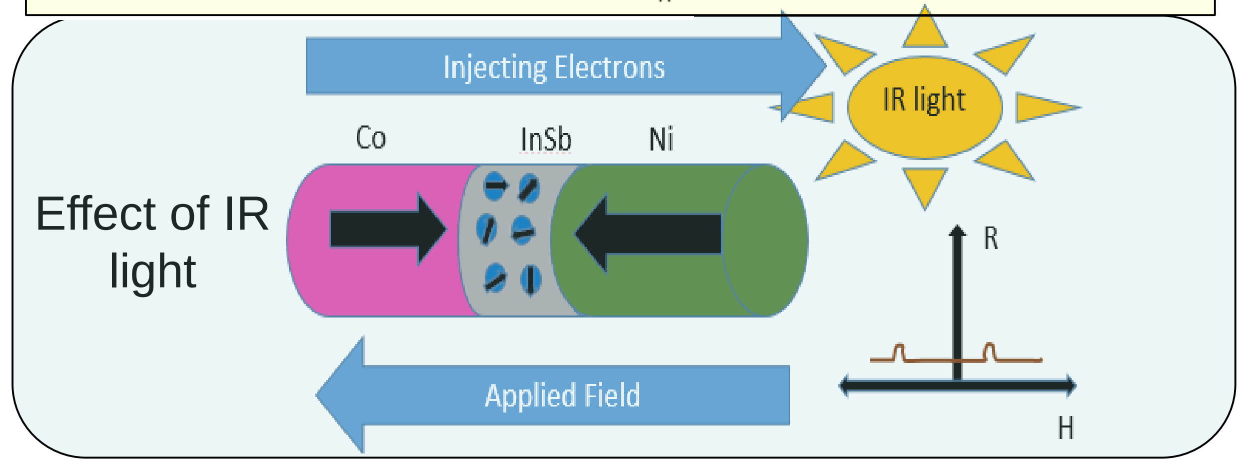
Coherent injection, detection and manipulation of spins in semiconductor nansotructures can herald a new genre of information processing devices that are extremely energy-efficient and non-volatile. For them to work reliably, spin coherence must be maintained by suppressing spin relaxation. We have fabricated 50-nm diameter InSb nanowire spin valves capped with Co and Ni nanocontacts in which a *single* conduction subband is occupied by electrons at room temperature. This extreme quantum confinement has lead to a 10-fold increase in the spin relaxation time due to dramatic suppression of the D'yakonov-Perel' spin relaxation mechanism (Small, 10, 4379 (2014)). We were also able to demonstrate multiple periods of Hanle oscillations in these spin valves. Recently, we have shown that the spin relaxation rate can be modulated with infrared light which portends a novel spintronic infrared photodetector with high light-to-dark contrast ratio.

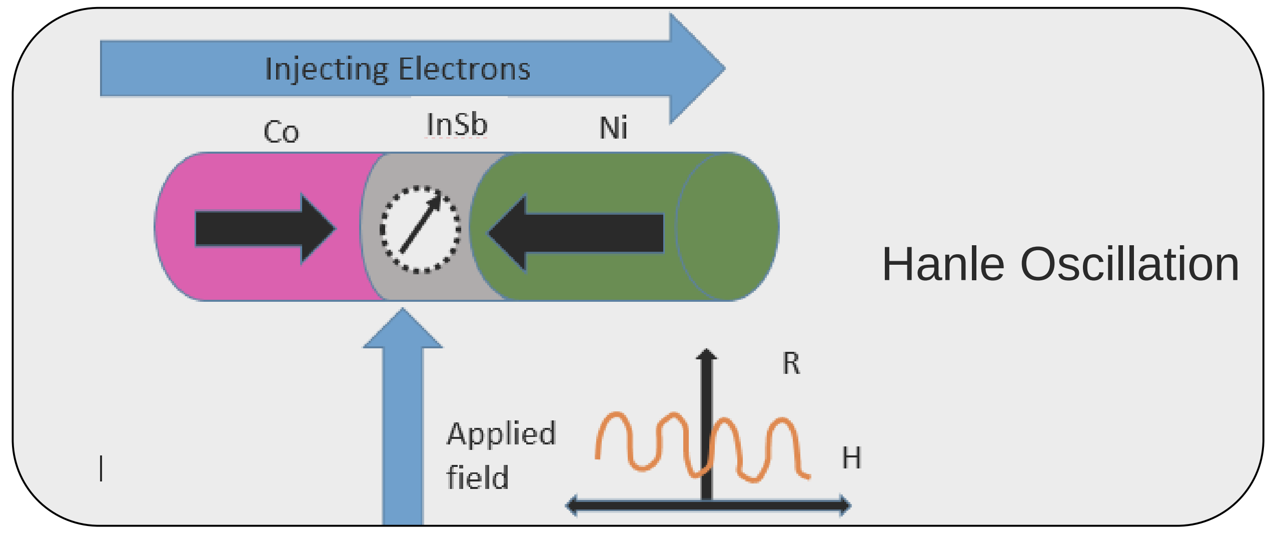
Background

The spin valve device is a trilayered structure consisting of two ferromagnetic contacts and a semiconductor spacer. One contact acts like a spin polarizer and injects spin-polarized electrons into the spacer. The other contact is a spin analyzer that transmits electrons depending on their spin polarization. The resistance of the spin valve is highest when the two contacts have anti-parallel magnetizations and lowest when they have parallel magnetizations. An external magnetic field applied transverse to the direction of current flow can induce spin precession in the spacer layer and hence cause the spin valve resistance to oscillate (Hanle oscillations). The longitudinal magnetoresistance, on the other hand, will exhibit either a peak or a trough between the coercive fields of the two magnetic contacts because the contacts flipping their magnetizations in the presence of the field. From these two effects – Hanle oscillations and spin valve peak/trough – it is possible to extract many valuable information.

Consider a nanowire spin valve whose two contacts have anti-parallel magnetizations. If there is no spin relaxation in the spacer, then ideally the conductance will be zero because the spins injected by one contact are completely blocked by the other. Infrared light induces spin relaxation in the channel and the flipped spins transmit, resulting in an increase in the conductance. This is the basis of photodetection.



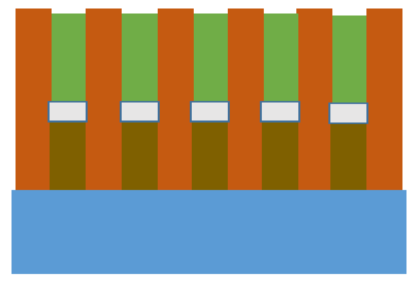




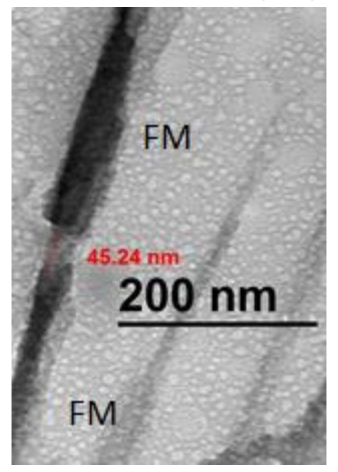
Sample Preparation

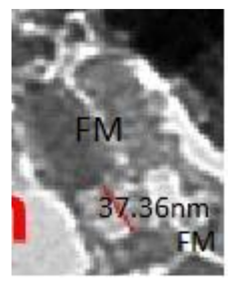
(1)Porous Alumina

2.Barrier layer removal



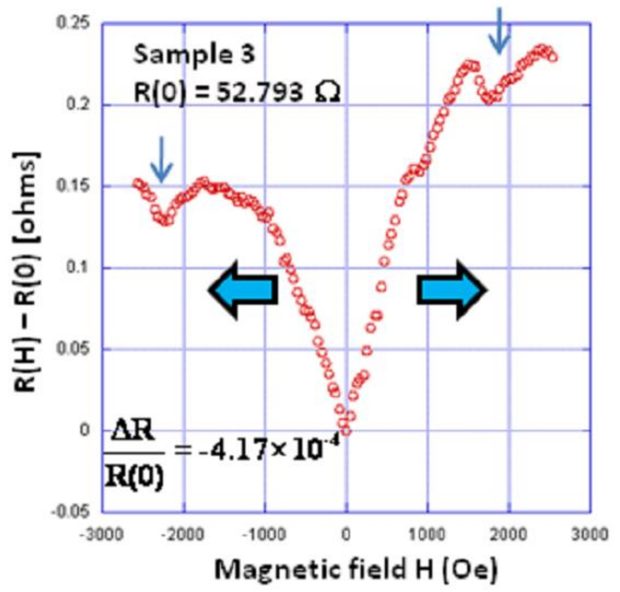
3. Nanowire synthesis by electrochemical deposition





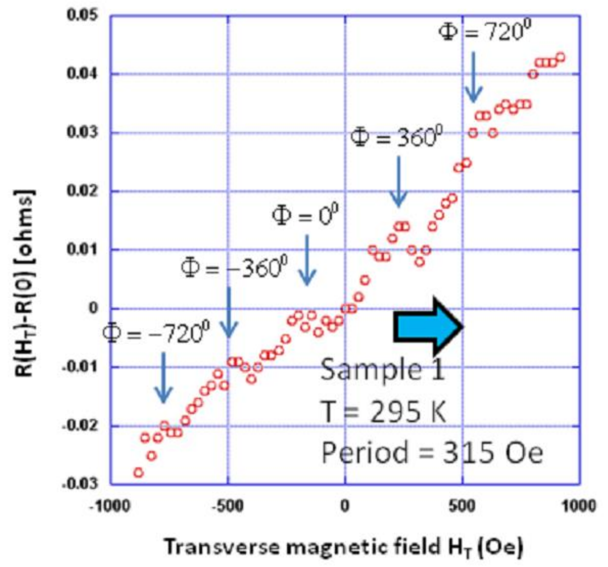
4. TEM images

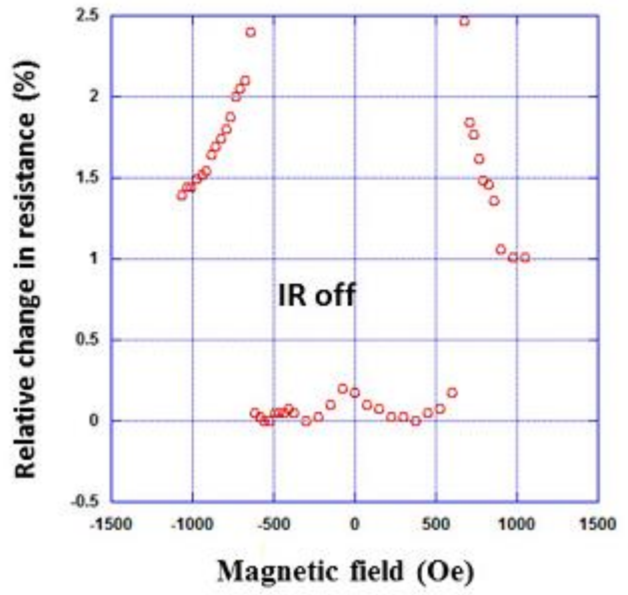
Results

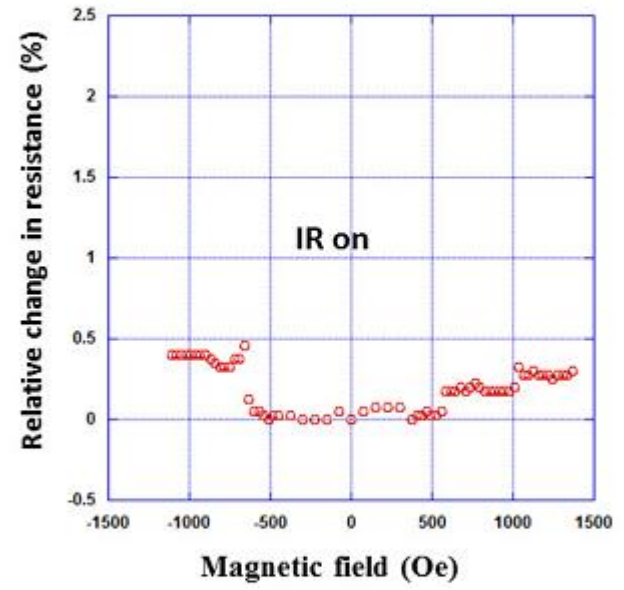


The spin valve effect at room temperature (295 K).

Hanle oscillations at room temperature (295 K). Transverse magnetoresistance plot of sample showing oscillations . The angle of spin precession is the quantity Φ.







Room-temperature magnetoresistance of a Co-InSb-Ni nanowire spin sample in the dark (above) and under illumination by an infrared lamp radiating in the wavelength range 2-5μm (below). The zero-field dark resistance was 4.2 ohms.

Discussions

- The decrease in the spin relaxation rate in nanowires due to the suppression of D'yakonov-Perel' spin relaxation mechanism is the first demonstration of this effect and room temperature and holds out hope for spintronic devices that rely on coherent spin transport for their operation such as the Datta-Das spin transistor.
- The ability to modulate the spin relaxation time with infrared light at room temperature portends a room temperature IR photodetector. The light-to-dark contrast ratio of such a detector will be

$$\frac{G_{\text{light}}}{G_{\text{dark}}} \approx \frac{1-\xi_1\xi_2+2\xi_1\xi_2\left(L/L_l\right)}{1-\xi_1\xi_2+2\xi_1\xi_2\left(L/L_d\right)}$$

$$\approx \frac{L_d}{L_l} \text{ if } \xi_1 \approx \xi_2 \approx 1$$

where the ξ-s are the spin injection and detection efficiencies at the two contacts, L is the spacer layer length, L_l is the spin relaxation length under illumination and L_d is that in the dark. Since $L_d >> L_l$, a photodetector is realized.

Bibliography

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[2] Hossain, M.I., Bandyopadhyay, S., Atulasimha, J., Bandyopadhyay, S. "Modulation of D'yaknov Perel' spin relaxation in InSb nanowires with infrared illumination at room temperature" submitted