Semiconductor spintronics: Progress and challenges

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Spin is the only internal degree of freedom of an electron. Employing it for creating new electrical, optical, and optoelectronic solid-state devices, including spin qubits for quantum computing, is the ambitious goal of semiconductor spintronics. Initial concepts included:

- injection of nonequilibrium spin populations from ferromagnetic sources;
- using spin-orbit coupling for achieving spin precession;
- employing static and resonant electric and magnetic fields for manipulating spin precession; and
- employing interference phenomena and quantum phases for modulating electric currents and producing pure spin currents.

Eliminating magnetic elements and time-dependent magnetic fields and using spin-orbit coupling for producing and manipulating spin populations by means of static and resonant electric fields only, is in the focus of the more recent work. Therefore, spin-orbit coupling becomes the central paradigm of semiconductor spintronics.

I will review current status of the theoretical work on spin dynamics and spin transport in media with spin orbit interaction, and also the related experimental work. The main difference between the charge and spin transport stems from the fundamental fact of charge conservation and spin non-conservation. As a result, the very terms in which these theories are formulated are different. For example, while the elements with spin-orbit coupling are considered as sources of spin currents injected into non-spin-orbit elements, inside the former elements spin currents cannot be properly defined. A consistent theory is formulated in terms of "observables", the components of the spin polarization and the electron concentration. Recent years witnessed fast progress in the development of the theory. However, it depends critically on the specific spin-orbit coupling mechanisms and geometric scales involved, and still remains highly challenging. In this context, concepts of a number of spintronic devices and model experiments demonstrating the basic principles at work will be presented.