Spin currents, which carry information via spins in lieu of charges, play a key role in spintronics. Spin currents were previously observed via spin accumulation at stopping edges or conversion to electrical signals. Direct and non-destructive measurement of pure spin currents where and while they flow is highly desired, but is very difficult because a pure spin current bears neither net charge current nor net magnetization, thus no direct electromagnetic induction. Here we propose the linear1 and second-order nonlinear2 optical effects of spin currents in direct-gap semiconductors. The linear coupling between a pure spin current and a polarized light (or a „photon spin current”) is possible since the pure spin current and the “photon spin current”, both keeping the time-reversal symmetry but breaking the space-inversion symmetry of the system, are of the same symmetry-breaking type. The effective coupling between the photon polarization and the electron spin polarization is rooted in direct-gap semiconductors such as GaAs via the intrinsic spin-orbit coupling in valence bands, but without involving the Rashba or Dresselhaus effect from the inversion asymmetries of the material. Such an effective interaction leads to an optical birefringence effect of the spin current. A symmetry analysis shows that in a semiconductor with inversion symmetry, the linear birefringence effect vanishes, and only the circular birefringence effect exists. The latter effect is similar to the Faraday rotation in magneto-optics but involves no net magnetization or time-reversal symmetry breaking. The symmetry analysis is confirmed by a systematic microscopic calculation. Inversion-symmetry breaking of pure spin currents lead to second-order nonlinear optical effects. Particularly, a longitudinal spin current in which the spins point parallel or anti-parallel to the current direction is a chiral quantity, we envisaged that it can be probed by the chiral sum-frequency optical spectroscopy which was recently developed to detect molecular chirality. By symmetry analysis in general cases and microscopic calculations in realistic models, we discovered that a pure spin current has sizable second-order optical susceptibility. All these findings lay the foundation of direct, non-destructive measurement of spin currents by standard optical spectroscopy, facilitating application of spintronics and research on spin-related quantum phenomena. With the unexpected optical effects of spin currents unveiled, a new field combining spintronics and photonics is to be explored.

References: