Terahertz Inverse Spin Hall Effect in Spintronic Nanostructures

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Terahertz (THz) radiation is situated between the infrared and microwave regions in the electromagnetic spectrum with a bandwidth ranging from 0.3 to 30 THz and has numerous applications in various fields, ranging from security screening, e.g., at airports, through ultrafast communications, radioastronomy, to nonionizing biomedical spectroscopy and imaging. One of the most interesting forms of THz radiation are subpicosecond in duration bursts of electromagnetic waves. These, so-called, THz transients are, typically, characterized by approx. a single picosecond time duration and a 0.1 to 6 THz spectral range. Spintronic nanostructures manipulate simultaneously electron's charge and spin and emerge as a new direction in generation of THz transients, due to their robust and simple thin-film technology, low cost, and emission of ultra-broadband signals. The inverse spin Hall effect (ISHE) is the core emission mechanism of THz transients from spintronic nanostructures, such as ferromagnet/heavy metal (FM/HM) nanobilayers. Heavy metals (e.g., Pt, Ir, Pd, or Au) are selected because of their large spin-orbit coupling (SOC). When a femtosecond laser pulse illuminates the FM layer, such as, e.g., Fe, Co, or their alloys, spin-up majority electrons are optically excited to sp-states above the Fermi energy and have a longer mean-free path, as compared to the spin-down minority electrons in d-states. Nonequilibrium spin electrons enter an adjacent HM layer and spin-up and spin-down electrons diffuse in opposite directions due to the SOC. Consequently, the injected transient longitudinal spin current density is converted into a transient (sub-picosecond) transverse charge current leading to emission of an electromagnetic radiation pulse whose power spectrum extends up to the THz frequencies. We performed exhaustive experiments using Pt or Ir as HM nanolayers on top of either soft (FeNi) or hard (FeCo) FM films as spintronic emitters and excited them with 100-fs-wide optical pulses, generated by a commercial Ti:Sapphire laser. As a result, we observed efficient generation of THz transients, fully in agreement with the ISHE model. Our detection scheme was an optical pump-probe sampling arrangement that allowed one to obtain a sub-picosecond time resolution of detected THz transients. We also demonstrated that when in a spintronic emitter, a 2-dimensional (2D) graphene was substituted for HM, one could also observe a large, emitted THz transient, even though the graphene intrinsic SOC energy is extremely low. The reason is the FM-induced Rashba texture in graphene, leading to the enhanced SOC value, and resulting in efficient spin-to-charge current conversion, called the inverse Rashba-Edelstein effect (IREE). In case of IREE, injection of a transient, optically-excited, 3D spin-polarized current (from FM) into a 2D material (graphene) creates an imbalance in the distribution of charge carriers and, consequently, a transient 2D charge current, leading to emission of a THz transient. Finally, we will briefly outline feasibility of implementing oxide perovskite materials for spintronic emitters.