Opposite spin-asymmetry of elastic and inelastic scattering of holes injected into a ferromagnet

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A magnetic tunnel junction not only gives rise to large tunnel magnetoresistance, but under large bias it can also be used to inject non-equilibrium carriers into a ferromagnet in order to achieve spin-transfer torque switching of the magnetization. Microscopically, the transfer of angular momentum depends on the scattering processes of the non-equilibrium carriers. Here we have investigated the spin-dependent scattering of non-equilibrium holes injected into a ferromagnet. We use a p-type magnetic tunnel transistor (MTT, see fig. 1) that combines a magnetic tunnel junction with a p-type Si substrate. It consists of a ferromagnetic (FM) emitter, a base with a single FM layer, and a collector of a Schottky contact between Au and p-type Si. Spin-polarized hot holes are injected by tunnelling into the FM base layer and collected in the valence band of the semiconductor after spin-dependent transmission through the ferromagnetic base. The magnetic response of the MTT is determined by the spin-dependent tunneling from the emitter, as well as spin-dependent scattering of the holes in the base.

MTT’s with p-Si/Au/Co/Al$_2$O$_3$/NiFe structure were deposited by thermal evaporation in a molecular beam epitaxy system and patterned by standard photolithography. The barrier height of the p-Si/Au Schottky diode is 0.3eV. The magnetocurrent (MC) and the transfer ratio have been studied as a function of Co base layer thickness and tunnel voltage applied to the emitter. Surprisingly, the magnetic response shows a reversal in sign as a function of bias voltage (see fig. 2) and as a function of thickness of the Co base (not shown). Moreover, the hole transmission decays exponentially but with two different attenuation lengths in the low and high thickness regime, respectively. The results are successfully explained in terms of a competition of two scattering contributions, elastic and inelastic, with opposite spin-asymmetry. The spin-asymmetry of the elastic contribution is consistent with spontaneous spin-wave emission of the injected non-equilibrium holes.
Fig. 1. Schematic diagram of the p-type magnetic tunnel transistor.

Fig. 2. Magnetic field response of the hole current induced in a p-type MTT due to injection of spin-polarized holes from an exchange biased Ni$_{80}$Fe$_{20}$ emitter into a 3.6nm thick Co layer. Curves at different emitter bias voltage show a sign change of the response, where the magnetocurrent is negative at small bias, and positive at large bias. T = 100K.