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Quantitative measurement of spin transfer torque in magnetic tunnel junctions by spin-transfer-driven ferromagnetic resonance[1]

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MgO-based magnetic tunnel junctions (MTJs) whose magnetic dynamics are controlled by spin-transfer torque are prime candidates for practical memory devices. Yet the bias dependence of the spin torque in these MTJs remains controversial, especially at high bias. Here we present spin-torque-driven ferromagnetic resonance (ST-FMR) measurements of the magnitude and direction of the spin torque. We use two complementary methods to determine the amplitude of the magnetic response during ST-FMR: (a) measurement near zero frequency of a mixing signal generated by the oscillating resistance and the applied microwave current that provides accurate torque measurements for small biases $|V|$ less than 0.15-0.3 V and (b) a new type of direct time-domain detection at GHz frequencies that enables quantitative measurements of the spin torque at higher biases from $|V| \sim 0.15$ V up to the breakdown voltage of the MTJ. We find that the two types of detection give consistent results at intermediate biases where they can both be employed. We measure a significant deviation from linear behavior for the bias dependence of the in-plane component of the spin torque (in the plane defined by the electrode magnetizations) with increasing bias, with a weaker torque for electron flow from the free magnetic layer to the fixed layer, compared to the opposite bias. The perpendicular component of the spin torque in symmetric CoFeB/MgO/CoFeB tunnel junctions is quadratic in bias at low bias, but is close to linear at high bias.

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