PROBING SPIN-POLARIZED TUNNELING AT HIGH BIAS AND TEMPERATURE WITH A MAGNETIC TUNNEL TRANSISTOR

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Introduction

The Magnetic Tunnel Transistor (MTT) is a three terminal hybrid device that consists of a tunnel emitter, a ferromagnetic (FM) base, and a semiconductor collector. In the MTT with a FM emitter and a single FM base (see Fig. 1), spin-polarized hot electrons are injected into the base by tunneling. After spin-dependent transmission through the ferromagnetic base they are collected in the conduction band of the semiconductor provided they have the right energy and momentum to overcome the Schottky barrier. Two factors determine the spin-sensitivity of the device: (i) spin-dependent tunneling from the emitter, and (ii) spin-dependent scattering of the hot electrons in the base. Since the magnetocurrent (MC) depends on the tunneling spin polarization, the MTT can be used to study the spin-polarization of ferromagnetic/insulator interfaces at high bias voltage. Moreover, the temperature dependence can be studied using a newly introduced lithographically defined MTT that allows us to probe the tunnel spin-polarization up to room temperature, removing a limitation of the standard technique of tunneling into a superconductor.

Experiment

Samples of n-Si/Au(7 nm)/Co(8 nm)/Al_2O_3(2.1 nm)/NiFe(10 nm)/Au(10 nm) were deposited by thermal evaporation in a molecular beam epitaxy system at a base pressure of 10^{-10} mbar. The metal films were grown on a lithographically defined Si area surrounded by a thick SiO_2 to reduce device size and eliminate edge leakage currents (see Fig.1). The leakage current across the Schottky barrier in the patterned MTT is less than 0.1nA at room temperature. The Al_2O_3 barriers were formed by plasma oxidation of a thin Al layer. MTT devices were fabricated using standard photolithography, ion beam etching, and lift-off techniques. The size of the active area of the devices varied from 10 μm to 100 μm and that of the base-collector diode from 20 μm to 130 μm in diameter.

Results and discussion

Fig. 2 shows the collector current at room temperature as a function of magnetic field, at an emitter bias of -900mV. The largest collector current of 18.2nA is obtained when both ferromagnetic layers are aligned parallel. In the anti-parallel state the collector current reduces to 10nA, resulting in a magnetocurrent (MC defined as $(I_C^P - I_C^{AP})/I_C^{AP}$) of 82% at room temperature. A MC of 82% corresponds to a tunnel spin polarization of the NiFe/Al_2O_3 emitter interface of 29%, demonstrating that the tunnel current is still highly spin-polarized at a high bias voltage of -900mV.

We have investigated the temperature dependence of the MC and the transfer ratio for MTT's with different emitter materials (Co and NiFe). As temperature is decreased to 100K, the MC increases for both emitter materials. For the MTT with the NiFe/Al_2O_3 emitter, we obtain an MC of 104% at 100K, corresponding to a tunnel spin polarization of 34% at -900mV. The MTT with the Co emitter shows slightly weaker temperature dependence than that with a NiFe emitter. The temperature dependence of the MC does not change with emitter bias voltage, whereas the temperature dependence of the transfer ratio ($I_{collector}/I_{emitter}$) does. The transfer ratio increases with increasing temperature for a bias just above the collector Schottky barrier height, while it decreases with temperature for larger bias.

We also examined the tunnel spin polarization of other ferromagnetic/insulator combinations using the MTT. We have modified the tunnel barrier by inserting SiO_2 at the interface between the FM emitter and Al_2O_3 in order to probe the intrinsic tunnel spin polarization of the NiFe/SiO_2 interface. By inserting 0.8nm of SiO_2, the MC almost disappears. This indicates that the tunnel spin polarization of NiFe is drastically reduced in contact with SiO_2.

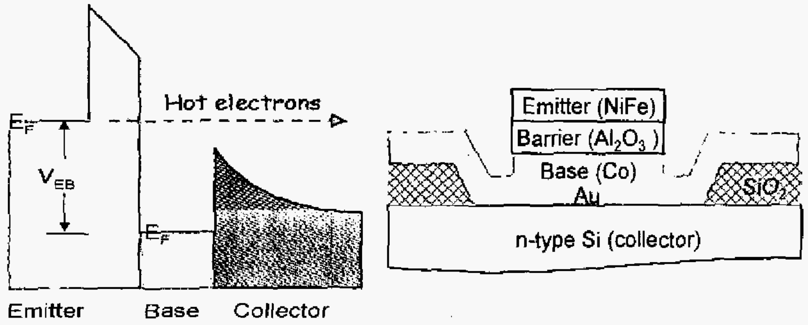

Fig. 1. Schematic energy diagram (left) and the layer structure (right) of a lithographically defined MTT.

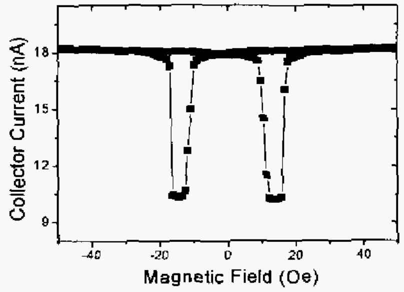

Fig. 2. Collector current versus magnetic field of a MTT with NiFe/Al_2O_3 emitter at room temperature. The magnetocurrent (MC) is 82% at an emitter bias of -900mV.

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