Probing the Field Induced Splitting of Kondo Resonance in Magnetic Double Tunnel Junctions

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Introduction

Small metallic nanodots can be formed in the middle of thin dielectric tunnel barriers by introducing metal layers, which are sufficiently thin (less than ~1 nm) that they are discontinuous. By sandwiching the tunnel barriers between magnetic electrodes magnetic tunnel junction devices are formed. We have explored devices in which the nanodots are formed from magnetic CoFe alloys[1]. In such devices we observe a strongly increased resistance as the temperature is reduced which is consistent with a Coulomb blockade (CB) phenomenon. However, at low temperatures well within the CB regime and at sufficiently low bias voltages, we find that the conductance of such double tunnel junction devices is *increased.* We surmise that this is due to Kondo assisted tunneling via the nanodots. Interestingly, we find that such behavior persists to very high temperatures, as high as ~100 K. In this same bias voltage and temperature regime, we find that the tunneling magnetoresistance (TMR) is suppressed. Kondo assisted tunneling has been observed in many low spin 1/2 systems, but it has been believed that high magnetic moment systems cannot produce a Kondo effect because it is overwhelmed by strong ferromagnetic interactions. Our surprising results suggest that pronounced Kondo assisted tunneling can occur even with high magnetic moments ($S>50\mu_B$). The strength of the zero bias resonance decreases logarithmically with bias voltage between 10 mV and 20 mV. The temperature evolution of the enhanced conductance also shows a logarithmic behavior at temperatures from 40K up to 100K. These dependences are typical signatures of the Kondo effect. Another distinctive signature of the Kondo effect is a splitting of the conductance peak in magnetic field. However, we were not able to observe this splitting in fields available in our laboratory (~10 T). This splitting would, however, only be visible above a critical field, B_c, given by $g\mu_B B_c \sim 0.5 k_B T_K$. We estimate this field is ~37 T.

Experimental

Magnetic double tunnel junction devices were fabricated by deposition on 1-inch diameter Si substrates through a sequence of metal shadow masks using dc magnetron sputtering at room temperature. We measured I-V and conductance-V curves using a standard four-probe method around 4 K at fields up to 45T in the 45T hybrid magnet system (Tallahassee).

Results and Discussion

At the NHFML we observed a dip in the differential resistance (corresponding to a peak in the tunneling conductance) in magnetic double tunnel junction devices which was similar to results we had previously found in experiments in our own laboratories (see Figure 1(a) below). However, the conductance peak was not much influenced by magnetic fields for strengths up to 45 T. The wafers on which we deposited the shadow masked devices were too large for the cryostat at the NHFML so they had to be cleaved into smaller pieces. One puzzling result was that some samples which exhibited a clear conductance peak on the uncleaved wafers showed no such peak after cleaving of the wafers. These samples showed only CB behavior as shown in Fig 1(b). This CB feature was broadened by the magnetic field consistent with cotunneling models. For future studies samples will be fabricated directly on small wafers to avoid this problem.

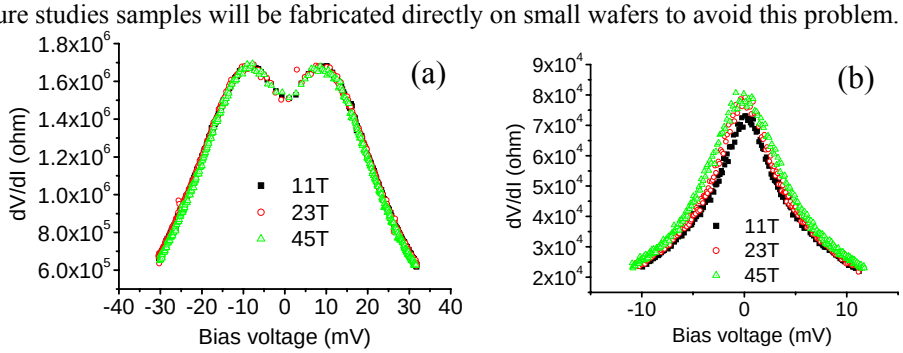

Fig 1. (a) The bias voltage dependence of differential resistance at 4K from a magnetic double tunnel junction device in which the middle electrode is formed from a CoFe layer 0.5nm thick. (b) Similar device on a cleaved wafer which show so conductance peak presumably because of micro-cracks introduced in the large area tunnel junctions by cleaving them. The samples have different tunnel barrier thicknesses which accounts for the very different resistance values.

[1] "Crossover from Kondo assisted suppression to co-tunneling enhancement of tunneling magnetoresistance", Hyunsoo Yang, See-Hun Yang and Stuart Parkin, Nano Lett. (accepted).