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Properties of Magnetic Tunneling Junction Devices with Characteristic Sizes in Sub-5-nm Range

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Introduction: Nanomagnetic devices in the sub-5-nm size range still do not exist, not only because of many fabrication and characterization challenges but also because of the poorly understood physics in this size range. Previous experimental studies from various groups have shown that the spin relaxation time can be increased by orders of magnitude with this size reduction. The increased spin lifetime leads to a combination of effects such as spin accumulation and tunneling magnetoresistance enhancement which in turn can significantly and favorably affect the device performance [1]. The goal of this study is to exploit this new physics through fabrication and testing of magnetic tunneling junction (MTJ) devices with a characteristic size of below 5 nm. To achieve this goal, we integrate magnetic nanoparticles into MTJ structures and measure their key properties such as I-V curves and magnetoresistance dependencies. The nanoparticles, with sizes ranging from below 2 to over 10 nm, are made of the ferrimagnetic spinel ferrite CoFe2O4 using co-precipitation chemistry. It has been theoretically predicted that these nanoparticles become half-metallic in this size range and thus can lead to unprecedented high magnetoresistance values. Indeed, the nanodevices under study display spin-filtering properties, as confirmed through measurements of magnetoresistance and I-V dependences [2]. This paper summarizes the measured room-temperature anomalous magnetoresistance and I-V curves with a Coulomb-staircase-like dependence characteristic of a single-electron transport.

Results: The main device structure which includes nanoparticles embedded into a 2-nm layer of MgO, which in turn is sandwiched between two 2-nm CoFeB layers is illustrated in Fig. 1a. A typical I-V curve of such a device is shown in Fig. 1b. The staircase like dependence of the I-V curve is a hallmark of the Coulomb Blockade (CB) characteristic of a single-electron transport through a double junction. A typical magnetoresistance (MR) curve for a 10-nA bias current is shown in Fig. 1c. The reversible MR oscillations can be explained by the magnetic field dependence of the Fermi energy in the region of the nanoparticles, as illustrated in Fig. 1d. The energy levels become strongly discrete due to the size reduction. It is possible that application of a magnetic field leads to field-dependent energy level splits due to the Zeeman effect as well as to a change of the degeneracy in each level similar to the case of Landau levels in low-dimensional systems, which in turn leads to the field dependence of the Fermi energy.

Conclusion: Integration of high-anisotropy ferrimagnetic nanoparticles into MTJ structures leads to characteristic single-electron type electron transport properties. The magnetoresistance of such devices displays an oscillatory dependence on the magnetic field, with an oscillation MR amplitude of over 100%. The oscillatory dependence can be explained by the highly discrete nature of the electron energy levels in such small size range devices and the field dependence of the Fermi energy. Due to the quantum-mechanical nature of these devices, our theoretical models predict a MR ratio on the order of 10^4 and above and thus pave a way to next-generation spintronic devices with an "On/Off" ratio comparable to that of CMOS devices.

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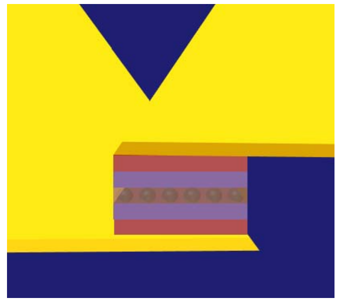
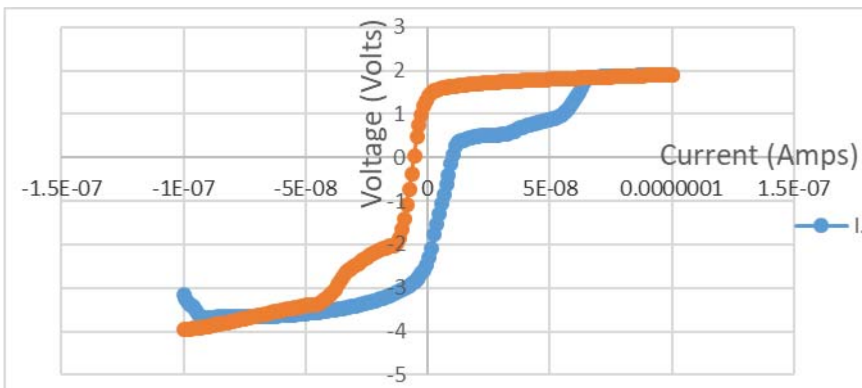
References:

[1] J. Hong, et al., "Energy-efficient spin-transfer-torque based sub-10-nm magnetic tunneling junctions," *J. Nanoparticle Research* 15 (4), pp. 1599-1603, (2013).

[2] N.M. Caffrey, et al., "Spin-filtering efficiency of ferrimagnetic spinels $CoFe_2O_4$ and $NiFe_2O_4$," Phys. Rev. B 87, 024419, 2013.



(a)



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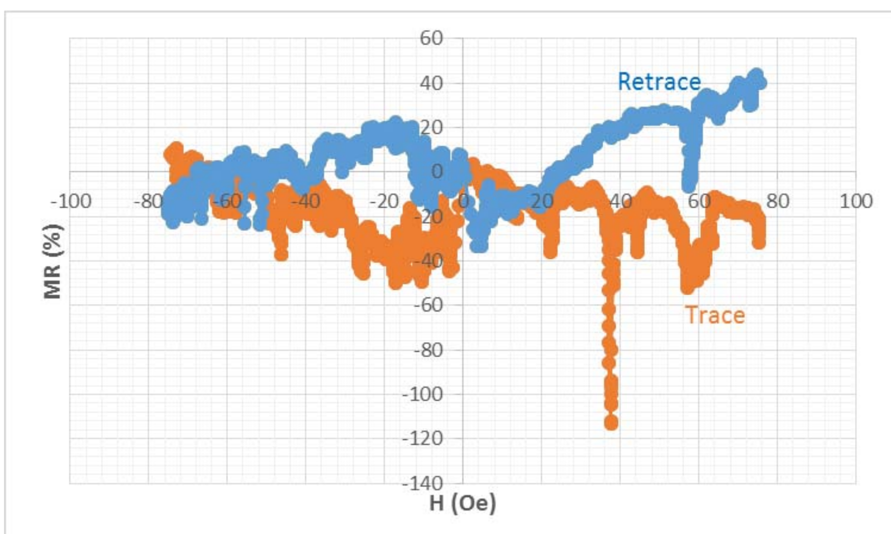
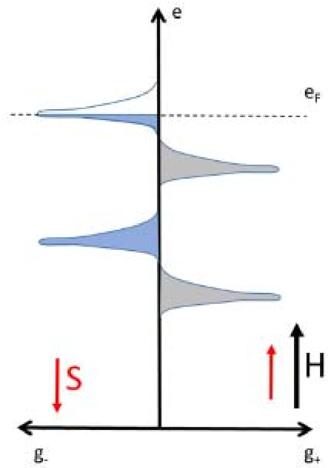


(c)



(d)

Figure 1. (a) an illustration of the nanoparticle MTJ; (b) a typical I-V curve. (c) a typical MR dependence. (d) Illustration of the field-dependent Fermi energy theory.