Researchers Succeed in Inducing Ferromagnetism in High-k Dielectric Materials (Update)

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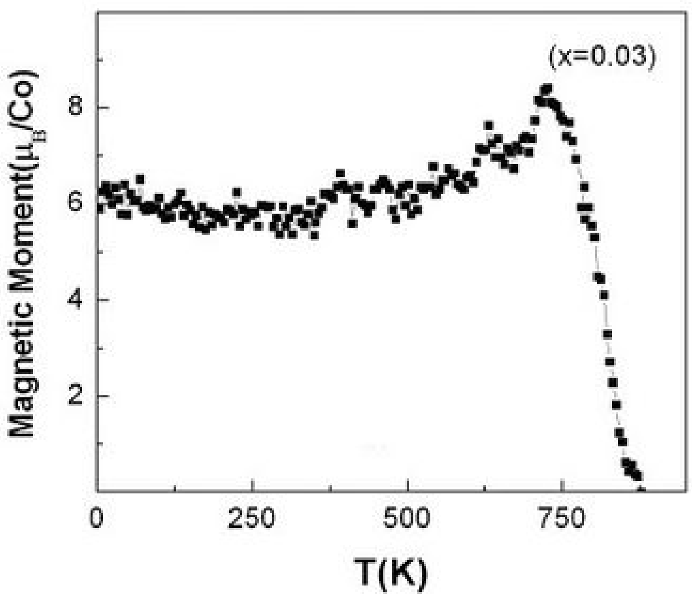

Magnetization as a function of temperature for epitaxial $Ce_{0.97}Co_{0.03}O_{2-d}$ film grown on $LaAlO_3$(001) substrate. Credit: NMRL, University of Utah, [A. Tiwari et al., Applied Physics Letters 88, 142511-1, 2006]

A multidisciplinary team of researchers led by Ashutosh Tiwari of Nanostructured Materials Research Laboratory (NMRL) of University of Utah has succeeded in inducing high temperature ferromagnetism in highly insulting epitaxial CeO_2 films by dilute doping of cobalt. These films are transparent in the visible regime and exhibit a very high Curie temperature ~875K with a giant magnetic moment. It has been shown that the ferromagnetic property is intrinsic to the CeO_2 system and is not a result of any secondary magnetic phase or cluster formation. Observation of high temperature ferromagnetism in lightly doped high-k dielectric materials with giant magnetic moment and such a high transition temperature is remarkable and represents a groundbreaking step in Spintronics.

Advances in the present-day microelectronics and magnetic data storage devices depend critically on the technological ability to produce device structures of ever-decreasing dimensions. With the typical device dimensions approaching nanometer scale and the materials design parameters getting pushed to their most optimum values, the continued miniaturization is becoming increasingly challenging.

There is now a general consensus that, the current rate of miniaturization can not be sustained and new approaches of device fabrication need to be developed. A new approach based on the synergetic use of charge and spin dynamics of electrons of multifunctional materials, termed as “Spintronics”, has recently emerged.

Spintronics has the potential to facilitate devices, which can store as well as process the information simultaneously thereby enormously enhancing the data processing time as well as the storage capacity of present-day devices. The most critical step in the functioning of a spintronic device is the injection and detection of spin-polarized carriers at the ferromagnet-semiconductor interface. Despite considerable efforts, efficient injection of spins into nonmagnetic semiconductors still continues to be a major hurdle in this field.

Ferromagnetic metals (such as Fe, Ni etc) which were conventionally used for injecting spin polarized carriers in semiconducting transport medium, result in very low degree of spin polarization of injected carriers which is not sufficient for reliable device operation in most of the applications. Lately it has been proposed that much higher degree of spin polarization of injected carriers can be achieved by the tunneling of non-polarized carriers through ferromagnetic insulator, which acts as a spin filter. But unfortunately, because of the lack of suitable room temperature ferromagnetic insulators, not much progress could yet be made in this field.

Now a multidisciplinary team of researchers led by Ashutosh Tiwari of Nanostructured Materials Research Laboratory (NMRL) of University of Utah has succeeded in inducing high temperature ferromagnetism in highly insulting dielectric films by dilute doping of cobalt.

As reported in April 6 issue of *Applied Physics Letters*, high temperature ferromagnetism has been observed in single crystal $Ce_{1-x}Co_xO_{2-\delta}$ films deposited on $LaAlO_3$ substrates by pulsed laser assisted deposition technique. These films are transparent in the visible regime and exhibit a very high Curie temperature with a giant magnetic moment. Specifically, it has been shown that 3% Cobalt doped $Ce_{1-x}Co_xO_{2-\delta}$ films retains their ferromagnetism even till 875K.

Magnetization of these films at 5 K is 6.1 μB/Co atom which remains quite constant upto about 500K. Above this temperature it starts increasing and attains a maximum value of 8.2 μB/Co atom at around 725 K. Beyond this temperature the magnetzation drops monotonically showing a Curie temperature at around 875K. Researchers mention that, this is the maximum moment of Cobalt ever observed in any oxide system. High resolution transmission electron microscopy investigations showed that these films are single phase without the presence of any kind of clustering pointing toward the intrinsic origin of the observed ferromagnetism.

As a result of detailed quantitative analysis of magnetic data, researchers showed that in these films Co ions exist in high spin state with unquenched orbital magnetic moment. They further demonstrated that apart from Cobalt ions, a significant contribution to magnetization also arises from CeO_2 matrix, which gets magnetically polarized. An F-center mediated exchange mechanism has been proposed to explain the observed magnetic behavior of the system.

Discovery of high temperature ferromagnetism in dielectric films pave the way for the realization of novel spin filters to be used in actual spintronic devices. Furthermore, since CeO_2 is a face centered cubic system possessing a fluorite crystal structure with closely matched lattice parameters as of Silicon, it has potential to facilitate the integration of next generation spintronic devices with current silicon based microelectronic devices.

Observation of high temperature ferromagnetism in lightly doped high-k dielectric materials with giant magnetic moment and such a high transition temperature is remarkable and represents a groundbreaking step in Spintronics.

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