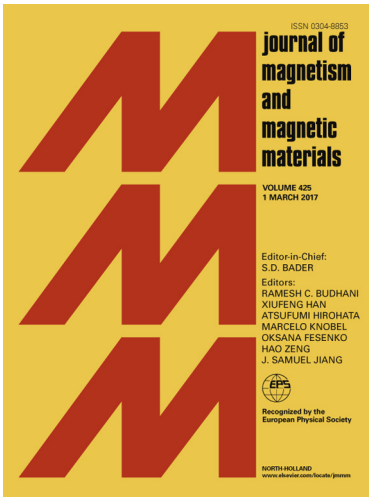

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PII: S0304-8853(17)33671-5
DOI: https://doi.org/10.1016/j.jmmm.2018.05.070
Reference: MAGMA 63982

To appear in: *Journal of Magnetism and Magnetic Materials*

Please cite this article as: S.R. Joshi, B. Padmanabhan, A. Chanda, N. Shukla, V.K. Malik, D. Kanjilal, S. Varma, Anisotropic super-paramagnetism in cobalt implanted rutile-TiO_2 single crystals, *Journal of Magnetism and Magnetic Materials* (2018), doi: https://doi.org/10.1016/j.jmmm.2018.05.070

Anisotropic super-paramagnetism in cobalt implanted rutile-TiO_2 single crystals

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(Dated: April 20, 2018)

The present study investigates the magnetic properties of single crystal rutile TiO_2 (110) implanted with cobalt ions for fluences between 5×10^{16} to 1×10^{17} ions/cm^2 with energy of 200 KeV. The temperature and field dependent magnetization for magnetic fields along [001] and $[1\bar{1}0]$ directions of the as implanted TiO_2 crystals show anisotropic super-paramagnetic behaviour due to formation of Co (hcp) nano-clusters unlike the complete ferromagnetic behaviour from previous reports. The ZFC and FC magnetization curves show a much higher blocking temperature (T_B) along $[1\bar{1}0]$ with values ranging from 30 to 150 K, while for field along (001) shows a lower T_B ranging from 8 to 70 K. The magnetization isotherms above T_B show a sharper rise and universal scaling behaviour, for field along $[1\bar{1}0]$ direction. At 2 K, M - H curves show hysteresis behaviour similar of easy and hard axis of a ferromagnet. The magnetic anisotropy of Co nano clusters are coupled by the magneto crystalline anisotropy of secondary phases of cobalt with TiO_2, thus indicating the highly oriented nature of the Co clusters. Role of dipole interactions and inter cluster exchange interactions have also been discussed.

I. INTRODUCTION

The study of magnetism in nano-particles has gained enormous interest in last two decades from technological as well as fundamental perspectives[1]. In nanoscale systems, magnetic nature can be drastically different, compared to bulk, since surface effects play crucial role. Thus diverse properties such as ferromagnetism, anti-ferromagnetism, super-paramagnetism (SPM) or spin-glass(SG) like behavior are observed[1–4]. Among these, SPM is a property that crucially depends on the size of the nano-particle and shows a giant paramagnetic moment proportional to the particle volume[3]. The SPM nano-particles are non-interacting, except for a weak dipole interaction and are randomly oriented in absence of external magnetic field. Due to this, the individual SPM cluster has a unique uniaxial anisotropic direction.

As the system is cooled through the SPM state, there comes a characteristic temperature called the blocking temperature (T_B). Above T_B, the magnetic moment of the individual SPM particle is oriented randomly like a normal paramagnet, which can rotate freely under the influence of external field. Below T_B, the individual SPM particle has its magnetic moment blocked along its respective easy anisotropy axis. The blocking temperature is prominently seen as a peak in Zero Field Cooled (ZFC) magnetization. Associated with this temperature is an energy