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Emergent nanoscale superparamagnetism at oxide interfaces

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Atomically sharp oxide heterostructures exhibit a range of novel physical phenomena that do not occur in the parent bulk compounds. The most prominent example is the appearance of highly conducting and superconducting states at the interface between the band insulators $LaAlO_3$ and $SrTiO_3$. We present a new emergent phenomenon at the $LaMnO_3/SrTiO_3$ interface in which an antiferromagnetic insulator abruptly transforms into a superparamagnetic state. Above a critical thickness of $LaMnO_3$ of five unit cells, our scanning nanoSQUID-on-tip microscopy [1] shows spontaneous formation of isolated magnetic islands with in-plane moment of 10^4 to 10^5 μ_B with characteristic diameter of 10 to 50 nm [2]. The nanoscale islands display superparamagnetic dynamics of random moment reversals by thermal activation or in response to an in-plane magnetic field [1]. We propose a charge reconstruction model of the polar $LaMnO_3/SrTiO_3$ heterostructure which describes a sharp emergence of thermodynamic phase separation leading to nucleation of metallic ferromagnetic islands in an insulating antiferromagnetic matrix. The model suggests that a gate tunable superparamagnetic-ferromagnetic transition can be induced, holding potential for applications in magnetic storage and spintronics. [1] D. Vasyukov et al., Nature Nanotechnology 8, 639 (2013). [2] Y. Anahory, L. Embon, C. J. Li, S. Banerjee, A. Meltzer, H. R. Naren, A. Yakovenko, J. Cuppens, Y. Myasoedov, M. L. Rappaport, M. E. Huber, K. Michaeli, T. Venkatesan, and E. Zeldov, arXiv:1509.01895