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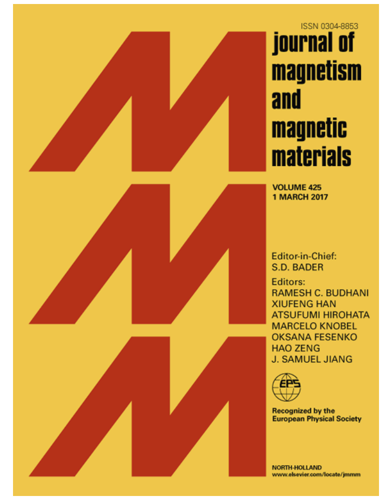

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On the evolution of antiferromagnetic nanodomains in NiO thin films: A LEEM study

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Abstract: Fractional order (1/2, 0) spots appear in the electron diffraction from NiO/Ag(001) films due to exchange scattering of low energy electrons by the antiferromagnetically ordered surface Ni moments. Utilizing these beams, imaging of the nanosized surface magnetic domains were carried out employing the high spatial resolution (∼10 nm) of the Low Energy Electron Microscopy (LEEM) in the dark-field (DF) mode. While selected through a contrast aperture, the four magnetic reflections produced by the $p(2 \times 2)$ antiferromagnetic sub-lattice lead to the visualization of the different magnetic twin domains. The intensity variations of different twin domains were measured as a function of electron beam energies *via* domain resolved LEEM I-V plots. The surface Né́el temperatures (T_N) of the films were measured using the temperature dependence of these half-order spot intensities. Detailed morphological studies of the size and shape of these nanodomains and their evolution as a function of the film thickness have been carried out with the help of pair-correlation function and fractal analysis. The size, shape and distribution of these magnetic domains are modified significantly by the strain relaxation mechanism beyond the critical film thickness. A method to estimate the relative domain sizes from a quantitative measure of the half-order spot intensities is manifested well below T_N.

keywords: Surface antiferromagnetism, Metal-Oxide film, Low energy electron diffraction, Low energy electron microscopy.

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I. INTRODUCTION

The magnetically compensated nature impedes most of the magnetic microscopies on antiferromagnetic materials, particularly at their reduced dimension where the magnetic domain length-scales are limited by the physical grain boundaries. Due to lack of laboratory-based high-resolution microscopic tools, studies on the surface, as well as thin film antiferromagnetism are still rare compared to ferromagnetic materials. However, studying the antiferromagnetism of lower dimensional systems are becoming important since last century due to their technological applications, e.g. magneto-electronics (MRAMs), ultrahigh density magnetic and magneto-optic recording media or GMR (Giant Magneto Resistance) based readout heads *etc*[1,2]. Therefore, attempts to explore new microscopic techniques for probing the surface antiferromagnetism are persistent since last few decades.

Among few available techniques, neutron diffraction[3–5], with its limited lateral resolution, is probably the oldest one to probe antiferromagnetic order. On the other hand, with the advancement in scientific research modern technology has developed magnetic exchange force microscopy[6] which has demonstrated its ability to image antiferromagnetism as well as non-collinear magnetism at the atomic scale. The spin-polarized scanning tunneling microscopy (SP-STM)[7] can be mentioned as an example of another laboratory-based approach towards surface antiferromagnetism. With the advent of synchrotron facilities, x-ray magnetic linear dichroism based photoemission electron microscopy (XMLD-PEEM)[8–11] became the most useful technique for antiferromagnetic domain imaging. This technique is widely accepted due to its element specificity, magnetic spin-axis sensitivity and responsiveness to surfaces. With a good spatial resolution (< 30 nm), this technique is useful in case of bulk samples where the domain sizes are of micron orders[12–15]. However, in the case of thin film systems, where domains have length scale of the order of few nanometers, the limitations of XMLD-PEEM to image them becomes apparent. In this context, the efficiency of low-energy electron microscopy (LEEM) as a useful laboratory based tool for imaging surface antiferromagnetic domain structure has already been reported in our earlier studies[16,17]. The low energy electrons, endowed with ultra surface sensitivity, probe the surface antiferromagnetism of bulk NiO(001) single crystal as well as NiO films of various thicknesses. The LEEM data obtained from the samples have been directly compared to the results of XMLD-PEEM performed at the same sample region and efficiencies of these two techniques have already been compared.

Due to unavailability of suitable high-resolution microscopic techniques, studies on reduced dimensional antiferromagnetic systems reamined almost overlooked. In fact, there are not many reports regarding the evolution of antiferromagnetic domains in ultrathin films and their growth with film thickness. In this article, we focus on statistical image analysis of the antiferromagnetic surface nanodomains of NiO/Ag(001) films of various thicknesses probed by the dark-field LEEM. The existence of four magnetic twin (T) domains, their growth and evolution with increasing film thickness and their response to incident electron energy will be discussed in this report. The relative growth of domain size with film thickness