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LETTER TO THE EDITOR

First-order magnetic phase transition in quasi-bulk Gd(0001)

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Abstract. The UHV-compatible AC initial magnetic susceptibility [$\chi^{AC} \equiv \chi(\omega = \text{constant}, T)$] technique is used to study (with nanometer resolution) the magnetic behaviour of Gd(0001)/W(110) thin films. The abruptness of the drop in χ^{AC} within 4 K above the Hopkinson maximum is interpreted as indicating the presence of a first-order magnetic phase transition.

Some years ago, Mills [1] predicted the phenomenon of surface enhanced magnetic order (SEMO), i.e. the coexistence of an ordered surface with a disordered bulk, provided the exchange in the surface is 'stiffened' enough with respect to that in the bulk. This interesting effect has been observed in two of the 4f rare-earth metals: gadolinium [2, 3] and terbium [4].

Quite recently, Kaneyoshi [5, 6] has reviewed this topic in detail. In order to detect SEMO, two experimental techniques have in the main been used: electron capture spectroscopy (ECS) and spin-polarized low-energy electron diffraction (SPLEED).

With regard to the nature of the magnetic surface phase transitions, Sanchez and Morán-López [7] recently foresaw that the (111) surface of an FCC spin $\frac{1}{2}$ Ising ferromagnet undergoes a first-order phase transition and pointed out that their findings could also be appropriate to the case of an HCP (0001) surface because of the geometrical resemblance of these two surfaces. This prediction has experimentally been confirmed by Weller and Alvarado [8], who showed that the magnetic-exchange scattering asymmetry (A_{ex}) of the surface of a semi-infinite Gd(0001) system abruptly falls off to zero in a narrow temperature range (2–3 K).

In this letter we present experimental results indicating the magnetic phase transition of Gd(0001) thin films (some nanometres thick) to be first order. In figure 1 the AC magnetic susceptibility of a 12 nm thick Gd(0001) film is shown as a function of temperature. This film thickness (about 42 atomic layers) is easily resolved by the recently developed UHV-compatible AC initial magnetic susceptibility [$\chi^{AC} \equiv \chi(\omega = \text{constant}, T)$] technique [9, 10]. The sample preparation and the experimental setup are described elsewhere [9].

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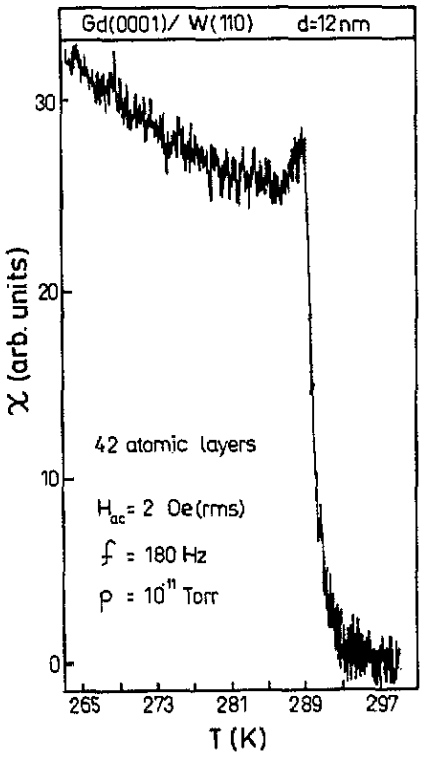

Figure 1. AC magnetic susceptibility of quasi-bulk Gd(0001) as a function of temperature. This spectrum was recorded *in situ* in UHV while cooling down the sample. The driving field was applied *ex situ* in the basal plane.

It can be seen from figure 1 that the Gd signal, above the Hopkinson maximum [11], drops off abruptly within 4 K. Thus quasi-bulk Gd(0001) *clearly retains the first-order character* of the phase transition which characterizes the Gd(0001) surface. Therefore, in the range of low magnetic fields, where spurious effects (e.g. forced magnetization) caused by high applied fields may be ruled out, the critical behaviour of χ^{AC} in epitaxial Gd(0001) thin films can be studied only in a restricted temperature range (not even over one full decade in reduced temperature) as the Curie point is approached from above ($T \rightarrow T_c^+$) [12]. We would like to point out that Kaneyoshi [6] has interpreted the A_{ex} versus T curve [8] of Gd(0001) as evidence of surface tricritical behaviour. In connection with this, our results might also confirm the occurrence of tricritical behaviour in quasi-bulk Gd(0001) films [13].

Finally, it should be stressed here that the *ex situ* pickup coil [9] used in this experiment, *probes the whole volume* of the Gd(0001) thin film. The susceptibility measurement provides information about the average properties of the sample but does not provide information about the vicinity of the surface [14]. For this reason we did not observe any SEMO at all. In this sense, the χ^{AC} results are complementary to those of ECS and SPLEED.

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