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Retrieval of depth profile of nano-scale thin films by one directional polarization analysis in neutron specular reflectometry

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ABSTRACT

Recently it has been shown that the modulus and phase of complex reflection coefficient can be determined using a magnetic substrate and polarized neutrons. Several other methods have also been worked out based on the measurement of polarizations of reflected neutrons from magnetic reference layers and magnetic substrate. However, due to the fact that available reflectometers are limited in the choice of polarization of reflected beam in the same direction as the polarization of the incident beam, neither of the methods, which are based on polarization analysis, have been proven to be experimentally practical. In this paper, we have proposed a new method for determining the phase of reflection coefficient that is based on two measurements of polarization, which correspond to two magnetic fields with the same magnitude and different orientations. The polarization analysis is performed in the same direction as the polarization of the incident beam and is well suited for available reflectometers.The problems envisaged in implementation of the method are also discussed.

1. Introduction

Measurement of intensity of neutrons reflected elastically and specularly from thin films, as a function of the glancing angle of incidence, provides us with useful information about the depth profile of the sample [1]. However, extracting the profile from the measured reflectivity, $|r(q)|^2$, as a function of wave vector q is difficult and no direct inversion scheme is possible in the absence of the full knowledge of reflection coefficient, $r(q)$ (modulus and phase) [1,2]. Due to the importance of phase information to the study of thin films structure, finding a practical solution to this so-called phase problem is of great interest. Recently, several experimental and theoretical efforts have been devoted to finding the phase [2–14], among which the reference method and variation of surroundings are of highest applicability. The reference layer method is based on the interference between the reflections of a known reference layer and the unknown surface profile [3,4], and the method of variation of surroundings medium makes use of the controlled variations of scattering length density of the incident and/or substrate medium instead of reference layers of finite thickness [5,6]. Although these methods are highly promising, only the method of variation of substrates has been experimentally proven to be practical [5]. Obviously, changing the surrounding medium is the most challenging part of the experiment. Majkrzak et al. [5] and Majkrzak and Berk [6] proposed using a gas–liquid or solid–liquid interface and extracted the phase information using H_2O and D_2O as substrate.

At present, several other promising methods have also been worked out that make use of the spin-dependent interaction of a neutron with a magnetic reference layer [7–10] or magnetic substrate [11,12]. In a more recent research, Leeb et al. [8] have developed the reference method using polarization of the reflected neutron and left and right reflection coefficients of the reference layer as known parameters. Correspondingly, we have developed Leeb's method of magnetic reference layer with polarization analysis in a straightforward manner by proposing a change in the placement of the known and unknown layers [9,10]. We have also developed the method of variation of surroundings, using a magnetic substrate and polarization analysis [11,12].

In those methods, which are based on polarization analysis, generally we have to measure the polarization of the reflected neutrons in different directions than the polarization direction of incident neutrons; besides the fact that more than one measurement of polarization is required. However, available reflectometers are limited to measurement of polarization of reflected neutrons in the same direction as the polarization direction of incident neutrons.

Recently, Leeb et al. [13] have worked out a method in which they considered this limitation by polarization analysis in two different directions. The problem is solved by changing the coordinate's direction by rotating the sample and measuring the polarization for

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