Письма в ЖЭТФ, том 58, вып.4, стр.251 - 255

NUCLEAR MULTILAYER STRUCTURE WITH ANTIREFLECTING COATING

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Submitted 2 July 1993

A combined application of resonant Bragg diffraction by nuclear multilayer structure and specular antireflection by coating film to provide a beam of synchrotron radiation with super narrow $\Delta E/E = 10^{-11}$ bandwidth is studied. A proposed structure includes two antireflecting films above and below the nuclear multilayer. Computer simulation shows the possibility to reach a high nuclear reflectivity with a suppression of electronic scattering down to $4 \cdot 10^{-7}$ at the angular position of nuclear Bragg reflection.

Excitation of nuclear ensemble by synchrotron radiation can serve perfectly for generation of coherent monochromatic x-radiation [1]. Since recently synthetic nuclear resonant multilayer structures are employed for these purposes [2,3]. A very big enhancement of radiative channel [4] is achieved in nuclear resonant Bragg scattering of synchrotron radiation by nuclear multilayer. It yields a large broadening of the resonance and a speedup [5] of nuclear de-excitation. In the ^{57}Fe/Sc multilayer for instance, the width of nuclear γ-resonance can be enlarged up to 40 Γ_0 [3] ($\Gamma = 4,7 \cdot 10^{-9}$ eV is the natural width of 14,413 keV ^{57}Fe nucleus level) and effective life time of the excited state can be decreased correspondingly down to ~ 4 ns (compared to 141 ns, the natural life time of ^{57}Fe first isomer state) [6].

The coherent γ-radiation emitted by nuclear multilayer can be especially useful in application to time domain hyperfine spectroscopy [7]. It can be used as a source radiation exciting during a short time all nuclear transitions between the different sublevels of the ground and the excited states in the studied sample. It gives the possibility to observe the subsequent evolution of the coherent nuclear fluorescence of the sample where quantum beats between the excited transitions should be revealed [8]. An advantage of nuclear multilayer application for these experiments comes up because nuclear reflectivity of multilayer exceeds essentially the electronic reflectivity. Thus an energy bandpass of nuclear multilayer is comparable with the energy of nuclear hyperfine interaction, with a negligible contribution of electronic scattering beyond resonant range. The suppression of electronic scattering is a necessary condition in case of synchrotron radiation sources of the third generation, which provide very high spectral density of radiation. In the energy band of 1 μev one can expect the x-radiation flux of about 10^7 quanta/s. For the modern fast counters of x-radiation it is the highest limit of operation. The object of the present paper is the studies of optimal conditions for suppression of the electronic scattering in a nuclear resonant multilayer.

A nuclear multilayer presents a synthetic regular structure where electronic and nuclear resonant density have different periodicity. By this reason Bragg diffraction of radiation by nuclei and electrons occurs at different angles. Since the space arrangement of multilayer is usually characterized by a large period,

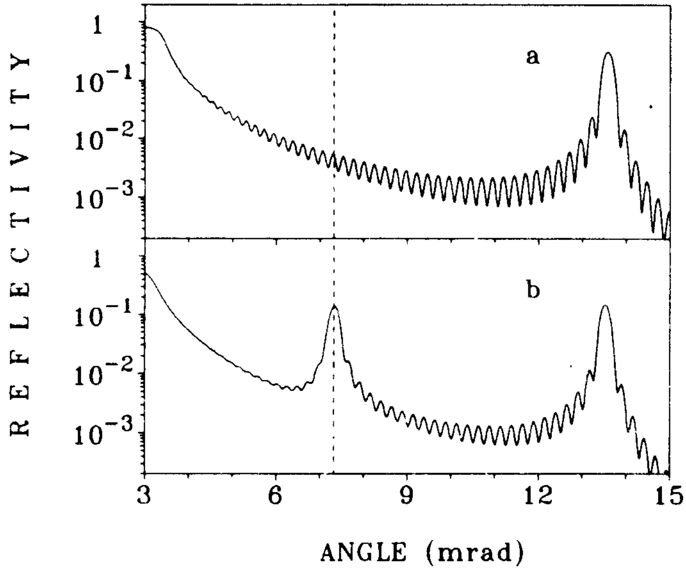

Fig.1. Computer simulated angular dependencies of (a) non-resonant electronic and (b) resonant nuclear scattering by the [^{57}Fe(22Å)/Sc(11Å)/Fe(22Å)/Sc(11Å)]·25/glass (NML/glass) nuclear multilayer without antireflecting coating. Dashed line shows an angular position of nuclear Bragg reflection

Bragg diffraction occurs rather close to the forward direction, not far from the range of the grazing incidence specular reflection. Therefore specular scattering from the boundaries (upper and lower ones) of a multilayer still gives weak contribution to the coherent signal. Due to this contribution one can observe the Fresnel interference pattern in the angular dependence of scattering. The idea of suppression of electronic scattering is designing such a structure of coating to provide effective destructive interference in the electronic coherent scattering at the angular position of nuclear Bragg diffraction.

Fresnel interference on interfaces is widely used in conventional optic. It was applied [9-11] to suppress x-rays scattering by GIAR (grazing incidence antireflecting) films. However the obtained decrease of electronic scattering by a factor of about 25 is rather small as compared to the demanded value (about 10^{-6}). As it is shown below, strong suppression of electronic scattering can be achieved on the way of combined usage of pure nuclear x-ray diffraction and Fresnel interference; in other words, with antireflecting nuclear multilayer.

The analysis of antireflecting nuclear multilayer was accomplished by computer simulation of angular and energy spectra of the γ-ray scattering. As a base for the present studies the previously investigated [^{57}Fe(22Å)/Sc(11Å)/Fe(22Å)/Sc(11Å)]·25/glass nuclear multilayer was taken (further denoted as NML/glass). Actual parameters of layers quality such as interface roughness and inhomogeneity of layer thickness were taken those achieved from the fit of the experimental data obtained with the mentioned nuclear multilayer [3,6]. Mean roughness was taken to be 4Å. Influence of thickness inhomogeneity of about 1% was considered as a convolution of angular dependencies with 15 arc sec Gauss distribution (FWHM). An impedance-match solution of the antireflecting

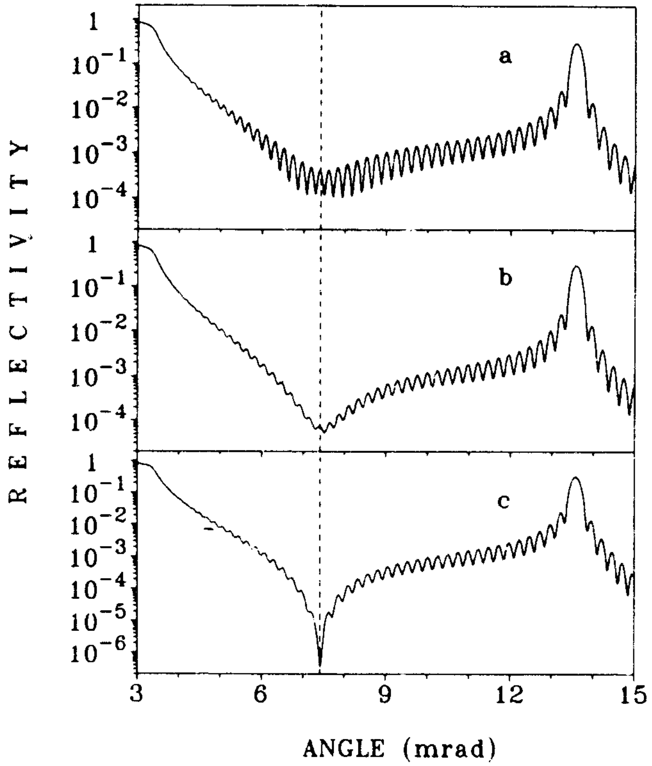

Fig.2. Computer simulated angular dependencies of electronic scattering by the (*a*) Ti(40Å)/ /NML/glass, (*b*) Ti(40Å)/NML/Te(20Å)/glass, and (*c*) Ti(18Å)/B(14Å)/NML/Te(20Å)/glass antireflecting nuclear multilayers. Dashed line shows an angular position of nuclear Bragg reflection

films theory [9] was analyzed. Namely we were looking for the antireflecting film of proper impedance that the waves scattered by the top and bottom interfaces of the film to the direction of pure nuclear reflection would have the equal amplitudes but were shifted in phase by 180°.

Fig.1(a, b) shows rocking curves of the nuclear multilayer without antireflecting film for the radiation (a) off and (b) on resonance with nuclear levels. An electronic reflectivity of non-resonant radiation at the angular position of nuclear Bragg reflection is about $5 \cdot 10^{-3}$ [12]. The oscillations of reflectivity resulting from the Fresnel interference are seen in both rocking curves.

An insertion of a Ti(40Å) antireflecting layer above the nuclear multilayer results in an attenuation of the wave, scattered by the top boundary of a sample: a broad minimum of electronic scattering occurs at the nuclear Bragg angle, electronic reflectivity decreases down to $2 \cdot 10^{-4}$ (Fig2a). However the suppression of scattering from the top boundary results in a strong increase of reflectivity oscillation, because now the waves, scattered by the two boundaries of the nuclear multilayer have close amplitudes. An increase of these beats should be regarded as a disadvantage because of a high probability of detector overloading due to minor shift of angular position of multilayer. An obvious solution is to employ another antireflecting layer below the nuclear structure to suppress the reflection from the bottom boundary as well. An insertion of a Te(20Å) antireflecting layer

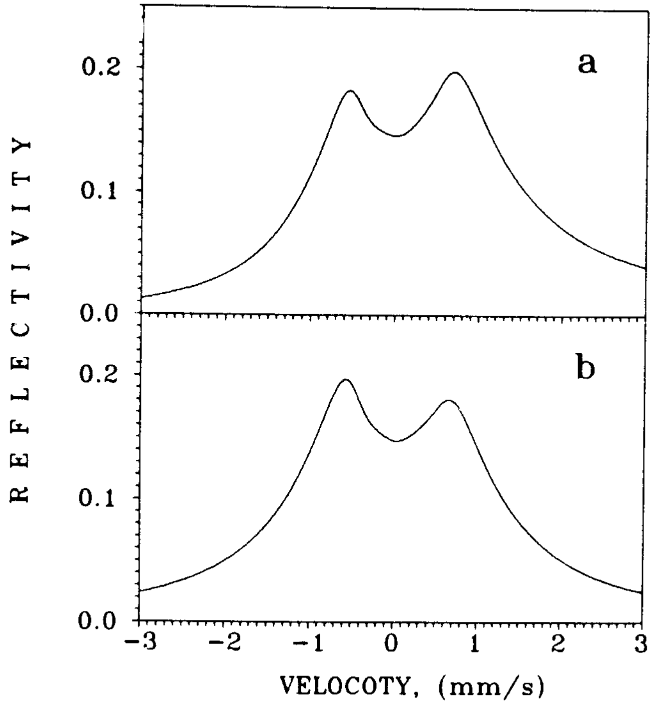

Fig.3. Moessbauer spectra of nuclear diffraction by (*a*) NML/glass and (*b*) Ti(18Å)/B(14Å)/ /NML/Te(20Å)/glass multilayers

between nuclear structure and glass substrate smooths the angular curve at the nuclear Bragg position and decreases electron reflectivity further to a value of about $5 \cdot 10^{-5}$ due to the suppression of scattering from the bottom boundary as well (Fig.2*b*). Thus the antireflecting Ti(40Å)/NML/Te(20Å)/glass multilayer results in a reduction of non-resonant scattering of about 2 orders of magnitude as compared with nuclear multilayer without antireflecting films.

In order to obtain a stronger reduction of electronic scattering one need to use an antireflecting film of more complex structure [9]. This is especially important for the top antireflecting layer, suppressing the main contribution of specular scattering. The optimal solution for this film was found to be the Ti(18Å)/B(14Å) bylayer. Fig.2*c* shows the electronic reflectivity of the Ti(18Å)/B(14Å)/NML/Te(20Å)/glass structure to be about $4 \cdot 10^{-7}$ at the angular position of nuclear Bragg reflection. It should be stressed, that this value was calculated with due account of the mentioned roughness and layer inhomogeneity parameters, which were proved to be available in practice.

An important question is how does an addition of the antireflecting films affect the resonant reflectivity of nuclear multilayer. Fig.3 shows, that a Moessbauer spectrum of nuclear diffraction is a little bit influenced, but neither mean nuclear reflectivity, nor energy bandpass has significant changes. The reason is that in the entire resonant range of energy a nuclear contribution into a refractive index is sufficiently large to destroy the impedance-match solution and prevent the reduction of nuclear reflectivity. Photoabsorption in the top antireflecting film is also of minor importance for the proposed multilayer.

Thus an application of antireflecting technique is predicted to be very promising for the suppression of electronic scattering by nuclear multilayer. The combination of antireflecting films and a nuclear multilayer seems to be much more easy in practice as compared with GIAR films due to the larger angle of scattering for nuclear multilayer. Hence angular extension of the antireflecting minima at rocking curves is also larger, and are not so sensitive to the multilayer quality. An optimal level of non-resonant electronic scattering of about 10^{-6} seems to be possible for this approach, while the parameters of nuclear resonant reflectivity are not affected by an introducing the antireflecting layers.

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12. Measured in the experiment [4] lower value of about $1 \cdot 10^{-3}$ seemed to be caused by the lower electron density of sputtered materials in the multilayer as compared with nominal values, used in the simulation.