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OBSERVATION OF RESONANCE ENHANCED NEUTRON STANDING WAVES USING CHARGED PARTICLE EMISSION AFTER NEUTRON CAPTURE

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Introduction

Neutron standing waves were first detected in 1956 [1]. Authors [2-9] conducted a series of experiments to investigate the specific features of such neutron wave field. Later, in [10] it was suggested to use X-ray standing waves to characterize the structure of crystals. At present, neutron standing waves are an every-day tool in investigations of crystals and layered structures. In the recent time, in connection with an increased demand for the characterization of magnetic and nuclear structures the development of methods of excitation of the neutron wave field mode in layered structures has become the subject of great interest [11-13].

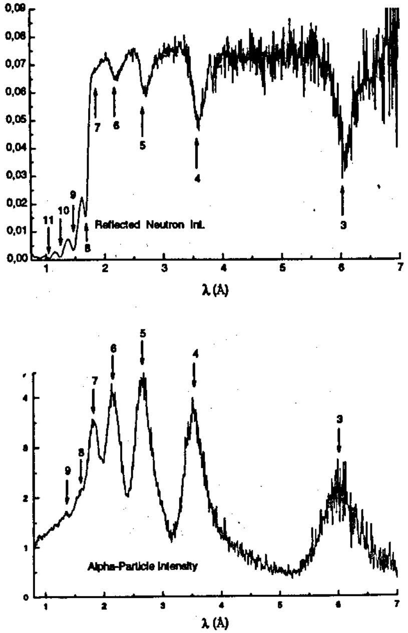
The investigated layered structure Cu/Ti/^{6}LiF has an optical nuclear potential of interaction where the potentials of Cu and ^{6}LiF are the barriers which, together with the negative potential of titanium, form a potential well. Under stationary irradiation with neutrons a periodic spatial distribution of neutron density is created in the titanium layer of the structures due to coherent summation of neutron waves with different reflection multiplicities from potential barriers. The absolute value of the neutron density is determined by the parameters of the potential well and it may largely exceed the density of the incident beam. The neutron wave field whose neutron density exceeds four initial neutron densities is called enhanced neutron standing waves (the ratio of the maximum neutron density in some area of space to the incident neutron density is called the initial density enhancement factor M_i ; the initial density enhancement factor divided by four is called the standing wave enhancement factor M_s). The standing wave enhancement mode is extremely sensitive to changes in the parameters of the layered structure, the extent of neutron beam monochromatization and collimation. The increase of the neutron density is limited due to different neutron absorption processes.

To characterize the constituent nuclei of a layered structure, different types of radiation following neutron capture in nuclei are used. Among the main of them are gamma-radiation, alpha-radiation, protons and nuclear fission fragments. In the reported investigation the ^{6}Li (n,α) ^{3}He reaction was used to observe neutron standing waves. Alpha-particles and tritons, the products of the reaction, were registered using an ionization chamber with a low background count level in the presence of gamma-radiation in the IBR-2 experimental hall.

Experimental equipment

The measurements were conducted on the spectrometer of polarized neutrons at the IBR-2 pulsed reactor. At the exit of the polarizer the neutron beam is formed by a diaphragm 0.2mm×40mm. The sample is at 3m from the diaphragm. The sample is a multilayer structure Cu(1000Å)/Ti(2000Å)/^{6}LiF(200Å) thermally sputtered on a glass substrate of the size 5mm×90mm×150mm(along the beam). To register alpha-particles and tritons emitted after neutron capture in ^{6}Li nuclei, the sample is placed into an ionization chamber with a grid. The Cu layer of the sample plays the role of the cathode with the applied voltage –3kV. The working gas in the chamber is argon with a 4% admixture of carbon oxide under the pressure 1.1 atm. The glancing angle of the incident neutron beam is 2.9 mrad. The reflected neutron beam is registered with a ^{3}He counter at a distance of 2.6 m from the sample. In front of the detector there is a 0.2mm cadmium diaphragm. Detection and data acquisition electronics in neutron and charged particle registration channels makes it possible to obtain spectra in relation to the time interval counted from the moment the neutron pulse arises in the moderator. The duration of the time channel is 64 mcsec.

Results and discussion



The Figure illustrates the wavelength dependence of the normalized neutron reflection intensities (the reflectometry curve is at the top) and the wavelength dependence of the emission intensity of charged particles (the emission curve is at the bottom) for the glancing angle 2.9 mrad. The reflectometry curve is obtained by the normalization of the reflected neutron flux to the incident neutron flux and the emission curve is obtained by the normalization of the charged-particle yield at the neutron glancing angle 2.9 mrad to the charged-particle yield at the glancing angle of the incident beam 30 mrad. For definite wavelengths, on the reflectometry curve there can be seen minimums (neutron absorption orders labelled with numbers 3÷11) and on the emission curve there are maximums (charged-particle emission orders labelled with numbers 3÷9). Charged particle emission orders correspond to neutron absorption orders. The absorption (emission) orders appear due to the fact that the standing wave antinode coincides with the ^{6}LiF layer. It can be seen that the width of peaks on the reflectometry curve is two times smaller than their width on the emission curve. This is because the measuring channels have different angular resolutions. The angular resolution in the reflectometry channel is $(\delta\theta/\theta)_R = 6\times10^{-3}$ and in the emission channel it is $(\delta\theta/\theta)_E = 1.6\times10^{-2}$. The maximum value of the enhancement factor in the titanium layer is larger than in the absorbing layer ^{6}LiF. For the angular resolution of the reflectometry channel the neutron density enhancement factor M_i in the ^{6}LiF layer is 4.9, 5.8, 5.6, 4.8, 4.8, 2.4, 1.8 for orders 3, 4, 5, 6, 7, 8, 9, respectively, and in the titanium layer it is 27.6, 18.5, 14.8, 11.2, 7.2, 2.5, 1.8, 1.6, 1.3 for orders 3, 4, 5, 6, 7, 8, 9, 10, 11, respectively. For the angular resolution of the emission channel the enhancement factor has smaller values.

In the estimation of the limiting capacity of the registration channel the important parameters are the effect count and the background count. In the charged-particle registration channel the effect count is determined by the yield of charged particles from the layer ^{6}LiF after the capture of neutrons from the neutron beam falling at the glancing angle. If the neutron beam has a mean square angular deviation of 40 mcrad, the glancing angle of the incident beam is 2.9 mrad and the sample size is 25mm(beam height on the sample)×150mm(along the beam) with the ^{6}LiF layer thickness 190Å, the effect count in the maximum at the wavelength 1.8Å is 0.8 (time channel)$^{-1}$sec^{-1}(incident neutron flux 1.3×10^3n/sec, beam cross section 0.11cm^2, initial neutron density enhancement factor 3).

The background count is determined by the particle yield from the ^{6}LiF layer induced by neutrons scattered on argon and it is 8.0×10^{-5} of the count caused by the effect. The minimum background count depends on the radiation situation (the beam is shut with a 2 mm cadmium sheet) and is 5×10^{-5} (time channel)$^{-1}$sec^{-1}. When the neutron flux through the chamber is less than 10^3 n/sec, the background count is determined by the radiation situation.

Conclusion

The conducted investigation has shown that neutron reflection experiments on the IBR-2 beams with an angular resolution of the order 5 mcrad (neutron flux on the sample is 100 n/sec) continue to provide sufficient measuring statistics. It is, therefore, possible to investigate the effect of standing waves in monocrystals as well as study layered structures with a neutron standing wave enhancement factor up to $M_s=100$. In this case, for a 1Å neutron absorbing layer the cross section of its constituent nuclei must be higher than 1 barn.

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Аксенов В.Л. и др. E3-98-383
Наблюдение резонансно-усиленных нейтронных стоячих волн
с помощью эмиссии заряженных частиц,
вызванной захватом нейтронов

Исследовано явление образования резонансно-усиленных стоячих нейтронных волн в структуре стекло/Cu (1000 Å)/Ti (2000 Å)/^{6}LiF (200 Å). При определенных значениях длины волны нейтронов наблюдено уменьшение интенсивности отраженных нейтронов и соответствующее увеличение эмиссии альфа-частиц и тритонов, вызванных захватом нейтронов ядрами ^{6}Li. Это свидетельствует об увеличении плотности нейтронов в слое ^{6}LiF при этих значениях длины волны и связано с наличием интерференции падающей нейтронной волны и волны, отраженной от слоя Cu. Экспериментальные данные и расчеты указывают на существование в слоях Ti и ^{6}LiF резонансно-усиленного нейтронного волнового поля.

Работа выполнена в Лаборатории нейтронной физики им. И.М.Франка ОИЯИ.

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Aksenov V.L. et al. E3-98-383
Observation of Resonance Enhanced Neutron Standing Waves
Using Charged Particle Emission after Neutron Capture

The effect of resonance enhancement of neutron standing waves in a structure glass/Cu (1000 Å)/Ti (2000 Å)/^{6}LiF (200 Å) is investigated. For particular neutron wavelengths there is observed a decrease in the intensity of the reflected neutrons and the corresponding increase in the emission of alpha-particles and tritons induced by neutron capture in ^{6}Li nuclei. It is the evidence of an increase in the neutron density of the ^{6}LiF layer for such wavelengths and is connected with the interference of the incident neutron wave and the neutron wave reflected from the Cu layer. The experimental and calculated data point to the existence of a resonance enhanced neutron wave field in the Ti and ^{6}LiF layers.

The investigation has been performed at the Frank Laboratory of Neutron Physics, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna, 1998