Multilayer interference structures made from strongly absorbing materials

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Multilayer interference structures based on strongly absorbing materials have been studied for the first time. The results show that these structures can be used to observe the "metallic" reflection of neutrons, to measure capture cross sections, and to observe resonant levels.

It was shown in Refs. 1 and 2 that the imaginary part of the nuclear potential (ImU) of the interaction of a neutron with strongly absorbing materials (Gd, Cd, Dy, etc.) leads to a significant change in the calculated neutron reflection coefficient R. The magnitude of the change is determined by the real part of the potential, ReU; by the ratio ImU/ReU; and by the component of the neutron velocity perpendicular to the surface of the material, $v_\perp$ (Ref. 2). Since the reflection is a reflection by a surface

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layer of thickness ~10–100 Å, a knowledge of the value of $\mathrm{Re}U$ in this layer is important in an experimental determination of R. The value of $\mathrm{Re}U$ in this layer may differ from the bulk value because of surface oxidation, the presence of impurities at the surface, and a density different from the bulk density. There is accordingly the question of whether the change in R can be observed and exploited.

This problem can be solved by producing a multilayer interference structure consisting of alternating layers of strongly and weakly absorbing materials. A structure of this sort forms a one-dimensional quasiperiodic potential in space. In the case of materials with[1] $\mathrm{Re}U_1 = \mathrm{Re}U_2$, the depth variation of the potential in the multilayer interference structure is determined entirely by $\mathrm{Im}U_1$ and $\mathrm{Im}U_2$. The interference of the neutron waves which are rereflected at the interfaces between layers results in a reflection from the multilayer interference structure of neutrons, with the value of $v_\perp$ determined by the Bragg condition, and to a coherent intensification of effects related to reflection from each layer. The reflection coefficient R is determined by the potential difference $|U_1 - U_2|$, by the number of pairs of layers (N), and by the period d. For strongly absorbing materials the relation $|\mathrm{Im}U \lesssim |\mathrm{Re}U|$ holds, so that $\mathrm{Im}U$ may strongly influence the value of R in multilayer interference structures. The existence of a reflection and its amplitude may serve as both proof of the presence of a reflection due to $\mathrm{Im}U$ and for estimating $\mathrm{Im}U$ and thus the neutron capture cross section. Figures 1 and 2 show results of calculations of the functional dependence $R(v_\perp)$ for multilayer interference structures consisting of the pairs of materials ^{113}Cd–^{62}Ni and ^{157}Gd–^{58}Ni and also for multilayer interference structures based on ^{157}Gd and ^{113}Cd with $\mathrm{Re}U_1 = \mathrm{Re}U_2$. These calculations made use of the method of recurrence relations proposed in Ref. 3. It was assumed that the thicknesses of the layers in the structure satisfy $d_1 = d_2 = d/2$ and that the capture cross section obeys the $1/v$ law $(\mathrm{Im}U = \mathrm{const})$. Figure 1 shows results for ^{113}Cd structures $(\mathrm{Re}U < 0)$. It can be seen from this figure that the reflection observed in this case is due essentially entirely to $\mathrm{Im}U(^{113}\mathrm{Cd})$. Its magnitude reaches ~15%. In the case of ^{157}Gd structures $(\mathrm{Re}U > 0;$

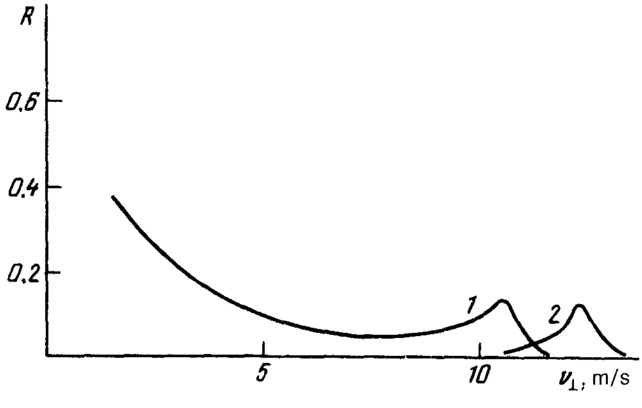

FIG. 1. $R(v_\perp)$ for ^{113}Cd–^{62}Ni ($d = 180$ Å, $N = 20$). Curve 2 incorporates only the imaginary part of the potential of the ^{113}Cd layers.

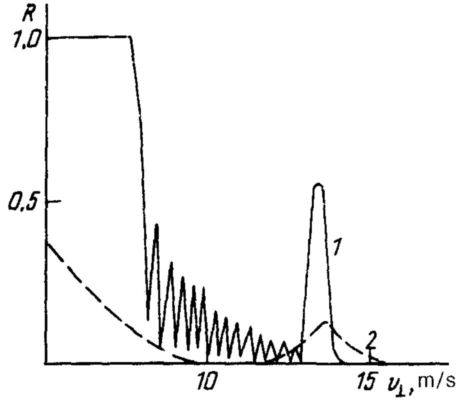

FIG. 2. $R(v_\perp)$ for ^{157}Gd–^{58}Ni multilayer interference structures ($d = 180$ Å, $N = 20$). Curve 1 ignores the imaginary parts of the potentials of the layers.

Fig. 2) the amplitude of the reflection is $\sim 13\%$ for ^{157}Gd–^{58}Ni structures (curve 2). For the canceled real part of the potential ($\mathrm{Re}U_1 = \mathrm{Re}U_2$), the functional dependence $R(v_\perp)$ is essentially the same as curve 2 and is therefore omitted from this figure. We see that there is a significant change in R because of the use of a strongly absorbing material in the multilayer interference structure. It can also be seen from this figure that there is a smearing of the quasistationary levels (curve 1) which are characteristic of the allowed bands of multilayer interference structures made from weakly absorbing materials. In certain cases this circumstance could also be utilized to measure $\mathrm{Im}U$. For ^{157}Gd structures, we note the effect of $\mathrm{Im}U$ on the behavior $R(v_\perp)$ and $v_\perp \to 0$.

The imaginary part of the potential, $\mathrm{Im}U$, may increase sharply in the case of a resonant capture of neutrons. Figure 3 shows results calculated on the amplitude value R at a reflection as a function of the total velocity of the neutron for ^{151}Eu–V multilayer interference structures ($E_R = 6\times10^{-4}$ eV, $\Gamma \cong 6.7\times10^{-2}$ eV). Shown in the same figure are results calculated for the case $\mathrm{Re}U_1 = \mathrm{Re}U_2 = 0$ (curve 2). It can be seen from this figure that the value of R near the resonance is $\gtrsim 10\%$. Corresponding

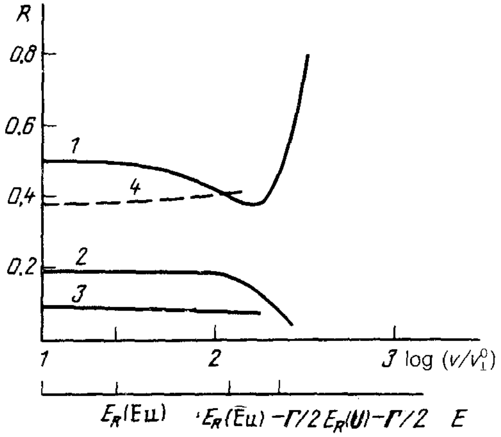

FIG. 3. The amplitude value of R at a reflection versus the neutron velocity for multilayer interference structures. 1, 2—^{151}Eu–V ($d = 160$ Å, $N = 30$); 2—only the imaginary part of the ^{151}Eu potential is taken into account; 3—^{235}U–V ($d = 200$ Å, $N = 300$); 4—^{235}U–Sn ($d = 160$ Å, $N = 300$). Here $v_\perp^0$ is the normal component of the neutron velocity corresponding to the amplitude value of R.

calculations were carried out for ^{235}U structures (curves 3 and 4 in Fig. 3) ($E_R = -0.02$ eV, $\Gamma \cong 1.2 \times 10^{-1}$ eV). Curve 3 corresponds to a structure with $\mathrm{Re}\,U_1 = \mathrm{Re}\,U_2 = 0$; curve 4 corresponds to a ^{235}U–Sb multilayer interference structure. The changes in R in these cases are $\cong 25\%$ and $\cong 10\%$. It follows from these examples that multilayer interference structures would definitely be useful for searching for resonant levels over a broad energy range for materials with a capture cross section $\sigma \gtrsim 100$ b.

We note in conclusion that the development of multilayer interference structures with a period ~100 Å presents no difficulty at the present technological level in vacuum deposition. Another important point is that the structure of the potential of the multilayer interference structures which are produced can be determined by x-ray-optics and other methods.

[1)] A cancellation of the real part of the potential of a multilayer interference structure can be arranged by using a mixture of isotopes to synthesize the layers.

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