Communications on Physics 2 41–43 (1977)

Corrigendum and first experimental evidence on neutron supermirrors

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Received 2 August 1976 and in revised form 5 January 1977

The idea of ' supermirror ' neutron polarizers was introduced by one of us (F. Mezei) in a paper which unfortunately contained some errors in the algebra. These are corrected in the present comment and in addition we present experimental data on successful supermirrors.

Previously [1] the structure of a supermirror was described by a function $d(n)$, where $d(n)$ is the lattice spacing of the nth bilayer. However, the derivation, and thus the result given as the last equation on p. 82 of [1] were in error. The correct argument is as follows :

The number of bilayers $N(n)$ in the region of the nth bilayer contributing to the Bragg reflection within $\pm 45°$ phase difference to the nth one is determined by the equation

$$\left.\begin{aligned} \frac{d(n)}{4} &= \sum_{j=-N(n)/2}^{N(n)/2} |d(n+j)-d(n)| = -\frac{\delta d(n)}{\delta n} \sum_{j=-N(n)/2}^{N(n)/2} |j| \\ \frac{d(n)}{4} &= -\frac{\delta d(n)}{\delta n} \cdot \frac{N^2(n)}{4} \end{aligned}\right\} \tag{1}$$

if $d(n)$ is a smooth, monotonically decreasing function of n.

We can regard $N(n)$ as the effective number of reflecting layers, and from *Equation* 2 of [1] we obtain the condition

$$N(n) = 2(d_c/d(n))^2 \tag{2}$$

(where d_c is a constant, equal to about 280 Å for iron ferromagnetic layers) for achieving the desired high reflectivity.

Combining these two equations we arrive at the differential equation

$$\frac{\delta d(n)}{\delta n} = -\frac{d^5(n)}{4d_c^{\,4}}$$

the solution of which defines the structure of a supermirror

$$d(n) = d_c/(n)^{1/4}$$

Thus we find that the thickness of the V (non-magnetic) layer in the nth bilayer should be

$$d_V(n) = \frac{d_c}{2n^{1/4}} = \frac{d(n)}{2} \tag{3}$$

and, correcting for refraction effects, the thickness of the M (ferromagnetic) layers is

$$d_M(n) = \left\{\left[\left(\frac{1}{d_V(n)}\right)^2 - \left(\frac{2}{d_c}\right)^2\right]^{1/2}\right\}^{-1} \tag{4}$$

The function $d(n)$ given in [1] underestimated the number of bilayers necessary for supermirrors. Thus for a $5\theta_c$ cut-off supermirror we find that $n \approx 600$ bilayers are required, in contrast to the 100 previously stated. Thus the practical upper limit for supermirror cut-off angles would be 4–$5\theta_c$ rather than the 5–$6\theta_c$ suggested before.

A number of trial supermirrors of 15–80 bilayers have been prepared in a standard 10^{-6} torr class vacuum evaporator, using resistive heated crucibles and glass substrates. The two layer materials were Fe and Ag. The thickness of the layers was measured by a commercial digital quartz-crystal microbalance with a rated resolution of 1 Å. Considering the instabilities of this device, we think that the actual accuracy was more likely around 5 Å.

The supermirrors were made according to *Equations* 3 and 4 above. We have found that for supermirrors with only about 20 bilayers the observed reflectivity agrees very well with the theoretical one, so that, using the theoretical value $d_c = 280$ Å in *Equations* 3 and 4, we obtained the expected high reflectivity in this case. The full line in *Figure* 1 shows the reflectivity versus

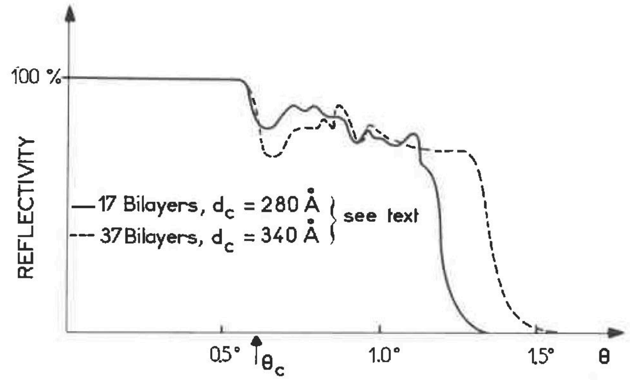

Figure 1 Curves of reflectivity versus glancing angle for neutron supermirrors using a polarized neutron beam ($\lambda = 6{\cdot}7$ Å, $\Delta\lambda/\lambda = 0{\cdot}5\%$).

glancing-angle curve for a supermirror with 17 bilayers as measured with a 6·7 Å wavelength, 0·5% monochromatic neutron beam, polarized by a similar supermirror. The structure in the reflectivity curve is an interference fringe effect due to the finite number of layers in the supermirror, which was neglected in our simple theory. The polarization efficiency of the supermirror was determined by the flipping-ratio method, and found to be $99{\cdot}0 \pm 0{\cdot}2\%$ above the critical angle θ_c of the ordinary total reflection, i.e. in the range where the supermirror effect gives the reflectivity. (There is no polarization up to about $\theta_c/2$, which corresponds to the down spin critical angle of this particular Ag–Fe structure, and in the ordinary mirror reflection range of $\theta_c/2$ to θ_c the polarization is about 97%.)

We have found that the reflectivity of the supermirrors started to drop rapidly compared to the theoretical value as we attempted to prepare structures with 40 or more bilayers. We believe that this is due to the deterioration of the quality of outer layers in the deposit. We found it possible to compensate for it for a while by increasing the effective number of layers, i.e. using a d_c higher than the theoretical one, but beyond 40–50 layers this method does not work. Our best supermirrors were those with 37 bilayers and $d_c = 340$ Å (dashed line in *Figure* 1), which show a high reflectivity above 70%, up to $2{\cdot}3\theta_c$. We do believe, however, that further development work aimed at the improvement of the quality of the deposited layers will bring us beyond the best supermirror cut-off angle achieved at present, namely $2{\cdot}3\theta_c$.

Reference

1 Mezei F *Comm Phys* **1** 81 (1976).