Table 4.4.2.4. *Properties of polarizing crystal monochromators (Williams, 1988)*

	$Co_{0.92}Fe_{0.08}$	Cu_2MnAl	Fe_3Si	^{57}Fe:Fe	$HoFe_2$
Matched reflection $\lvert F_N \rvert \sim \lvert F_M \rvert$	200	111	111	110	620
d spacing (Å)	1.76	3.43	3.27	2.03	1.16
Take-off angle $2\theta_B$ at 1Å (°)	33.1	16.7	17.6	28.6	50.9
Cut-off wavelength, $\lambda_{\max}$ (Å)	3.5	6.9	6.5	4.1	2.3

4.4.2.6.2. *Polarizing mirrors*

For a ferromagnetic material, the neutron refractive index is given by

$$n_{\pm}^2 = 1 - \lambda^2 N(b_{\rm coh} \pm p)/\pi, \qquad (4.4.2.11)$$

where the magnetic scattering length, p, is defined by

$$p = 2\mu(B - H)m\pi/h^2N. \qquad (4.4.2.12)$$

Here, m and μ are the neutron mass and magnetic moment, B is the magnetic induction in an applied field H, and h is Planck's constant.

The $-$ and $+$ signs refer, respectively, to neutrons whose moments are aligned parallel and antiparallel to B. The refractive index depends on the orientation of the neutron spin with respect to the film magnetization, thus giving rise to two critical angles of total reflection, γ_- and γ_+. Thus, reflection in an angular range between these two critical angles gives rise to polarized beams in reflection and in transmission. The polarization efficiency, P, is defined in terms of the reflectivity r_+ and r_- of the two spin states,

$$P = (r_+ - r_-)/(r_+ + r_-). \qquad (4.4.2.13)$$

The first polarizers using this principle were simple cobalt mirrors (Hughes & Burgy, 1950), while Schaerpf (1975) used FeCo sheets to build a polarizing guide. It is more common these days to use thin films of ferromagnetic material deposited onto a substrate of low surface roughness (*e.g.* float glass or polished silicon). In this case, the reflection from the substrate can be eliminated by including an antireflecting layer made from, for example, Gd–Ti alloys (Drabkin *et al.*, 1976). The major limitation of these polarizers is that grazing-incidence angles must be used and the angular range of polarization is small. This limitation can be partially overcome by using multilayers, as described above, in which one of the layer materials is ferromagnetic. In this case, the refractive index of the ferromagnetic material is matched for one spin state to that of the non-magnetic material, so that reflection does not occur. A polarizing supermirror made in this way has an extended angular range of polarization, as indicated in Fig. 4.4.2.10. It should be noted that modern deposition techniques allow the refractive index to be adjusted readily, so that matching is easily achieved. The scattering-length densities of some commonly used layer pairs are given in Table 4.4.2.5

Polarizing multilayers are also used in monochromators and broad-band devices. Depending on the application, various layer pairs have been used: Co/Ti, Fe/Ag, Fe/Si, Fe/Ge, Fe/W, FeCoV/TiN, FeCoV/TiZr, $^{63}Ni_{0.66}{}^{54}Fe_{0.34}$/V and the range of fields used to achieve saturation varies from about 100 to 500 Gs.

Polarizing mirrors can be used in reflection or transmission with polarization efficiencies reaching 97%, although, owing to the low incidence angles, their use is generally restricted to wavelengths above 2 Å.

Various devices have been constructed that use mirror polarizers, including simple reflecting mirrors, V-shaped transmission polarizers (Majkrzak, Nunez, Copley, Ankner & Greene, 1992), cavity polarizers (Mezei, 1988), and benders (Hayter, Penfold & Williams, 1978; Schaerpf, 1989). Perhaps the best known device is the polarizing bender developed by Schärpf. The device consists of 0.2 mm thick glass blades coated on both sides with a Co/Ti supermirror on top of an antireflecting Gd/Ti coating designed to reduce the scattering of the unwanted spin state from the substrate to a very low Q value. The device is quite compact (typically 30 cm long for a beam cross section up to 6 × 5 cm) and transmits over 40% of an unpolarized beam with the collimation from a nickel-coated guide for wavelengths above 4.5 Å. Polarization efficiencies of over 96% can be achieved with these benders.

4.4.2.6.3. *Polarizing filters*

Polarizing filters operate by selectively removing one of the neutron spin states from an incident beam, allowing the other spin state to be transmitted with only moderate attenuation. The spin selection is obtained by preferential absorption or scattering, so the polarizing efficiency usually increases with the thickness of the filter, whereas the transmission decreases. A compromise must therefore be made between polarization, P, and transmission, T. The 'quality factor' often used is $P\sqrt{T}$ (Tasset & Resouche, 1995).

The total cross sections for a generalized filter may be written as

$$\sigma_{\pm} = \sigma_0 \pm \sigma_p, \qquad (4.4.2.14)$$

where σ_0 is a spin-independent cross section and $\sigma_p = (\sigma_+ + \sigma_-)/2$ is the polarization cross section. It can be

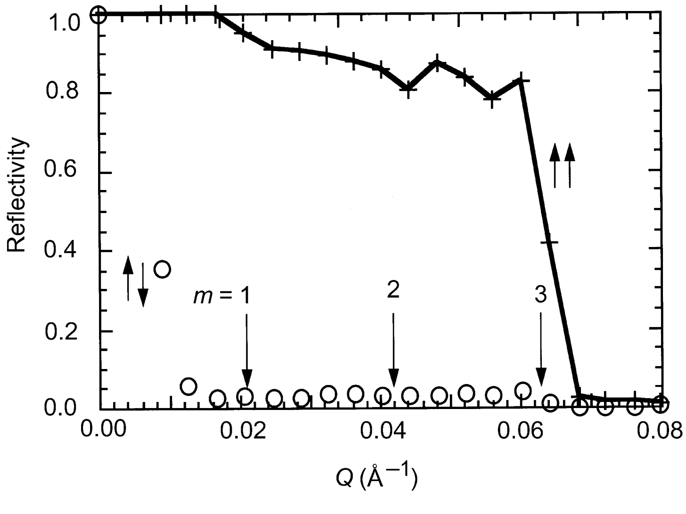

Fig. 4.4.2.10. Measured reflectivity curve of an FeCoV/TiZr polarizing supermirror with an extended angular range of polarization of three times that of γ_c(Ni) for neutrons without spin flip, ↑↑, and with spin flip, ↑↓.