Mirrors are available for all characteristic wavelengths used in laboratory X-ray powder diffractometers. A wealth of different materials are being used as double layers (reflector/spacer), including but not limited to W/Si, W/B_4C, Ni/C, Ru/B_4C, Ti/B_4C, V/B_4C, Cr/B_4C and Mo/B_4C. The double-layer materials may be selected according to the energies of their absorption edges to make the mirror act as a filter as well. While none of these mirrors is strictly speaking a monochromator, appropriate selection of the double-layer materials, depending on the wavelength used, will allow monochromatization of the radiation to $K\alpha$ while $K\beta$ and *Bremsstrahlung* are suppressed.

Within the past two decades mirror systems have become invaluable for all applications requiring a small and/or highly parallel beam. In particular, coupling of a parallel-beam mirror with multiple-reflection channel-cut monochromators allows the use of a wider solid-angle range of the X-ray source and a gain of nearly two orders of magnitude in intensity (Schuster & Göbel, 1995). For applications requiring ideal powders, however, too-small as well as too-parallel beams may result in too small a number of diffracting crystallites, which will generally reduce the diffracted intensity, and may additionally lead to particle statistics errors (see also Section 2.1.6.1).

Today, advanced sputtering techniques allow the fabrication of a wealth of different multilayer optics with virtually arbitrary beam divergences to generate focusing, parallel and divergent beams, for both point- and line-focus applications. The most comprehensive overview of currently available mirrors and up-to-date specifications will be found in manufacturers' brochures.

2.1.6.3.3.2. *Capillaries*

X-ray capillary optics are finding increasing use in applications where a small focused beam with high intensity is required. Their design, important properties and applications are discussed by *e.g.* Bilderback (2003), He (2009), and the VDI/VDE Guideline 5575 Part 3 (2011).

X-ray capillary optics employ total external reflection by the inner surface of hollow glass tubes to guide and shape X-ray radiation. For incidence angles lower than the critical angle of total reflection the X-ray radiation is guided through the optics at very low losses. The transmission efficiency depends upon the X-ray energy, the capillary materials, reflection surface smoothness, the number of reflections, the capillary inner diameter and the incident beam divergence, and is thus determined by the particular design of the given optics. Generally, the transmission efficiency decreases with increasing X-ray energy owing to the decreasing critical angle of total reflection. The role of X-ray capillary optics as energy filters is insignificant, therefore capillaries are usually used in combination with monochromatization devices such as metal filters, incident-beam graphite monochromators or graded multilayers. Gains in flux density of more than two orders of magnitude compared to pinhole systems have been reported. The most common X-ray capillary optics currently used in laboratory X-ray powder diffractometers can be categorized as either monocapillaries or polycapillaries.

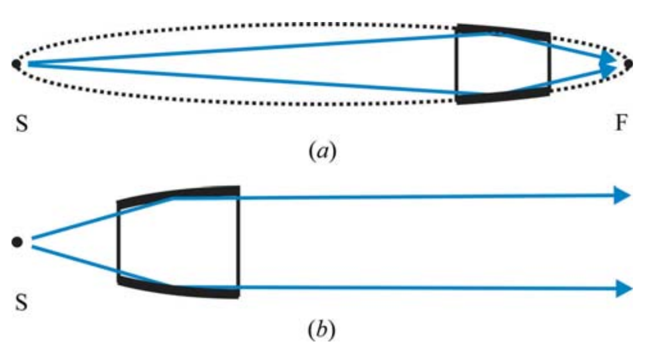

Figure 2.1.21
Schematic of monocapillary optics. (*a*) Elliptical and (*b*) parabolic monocapillary. S = source; F = focal point.

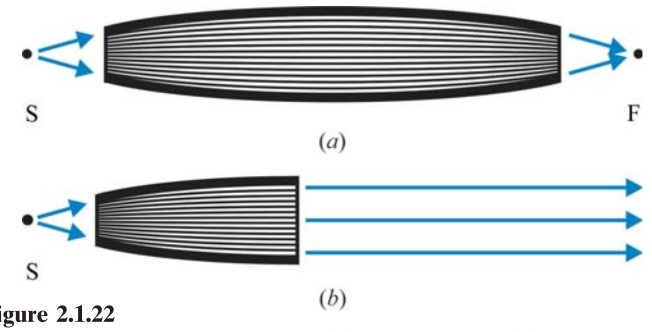

Figure 2.1.22
Schematic of polycapillary optics. (*a*) Focusing and (*b*) parallel-beam polycapillary. S = source; F = focal point.

Monocapillaries consist of ellipsoidal or paraboloidal capillaries for focusing or parallelizing X-rays by means of single or multiple total reflections, as illustrated in Fig. 2.1.21. The exit-beam divergence is controlled by the capillary diameter and length as well as the critical angle of total reflection; typical spot sizes range from some 20 mm down to less than 1 µm. Single-reflection monocapillaries are achromatic and almost 100% efficient. Their most important limitations are figure slope errors limiting the spot size. Multi-reflection monocapillaries can have the smallest spot sizes, which do not depend on the source size. An important drawback is that the beam is smallest at the capillary tip. In order to obtain the smallest possible spot size the sample has to be positioned to within 10–100 times the diameter of the tip exit size, *e.g.* 10–100 µm for a capillary with a 1 µm tip exit size.

Polycapillaries (*e.g.* Kumakhov & Komarov, 1990) are monolithic systems of micro-structured glass consisting of thousands up to several millions of channels, which are tapered at one or both ends to form desired beam profiles as illustrated in Fig. 2.1.22. A single channel can efficiently turn an 8 keV beam by up to 30° by multiple total reflections. Polycapillaries can collect a very large solid angle up to 20°, resulting in very high intensity gains. Typical spot sizes range from some 20 mm down to about 10 µm and are energy dependent, getting larger at lower energies.

2.1.6.3.4. *Combi-optics*

The steadily growing trend towards multipurpose instrumentation has led to a multitude of X-ray optics combined in single modules to eliminate reassembling and realignment. Such 'combi-optics' are usually motorized and allow a fully automatic, software-controlled switch between different beam paths to switch between different instrument geometries or to optimize beam conditioning (*e.g.* high flux *versus* high resolution).

A frequent requirement is the ability to switch between the divergent-beam Bragg–Brentano and parallel-beam Debye–Scherrer geometries, which can be achieved by two combi-optics as illustrated in Fig. 2.1.23. In this example, the incident-beam combi-optics consist of a variable slit and a Göbel mirror. When operating as a variable slit (Fig. 2.1.23*a*), the parallel-beam path is blocked by the variable slit. Turning the variable slit parallel to the divergent beam (Fig. 2.1.23*b*) enables the parallel beam and blocks the divergent beam. The diffracted-beam combi-optics consist of a set of two parallel-plate collimators, which are

references