that is not acceptable, for example, for the study of small-angle scattering (SAXS, Chapter 2.6). The effect of the tails can be reduced significantly through the use of multiple Bragg reflections.

The use of multiple Bragg reflections from a channel cut in a monolithic silicon crystal such that the channel lay parallel to the (111) planes of the crystal was shown by Bonse & Hart (1965) to remove the tails of reflections almost completely. This class of device, referred to as a (symmetrical) channel-cut crystal, is the most frequently used form of monochromator produced for modern X-ray laboratory diffractometers and beamlines at synchrotron-radiation sources (Figs. 4.2.5.2, 4.2.5.5).

The use of symmetrical and asymmetrical Bragg reflections for the production of highly collimated monochromatic beams has been discussed by Beaumont & Hart (1973). This paper contains descriptions of the configurations of channel-cut monochromators and combinations of channel-cut monochromators used in modern laboratory diffractometers produced by Philips, Siemens, and Bede Scientific. In another paper, Hart (1971) discussed the whole gamut of Bragg reflecting X-ray optical devices. Hart & Rodriguez (1978) extended this to include a class of device in which the second wafer of the channel-cut monochromator could be tilted with respect to the first (Fig. 4.2.5.6), thereby providing an offset of the crystal rocking curves with the consequent removal of most of the contaminant harmonic radiation (Fig. 4.2.5.4). The version of monochromator shown here is designed to provide thermal stability for high incident-photon fluxes. Berman & Hart (1991) have also devised a class of adaptive X-ray monochromators to be used at high thermal loads where thermal expansion can cause a significant degradation of the rocking curve, and therefore a significant loss of flux and spectral purity. The cooling of Bragg-geometry monochromators at high photon fluxes presents a difficult problem in design.

Kikuta & Kohra (1970), Matsushita, Kikuta & Kohra (1971) and Kikuta (1971) have discussed in some detail the performance of asymmetrical channel-cut monochromators. These find application under circumstances in which beam widths need to be condensed or expanded in X-ray tomography or for micro X-ray fluorescence spectroscopy. Hashizume (1983) has described the design of asymmetrical monolithic crystal monochromators for the elimination of harmonics from synchrotron-radiation beams.

Many installations use a system designed by the Kohzu Company as their primary monochromator. This is a separated element design in which the reference crystal is set on the axis of the monochromator and the first crystal is set so as to satisfy the Bragg condition in both elements. One element can be tilted slightly to reduce harmonic contamination. When the wavelength is changed (*i.e.* $\theta$ is changed), the position of the first wafer is changed either by mechanical linkages or by electronic positioning devices so as to maintain the position of the outgoing beam in the same place as it was initially. This design of a fixed-height, separated-element monochromator was due initially to Matsushita, Ishikawa & Oyanagi (1986). More recent designs incorporate liquid-nitrogen cooling of the first crystal for use with high-power insertion devices at synchrotron-radiation sources. In many installations, the second crystal can be bent into a cylindrical shape to focus the beam in the horizontal plane. The design of such a sagittally focusing monochromator is discussed by Stephens, Eng & Tse (1992). Creagh & Garrett (1965) have descibed the properties of a monochromator based on a primary monchromator (Berman & Hart, 1991) and a sagittally focusing second monochromator at the Australian National Beamline at the Photon Factory.

A recent innovation in X-ray optics has been made at the European Synchrotron Radiation Facility by the group led by Snigirev (1994). This combines Bragg reflection of X-rays from a silicon crystal with Fresnel reflection from a linear zone-plate structure lithographically etched on its surface. Hanfland *et al.* (1994) have reported the use of this class of reflecting optics for the focusing of 25 to 30 keV photon beams for high-pressure crystallography experiments (Fig. 4.2.5.7).

Further discussion on these monochromators is to be found in this volume in Subsection 2.2.7.2, §2.3.5.4.1, Chapter 2.7, and Section 7.4.2.

#### 4.2.5.4.4. *Polarization*

All scattering of X-rays by atoms causes a probable change of polarization in the beam. Jennings (1981) has discussed the effects of monochromators on the polarization state for

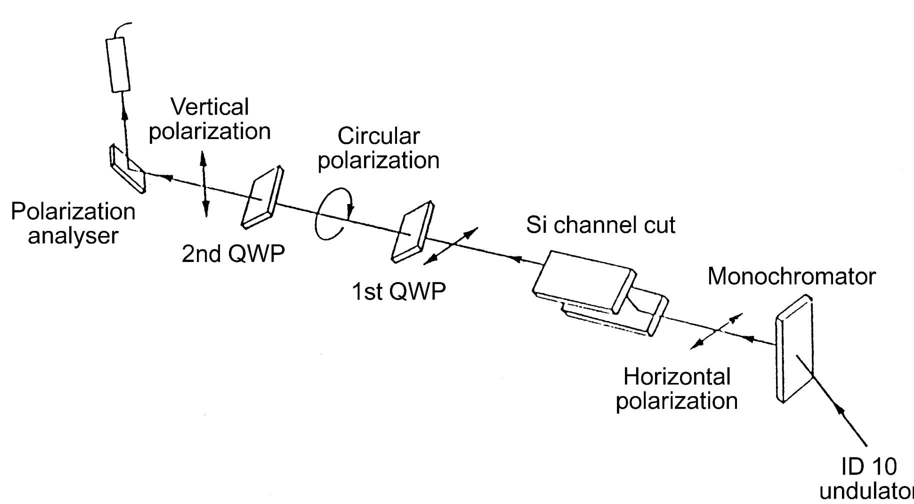


Fig. 4.2.5.5. A schematic diagram of a beamline designed to produce circularly polarized light from initially linearly polarized light using Laue-case reflections. Radiation from an insertion device is initially monochromated by a cooled diamond crystal, operating in Laue geometry. The outgoing radiation has linear polarization in the horizontal plane. It then passes through a silicon channel-cut monochromator and into a silicon crystal of a thickness chosen so as to produce equal amounts of radiation from the $\sigma$ and $\pi$ branches of the dispersion surface. These recombine to produce circularly polarized radiation at the exit surface of the crystal.





references