Appl. Phys. A 74 [Suppl.], S255–S257 (2002) / Digital Object Identifier (DOI) 10.1007/s003390201658

Applied Physics A
Materials
Science & Processing

MACS low-background doubly focusing neutron monochromator

S.A. Smee[1,2,3,4,*], **J.D. Orndorff**[3], **G.A. Scharfstein**[3], **Y. Qiu**[3], **P.C. Brand**[2], **C.L. Broholm**[3,2], **D.K. Anand**[2]

[1] Department of Mechanical Engineering, University of Maryland, College Park, MD 20742, USA
[2] National Institute of Standards and Technology, Gaithersburg, MD 20899, USA
[3] Department of Physics and Astronomy, Johns Hopkins University, Baltimore, MD 21218, USA
[4] Oak Ridge National Laboratory, Spallation Neutron Source, Oak Ridge, TN 37830, USA

Received: 13 July 2001/Accepted: 11 December 2001 –

Abstract. A novel doubly focusing neutron monochromator has been developed as part of the Multi-Analyzer Crystal Spectrometer (MACS) at the NIST Center for Neutron Research. The instrument utilizes a unique vertical focusing element that enables active vertical and horizontal focusing with a large, 357-crystal (1428 cm^2), array. The design significantly reduces the amount of structural material in the beam path as compared to similar instruments. Optical measurements verify the excellent focal performance of the device. Analytical and Monte Carlo simulations predict that, when mounted at the NIST cold-neutron source, the device should produce a monochromatic beam ($\Delta E = 0.2$ meV) with flux $\phi > 10^8$ n/cm^2 s.

PACS: 61.12.Ex

Neutron spectroscopy can provide unique information about nano-scale structure and dynamics in condensed matter. Often the instrument of choice is the triple axis spectrometer (TAS). Over the past forty years the basic layout for the TAS has not changed substantially. However, there have recently been significant improvements in beam delivery and detection systems. As sample sizes shrink and the understanding of complex correlated phenomena becomes increasingly dependent on more detailed, time-consuming, surveys of energy and momentum space, the need for higher sample flux, lower background, and faster data acquisition become increasingly important. To meet this demand in the long wavelength regime (~ 2 Å $\leq \lambda \leq 6$ Å), an advanced cold neutron spectrometer [1], MACS (Multi Analyzer Crystal Spectrometer), is being developed for the NIST Center for Neutron Research (NCNR). This spectrometer incorporates traditional TAS capabilities with double focusing of the incident beam and a massively parallel detection system. Combined, the advancements incorporated in MACS will enhance sensitivity by almost two orders of magnitude over a traditional TAS.

The heart of MACS is a very large doubly focusing monochromator (MACS-DFM) with unprecedented focusing flexibility and low background architecture. This 1428 cm^2 monochromating array consists of 357 pyrolytic graphite (PG) crystals and will subtend a solid angle of ~ 3.6 mSr at the NCNR cold source. Automated fixed and non-fixed wavelength focusing is facilitated by a novel vertical focusing element, which enables both variable vertical and variable horizontal focusing of the array; each vertical column having independent rotational control. Background is mitigated through use of the low-mass vertical focusing mechanism and a shielded low-mass structural design. In what follows, the exected performance of the MACS-DFM is presented along with details of the instrument design.

1 A low-background focusing element

The MACS-DFM derives its utility from a novel elastic vertical focusing element [2], see Fig. 1. The device shown consists, simply, of a thin elastic blade supported at each end by pivots. Mounted to the blade is a one-dimensional array of crystals. By controlling the relative displacement of the pivots, δx, the blade buckles forming the shape of a circular arc thus vertically focusing neutrons emanating from a source onto a sample. Double focusing is facilitated by a horizontal array of rotatable blades.

The advantages of such a device are clear. It is simple, modular, and easily scalable thus it facilitates the construction of large double focusing arrays containing hundreds of individual crystals. Backlash, typical of lead-screw driven mechanisms, is nonexistent. And, most importantly, background is minimized due to the very low mass design and the monolithic nature of the device, which eliminates the need for highly scattering materials in the beam.

The challenge with such a device is achieving, within a high degree of accuracy, a circular focal surface that can be adjusted over a broad range of curvature via a single degree of freedom, i.e. the pivot displacement δx. This problem has been solved through the use of a variable thickness blade profile [2]. In so doing, a variable thickness, 19 mm wide, 440 mm long, 43 g, aluminum blade has been constructed that, when populated with crystals, buckles into a circular arc

---

[*] Corresponding author. (Fax: +1-410/516-6664, E-mail: smee@pha.jhu.edu)

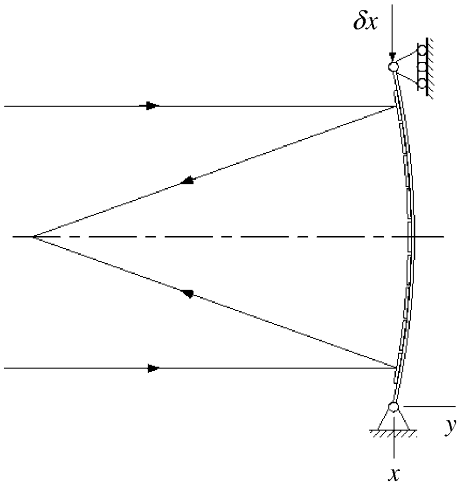

Fig. 1. Conceptual sketch of an elastic, variable curvature focusing element. Crystals are attached to the concave side of a thin blade. The radius of curvature is controlled by the relative pivot displacement δx

of constant radius to within 0.15° over a very broad range of radii, $900\,\mathrm{mm} < R < 10\,000\,\mathrm{mm}$. This slope error is small compared to the $\sim 0.7°$ FWHM crystal mosaic.

2 MACS-DFM design

The MACS-DFM is shown in Fig. 2a and b. Its doubly focusing array is constructed from 21 blades, each consisting of 17 $20 \times 20 \times 2\,\mathrm{mm}^3$ PG (002) crystals (the figures depict the optical test configuration where crystals are replaced by identically sized reflective platelets). The 357 crystals combine for a total diffracting area of $1428\,\mathrm{cm}^2$. Both vertical and horizontal focusing are variable and remotely adjusted using software controlled stepping gearmotors. Vertical focusing is achieved by uniformly buckling all 21 blades to the desired radius of curvature. Horizontal focusing is achieved by independently rotating each blade to the proper Bragg angle. The entire apparatus is mounted on an $r-\theta$ stage; the former is for fine-tuning of the focused spot position, the latter enables adjustment of the scattering angle.

The elastic vertical focusing device used here represents a significant reduction in beam mass compared to conventional lead-screw and lever actuated focusing mechanisms [3, 4], see Fig. 2b; an important consideration when a very clean monochromatic beam is required. Background is also reduced by limiting the structural components within the aperture to three thin-walled aluminum tubes and by placing the remainder of the aluminum structure and all of the actuating mechanisms (gearmotors, etc.) above and below the beam. Background is further reduced by encasing the top and bottom of the structure with 2 mm thick neutron absorbing ^{10}B:aluminum shielding.

3 Performance

The MACS-DFM receives a polychromatic beam from an approximately $6 \times 12\,\mathrm{cm}^2$ area on the cold neutron source and

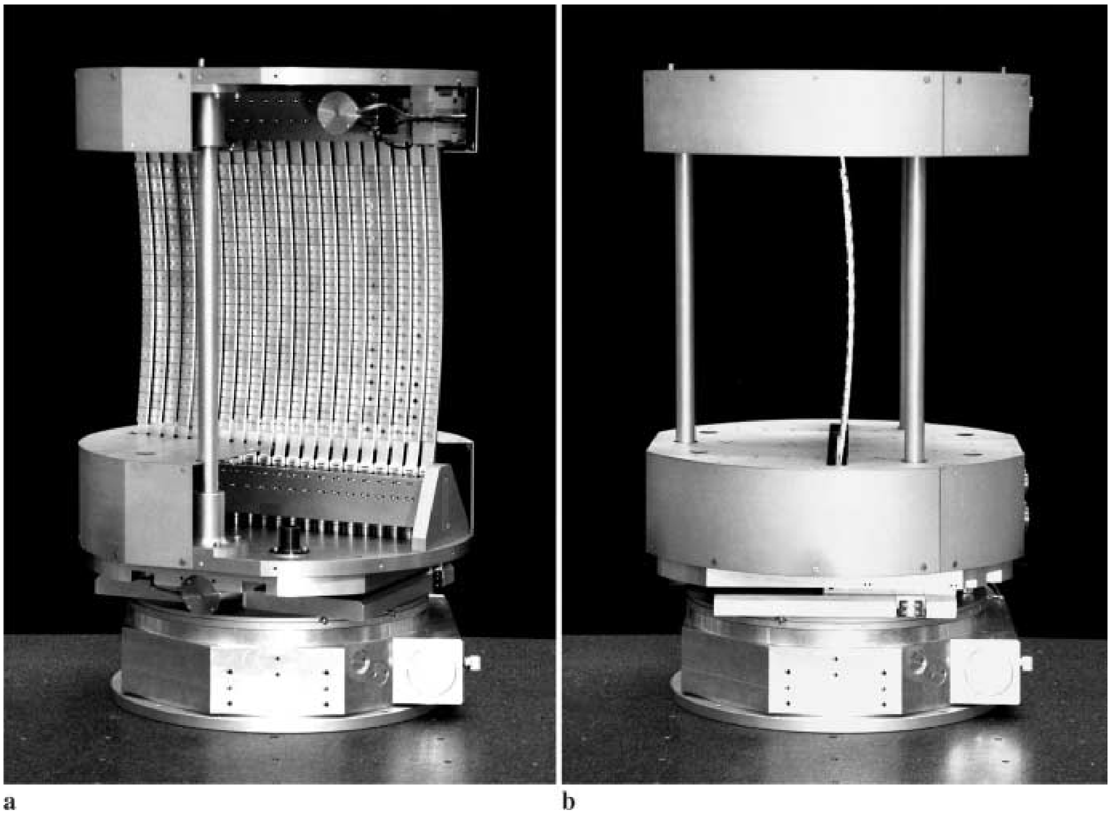

Fig. 2. Photographs of the MACS-DFM. Platelets with reflective centers are shown in lieu of PG crystals. **a** isomentric view with one pie section of the shielding removed from both the top and bottom of the instrument, **b** side view

produces a 3:1 demagnified image (2 cm wide × 4 cm tall) at the sample position. The peak sample averaged flux has been calculated using the MCSTAS [5] Monte Carlo simulation software and is found to exceed $1.0 \times 10^8\ \mathrm{n/cm^2/s}$ for $\Delta E = 0.2$ meV at $E = 10$ meV.

To illustrate the relative gain with such a large doubly focusing monochromator, simulations comparing the sample averaged flux of the MACS-DFM to flat crystal and vertical focusing monochromators were performed. The results are shown in Fig. 3. In these simulations, the horizontal collimation for the flat and vertical focusing configurations was chosen so that the energy resolution matched the doubly focusing case. It is clear from the results that a significant gain in flux is achieved with the use of double focusing; a factor of ~ 3 compared to a strictly vertical focusing monochromator and a factor of ~ 20 greater than a flat crystal.

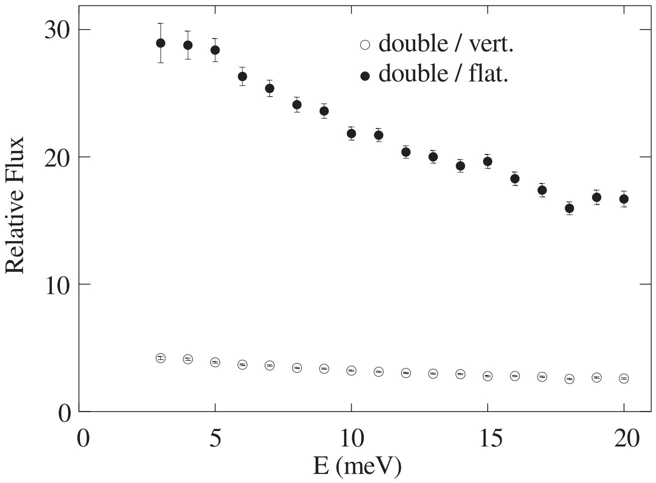

Fig. 3. Relative increases in flux with respect to flat and vertical focusing monochromators for the MACS-DFM

Focusing performance has been verified optically and confirms a crystal placement accuracy of 0.15° and a repeatability of 0.03°.

4 Conclusion

A low-background double focusing monochromator has been developed. This device utilizes a novel vertical focusing element that has lead to the construction of a very large, 357 crystal, $1428\ \mathrm{cm}^2$, diffracting array with minimal structural support material in the beam. The device implements remote control of both variable vertical and horizontal focusing, which enables flux optimization over a broad range of incident energy. In addition, independent unobstructed, rotational control of each vertical array facilitates non-fixed wavelength focusing, a feature that is unavailable on existing double focusing monochromators. Combined, these attributes represent a significant advance in double focusing technology.

Acknowledgements. It is a pleasure to acknowledge Dwight Barry, Tom Reeves, Scott Spangler, Igor Zaliznyak, and Jeff Lynn for their contributions during various phases of the project.

References

1. C. Broholm: Nucl. Instrum. Methods. Phys. Res., Sect. A **369**, 169 (1996)
2. S. Smee, P. Brand, D. Barry, C. Broholm, D. Anand: Nucl. Instrum. Methods. Phys. Res., Sect. A **446**, 513 (2001)
3. W. Buhrer: Nucl. Instrum. Methods. Phys. Res., Sect. A **338**, 44 (1994)
4. R. Lechner, R. Wallpach, H. Graf, F. Kasper, L. Mokrani: Nucl. Instrum. Methods. Phys. Res., Sect. A **338**, 65 (1994)
5. McStas Version 1.4, Supported by Riso National Laboratory, Roskilde, Denmark