Facility Highlights

Final G-line Optics Build: 9 Weeks of Hustle!

E. Fontes and D.-M. Smilgies
Cornell High Energy Synchrotron Source, Cornell University

The G-line project expanded the CHESS facility by one third, raising the number of experimental stations from 9 to 12. This project began during a brainstorming session in 1997 about how we might make use of unused x-rays produced by the "backfire" beams coming out of CHESS wigglers. Don Bilderback and Karl Smolenski sketched initial concepts to extract two beams for high flux experiments at "G-line". The project evolved into a unique opportunity for Cornell faculty to extend their scientific laboratories to CHESS and have their student research groups participate in and learn from building and running x-ray beamlines. The new stations fulfilled a long-sought need of local groups to have access to extremely high intensity x-ray beams for long-term experimental programs. Because the user program at CHESS serves many different communities, the typical beamtime allotments on the A to F-line stations are 2-6 days. The three G-line stations can host short visits, of course, but they can also give students and faculty the opportunity to build dedicated equipment and take data over many weeks and under varying conditions, when needed. Early targeted experiments included x-ray starved measurements in weakly scattering materials and soft-matter studies and real-time growth of novel semiconductor materials. The initial science programs for these stations were explained in some detail by Joel Brock in the 2002 CHESS Newsmagazine and are highlighted in several articles in this issue. (See www.chess.cornell.edu for electronic copies of past magazines.)

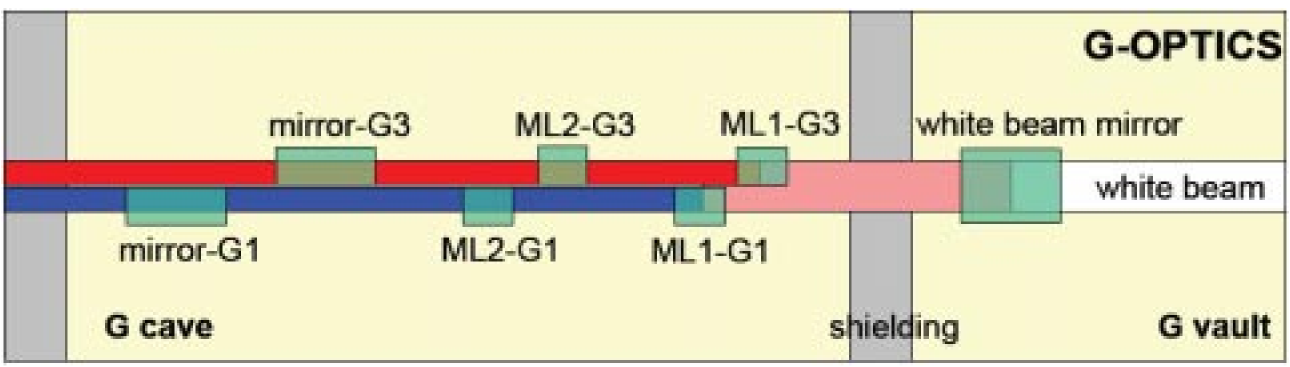

Fig 1: Schematic of the beam splitting and focusing optics design to provide separate, tunable x-ray beams for the G1, G2 and G3 stations. Entering from the right, a heavily water-cooled white beam mirror filters and reflects the raw wiggler radiation. Two multilayers in the first optics box (ML1) each deflect half the radiation either upwards for G1 (blue trace) or downwards for G3 (red trace). Matching multilayer mirrors in the second optics box (ML2) make the beams again parallel and directed towards the final vertical focusing silicon slab mirrors. The G3 beam is eight inches below the G1 beam as it exits the optics room and passes through the G1 hutch. This lower beam is split again in the G2 hutch, as explained in the following article.

The optics design for G-line was considerably harder and more complex than for any previous CHESS beamline. To extract the highest possible x-ray flux from the Cornell storage ring, a new 50-pole permanent magnet wiggler was designed and built by Staff Scientist Ken Finkelstein. This wiggler feeds both the A and G-line stations simultaneously and has a critical energy of 15 keV to optimize photon flux for standard experiments. Both beamlines use glidcop water-cooled mirrors to absorb unneeded higher energy photons and collimate the diverging beam. The rhodium-coated mirrors have cut-off energies of 16 keV at an incident angle of 4 mrad, absorbing nearly 60% of the unwanted power in the beam. In addition to reducing the harmonic content of the x-ray beam, these mirrors extend the service life of the silicon and multilayer optic elements downstream.

From the very start we wanted the G-line x-ray optics to provide separately tunable beams into all three independent stations. To achieve the highest possible flux, synthetic multilayer (ML) monochromator mirrors had to be used. However, ML mirrors deflect the beam at small angles, which makes it difficult to design and build non-overlapping translation and rotation stages. The two ML crystals initially split the beam into two parts, but because of the small diffraction angles, the second ML crystals need to be several meters downstream to achieve a 200 millimeter vertical offset between the G1 and G2/G3 beams. As a result, the second MLs have to translate downstream between 1-2 meters as the energy is scanned from 8-16 keV. This long motion required building the largest vacuum box CHESS has ever seen (Figure 2). The staff had to devise new solutions for cable management and physical clearance and we bought one of the largest turbomolecular pumps in production. Once the two beams are separated vertically, the G2/G3 beam travels through the G1 hutch along a beampipe lying directly upon the optical table. The G2 station uses a transparent crystal to deflect a small energy slice of the beam into the G2 hutch.

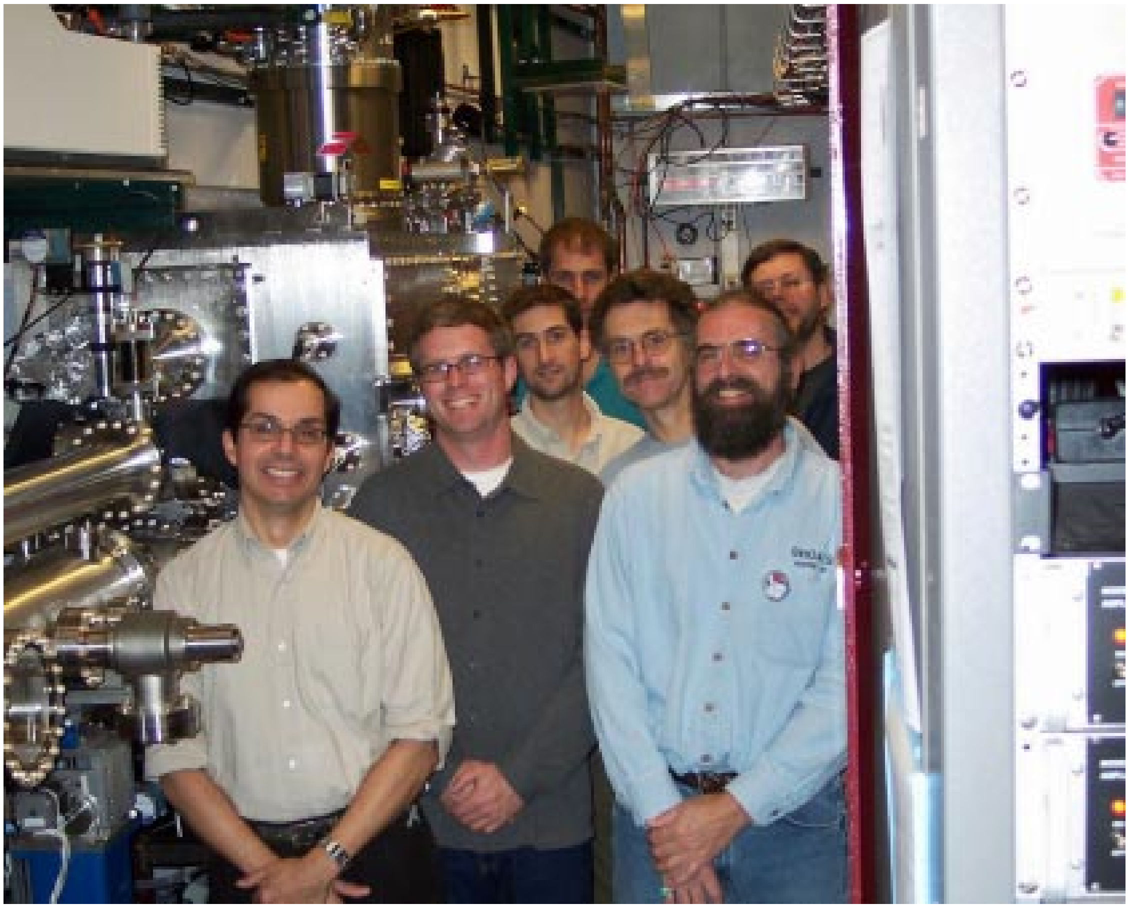

Fig 2: Design and construction team leaders inside the new G-cave optics room. In the far back are Dana Richter (left) and Detlef Smilgies; in the middle are Chris Conolly (left) and Bob Seeley, and in front are Ernie Fontes (left), Alan Pauling and Jeff White.

The design and construction of the optics systems was constrained by the relatively small window of opportunity we had for installation and commissioning. Alan Pauling put pencil to paper (or mouse to screen?) for several years designing the seven separate vacuum boxes needed by the beamline. In order to not waste valuable x-ray time, we built the entire optics room in only 9 short weeks during a CLEO running period. Out of necessity the fabrication of the vacuum boxes and equipment was done offline over the 12 months before the down period. This involved building the optics boxes on stands with wheels so that they could be moved around the laboratory for construction, vacuum processing, electrical wiring, testing, and then storage. During the installation process the boxes were sequentially rolled into place and vacuum and cabling restored as rapidly as possible. At the same time, the G1 station was emptied and turned into a temporary cleanroom that we used to assemble and test the long translation stages and goniometers for the second multilayer optics as well as the 1-meter long superpolished silicon vertical focusing mirrors (Figure 3). The long vacuum box for the second MLs arrived during the down period and was unloaded from the truck, installed, cleaned and pumped down to 10^{-8} torr pressure in only 8 days time. This is just one example of the outstanding effort and efficiency of the CHESS technical staff.

The hardware and optics commissioning with x-ray beams began during the winter x-ray running period in February and March 2004. Unfortunately, difficulties with water leaking from the first ML mirror forced a backup plan that did not provide beam to G1. An important part of commissioning the new optics room was the extensive radiation surveys conducted by Jeff White, Dana Richter, and Detlef Smilgies. After vacuum conditioning the new white beam mirror and first ML, an x-ray beam was threaded through four bounces (two mirrors and two multilayers) into the G2 and G3 stations by the G-line students and staff. Though not yet optimal, these stations did get x-ray beams and students collected experimental data in G2 with a new cave and focusing crystal and in G3 with a newly aligned vacuum diffraction chamber. The preliminary optics didn't provide the full-sized beams so the planned vertical and horizontal focusing arrangements could not be tested. Hardware upgrades during this April-May will put in place all the hardware we need to fully commission the beamline and stations during July.

Needless to say, an enormous number of people and subsystems had to come together to make the G-line optics and stations possible, including civil, water, wiring, electronics, safety, optics, vacuum, motors, computer control and analog and video monitoring. Over the course of a year our weekly design meeting evolved from chalkboard drawings to professionally engineered 3-dimensional models rotating live onscreen. The main involvement of the staff included conceptual and mechanical design by Alan Pauling and Detlef Smilgies; facility infrastructure was built by Dana Richter, Dave Jones and Jerry Houghton; electronics and wiring were done by Ted Luddy and Gino Melice; safety oversight and design involved the CHESS Safety Committee headed by Jeff White; optics fabrication involved Chris Conolly, Darren Dale, Jim Savino, Tom Krawczyk and Alan Pauling; vacuum work was carried out by Bob Seeley, Jonathan Page, Ellen Kathan and Sterling Cornaby; motor systems were built and checked by Aaron Fleet, Dan Blasini, Dave Novak, Sterling Cornaby, Detlef Smilgies, and undergraduate Harold Barnard; computer control and monitoring were provided by Phil Sorensen, Aaron Fleet, Lee Shelp, Peter Revesz, and Detlef Smilgies. Figure 2 shows the construction group leaders.

In conclusion, the final optics installation just described ended a temporary, phase I G-line operation that made use of a simple double-bounce multilayer monochromator. That temporary situation provided x-rays for commissioning the experimental stations while the main optics were being designed and built. During that year, many experiments were scheduled, some of them with very long data collection periods, and some of them involving the first outside users. A number of student and staff publications and conference contributions were based on the data obtained during that time. Overall, these past two years have provided invaluable experience in building, commissioning and running three new experimental stations. Accomplishing so much in just a few years is a credit to the high motivation and superb effort of the G-line students in close collaboration with a multitalented CHESS staff. With the final optics hardware now in place, high flux double-focused x-ray beams into all three stations should make G-line a very busy place this summer and for years to come.

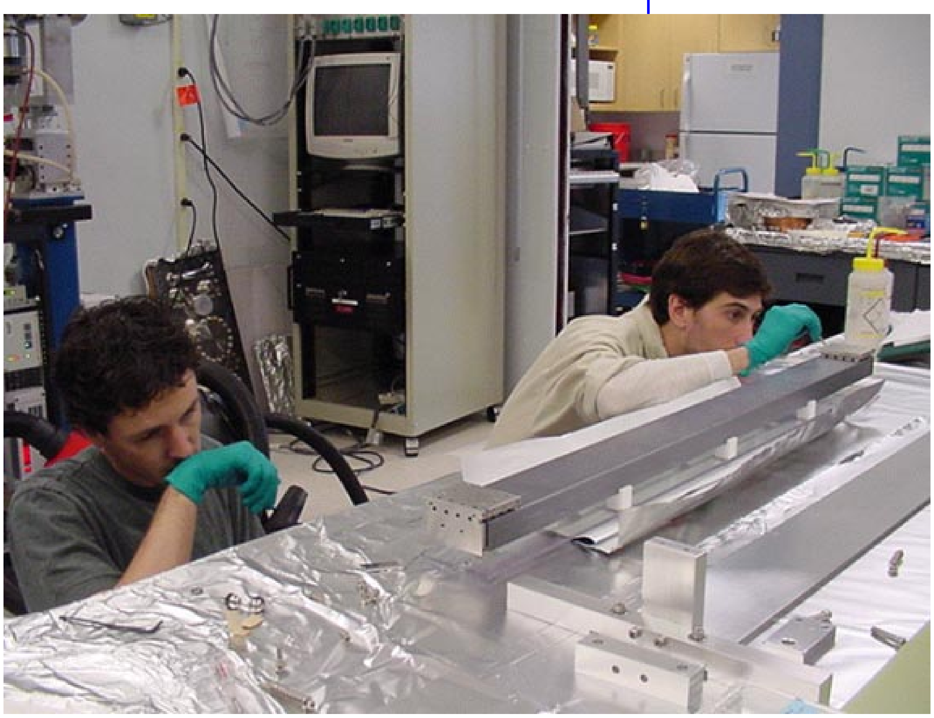

Fig 3: Graduate student Darren Dale (left) and CHESS Head Operator Chris Conolly inspect the bending mounts attached to the ends of the 1-meter long superpolished silicon mirror. After bending rods attach to these mounts, the mirror can be bent into an elliptical shape, as needed, to focus the x-ray beams to their smallest vertical sizes.