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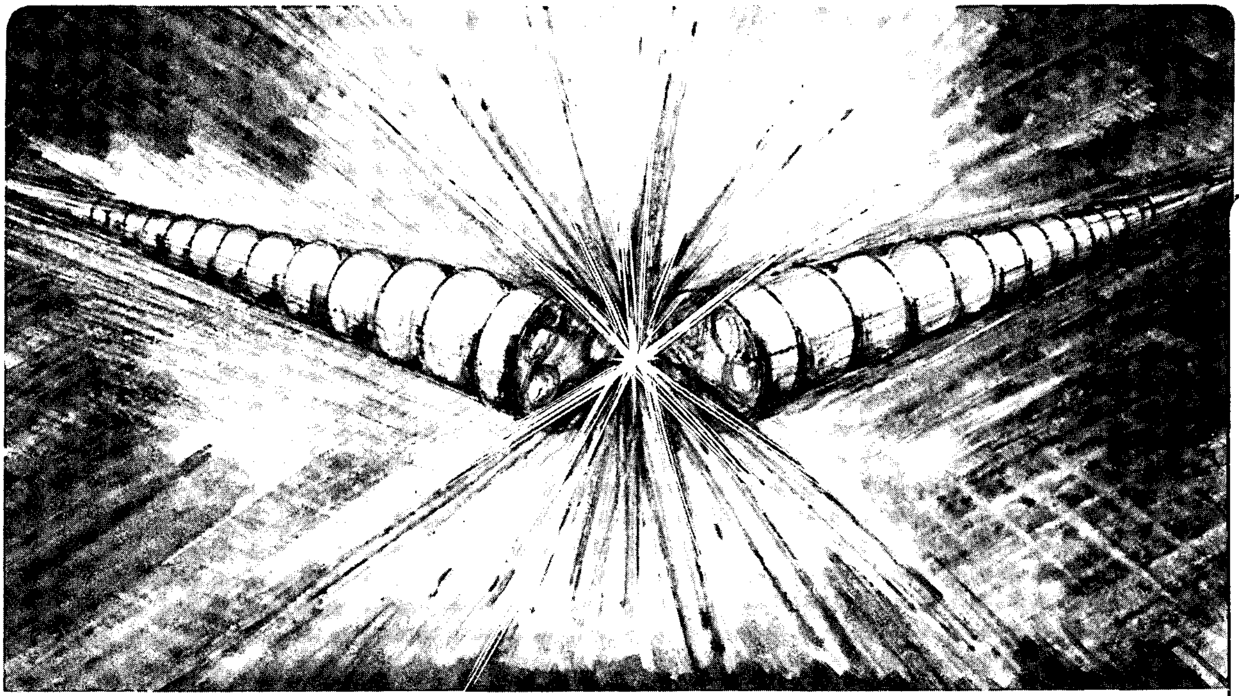

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DISCLAIMER

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1. Introduction

The Lawrence Berkeley Laboratory 55-m spherical grating monochromator (SGM) beamline is located as a branch line of the 54-pole wiggler/undulator at the Stanford Synchrotron Radiation Laboratory (SSRL). It was designed and constructed by LBL's Center for X-Ray Optics and the engineering staff of LBL's Advanced Light Source with the cooperation and assistance of the research group of David Shirley at LBL and the staff of SSRL. The main goals of the project were to test the SGM concept and to develop a capability for designing and building a water-cooled mirror and grating capability in anticipation of the ALS.

As shown in Fig. 1, a water-cooled plane mirror deflects the beam horizontally, taking in general a small fraction of the flux from the 54-pole insertion device. This mirror[1] is a brazed assembly of Glidcop (a proprietary alumina-dispersion-strengthened copper alloy) and OFHC copper. Its surface was finished in polished electroless nickel, then overcoated with gold as all optics in the beamline are overcoated. Next in the line is a fused silica toroid which focuses the SPEAR source vertically onto the entrance slit of the monochromator and horizontally onto the nominal position of the exit slit, in the manner of Rense and Violett.[2] The magnification factors are 0.3x vertically and 0.7x horizontally. The monochromator is a Rowland-circle design; both slits move on large granite-based slides that maintain flatness of travel to ±2 μm in peak-to-peak variation from straightness.

2. Optical Design Goals

An SGM was chosen to avoid the high line curvature aberration of toroidal grating monochromators (TGMs), which severely limits their resolution. In the SGM, the deliberately introduced astigmatism of the toroidal premirror compensates for the large natural astigmatism of the spherical grating. In addition, spherical surfaces can be made with significantly tighter figure tolerances than aspheric optics[3]. The fused silica grating from Ferranti-Astron that is currently installed while the water-cooled gratings are being fabricated is exceptional in this respect, having an rms slope error of approximately 1-2 μrad (according to measurements made with the long-trace surface profiler built by Peter Takacs at Brookhaven National Laboratory) and a surface microroughness of 5 Å (as measured with a Wyko Profilometer, 2.5x objective). We have obtained four watercooled, nickel-coated and polished substrates manufactured with the technology used for M0, and we plan to make them into gratings in a developmental program in cooperation with grating vendors.

3. Mechanical Design Features

Remarkably good packaging was achieved in the design of the grating chamber despite the added complexity of water cooling. Each grating can be kinematically mounted and independently adjustable in six degrees of freedom from outside the vacuum chamber. Three water cooled gratings can be mounted, and can be interchanged from outside the chamber. They are mounted onto a carriage which is kinematically attached to a rail by ball bearing rollers. The water cooling serially flows through an adjustable mask, and the three gratings. Adjustments as fine as 80 threads per inch do not gall in the UHV due to careful selection of materials. A guard space, which can be either exposed to atmosphere or evacuated extends all the way to the inside of the grating blanks, eliminating water-to-UHV joints. The grating chamber is diagrammed in Fig. 2.

The tank is sealed with a REM seal (radially expanding metal) that was developed at LBL. The tank is mounted on three water-filled, insulation-wrapped legs for kinematic stability, high thermal mass, and long thermal time constant to prevent the chamber from moving motion as the temperature changes. A six-strut kinematic mounting connects the tank to the legs. The struts, made of Invar for dimensional stability, have spherical bearings and can adjust the entire chamber to ± 0.001 inch which is shown on dial indicator readout. A key element in the design is the main structural member. This thick plate extends through the chamber walls into the UHV, allowing the grating carriage and the entire wavelength readout system to be mounted as an integral unit. The top and bottom of the chamber are separately welded to this cylindrical main structural member, which is available for mounting both inside and outside the vacuum.

The laser interferometer, although expensive, was chosen to provide the high angular resolving power necessary. Encoding the grating axis directly would have been more elegant, but present technology could not have provided the necessary resolution. The drive incorporates a custom mechanical stage with 4 inches of travel, and a ± 1 micron incremental glass-scale readout with an absolute fiducial standard to back up the laser encoder. The philosophy of the wavelength drive (used extensively in industry) is to achieve considerable savings, building precision only into the drive system and building accuracy (0.1μm) into the readout system. The latter operates in closed loop mode with the drive motor having several steps for each increment of the laser interferometer (Fig. 3). The functional relation between the wavelength setting and the laser interferometer distance allows setting the monochromator wavelength with an absolute accuracy of better than 1eV by dead reckoning and much better by calibration.

The slits are based on parallelogram flexures in a design similar to one developed at Brookhaven. The jaws are Glidcop for greater dimensional stability at elevated temperatures, and can achieve straightness and parallelism better than 0.1 slit width down to a 3 µm opening. The slit motions are provided by custom mechanical slides manufactured by Microautomation Technology of Berkeley (now Orasis Corp. of Sunnyvale, CA). Stepper motors drive the slides using feedback from glass scale readouts in closed loop fashion. A dedicated microprocessor controls both of the slides and the wavelength drive. Each of the 3 loops can be instructed simultaneously by serial link to the MicroVAX computer that controls the beamline. Alternatively, sequences of 100 commands can be downloaded into the microprocessor for later execution.

3.1. Alignment

Aligned tooling balls were included in all the important mechanical structures. These fiducials were carefully positioned with respect to the optical components by standard machine-shop practice using a granite surface plate, rulers, and height gauges. The slits were calibrated by a microscope with a two-axis glass-scale encoded measuring stage. The slit slides and chambers were then placed into position using standard surveying techniques.

The grating was aligned to the rotation axis in the monochromator tank by directing a laser beam at an arbitrary angle of incidence through a port onto the center of the grating. The two rotations of the grating grooves with respect to the wavelength rotation axis were then adjusted until the zeroth and ± first orders of diffraction fell on the same spot on the wall several meters away as the grating carriage was rotated on its axis; see Fig. 4. After the grating was adjusted with respect to the grating rotation axis, the grating tank was aligned as shown in Fig. 5. The transit was aligned on a line between the survey monuments at the correct height to view the grating. With the transit rotated to look at the ceiling several meters above, the laser was adjusted to hit the ceiling at the point marked by the crosshairs. The transit was then turned toward the tank and the spot on the ceiling was viewed through the diffracted light from the grating using the scattered light from the spot. This technique permitted adjustment of the grating tank in both rotation axes.

The slits were aligned by adjusting the roll until the Fraunhofer diffraction pattern of a very narrow setting was in the plane of the transit in Fig. 5 The HeNe laser illuminated the slits in this case. These processes were sufficient except for minor height adjustments to center the beam onto the optics. These height adjustments were particularly easy to accomplish for the main chamber, where the six strut kinematic mounts allowed precisely indexed vertical motion.

4. Results

The first spectra have been reported and interpreted by Heimann et al. at the VUV-9 conference.[4] We reproduce here the output of the monochromator from 180 to 820 eV, measured with an aluminum photodiode at the exit slit of the monochromator. (Fig. 6) Approximately 4×10^{10} photons/sec were observed at 440 eV photon energy and 40 mA beam current. It is expected that this value will increase by about a factor of 10 when certain deficiencies in the M-zero mirror are corrected. Both slits were set at 100 µm which corresponds to 0.5-eV resolution. Heimann et. al.[4] estimate the second order of the grating to be approximately 28% near the C edge. We also reproduce the spectrum of N at 10 mTorr taken with an ion chamber that was isolated from the UHV by a 1500-Å Al window (Fig. 7). Deconvolution of this spectrum[4] permits the inference of a resolution of 80 meV for 10-µm slits, and 60 meV for 5-µm slits. To date, this demonstrates a conservatively estimated resolving power of 6600 at 400 eV.

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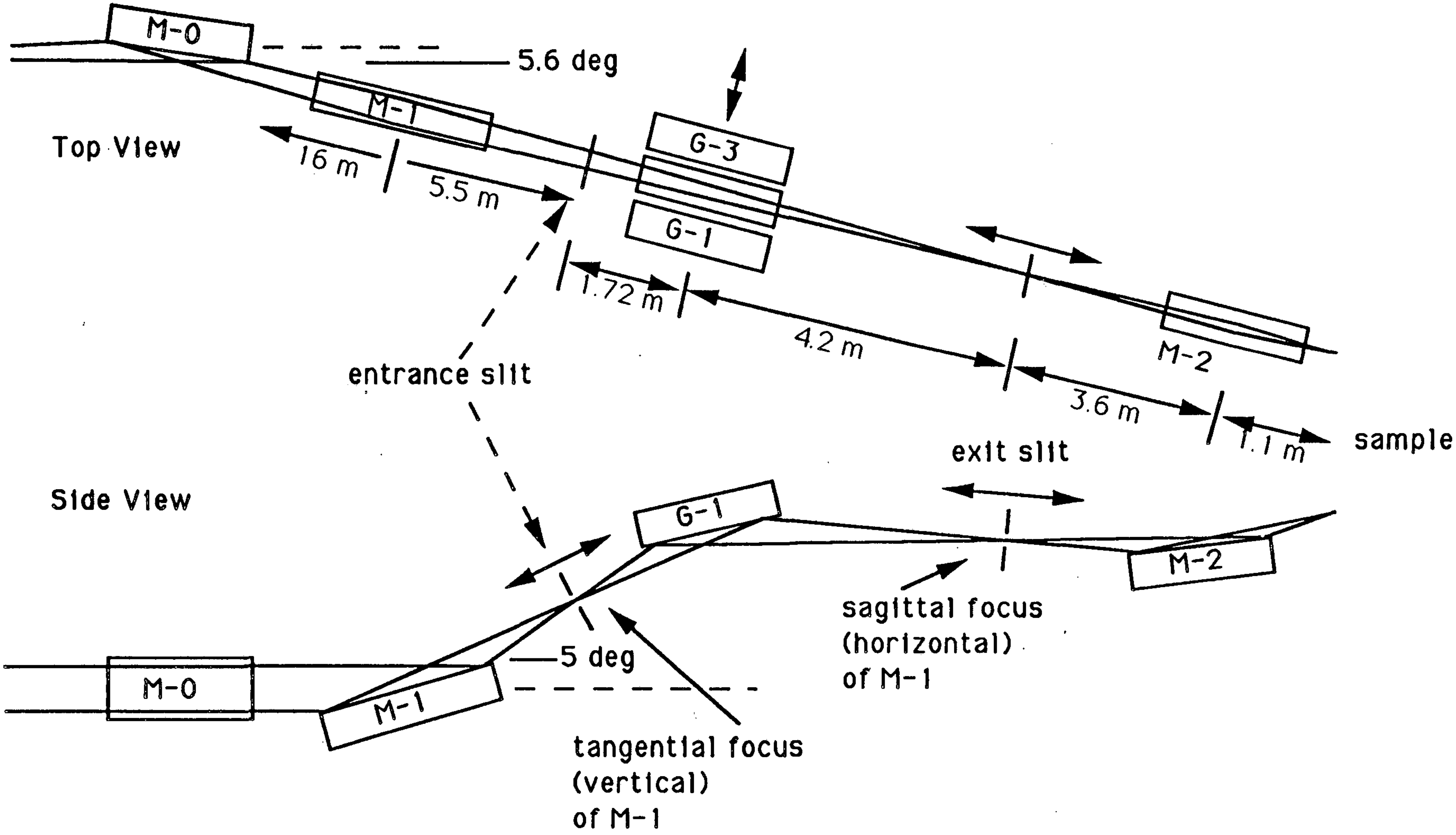
[2] Rense, W. A., and Violett. T. "Method of Increasing the Speed of a Grazing-Incidence Spectrograph," Journal of the Optical Society of America, 49 (1959), 139.

[3] Hogrefe, H., Howells, M. R., and Hoyer, E., "Application of Spherical Gratings in Synchrotron Radiation Spectroscopy," International Conference on Soft X-Ray Optics and Technology, Berlin, FRG, December 8-11, 1986, SPIE Vol. 733 Soft X-Ray Optics and Technology, 1987.

[4] Heimann, P. A., et al. "High Resolution Results from the LBL 55-Meter SGM at SSRL," proceedings of the Ninth International Conference on Vacuum Ultraviolet Radiation Physics, Honolulu, Hawaii, July, 1989 (to be published).

Figure 1. Optical Schematic



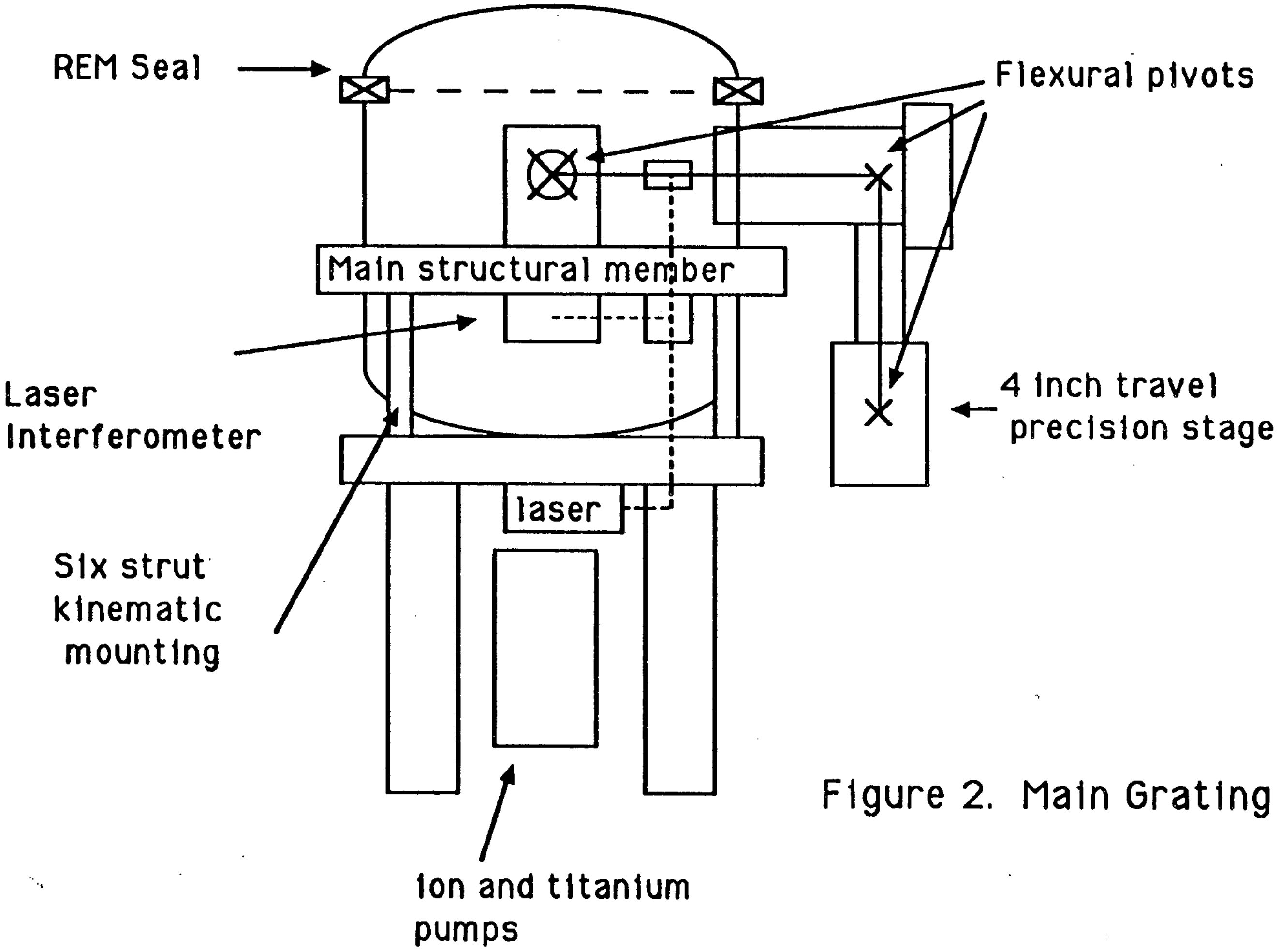


Figure 2. Main Grating Chamber

Wavelength readout system

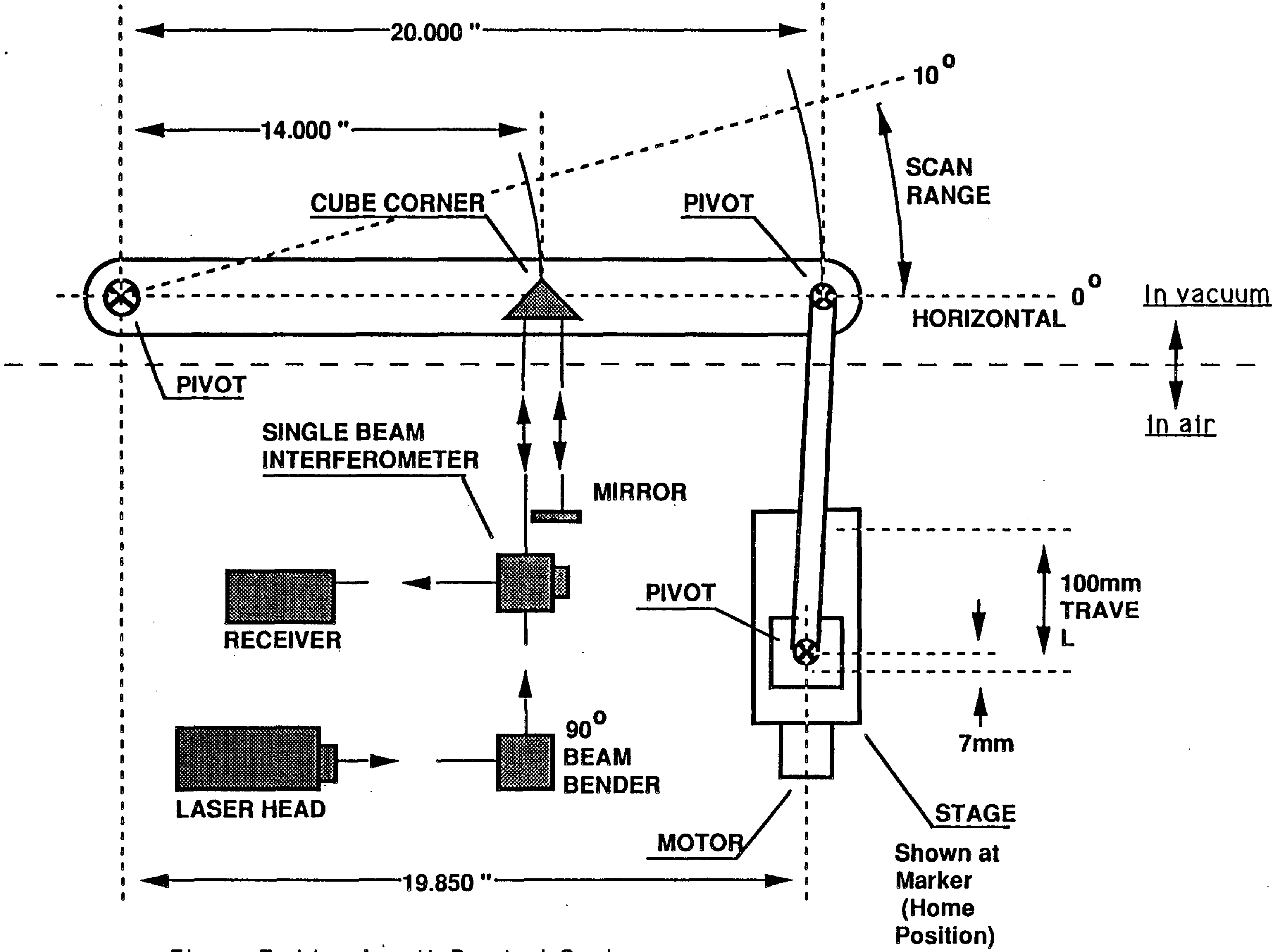


Figure 3. Wavelength Readout System

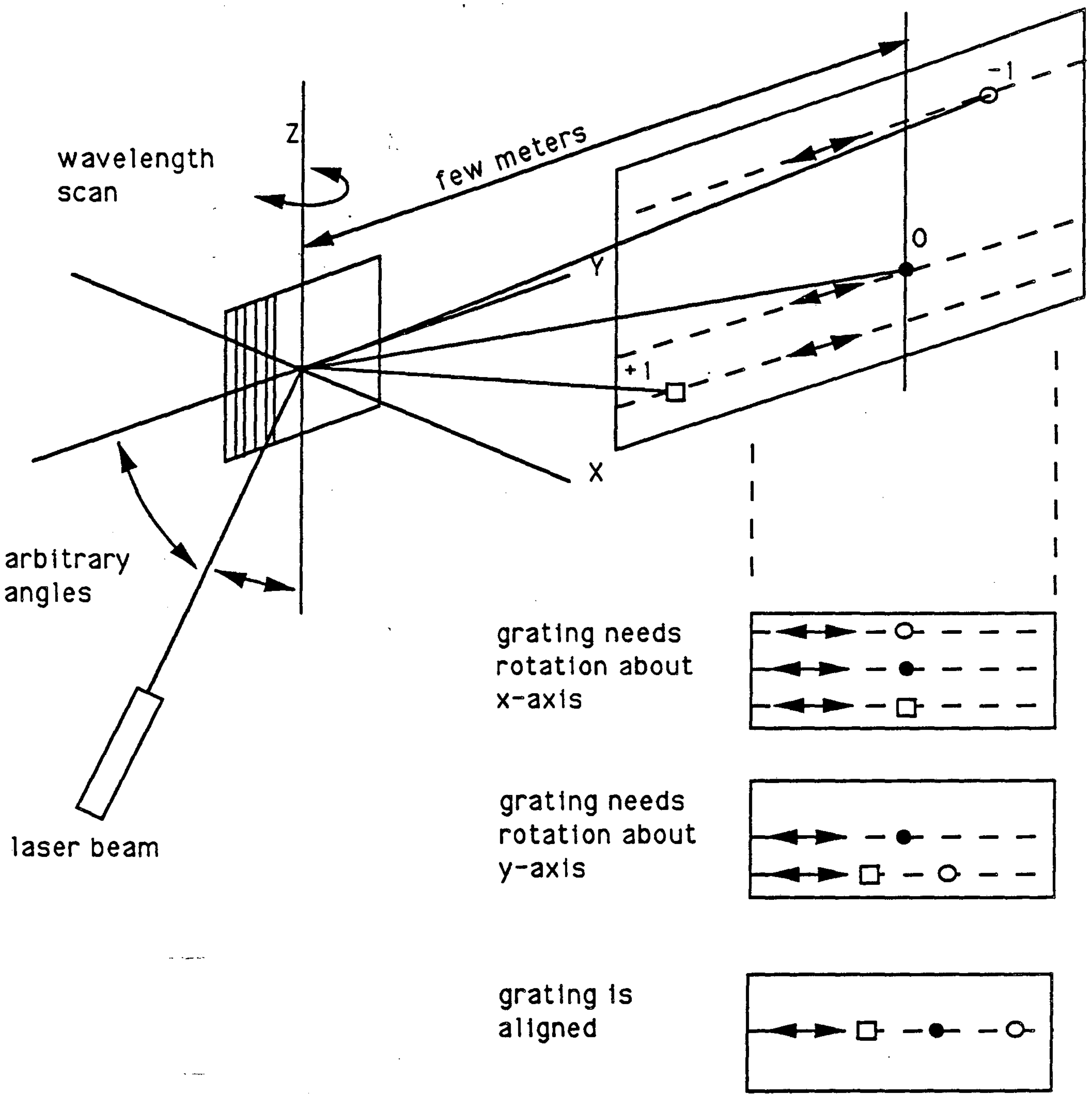


Figure 4. Adjustment of the grating grooves with respect to the wavelength drive's rotation axis. The dotted lines are swept by the diffracted laser beams when the grating rotates.

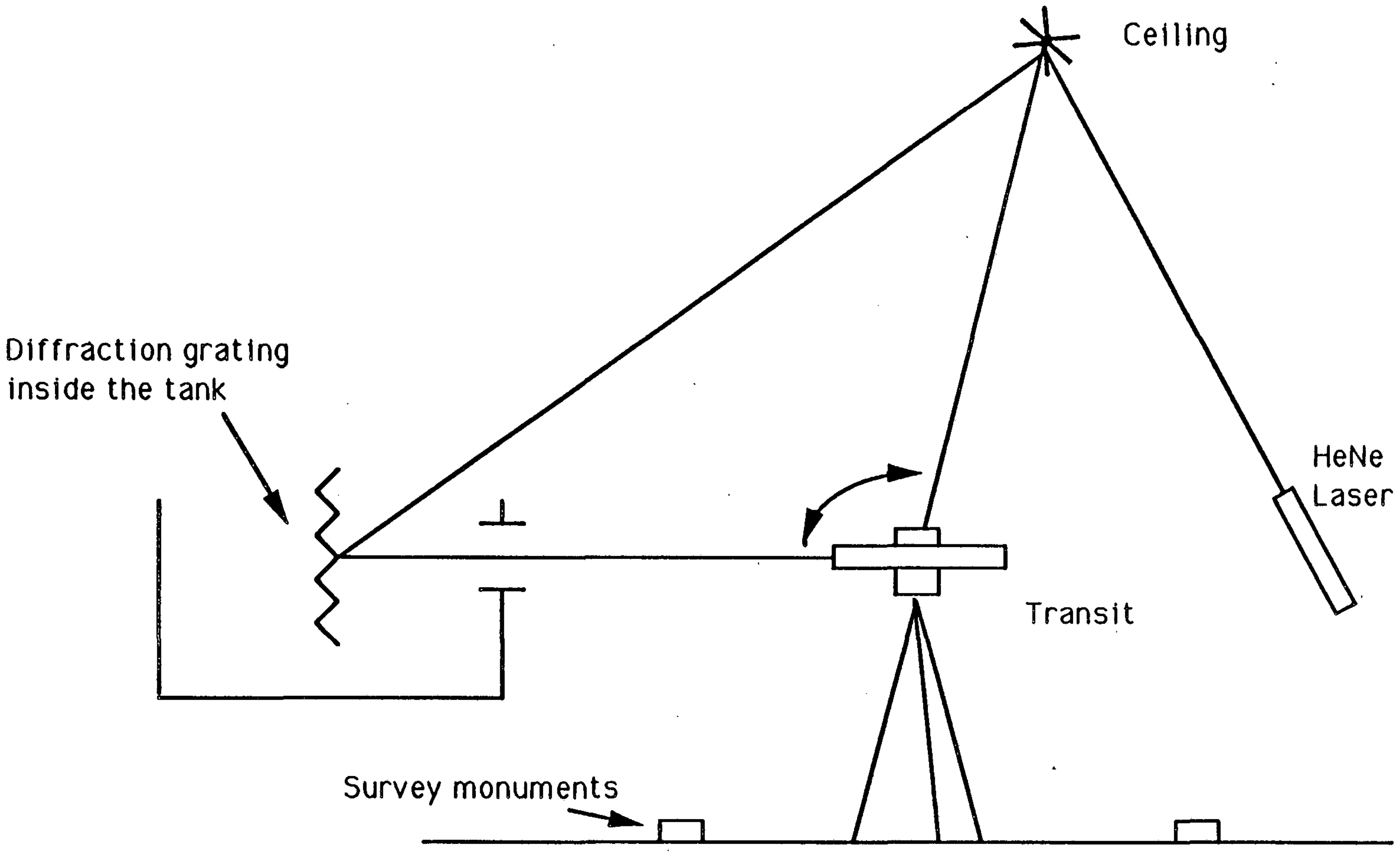


Figure 5. Alignment of the Grating Chamber

Figure 6. Monochromator output measured with an Al photodiode.

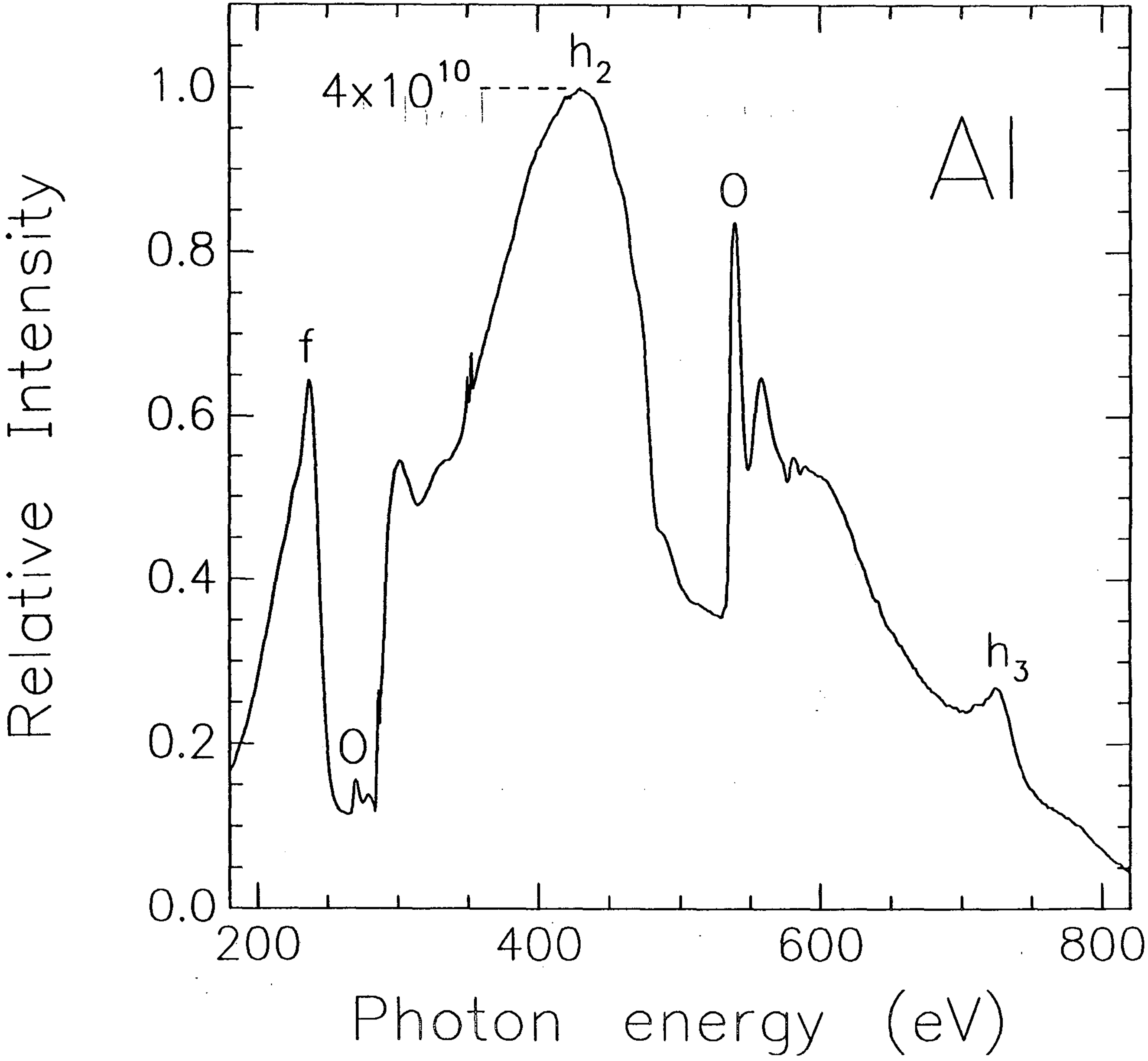


Figure 7. Spectrum of Nitrogen taken at 10 mtorr.