# Atomic Force Microscope Specification

## 6.8.83.1 Rev. 0

Date: October 8, 2002



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## REVISION HISTORY

| *Revision* | *Date* | *Description* | *Author* |
|---|---|---|---|
| A | September 27, 2002 | Original Draft | Brian Yates |
| B | October 8, 2002 | Editorial changes made. | Brian Yates |
| 0 | October 8, 2002 | Issued for use. | Brian Yates |

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# 1.0 INTRODUCTION

## 1.1 PURPOSE

An optical metrology laboratory will be set up at the Canadian Light Source, Inc. (CLS) to characterize the figure and the finish of the beamline optics. This document contains the technical specification for the atomic force microscope (AFM) within this laboratory.

## 1.2 SCOPE

This document specifies the requirements for the CLS Optical Metrology Laboratory atomic force microscope. This work includes, but is not limited to:

- Equipment
- Function and Performance Requirements
- Inspection, Testing and Commissioning
- Reliability and Maintainability
- Documentation
- Delivery to the CLS site
- Assistance in setting up the atomic force microscope at CLS

## 1.3 BACKGROUND

The Canadian Light Source is a national scientific research facility under construction at the University of Saskatchewan campus in Saskatoon, Saskatchewan, Canada. The CLS is a 3rd generation synchrotron light source, that will house a variety of scientific beamlines and their associated optics. This synchrotron facility will be a high intensity source of infrared, visible, ultraviolet, and x-ray radiation.

The CLS optics metrology laboratory shall be dedicated to optical surface characterizations in terms of figure, slope errors, and surface roughness. Measurements are generally carried out on the optical surface in non-contact mode, using optical instruments. The obvious exception to this is the atomic force microscope, which is essentially a contact mode technique between the probe tip and the optical surface.

The beamline mirrors will range in size from ~0.025m to 1.5m in length, and consist of a variety of substrate materials (i.e. Zerodur® glass ceramic, ultra low expansion glass ceramic (ULE®), fused silica, silicon, silicon carbide, Glidcop®)

and reflection coatings (rhodium, platinum, palladium, gold, nickel, graphite, or none). Typical reflectivities for the optics are >80%, both in the visible and x-ray regions. These optical elements can be quite large and heavy. A typical "long" mirror made of copper alloy may be 1.5 m (length) x 100 mm (width) x 100 mm (height) in dimension, and weigh ≤134 kg (~295 lbs).

Of primary importance for the atomic force microscope will be the measurements that are made on the beamline gratings. Measurements of the groove density (in lines/mm) or "d-spacing (d)" (in Å/line) variation, and the groove profile shape of these gratings will be of the utmost importance. For both constant and variable line spaced gratings, a precision ($\delta d/d$) of about 0.001% will be required along the entire length of the grating. In addition, the groove profile shape will be of critical importance, since this contributes to the grating efficiency (in both the desired order and generally undesired higher orders) and scattered light contribution.

A general groove density range for the gratings will be between ~100-2000 lines/mm. Both laminar (square wave groove profile) and original ruled gratings (saw-tooth groove profile) will be used at CLS, with similar substrate materials and reflection coatings being used as for the mirrors. For the laminar groove profiles, depths range from ~5-100 nm (50-1000 Å), groove periods range from ~50-500 nm (500-5000 Å), and land width to groove periods ratios range from ~30-50%. A typical grating made of copper alloy may be ≤300 mm (length) x ≤100 mm (width) x ≤100 mm (height) in dimension, and weigh ≤26.8 kg (59 lbs).

Table 1 illustrates the current CLS range of mirror/grating specifications. It does not currently include any supersmooth mirrors, although CLS has a keen interest in their future potential.

**Table 1: Summary of CLS Mirror/Grating Specifications**

| Measurement[1] | Minimum | Maximum | Tolerance (± %) |
|---|---|---|---|
| Toroid or Cylinder Mirrors: | | | |
| Radius of curvature- tangential[2] | $0.115 \times 10^3$ m | $10 \times 10^3$ m | <0.1[2] |
| Radius of curvature- sagittal[2] | 0.035 m | 0.833 m | <0.1[2] |
| Spherical Gratings: | | | |
| Radius of curvature | ~2 m | ~100 m | <0.1 |
| Slope error- tangential (rms)[3] | 1 µrad | 12 µrad | <10 |
| Slope error- sagittal (rms)[3] | 5 µrad | 25 µrad | <10 |
| Surface roughness (rms)[4] | 1 Å | 15 Å | <15 |

1 Clear aperture (width) general ranges from 25-60 mm. Width of optic is larger than this, but <~100 mm. Average clear aperture (width) ~30-40 mm. For these optical elements, the photon beam footprint generally underfills the clear aperture.
Occasionally 2-3 stripes of different reflective metals are put down, for harmonic order rejection and light intensity optimization.
Length of optics varies tremendously, from 25-1500 mm, and generally >90% is clear aperture (length).

2 Desirable tolerances. It is understood that different measurements are required for sagittal and tangential radius of curvatures (ROC's). The tolerance of <±0.1% can be often be relaxed to <±1%, if one has the freedom to alter the angle of incidence on the mirror by a few %.

3 For plane mirrors, slope errors <0.5 µrad are sometimes required.

4 For measurements on supersmooth planar mirrors, minimum~0.2 Å, maximum=1 Å, tolerance<±10%.

## 1.4 DEFINITIONS AND ABBREVIATIONS

| | |
|---|---|
| AFM | Atomic Force Microscope |
| PZT | Piezoelectric Transducer |
| PSPD | Position Sensitive Photodetector |
| FFT | Fast Fourier Transform |

Surface Texture Parameters:

| | |
|---|---|
| rms | Root-Mean-Square |
| $R_p$ | Highest peak within the sample. |
| $R_v$ | Lowest valley within the sample. |
| $R_t$ | Maximum peak-to-valley height over the sample. |
| $R_{max}$ | Vertical distance between the top of the highest peak and the bottom of the deepest valley within the sampling length, i.e. the maximum of all the peak-to-valley values ($R_t$). |
| $R_{tm}$ | Average peak-to-valley roughness. |
| $R_z$ | Average absolute value of the five highest peaks and the five lowest valleys over the evaluation length. |
| $R_a$ | Average surface roughness. |
| $R_q$ | Root-mean-square average of the measured height deviations taken with the evaluation length or area and measured from the mean linear surface. This represents the standard deviation of the profile heights. |
| PV | Peak-to-Valley |

## 2.0 REQUIREMENTS

The CLS optical metrology laboratory requires a complete high resolution atomic force microscope to measure the three dimensional surface profile of these beamline optics. Both 2D and 3D surface metrology measurements of the test surface will be required using “contact” mode. From the surface profile, required parameters like the surface roughness, slope profile/error and power spectral density need to be derived. “Intermittent contact mode” will be considered as an option, due to it’s additional experimental flexibility and superior profile measurement accuracy. The instrument will be located within a class 10000 cleanroom.

### 2.1 FUNCTION

A complete “stand-alone” atomic force microscope system is to be supplied. This should include the cantilever, tip/probe, motorized XY positioning stage with associated {servo,stepper}-motors and controllers/encoders, PZT tube with amplifiers/power supplies, laser source/position sensitive photodetector with associated controller electronics/power supplies, other necessary electronics/power supplies, interface cables, system and power cables for AC power operation, computer and required instrument interface boards, and software for control of the atomic force microscope and for data analysis. In addition, an integrated vibration isolation table and acoustic enclosure is to be provided. A list of required equipment to be supplied is furnished below. In addition, a list of optional equipment/service is supplied.

## Atomic Force Microscope (Required equipment to be supplied)

### System

| | |
|---|---|
| AFM environment | The atomic force microscope will be operated in ambient (air), within a Class 10000 cleanroom. |
| Measurement capability | 3D "contact" surface profile measurements. The (X,Y,Z) motion required to image the surface must be accomplished with a piezoelectric transducer (PZT) tube, and **not** via motion of the positioning stage. |
| Measurement techniques | Require "contact" AFM mode. |
| Light Source/Detector | Helium-Neon laser light source. Detector should be a position sensitive photodetector (PSPD) that is optimized for the HeNe laser light wavelength (632.8 nm). The preferable geometry would have the laser beam passing through the PZT tube, and bouncing off the cantilever before striking the position sensitive photodetector. |
| Image viewing | Dual colour monitors for simultaneous data acquisition/image display and management/control. |
| Sample stage/holder | A motorized (X,Y) positioning stage is **not** required to measure the beamline optics. However we will consider purchasing a motorized (X,Y) positioning stage and vacuum chuck (sample holder) **as an option** for the benefit of other University researchers– **for details see the optional equipment/service section**.<br><br>A frame spacer to provide increased clearance under the scanning head will be required, and should be provided in the quotation. |

| | |
|---|---|
| AFM "Geometry" | To measure the beamline optics, the motorized (X,Y) positioning stage and vacuum chuck need to be removed. Movement of the test optic will be done manually.<br><br>Test optics ≤300 mm (length) x ≤100 mm (width) x ≤100 mm (height) in dimension **must** be able to fit underneath the scanning head within the vibration isolation table/acoustic enclosure – this should allow all the critical grating measurements to be performed. Weight of such optical elements ≤26.8 kg (59 lbs). A frame spacer will be required to provide increased clearance, and should be provided.<br><br>Measurements on the optics that are longer than this (i.e. ≥300 mm (length) but ≤1500 mm (length)) should be performable on the instrumentation in some fashion- e.g. via removal or rearrangement of the acoustic enclosure and perhaps a longer supplied table. Weight of such optical elements ≤134 kg (~295 lbs).<br><br>We **request** that the manufacturer respond to these issues in the documentation provided in the quotation and show how the proposed system might allow such measurements, albeit at perhaps reduced resolution. |
| vibration isolation table/ acoustic enclosure | An integrated vibration isolation table and acoustic enclosure is to be provided. |
| Tip Viewing | AFM scanning cantilever/probe and test optical surface should be viewable on axis in real time via microscope optics. A motorized zoom and focus, computer-controlled illumination, and video image capture should be available. |

**Computer and Software**

A minimal computer system would consist of the following components:

1. ≥Pentium III CPU (≥1 GHz speed)
2. ≥17 inch, ≥SVGA dual colour monitors for simultaneous data acquisition/image display and management/control
3. ≥256 MB RAM
4. ≥20 GB Hard Drive
5. CD-RW drive
6. 3.5 inch 1.44 MB Floppy disk drive
7. mouse
8. keyboard
9. RS-232 interface
10. parallel port (minimum of 1)
11. no printer required, but software must support printing to network printer
12. 10/100 Mbps ethernet network card (100BaseT)
13. interface boards required to control the atomic force microscope
14. computer cables and interface cables to the atomic force microscope
15. computer operator's manuals
16. Microsoft Windows 2000 Professional or XP Professional operating system preferably, supporting TCP/IP for networking (no NetBEUI, netware, etc.)

See sections 2.1.1 and 2.1.2 for additional details on computer/software requirements.

## Optional Equipment/Service

| | |
|---|---|
| Measurement capability | 3D "Intermittent contact mode" upgrade option (from "contact mode"). Specify details for this complete "upgrade" option. |
| Sample stage/holder | A motorized (X,Y) positioning stage would be of benefit to other University researchers. The stage should be able to inspect an area of ~125 mm x ~100 mm, and allow manual rotation. A standard 150 mm vacuum chuck (sample holder) with vacuum pump should be included so that semiconductor wafers can be measured.<br><br>**Note:** The motorized (X,Y) positioning stage and vacuum chuck (sample holder) **must be removable**, since the beamline optics will be measured **with the positioning stage and vacuum chuck removed**. |
| reference standards for instrument calibration | 1) Lateral calibration standard(s) are to be supplied, to calibrate the lateral (X,Y) distances measured. NIST traceable preferred.<br><br>2) An approximately 25 mm wide precision reference flat (SiC preferred) should also be supplied, with flatness ≤12.5 nm (≤125 Å) and surface roughness ≤0.2 nm (≤2 Å). NIST traceable preferred.<br><br>3) A step height standard is to be supplied, to calibrate the Z-direction distances measured. Since the vertical structure in some of our laminar gratings is ~≤100 nm, a similar step height to match would be ideal. NIST traceable preferred. |
| recommended spare parts | A schedule of recommended spare parts should be included, with pricing. |

| | |
|---|---|
| Service Options | List all applicable for the first year, that go beyond the standard warranty (e.g. extended warranty, priority support, etc.). |

2.1.1 The manufacturer shall provide the computer hardware and software required for the operation of the atomic force microscope. Since the instrument will be located in a Class 10000 cleanroom, the system should be capable of printing to a network printer. The ethernet network card and software should be configured for DHCP over TCP/IP. Should the control software require an alternate operating system, our preferences are secondly Red Hat Linux 6.2 or higher, or thirdly Microsoft Windows NT.

We **request** that the manufacturer state what permission the control system software requires (i.e. administrator, power user, user, restricted user)- our preference is for user (or restricted user), so that a user cannot accidentally delete system files or alter configurations.

2.1.2 The software supplied by the manufacturer for controlling the atomic force microscope should allow the user to measure the surface roughness, slope profile/error, amplitude/power spectrum, and power spectral density. The software should be able to display the surface as a function of surface heights, in either 2D or 3D formats.

AFM imaging software and a full complement of image analysis software should be available.

2.1.2.1 File Specification and file compatibility: CLS needs to be able to compare measurements made on multiple instruments to look at different spatial scales. The ability to read in surface map files from other instruments is a plus. At the very least, the vendor needs to provide a description of their file format sufficient to enable reading of their data into a MathCAD array.

We **request** that the manufacturer outline the following issues with respect to the software supplied –

1. What type of Import/Export data file capabilities exist in the software? List the file formats that are supported for each. (JPEG, ASCII, etc).

   Can the software read/write data files from other instruments, from the same manufacturer? Specify details.

   Can the software read/write data files from other instruments, from different manufacturers? Specify details.

2. What file format conversion routines/programs (other than the Import/Export option) are there available?

3. Are dynamic link libraries (dll) supported for customized data file format input/output?

4. Are the file structures of the data collected by the instrument available in the documentation that will be made available upon purchase? If

not, can the file structures required be obtained free of charge from the manufacturer? If not (to both prior questions), is this because the file structures are considered proprietary?

2.1.2.2 The software should support the ANSI 2D “R-values”, and their 3D “S-value” analogs. The following surface statistics are considered minimum requirements:

1. Extreme Amplitude Results - $R_p$, $R_v$, $R_t$, $R_{max}$
2. Averaged Extreme Amplitude Results - $R_{tm}$, $R_z$
3. Averaged Amplitude Results - $R_z$, $R_a$, $R_q$ (rms)

2.1.2.3 The following slope results should be available- Peak, Valley, PV, rms, and average, in angular or "pitch" (rise/run) units.

2.1.2.4 In addition, the user should be able to filter the data using most of the following:

1. Average, low pass or high pass filters
2. FFT High Pass, Low Pass, Band Pass, and Band Reject filtering
3. Filtering to remove Plane, Sphere, or Cylinder figure from surfaces, which is of critical importance for our beamline optics. Removal of polynomials up to $4^{th}$ order is desirable.

2.1.2.5 The software needs to have the capability of subtracting measurements on a point-by-point basis. It is necessary to have this capability at the level of a button or dialog box without having to prompt the user for a filename and manually subtracting files.

2.1.2.6 A topographic surface map representing the “instrument error” surface needs to be easily generated by the user. This surface is generated by averaging 15-30 measurements of a reference surface with randomly distributed roughness as the surface is moved between measurements. This “instrument error” surface will be affected by changes in the tip/tilt of any optical surface in the path so only the test surface should be tilted. Focus can be adjusted between measurements to ensure the best possible estimate of the “instrument error” surface. This “instrument error” surface needs to be able to be automatically subtracted from subsequent measurements without user prompting.

2.1.2.7 It is desirable to have an automatic mode for taking measurements that can be set up by the user. This mode should enable the user to set up measurement times or measurement intervals and save either all the data or save specific statistical and calculated data to a database.

2.1.2.8 Scale factors that can be calibrated are necessary for vertical and lateral calibration.

## 2.2 PERFORMANCE

The following table is a summary of the desired performance specification requirements for the atomic force microscope:

**Table 2: Atomic Force Microscope Performance Specifications**

| | |
|---|---|
| Vertical (Z) range | ~6 µm |
| Vertical (Z) Noise Level[1] | ≤ 0.05 nm (0.5 Å) rms |
| Lateral range | X-Y imaging area up to ~90 µm square |
| Lateral resolution[2] | ~5 nm (50 Å) |
| Lateral accuracy | 1% typically, 2% maximum (of scan length) |
| PZT tube resolution | Full 16-bit resolution on all axes (X,Y,Z) of the sample surface, for all scan sizes and offsets. |
| "Image" data resolution | Software should allow ≥512 x ≥512 "pixels", for the selected scan size. |
| Beamline Optics[3] - Sample Size | Optics ≤300 mm (length) x ≤100 mm (width) x ≤100 mm (height) in dimension **must** be able to fit underneath the scanning head within the vibration isolation table/acoustic enclosure– this should allow all the critical grating measurements to be performed. Weight of such optical elements ≤26.8 kg (59 lbs).<br><br>Measurements on the optics that are longer than this (i.e. ≥300 mm (length) but ≤1500 mm (length)) should be performable on the instrumentation in some fashion– e.g. via removal or rearrangement of the acoustic enclosure and perhaps a longer supplied table. Weight of such optical elements ≤134 kg (~295 lbs).<br><br>We **request** that the manufacturer respond to these issues in the documentation provided in the quotation and show how the proposed system might allow such measurements, albeit at perhaps reduced resolution. |
| Measurement of grating groove density (lines/mm) | A precision (δd/d) of about 0.001% will be required along the entire length of the |

| | |
|---|---|
| or “d-spacing (d)” (Å/line) | grating. |
| Optical microscope to view AFM probe tip and test optical surface | Resolution of ~≤1.5 µm<br>~150-675 µm horizontal viewing area.<br>Motorized zoom and focus.<br>Computer-controlled illumination.<br>Video image capture should be available. |
| Motorized Positioning Stage[3] | Resolution ~≤2µm<br>Repeatability (unidirectional)- ~≤3µm typical, ~≤10µm maximum<br>Repeatability (bi-directional)- ~≤4µm for x-axis, ~≤6µm for y-axis typical<br>Inspectable area ~125mm x ~100mm<br>Manual sample rotation. |

[1] Unless stated otherwise, measurements are to be taken using the vibration/acoustic isolation system supplied by the vendor.

[2] Using the smallest tip radius available.

[3] To measure the beamline optics, the motorized (X,Y) positioning stage and vacuum chuck need to be removed. Movement of the test optic will be done manually. A frame spacer will be required to provide increased clearance.

## 2.3 SAFETY AND ENVIRONMENTAL

2.3.1 The atomic force microscope will be operated in ambient (air), within a Class 10000 cleanroom.

2.3.2 The temperature in the Optical Metrology Laboratory Facility will be $23^{o}C \pm 1^{o}C$. The normal relative humidity is expected to vary between 20% and 55%.

2.3.3 Software limit switches for the (X,Y) positioning stage should be available, in order to prevent a run-away condition, and possibly damaging the test surface.

## 2.4 APPLICABLE CODES, STANDARDS AND PROCEDURES

The manufacturer shall comply with the codes, standards, and procedures for the CLS[1], or identify in the quotation how they deviate.

## 2.5 QUALITY ASSURANCE

The manufacturer shall maintain and apply a quality assurance program compliant with ISO-9001 for the design, manufacture and testing of the equipment.

## 2.6 INSPECTION, TESTING AND COMMISSIONING

2.6.1 The manufacturer shall propose a series of acceptance tests to verify the performance specification requirements listed in Table 2. The acceptance tests and the test equipment used shall be reviewed and approved by CLS.

Acceptance tests similar to those found in Appendix A of the Non-contact Surface Profiler Specification *(6.8.83.4 Rev. 0)*, with appropriate modifications to make it suitable for the Atomic Force Microscope, would be satisfactory.

2.6.2 The acceptance tests will take place at the manufacturer's plant before shipment, and then repeated after the atomic force microscope has been installed at CLS. The manufacturer is responsible for setting up, commissioning and acceptance testing the atomic force microscope at the CLS with the assistance of CLS personnel.

## 2.7 RELIABILITY AND MAINTAINABILITY

The manufacturer shall provide hard copies of an operating and maintenance manual for the atomic force microscope, including electrical drawings/wiring diagrams and AutoCAD or Visio drawings, as outlined in the CLS documentation specification[2]. Hard copies[2] of a spare parts list should be provided, with the manufacturer part numbers and current prices. The manufacturer shall also provide hard copies[2] of a detailed parts list, with original manufacturer's part number, name, address, and telephone number. An electronic version of these manuals, diagrams, drawings, and spare/detailed parts lists are to be provided on CD-ROM (in addition to the hard copies). All manuals, documentation and lists are to be written in English. In addition, software source code for the control program should be included on the CD-ROM (if this cannot be provided for proprietary reasons, a statement to that effect **must** be included in the supplied quotation documentation). The original third party component manuals (i.e. computer, {servo,stepping}-motors and controllers/encoders, power supplies, HeNe laser source, position sensitive photodetector, etc.) should also be supplied.

## 2.8 VIBRATION AND ACOUSTIC NOISE

2.8.1 The vibrations in the main floor of the CLS hall have amplitudes in the sub-micrometer range, and should not affect the measurements. The manufacturer will supply a vibration/acoustic isolation enclosure however, to ensure independence from such environmental effects, and allow measurements at the CLS to reach the performance specifications outlined in Table 2.

## 2.9 SERVICES

2.9.1 The manufacturer shall state the detailed requirements for all services (for example- water [purity, pressure range, flow rate, recommended temperature range], pressurized air [purity and recommended filter equipment, pressure range], electrical services, etc.), needed for the operation of the atomic force microscope. Pressurized air, if required, shall not exceed 80 psi.

2.9.2 The electrical services available are 120 V AC and 208 V AC, 60 Hz. The manufacturer shall state the electrical services needed, including the power requirements for each voltage needed. CLS would prefer 120 V AC, 60 Hz service if possible.

### 2.10 OTHER REQUIREMENTS AND CONSTRAINTS

2.10.1 All documentation to the CLS shall be in English and conform to the CLS documentation specification [2].

2.10.2 The shipping containers shall be properly labeled in English to ensure proper care during shipment.

2.10.3 Crates shall be designed such that they can be moved using standard handling devices (forklift or pallet jack).

2.10.4 Tolerances and specifications, where not defined or difficult to achieve, are subject to negotiations.

## 3.0 REFERENCES

1 E. Matias, “Control System Technical Specification”, 7.4.39.1 Rev. 2, April 24, 2002.

2 D.S. Lowe, “CLS Documentation Specification”, 0.4.1.1 Rev. 2, December 14, 2000.