Specifications for Scanning Electron Microscope System

The Naval Research Laboratory, Washington, DC (NRL-DC) requires a computer-controlled Schottky field-emission scanning electron microscope (SFE-SEM) system for use by researchers in imaging and measurement of nanometer – millimeter size features. The instrument must be capable of imaging a wide variety of structures defined through lithographic processes on both conductive and insulating substrates. The system must provide automated control of primary beam parameters, stage motion, image acquisition and archiving. The SEM instrument must have an electrostatic beam blanker. Optional subsystems specified in this document are an Energy Dispersive Spectrometer (with light element capability), an Electron-beam Writer Attachment, and an optical microscope capable of viewing the surface of a sample with reflected light. The system will be installed at NRL-DC and be used by a variety of qualified scientists, engineers and technicians. The contractor will furnish all labor, material, tools, and transportation for installation of the system.

Abbreviations

EDS	Energy Dispersive Spectroscopy
eV	electron Volts
keV	Kilo-electron Volts
kV	KiloVolts
kX	Magnification, in units of 1000
nA	nanoAmp
nm	nanometer
mm	millimeter
pA	picoAmp
SEM	Scanning Electron Microscope
TTL	Transistor-transistor logic

The contractor shall meet or exceed the following specifications:

1.0 Scanning Electron Microscope (SEM)

1.1 Accelerating voltage range. 0.2 – 30 kV

1.2 Resolution.

1.2.1 Less than or equal to 1.2 nm at 20 kV for working distance within the range of 1 – 10 mm.
1.2.2 Less than or equal to 2.5 nm at 1 kV for working distance within the range of 1 – 10 mm.
1.2.3 Less than or equal to 5.0 nm at 0.2 kV for a working distance within the range of 1 – 10 mm.

1.2.4 Resolution must be demonstrated to meet or exceed these specifications after installation at the NRL site using NRL-supplied standard resolution samples (e.g. gold on carbon).

1.3 Magnification. 25X – 750kX, minimum. The magnification indicators must automatically correct for changes in operating voltage and/or working distance.

1.4 Beam current (measured at stage).

1.4.1 Minimum range of beam current: 5 picoAmp – 10 nanoAmp.
1.4.2 Beam current variation less than or equal to 0.5% per hour.
1.4.3 Beam current noise less than or equal to 1%.
1.4.4 A calibrated beam current ammeter must be supplied with the instrument.
1.4.5 A Faraday cup must be supplied to allow accurate beam current measurement.

1.5 General Source and Column Requirements.

1.5.1 Automatic run-up of electron source required.
1.5.2 Display of beam voltage, emission current, filament current and column vacuum.
1.5.3 Computer control of stigmation, working distance (focus), focus wobble, and magnification required.
1.5.4 Dynamic focus/automatic tilt compensation required.
1.5.5 The system must be configured with high-speed, electrostatic beam blanking capability. External control of the beam blanker is required via digital TTL (transistor transistor logic) or similar interface.
1.5.6 Must have electronic beam shift capability of 10 micrometers in x and y directions.
1.5.7 A minimum of five beam apertures required. Apertures must be settable through computer control.
1.5.8 Working distance range: 3 – 20 mm, minimum.

1.6 Chamber Detectors

1.6.1 Phosphor scintillator detector with optically coupled photomultiplier, standard configuration in chamber.
1.6.2 In-the-lens scintillator detector with optically coupled photomultiplier.
1.6.3 Internal video camera image of stage.
1.6.4 (Optional) Cathodoluminescence detector.

1.7 Imaging Modes

1.7.1 Must have raster scan mode.
1.7.1 Partial field raster/image capability must be provided. The x and y dimensions of the partial field image must be independently adjustable up to the entire screen size. Partial field position must be adjustable over the entire range of the screen. There must be a movable cursor available in both full and partial field images.

1.7.2 Must have spot mode capability, with spot position capable of being placed at any position within the field of view.
1.7.3 Must have linescan mode.
1.7.4 Must have image averaging display mode, allowing noise reduction by averaging successive frames of an image raster. The system must be capable of averaging at least 4 successive raster frames.
1.7.5 The microscope must provide digital images with a resolution of at least 1024x768 pixels. Files must be capable of storage in the TIFF (tagged image file format) format.
1.7.6 External control. The system must allow external control of electron beam raster and video capture.
1.7.7 (Optional) Archival software and storage for multiple users allowing thumbnail display and selection of stored files in a central database.

1.8 Specimen Chamber and Stage

1.8.1 The specimen chamber must be large enough to accommodate specimens of at least 6 inch diameter and 0.25 inch height. The specimen chamber must accommodate the secondary electron detector and optional X-ray detector, viewport/airlock and electrical feedthroughs. The specimen chamber must be mounted in such a way as to be isolated vibrationally from the workstation.
1.8.2 The system specimen stage must allow motorized travel in each of the five axes x, y, z, tilt and rotation. Each axis must meet the requirements as listed below:
a. x, y travel range: 100 mm, minimum (with at least 10 micrometer positional accuracy)
b. z travel range: 50 mm, minimum
c. must have continuous rotation
d. Tilt: 0 – 70 degrees, minimum
1.8.3 (Optional) External interface control. The system must provide a digital interface to allow the stage to be programmed to coordinates defined in third party applications.
1.8.4 (Optional) Stage navigation software allowing the user to position the stage at any x, y, z and rotation coordinate by computer control by both absolute and relative motion commands. Software must include ability to rotate stage at any sample point and maintain the sample x-y coordinate (imaged point) in the SEM field of view. (This applies for the field of view 10 micrometers or greater.)

1.9 Vacuum System

1.9.1 The vacuum system must provide an oil-free specimen chamber. There must be a gun isolation valve that is interlocked with the airlock and the accelerating voltage control. The electron gun chamber vacuum must be 10 nanoTorr or less. A gauge for measurement of the vacuum in the specimen chamber must be provided. Base vacuum of the chamber must be 5 microTorr or less.
1.9.2 Pumpdown time. Systems not equipped with an intro chamber must be capable of secondary electron image generation in five minutes or less after initiation of pumping sequence. (See optional intro chamber requirements below.)

1.9.3 The evacuation and up-to-air procedures must be automatic and equipped with fail-safe interlocks to prevent catastrophic failure.

1.9.4 (Optional) Airlock/Specimen Introduction. The microscope design may include an airlock for the introduction of specimens to the chamber. The dimensions of the introduction port and the airlock must be large enough to accommodate at least 3 inch diameter silicon wafer samples. Introduction of samples from the airlock into the chamber should be guided to ensure proper positioning. The pumpdown time for the airlock must be less than or equal to 1 minute in order to allow rapid specimen exchange. Systems with this option must be capable of allowing entry of samples up to 6 inch diameter x 0.25 inch, either through the intro chamber or main chamber door.

1.10 Computer System.

1.10.1 Operating system: Windows OS required; Windows NT 4.0 or Windows 2000, or later version.
1.10.2 Processor: Intel Pentium III or higher, 550 MHz or higher.
1.10.3 128 Mbyte RAM, minimum.
1.10.4 Network capability: Must have 10 – 100 BaseT capability.
1.10.5 Hard drive, 9 Gbyte, minimum. (Preference given for SCSI or other high-speed data buses.)
1.10.6 Must provide RW CD-ROM and ZIP-drive storage.
1.10.7 Minimum one 18" or larger flat panel display. (All displays must be flat panel type.)
1.10.8 Backup hard drive containing all software and control parameters necessary to operate the instrument is required.

1.11 Health/Safety Requirements.

1.11.1 The system must include radiation leak shielding consistent with U.S. Navy Radiological Affairs Support Program Manual (RAD-010), Item 9.5.1-15. Electrical systems must comply with 29CFR Part 1910, Subpart S, Occupational Safety and Health Standards for General Industry. Safety interlocks must be provided to prevent system damage or personal injury.

1.12 Training.

1.12.1 The contractor shall provide on-site (NRL-DC) operator training for at least 5 NRL employees for a minimum of two days. Operator training must include SEM operation and routine maintenance procedures following installation of the instrument. Training must be done within four weeks of completion of testing and acceptance of the instrument.
1.12.2 Two operator manuals must be provided.

1.13 Warranty and Service.

1.13.1 The contractor shall provide a commercial warranty for a four year period to cover travel, parts, and labor (Total coverage: Basic 1 yr + 3 yrs).

Items in Section 1.14 are Options

1.14 SEM Options.

1.14.1 The contractor shall provide a high resolution color dye-sublimation printer having resolution of 1280 x 1038 or higher and be capable of printing to 8 ½" x 11" paper or print.
1.14.2 The contractor shall provide a water-water cooling system having sufficient cooling power to maintain operation of SEM system. NRL will provide sufficient primary chilled water through the site's process water system.
1.14.3 The contractor shall provide an uninterruptible power supply to provide conversion and filtration of NRL base power and battery lifetime to support the SEM system under full operational load conditions for at least five minutes.
1.14.4 The contractor shall provide a magnetic field cancellation system having three-axis active cancellation. Performance must be equivalent or better than the Model SC-12 manufactured by Spicer Consulting (Bedfordshire, UK).
1.14.5 The contractor shall provide 640 square feet wall-coating material for acoustic noise reduction. Material must be SONEXone™ 3-inch thick Hypalon or performance equivalent provided by illbruck, Inc., Minneapolis, MN. NRL-DC personnel will install the material.

Items in Section 2 are Options

2.0 Energy Dispersive Spectrometer (EDS)

2.1 EDS System Components

2.1.1 The system must include:
a) a Si-Li x-ray detector.
b) digital pulse-processing electronics.
c) multichannel analyzer.
d) computer and software for data acquisition, storage, and quantitative composition analysis.

2.2 EDS Detector

2.2.1 The detector crystal must have an active area of 30 square millimeters.
2.2.2 The energy resolution of the detector (full-width at half maximum) must be less than or equal to 136 eV at 5.898 keV (Mn K-alpha) at a count rate of 1000 counts per second.
2.2.3 The system must be configured with an atmospheric window and be able to withstand 1 Atmosphere or more of pressure.

2.2.4 The detector and window must have enhanced "light element" capabilities for elements having low atomic mass. The system must be capable of detecting elements having atomic mass of 5 amu (boron) or greater.

2.2.5 The atmospheric thin window must be opaque to ambient levels of visible light to eliminate excitation of the detector by cathodoluminescence of specimens.

2.2.6 If the detector is cooled, it must be equipped with a temperature or liquid-level monitor to shut down the high-voltage detector power to prevent damage in the event of detector warm-up and sound an alarm in time to allow maintenance prior to warm up. It must be possible, without damage to the detector, to allow it to warm to room temperature when not in use. Cool-down to operating temperature must be automatically monitored to allow start-up only after sufficient detector cooling.

2.2.7 The EDS detector must be equipped with a magnetic electron trap to prevent backscattered electrons of energies up to 30 keV from reaching the detector crystal or producing spurious x-ray peaks by exciting elements in the detector window. The performance of the electron trap must be sufficient to give a spectrum from a pure Cu (copper) specimen with a Cu K-alpha peak-to-background ratio of at least 4000 to 1 taken with a 30 keV electron beam energy and a 45 degree x-ray take-off angle from the specimen surface. The spectra from a pure Cu specimen taken at a 45 degree x-ray take-off angle and electron beam energies of both 30 and 3 keV must be free from spurious x-ray peaks from elements in the detector window for integrated x-ray spectra of at least 50,000 total counts.

2.3 EDS Software for Acquisition, Quantitative Analysis, and Display.

The system must include a complete integrated software package for the following:

2.3.1 spectral data acquisition for a point and rectangular region.

2.3.2 automatic and manual peak identification and labeling.

2.3.3 high-performance quantitative analysis for both standardless analysis and analysis with standards.

2.3.4 automatic and manual spectrum calibration.

2.4 Computer.

2.4.1 The contractor shall provide a computer capable of performing the required spectral, graphics, and mapping operations described herein with a minimum processor speed of 550 MHz. Flat panel monitors must be provided for all computers. The vendor may utilize the same computer used to control the SEM for this subsystem with concurrence of the SEM vendor. The computer must support Transport Control Protocol / Internet Protocol (tcp/ip) protocols over 10-100 Base-T ethernet.

2.5 EDS/SEM Interface

2.5.1 The system must have a detector interface and the necessary electrical connections to the digital field emission SEM.

2.5.2 The system must be interfaced to operate on a digital field emission SEM such that the vacuum integrity of the microscope is maintained in the presence of the necessary electronic and mechanical connections.

2.6 Health/Safety Requirements.

2.6.1 The system must include radiation leak shielding consistent with U.S. Navy Radiological Affairs Support Program Manual (RAD-010), Item 9.5.1-15. Electrical systems must comply with 29CFR Part 1910, Subpart S, Occupational Safety and Health Standards for General Industry. Safety interlocks must be provided to prevent system damage or personal injury.

2.7 Training.

2.7.1 The contractor shall include on-site (NRL-DC) operator training for at least 5 NRL employees for a minimum of two days. Operator training is to include EDS operation and routine maintenance procedures following installation of the instrument. Training must be done within four weeks of completion of testing and acceptance of the instrument.

2.7.2 Two operator manuals must be provided.

2.8 Warranty and Service.

2.8.1 The contractor shall provide a commercial warranty for a four year period to cover travel, parts, and labor (Total coverage: Basic 1 yr + 3 yrs).

Items in Section 3 are Options

3.0 Ebeam Writing Attachment.

The ebeam writing attachment allows an external system to control the x-y raster and beam blanking electronics of the SEM for writing of computer-designed features into ebeam resist. The system must provide computer aided design (CAD), drive electronics and support software. The following are requirements for such a system.

3.1 CAD Requirements.

3.1.1 The CAD software must allow for easy creation of lines, filled squares, filled rectangles, filled circles and filled polygons of arbitrary side length and up to 200 vertices. The software must also allow easy creation of unfilled circles and polygons.

3.1.2 The software must allow for user placement of coordinate system origin and have the capability to provide distance measurements between any two points in an (x,y) format.
3.1.3 The software must be capable of reading and storing pattern information using industry standard Calma GDS-II stream file format files.
3.1.4 The CAD must allow for definition of the beam scan axis along an axis chosen by the user. For circular structures, the CAD must execute beam scan tangential to the circumference.
3.1.5 Automatic fracturing of large patterns is required to allow the scan axis to automatically orient to the longest side of a fractured sector of a feature.
3.1.6 Each unique feature must have an associated dose control that specifies the dwell at each exposed pixel.
3.1.7 The CAD system must have minimum position resolution capability of 1 part in 65,536 in each of the x and y directions, or better, over the full file image.
3.1.8 The CAD must be capable of manipulating at least 16 separate layers identified with unique colors or fill styles.
3.1.9 The CAD must allow easy construction of array structures from the definition of a single element of the array and copy/move commands.
3.1.10 The CAD software license must allow concurrent operation for up to 2 copies running on different computers.

3.2 Physical Interface.

3.2.1 The system must provide x, y (scan) and z (blanking) signals as outputs and be capable of monitoring the SEM video image. External cables to interface to the SEM must be provided.
3.2.2 The system must be capable of scanning between full scale x and y voltage limits with a settling time not to exceed 10 microseconds when connected to the microscope.
3.2.3 The system must be capable of providing a TTL blanking signal at a rate equivalent to 100 kHz, or higher.
3.2.4 The x and y output voltages must be deglitched.
3.2.5 The e-beam writing system must be capable of a minimum of 16 bit resolution (1 part in 65536) of the x and y voltage range.

3.3 General.

3.3.1 Alignment markers: The system must allow screen capture of at least three independently configurable subfields of the full scan area to allow for overlay of the CAD image to sample alignment features.
3.3.2 The system must allow for placement of alignment markers and implement an automatic alignment algorithm to establish a coordinate system on the sample relative to the CAD coordinate system. The system must have and easily implement combined rotation, shift, and magnification adjustments to establish the CAD to sample coordinate system transformation.

3.3.3 The system must allow for capture and averaging of the secondary electron image. The image must be capable of being stored to a TIFF or JPEG graphical format file.
3.3.4 The system must allow easy annotation of the SEM image by overlay of text.
3.3.5 The system must be equipped with a pico-ammeter that is integrated to the system to allow direct measurements of SEM ebeam current in a vendor supplied Faraday cup. Current readings must be integrated to allow for active dose correction during exposure.
3.3.6 The software must be capable of interfacing to the SEM stage driver to execute relative or absolute stage shift.
3.3.7 This system must not be a 'beta' version and the supplier must have a demonstrated record of successful installation and operation.

3.4 Training.

3.4.1 The contractor shall include on-site (NRL-DC) operator training for at least 5 NRL employees. Operator training is to include CAD training and ebeam writing of features to a PMMA-coated silicon wafer and routine maintenance procedures. Training must be done within four weeks of completion of testing and acceptance of the ebeam writing option.

3.5 Warranty and Service.

3.5.1 The contractor shall provide a commercial warranty for a four year period to cover travel, parts, and labor (Total coverage: Basic 1 yr + 3 yrs).

Item in Section 4 is an Option

4.0 Optical Microscope

An optical inspection microscope is useful for fast viewing of features on a sample.

4.1.1 The microscope must be of the metallurgical type and must have the following capabilities.
4.1.2 Four-turret objective, that provides range of optical magnification of 50X – 1000X.
4.1.3 Objectives must be capable of bright field and dark field imaging.
4.1.4 Trinocular observation tube.
4.1.5 Differential interference contrast capability.
4.1.6 Light source: 100 Watt or greater halogen lamp.
4.1.7 Manual stage x-y-z position control.
4.1.8 Color digital image capture capability to TIFF or JPEG format, having minimum 1024x768 resolution.