SPECIFICATIONS FOR OXIDE MOLECULAR BEAM EPITAXY (MBE) SYSTEM

1.0 Scope

The Naval Research Laboratory (NRL) has a requirement for a Molecular Beam Epitaxy System to be installed at NRL, Washington, DC 20375. This system will be used to deposit thin-film coatings of oxide-based dielectric materials onto wafers or substrates under high vacuum conditions including $1x10^{-6}$ Torr to $1x10^{-4}$ Torr oxygen background. The system must be physically connected to NRL's existing VG V80H Preparation chamber as a second growth chamber, and be configured to permit routine transfer of substrates from the existing system to the Oxide MBE system specified in this specification. The offeror should provide all system design drawings, results of calculations using physical models, and experimental data necessary to demonstrate the offeror's ability to satisfy these requirements to NRL with their proposal. This system must meet or exceed the following minimum specifications:

2.0 Molecular Beam Epitaxy (MBE) System (CLIN 0001)

This system must be composed of an ultra-high vacuum (UHV) chamber that is designed for MBE. The system must have a symmetric arrangement of 10 each 4.5" outside diameter (OD) Con-Flat (CF) effusion cell ports. Corresponding source shutters must be mounted on individually-demountable flanges. The system must be designed for uniform deposition of materials on up-to 3" OD substrates. The substrate must be mounted in a refractory metal holding ring which is compatible with the V80H design. The heating stage must be capable of heating a 3" OD silicon substrate to a minimum of 1000 °C real surface temperature. The uniformity and temperature capability of the proposed system should be demonstrated by evidence submitted with the offeror's proposal.

The system must attach to an existing VG V80H MBE and Preparation chamber system and permit the transfer of V80H wafer mounts to-and-from the existing and the proposed Oxide MBE system without breaking vacuum or changing wafer mounts and by using a "wobble stick" and/or a "transfer arm". To minimize the system footprint, the use of an adapter chamber between the existing and proposed MBE systems is strongly discouraged. The offeror must include the cost of any necessary adapter chamber and associated hardware in its proposal for this line item. The wafer transfer system for the proposed Oxide MBE system must use the existing V80H transfer track. Modifications to the existing transfer trolley are permitted provided that the modifications permit routine transfer of V80H wafer mounts to and from both MBE systems. The contractor shall perform any necessary modifications to the existing trolley. The offeror must include the cost of any required modifications in its proposal for this line item.

The ability to transfer a wafer to the VG V80H trolley system must demonstrated by evidence submitted with the offerer's proposal.

The system should be designed to use effusion cells that are dimensionally interchangeable with the in vacuum length (326 mm) and in-vacuum outside diameter (up to 62 mm) of the existing V80H MBE so that the effusion cells can be used either in the proposed system or in the existing V80H MBE system.

2.1 Vacuum Chamber

2.1.1 The MBE vacuum chamber must be constructed of 304-series stainless steel using ultra-high vacuum fabrication techniques. It must include at least one liquid nitrogen (LN2) -cooled cryoshroud, designed to cool the area around the effusion cells, and around the substrate manipulator. A LN2-cooled cryoshroud for a titanium sublimation pump (TSP) must also be supplied. The TSP shroud may be integrated with the cryoshroud(s) provided above or may be mounted on a separate high conductance UHV pumping port.

2.1.2 Vacuum requirements. The Oxide MBE chamber must reach a minimum vacuum of $5x10^{-11}$ Torr within 48 hours after bakeout with LN2 cooling if pumped with cryopump or ion pump; or a minimum pressure of $5x10^{-10}$ Torr if pumped by a turbo pump. The system must have no detectable leaks when it is checked with a helium leak detector with a sensitivity of at least of $2x10^{-10}$ Torr-liters/s, or with a residual gas analyzer (RGA) with a sensitivity of at least $2x10^{-12}$ Torr. The RGA spectrum must have no peaks over $5x10^{-12}$ Torr for AMU/q greater than 44.

2.1.3 The UHV pump supplied with the Oxide MBE chamber must be of the turbo-molecular type. The pump must be compatible with corrosive environments and with high pressures of oxygen (up to $1x10^{-4}$ Torr). A dry pump specifically designed to minimize particle generation is required as a foreline backing pump for the system. The turbo-pumped pumped system must be configured with automatic vent valves to safely spin down the pump during shutdown and emergency power outages. The nitrogen pumping speed of the turbo pump must be at least 1250 liters/s, and it must use a 10" OD CF flange. The turbo pump must be configured with "chemical resistant" bearings and a "purge gas" system to protect the bearings and the pump motor from corrosion. No oil- or grease-lubricated bearings are permitted in the high-vacuum side of the pump. The dry backing pump must be sized to handle the purge gas load. The UHV pump must be supplied with all necessary power supplies, controllers, wiring, protection screens, oil or grease for the low-vacuum side bearings, and plumbing necessary for turn-key operation. The foreline pump must be supplied with all necessary power supplies, controllers, wiring, traps, and plumbing necessary for turn-key operation. The offeror must specify the brand and model of the turbomolecular pump and the dry backing pump proposed in its proposal.

2.1.4 Ports. As a minimum, the Oxide MBE vacuum chamber must have the following dedicated ports with UHV Con-Flat flanges:

2.1.4.1 At least ten (10) each 4.5" OD CF symmetrically arranged flanges for effusion cell ports.
2.1.4.2 At least ten (10) each 2.75" OD or larger CF symmetrically arranged flanges for shutter ports. (One port for each port supplied in 2.1.4.1)
2.1.4.3 One (1) each 2.75" OD or larger CF centrally located substrate pyrometer viewport. The port must be suitable for use with a heated viewport.
2.1.4.4 One (1) each 6.0" OD CF main viewport.
2.1.4.5 One (1) each 2.75" OD CF Reflection High Energy Electron Diffraction (RHEED) gun port.
2.1.4.6 One (1) each 2.75" OD CF Residual Gas Analysis port.
2.1.4.7 One (1) each 6.0" OD CF RHEED screen port.
2.1.4.8 One (1) each 10.0" OD CF UHV pumping port for turbomolecular pump.
2.1.4.9 One (1) each 2.75" OD CF rough pumping port.
2.1.4.10 One (1) each 2.75" OD CF nude ionization gauge port.
2.1.4.11 One (1) each 8.0" OD CF UHV sample transfer port.
2.1.4.12 One (1) each 2.75" OD CF wobble stick or transfer arm port.
2.1.4.13 One (1) each 2.75" OD CF illuminator viewport.
2.1.4.14 One (1) each CF manipulator port.
2.1.4.15 One (1) each 2.75" OD CF titanium sublimation pump (TSP) port on the corresponding cryoshroud.
2.1.4.16 One (1) each 4.5" OD or larger CF radially located Quartz Crystal Monitor (QCM) port. This port must be designed to permit installation of a retractable QCM as discussed in paragraph 3.7 below.

2.1.5 Included Hardware. The system must include the following hardware, installed:

2.1.5.1 One (1) each 2.75" OD or larger CF pyrometer viewport and viewport shutter.
2.1.5.2 One (1) each 2.75" OD CF wobble stick or transfer arm for wafer transfer.
2.1.5.3 One (1) each 6.0" OD CF main viewport and viewport shutter.
2.1.5.4 One (1) each 2.75" OD CF illuminator viewport and lamp.
2.1.5.5 One (1) each 6" manual UHV SS gate valve (8.0" OD CF flanges) with metal bonnet seal and Viton O-ring seal to isolate the Oxide MBE chamber from the Preparation chamber. The valve must be bakable to 200 °C.

2.1.5.6 One (1) each 8.0” pneumatic UHV gate valve (10.0" OD CF flanges) with metal bonnet seal, and Viton O-ring seal to isolate the UHV pump from the Oxide MBE chamber. The valve must be bakable to 200 °C.

2.1.5.7 One (1) each 2.75” OD SS CF metal sealed chamber rough pumping valve and associated hardware to connect to the existing V80H roughing manifold.

2.1.5.8 All unused ports must be blanked off with appropriately sized CF blank flanges. All necessary bolts, nuts, gaskets, and blanks must be included.

2.1.6 Vacuum gauging. The system must provide a UHV ionization gauge within the growth chamber to monitor chamber pressure conditions. The gauge controller must simultaneously display the pressure from at least two ionization gauges. A Granville Phillips 350-series controller is strongly preferred. All cabling for the controller must be provided. The controller must meet or exceed the following minimum specifications: a) have electrometers capable of measuring and displaying pressures below $1x10^{-11}$ Torr for the Oxide MBE chamber and the flux monitoring Bayard-Alpert type UHV ionization gauges. b) have adjustable sensitivity of 3/Torr to 50/Torr. c) have the ability to switch filaments of dual-filament gauges without changing the gauge wiring. d) provide analog output which is logarithmic with pressure at 1 V/decade with 0 - 10 V full scale range. e) have user-controllable display units (Torr, mbar, Pascal). and f) include e-beam degas capabilities. The offeror should specify the brand and model of the UHV gauge and the controller proposed in its proposal.

2.1.7 Bakeout system. The Oxide MBE system must include all necessary heaters, temperature and time controllers, and an insulated enclosure to permit uniform temperature bakeout of the Oxide MBE chamber at temperatures up to 200 °C.

2.2 Sample Manipulator

The sample manipulator must be configured with a sample stage to hold a refractory metal wafer holder of the V80H design and to allow transfer of the wafer holder to and from the Preparation chamber. It must also provide continuous azimuthal rotation for improved thickness uniformity, and provide a main shutter to protect the sample from incident fluxes. Offerors should submit a set of photographs or drawings of the manipulator design which illustrate the proposed transfer of the V80H style wafer mount to the manipulator with their proposal.

2.2.1 Substrate size. The sample stage must be capable of holding substrate wafers up to a 3" OD and be able to accommodate other various-sized smaller pieces when mounted in appropriate compatible mounts.

2.2.2 Rotation. The stage must be capable of continuous rotation around the sample normal axis and must be controllable by the use of computer control. Rotation speed is to be continuously adjustable from 0 - 60 RPM, minimum, and operate during MBE deposition processes. The rotation must also be manually adjustable in fine increments (better than 0.5-degree) to observe RHEED diffraction patterns and for alignment during wafer transfer.

2.2.3 Heat shielding. The manipulator must incorporate heat shielding made of UHV-compatible refractory materials to protect the substrate heater from unintended deposition of materials, protect any rotary bearings and hook-up wiring, and to minimize heat loss from the substrate heater.

2.2.4 Sample transfer. The stage must accept transfer of the sample wafer mount, to- and from- an existing V80H trolley and track assembly using a wobble-stick and/or transfer arm. The use of a single transfer tool to pick up the wafer mount from the V80H trolley and insert it into the substrate manipulator and to perform the reverse operation is preferred.

2.2.5 Substrate heater. The substrate heater should be based on a graphite or silicon carbide heating element and be protected with refractory coatings to make it suitable for use in an oxygen-rich vacuum environment with oxygen partial pressures up to $1x10^{-4}$ Torr. Wire filament heating elements are not acceptable unless approved in advance by the NRL Authorized Government Representative (AGR). It must be able to uniformly heat a 3" OD silicon wafer to at least 1000 °C (real substrate temperature) in an oxygen partial pressure of $2x10^{-5}$ Torr without damage to the heater or any other component of the Oxide MBE system. It must include a fixed Type-C thermocouple to monitor the heater temperature. The offeror should demonstrate that the proposed heater can meet these specifications by submitting evidence with its proposal.

2.2.6 Shutter. Sample isolation from the source material fluxes must be achieved by a computer-controllable substrate shutter with a blade fabricated from UHV-compatible refractory materials. The shutter must not block the RHEED beam or the RHEED diffraction pattern.

2.2.7 The wafer holder stage assembly must be grounded to minimize charging effects.

2.3 <u>Equipment Racks and Electronics</u>

The system must include all necessary power supplies, pump control units, bakeout temperature control units, ion gauge control units, shutter control units, and substrate rotation and manipulator control units for the preceding items in an electronics rack.

2.4 MBE Deposition Requirements

The system must be capable of *in situ* deposition of oxide-based dielectric films on semiconductor substrates. The system must be designed to work with high and low temperature effusion sources, gas sources, and compact e-beam sources mounted in effusion cell ports. The Oxide MBE deposition system design must be configured as follows:

2.4.1 The Oxide MBE chamber design must have demonstrated its capability for depositing films of uniform thickness. In particular, the total thickness variation (TTV) of either GaAs or AlAs, deposited nitride, or deposited oxide film thickness across the central 2.75" diameter of a rotated 3” wafer must be less than 2%. (TTV = 100% * (maximum film thickness minus the minimum film thickness) / mean film thickness.) The offeror must demonstrate that the proposed chamber design can meet these specifications by submitting evidence (measured or modeled data based on the actual system geometry) with its proposal.

2.4.2 Oxygen Source. NRL will provide an RF plasma source and a 600 W RF power supply to the successful offeror for integration with the system. The manufacturer of the RF plasma source is Oxford Applied Research. The manufacturer of the RF power supply is Applied Energy.

2.4.3 All components and systems supplied as part of this MBE system must be compatible with oxygen service at elevated temperatures (substrate temperatures up to a maximum of 1000 °C and simultaneous oxygen background pressures up to $2x10^{-5}$ Torr).

3.0 OPTION ITEMS

3.1 Additional Ports (CLINS 0002-0006)

The contractor shall provide some, none, or all of the following additional ports:

3.1.1 Four (4) each or more 2.75" OD CF substrate monitoring ports. These ports must be designed to symmetrically surround the central substrate pyrometer viewport and be focused on the center of the substrate. (CLIN 0002)

3.1.2 Two (2) each or more 2.75" OD CF effusion cell "sniffer" ports. These ports must be designed to have a direct line-of-sight view of an effusion cell so that the exiting flux can be monitored when the shutter is open. The offeror should indicate which effusion cell ports will be sniffed. (CLIN 0003)

3.1.3 One (1) each auxiliary pumping port with 10" or larger OD CF flange to permit the future addition of another UHV pump. (CLIN 0004)

3.1.4 Two (2) each 2.75" OD CF ellipsometry ports. (CLIN 0005)

3.1.5 Two (2) each 2.75" OD CF atomic absorption ports. (CLIN 0006).

3.2 Aluminum Effusion Source (CLIN 0007)

3.2.1 Aluminum Effusion Source (CLIN 0007) The aluminum effusion source will be used to evaporate aluminum and to direct a flux to the sample stage to provide material for deposition of aluminum oxide and related materials. The design of the effusion cell should be compatible with the existing V80H MBE system as discussed in paragraph 2.0 above.

3.2.1.1 The aluminum beam diameter at the substrate must be sufficiently broad and uniform to give better than 5% total thickness variation (TTV) across the center 2.75" diameter of a rotated 3" OD substrate. The offeror should demonstrate that the proposed aluminum beam diameter can meet these specifications by submitting evidence with its proposal.

3.2.1.2 The effusion cell must be specifically designed for aluminum, including incorporating a "cold lip" to prevent molten aluminum from creeping out of the crucible.

3.2.1.3 The aluminum effusion cell must be constructed with refractory materials which permit UHV-operation at temperatures up to 1400 °C.

3.2.1.4 The aluminum effusion cell must incorporate Type-C thermocouples to monitor the temperatures in the tip and main filament regions of the cell.

3.2.1.5 The aluminum effusion cell must incorporate water-cooling to minimize the heat load on the cryoshrouds.

3.2.1.6 The aluminum effusion cell must evaporate aluminum in a background oxygen environment to produce aluminum oxides with thickness of 1 to 200 nm with total thickness variations (TTV) of less than 5% over the center 2.75" diameter of rotated 3” diameter substrates. The source must be capable of operation at pressures up to $2x10^{-5}$ Torr oxygen background pressure while providing a flux high enough to grow their respective oxides at rates of 0.01 to 1.0 nm/s. The effusion source must include a spare crucible. The crucible design must meet the uniformity specifications, and the crucible material must be compatible with the source material and the rest of the Oxide MBE system. The offeror should supply data with its proposal to support their choice of effusion cell and crucible which demonstrates uniformity and compatibility. The contractor shall supply all necessary thermocouple and power cables and connectors to the effusion cell. The thermocouple and power cables and connectors must be bakable to at least 200 °C.

3.3 Aluminum Effusion Cell Shutter (CLIN 0008)

3.3.1 Aluminum Effusion Cell Shutter Assembly, Actuator, and Control Module. A complete shutter assembly, actuator, and control module for the aluminum effusion cell shall be provided.

3.4 Aluminum Effusion Source Power Supplies (CLIN 0009) and Temperature Controllers (CLIN 0010)

The contractor shall provide and install stable, low-ripple DC power supplies (CLIN 0009) to power the aluminum effusion source heater filaments. These supplies must be capable of continuous operation at full rated power, with load current regulation of 0.02% +/- 5 mA or better at all power levels, and of sufficient capacity to drive the respective effusion cell to its maximum temperature. The output current from the DC supplies must be programmable by a 0-5 V or 0-10 V DC analog input signal.

NRL has hardware and software infrastructure based on Eurotherm 2400- and 2600-series temperature controllers. As such, the temperature controllers for this proposed Oxide MBE system must be from Eurotherm. The contractor shall provide and install high-stability, single-loop, proportional integral derivative (PID) temperature controllers (CLIN 0010) from the Eurotherm 2400 or 2600-series. Different Eurotherm models may be provided only if agreed to in advance by the NRL AGR. The controllers must meet or exceed the following minimum specifications: a) The controllers must be compatible with Type-C thermocouples. b) The controllers must have better than 2 μV sensitivity for thermocouple inputs, and better than 0.2 °C +/- 1 least-significant-digit linearity. c) The controller must provide 0-10 V isolated DC output. d) The controller must provide automatic cold thermocouple junction compensation with better than 30:1 rejection of ambient temperature changes. e) The controllers must be configured for serial communications using an RS-485 interface using the EI-BiSync protocol. Offerors shall propose temperature controllers for each powered filament for the aluminum effusion source. (CLIN 0007)

3.5 Residual Gas Analysis System (CLIN 0011)

An integrated residual gas analysis (RGA) and leak detection system is required. The unit must include the following:

3.5.1 Must be of the quadrupole-type design.
3.5.2 Must be designed for a minimum range of 1-200 AMU/q detection and analysis.
3.5.3 Must operate with 120 volts and 60 Hz AC power.

3.5.4 Must be interfacable with a Windows PC and permit recording and analysis of gas spectra using Windows software in near real-time and offline.

3.6 RHEED Electron Gun (CLIN 0012)

For compatibility with NRL's existing hardware and software infrastructure, the contractor shall provide and install a analytical RHEED analysis system consisting of a differentially pumpable Staib 20 keV RHEED electron gun with K-Space KSA-400 video analysis hardware and software. A leaded-glass phosphor screen and viewport for a 6“ OD CF RHEED port shall be included with the system, along with a viewport shutter.

3.7 Quartz Crystal Rate Monitor (QCM) (CLIN 0013)

3.7.1 A quartz-crystal rate monitor (QCM) system shall be provided. It must be mounted in a position where it can reproducibly measure the deposition rate on the substrate. The QCM must also be able to monitor the flux and feed back control information to an e-beam source controller during evaporation from a compact e-beam source mounted on an effusion cell port. The QCM must be mounted on a 4.5" OD or larger CF flange with a retractable X-Y-Z translation stage to enable retraction of the sensor head from the beams. The QCM must also include a gate valve and vacuum hardware to permit changing of the quartz crystals in the sensor head and returning the QCM to operation without breaking the vacuum in the growth chamber. The offeror should specify the brand and model number of the QCM to be provided in its proposal.

3.7.2 The in-vacuum quartz crystal sensor head must be equipped with a shutter to prevent deposition on the crystal. The shutter must be controllable with a personal computer.

3.7.3 The deposition rate must be displayable on a system computer screen via software supplied with the system.

3.8 Sample Wafer Holders (CLIN 0014)

2 each sample wafer holders designed for holding 2” OD and/or 3” OD silicon wafers shall be provided. These must be manufactured from refractory metal and be functionally and dimensionally compatible with existing V80H wafer holders. The offeror should specify the refractory metal to be provided in its proposal.

3.9 Spare parts kit (CLIN 0015)

The contractor shall supply a spare parts kit for items requiring regular maintenance. This kit is to include ion gauge filaments, replacement seals, and fuses.

3.10 <u>System Automation</u> (CLIN 0016)

The system must be controllable using a personal computer (PC).

3.10.1 System control is to be provided through a dedicated computer with a Windows 2000 or Windows XP Professional operating system. For compatibility with other NRL PCs and software, Windows Vista is not acceptable. The computer must have a 17" or larger flat-panel liquid crystal display (LCD) monitor, minimum 1 (one) giga-byte (GB) memory, minimum one (1) GHz processor speed, minimum 80 GB hard drive, optical mouse, Read/Write CompactDisk capability, and network interface capability for 100-Base T network operation using the Internet-standard TCP/IP protocol.

3.10.2 The computer software must provide for display of all significant system parameters, including: pump on/off status, MBE growth chamber pressure, effusion cell temperatures, oxygen gas flow rate, RF incident and reflected power, and the status of all source shutters and pneumatic valves.

3.10.3 The PC control system must operate all effusion cell power supplies and shutters, the substrate heater power supply, and be capable of chaining steps and recipes for dielectric deposition.

3.10.4 The system must have data logging and recipe files that can be externally viewed and edited.

3.10.5 The software must be capable of supporting multiple users each with individual accounts.

3.11 Flux Monitoring Ion Gauge (CLIN 0017)

A separate flux-monitoring UHV ionization gauge (mounted so as to be rotated into the growth position, or retractable and movable into the growth position) must be provided to monitor beam fluxes from the effusion cells. The gauge must be operated by the controller provided in section 2.1.6 above, meet those requirements, and include all cables. The flux monitoring ion gauge pressure must be displayed simultaneously with the system pressure.

4.0 GENERAL REQUIREMENTS

4.1 <u>Installation Site</u>

The contractor shall install the system at the Naval Research Laboratory, Bldg. 208, at a specific location to be designated by AGR. NRL will provide process cooling water, pressurized air, pressurized dry nitrogen gas, oxygen process gases, liquid nitrogen and 208/240 VAC single and three-phase electrical power. The contractor shall specify all utilities required, and the dimensions and approximate weights of all equipment provided with the proposal. Mechanical pumps must be located within the same laboratory as the MBE system. The contractor is responsible for providing the vacuum tubing and electrical cables necessary to connect these components to the system.

4.2 On-Site System Training, Acceptance, and Manuals

Upon completion of the installation, the contractor must provide training at NRL. At a minimum, training must include system operation and review of maintenance procedures for two NRL users for a minimum of two days. System capabilities must be demonstrated by the contractor and will be reviewed prior to final acceptance of the system. Acceptance is contingent on passing the requirements in Section 2 and the requirements in the optional items in Section 3 for any option items which are exercised at time of contract award. User manuals will be provided to NRL for all furnished equipment and systems.

4.3 Documentation, Drawing, and Warranty Requirements

A full set of all written documentation customarily provided to the public with a commercial item shall be provided. This shall include user manual(s) or equivalent as well as copies of any software, and any manuals for the software included with the system, if customarily provided. This documentation must be received at NRL with the system hardware, unless other arrangements are agreed to by the AGR. The offeror shall submit design drawings for the MBE machine and for the port configuration with its proposal. Any and all necessary changes and modifications to the design drawings submitted by the successful offeror shall be approved by the NRL AGR prior to manufacture.

The contractor shall offer the Government at least the same warranty terms, including offers of extended warranties offered to the general public in customary commercial practice. These warranty terms must be included in the system price. The period of the warranty shall begin upon acceptance.