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 must provide all system design drawings and experimental data used 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 source flange must consist of 10 each 4.5" outside diameter (OD) Con-Flat (CF) effusion cell ports arranged symmetrically on an inclined source flange. 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 molybdenum metal holding ring of 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 must 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 single "wobble stick". The use of an adapter chamber or adapter mounts between the existing and proposed MBE systems is not acceptable. 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 ability to transfer a wafer to the VG V80H trolley system must demonstrated by evidence submitted with the offerer's proposal. Effusion cells must be interchangeable with existing components on the existing V80H MBE.

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 two (2) liquid nitrogen (LN2) -cooled cryoshrouds: one around the effusion cells, and a second around the substrate manipulator and titanium sublimation pump.

2.1.2 Vacuum requirements. The Oxide MBE chamber must reach a minimum vacuum of $5x10^{-11}$ Torr within 24 hours after bakeout with LN2 cooling if pumped with cryopump or ion pump; or a minimum pressure of $1x10^{-10}$ Torr if pumped by a turbo pump under the same conditions.

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 maximum dimension of the pump cannot exceed 14.0" in height and 11.5" in diameter (excluding the control electronics and exhaust port). The turbo pump must be configured with "chemical resistant" bearings and a "purge gas" system to protect the bearings and 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.

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

2.1.4.1 Ten (10) each 4.5" OD CF symmetrically arranged flanges for effusion cell ports.
2.1.4.2 Ten (10) each 4.5: OD CF symmetrically arranged flanges for shutter ports.
2.1.4.3 One (1) each 4.5" OD CF centrally located substrate pyrometer 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.
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 6.0” OD CF flux monitoring ion gauge / main shutter port.
2.1.4.13 One (1) each 2.75” OD CF wobble stick port.
2.1.4.14 One (1) each 2.75” OD CF illuminator viewport.
2.1.4.15 One (1) each 10.0” OD CF manipulator port.
2.1.4.16 One (1) each 2.75” OD CF titanium sublimation pump (TSP) port.

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

2.1.5.1 One (1) each 4.5" OD CF pyrometer viewport and viewport shutter.
2.1.5.2 One (1) each 2.75” OD CF wobble stick 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 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.
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.
2.1.5.7 One (1) each N2 vent valve.
2.1.5.8 One (1) each metal sealed chamber rough pumping valve and associated hardware to connect to the existing V80H roughing manifold.
2.1.5.9 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 one UHV ionization gauge within the growth chamber to monitor chamber pressure conditions. A Granville-Phillips 350-series controller is required.. A separate retractable flux-monitoring UHV ionization gauge is required to monitor beam fluxes from the effusion cells. All cabling and controllers for the gauges must be provided. The controllers 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.

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 molybdenum metal wafer holder of the V80H design and to allow transfer of the wafer holder to and from the Preparation chamber using a single wobble-stick assembly. It must also provide continuous azimuthal rotation for improved thickness uniformity, and provide a main shutter to protect the sample from incident fluxes.

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 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 0.1-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 single wobble-stick transfer tool.

2.2.5 Substrate heater. The substrate heater must 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 1×10^{-4} Torr. Wire filament heating elements are not acceptable. It must be able to heat a 3” OD silicon wafer to at least 1000 °C (real substrate temperature) in an oxygen partial pressure of 2×10^{-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 must 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-controlable substrate shutter with a blade fabricated from UHV-compatible refractory materials.

2.2.7 The wafer holder stage assembly must connect to system electrical ground to minimize charging effects.

2.3 Equipment Racks and Electronics

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 a variety of other effusion sources and compact e-beam sources. The deposition rate must be stable and controllable in the 0.01 to 0.1 nm/s range. The Oxide MBE deposition system design must be configured as follows:

2.4.1 The Oxide MBE chamber design must have demonstrated total thickness variation (TTV) of either GaAs or AlAs film thickness across the central 2.75" diameter of a rotated 3" wafer of 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 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

The contractor shall provide some, none, or all, of the following option items:

3.1 Additional Ports (CLINS 0002-0007)

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

3.1.1 One (1) each 4.5" OD CF quartz crystal monitor (QCM) port. This port must be designed to permit installation of a retractable QCM as discussed in section 6.7 below. (CLIN 0002)

3.1.2 Six (6) each 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 0003)

3.1.3 Two (2) each 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. (CLIN 0004)

3.1.4 One (1) each auxiliary pumping port with 12" OD CF flange to allow replacement of the TSP pump with a cryopump or other UHV pump. (CLIN 0005)

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

3.1.6 Two (2) each 2.75" OD CF atomic absorption ports. (CLIN 0007). It is acceptable for CLIN 0002 to replace one of these two ports.

3.2 Aluminum Effusion Source (CLIN 0008)

3.2.1 Aluminum Effusion Source (CLIN 0008) 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 and crucible must be compatible with the existing V80H MBE system.

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 must 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 $2x10^{-5}$ 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 contractor shall supply data with the proposal to support their choice of effusion cell and crucible to demonstrate 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 <u>Aluminum Effusion Cell Shutter (CLIN 0009)</u>

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 <u>Aluminum Effusion Source Power Supplies (CLIN 0010) and Temperature Controllers (CLIN 0011</u>)

The contractor shall provide and install stable, low-ripple DC power supplies (CLIN 0010) 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 from the Eurotherm 2400 or 2600-series. 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 (CLIN 0011) for the aluminum effusion source.

3.5 Residual Gas Analysis System (CLIN 0012)

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 0013)

For compatibility with NRL's existing hardware and software infrastructure, the contractor shall provide and install a analytical RHEED analysis system consisting of a 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 0014)

3.7.1 A quartz-crystal rate monitor (QCM) system is required. It must be mounted in a position where it can reproducibly measure the deposition rate on the substrate. The QCM must be mounted on a 4.5" OD CF flange with a retractable X-Y-Z stage and include a gate valve and vacuum hardware to enable retraction of the sensor head from the beams. The QCM must also permit changing of the quartz crystals in the sensor head and returning the QCM to operation without breaking the vacuum in the growth chamber.

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 QCM system.

3.8 Sample Wafer Holders (CLIN 0015)

2 each sample wafer holders designed for holding 2” OD and 3” OD silicon wafers are required. These must be manufactured from molybdenum metal and be functionally and dimensionally compatible with existing V80H wafer holders.

3.9 Spare parts kit (CLIN 0016)

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 System Automation (CLIN 0017)

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 state of all source shutters and pneumatic valves.

3.10.3 The PC control system must operate all effusion cell power supplies and shutters, and 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.

4.0 GENERAL REQUIREMENTS

4.1 Installation Site

The contractor shall install the system at the Naval Research Laboratory, Bldg. 208, at a specific location to be designated by the Authorized Government Representative (AGR). NRL will provide process cooling water, pressurized air, pressurized dry nitrogen gas, oxygen process gases, liquid nitrogen and 208 VAC single and three-phase electrical power. The system must operate on 208 VAC single or three phase power and/or 120 VAC single phase power, as required. 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 authorized Government representative. The offeror shall submit design drawings for the MBE machine and for the port configuration with the proposal. Any and all necessary changes and modifications to the design drawings submitted by the successful offeror shall be approved by NRL 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.