Issue 1

Requirements for a replacement electron beam coater

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Introduction

An evaporation system is required to deposit up to two metal films by electron beam physical vapour deposition (PVD) onto metal and ceramic substrates at elevated temperatures. These deposited films shall be able to be exposed at an elevated temperature to partial pressures of purified hydrogen gas. This is preferred to occur in a separate chamber separate to prevent the evaporation chamber material in the crucible reacting with the gas. Transfer between chambers shall be carried out under vacuum. The system life shall be more than 10 years.

The requirement is to design and manufacture the system and install the system at AWE (Atomic Weapons Establishment). Proposals with; commercial off the shelf (COTS) components/sub systems/systems; which require minimal redesign from an existing proven system design; which have low technical risk and high reliability are preferred.

Operation and maintenance manuals, electrical and mechanical drawings for the system shall be supplied to AWE on AWE supplied drawing frames.

In the event of the manufacturer ceasing trading or no longer supporting the equipment the full set of engineering drawings and system software required to manufacture a complete system shall be supplied to AWE to allow alternate manufacture of replacement system components. The system shall be CEUK marked.

Evaporation

The electron beam deposition system is required to deposit two materials sequentially or simultaneously to form alloys via co-evaporation from two sources. In sequential operation Source 1 is required to deposit 1 micron plus of a transition element metal, source 2 is then required to deposit a multi micron film of a lanthanide metal. The minimum material capacities are 40 cc and 120 cc for sources 1 and 2, respectively. Several batches are required from these capacities. Each electron gun shall have a separate shutter. Ultra-high vacuum (UHV) compatible and robust designs are required. The electron beam guns shall be easily accessible for servicing. For example, if the guns were flange mounted a rail system would be suitable to allow the flange and guns to slide outside the system for servicing. The water-cooling system shall be welded or metal sealing on the vacuum side.

A separate solid-state power supply is required for each electron gun. The power supplies shall be identical to provide redundancy in the event of a single unit failure.

For co-evaporation both electron guns require separate quartz crystal film thickness monitors with feedback control to the electron gun. Each crystal head requires a shutter. Multiple crystals are required with in vacuum change-over. Six or more crystals are required for each gun.

The difference between the maximum and minimum film thickness measures across the 100 mm substrate shall be less than 5% of the minimum film thickness.

Observation of the electron beam melt shall be via a shuttered or rotatable mirror system. The option to use multiple mirrors is desirable to allow a fresh mirror to be easily positioned in place when its predecessor becomes coated without breaking vacuum or coating the viewport.

Substrates

The multiple substrates are currently assembled onto a 100 mm diameter molybdenum tray that simulates a 100 mm diameter silicon wafer. The tray can be handled on its bottom surface or edge as per a wafer. This format can be used, or the substrates can be distributed on a larger format with the approval or AWE
The tray and substrates are 15 mm thick. Their maximum mass shall be less than 1 Kg. Substrate trays shall be able to be transferred between chambers whilst remaining under vacuum.

Substrate heating

Evaporation chamber

The system shall be able to heat the substrates uniformly at a temperature of 800 °C with less than a 5 °C difference in temperature across the substrate. The maximum heating rate is 10 °C/minute. The system should be able to rotate the substrates at up to 10 rpm.

Gas reaction chamber

The system shall be able to heat the substrates uniformly at a temperature of 500 °C with less than a 5 °C difference in temperature across the substrate. The maximum heating rate is 10 °C/minute.

Substrate temperature measurement

Evaporation chamber

Two thermocouples shall be available for the measurement and control of the substrate heater element. Thermocouple one shall control the system. Thermocouple two shall provide a comparison to thermocouple one and redundancy if thermocouple one fails. The system operator shall be able to switch control between the thermocouples. A temperature probe is required that can be moved into contact with the side of the substrate tray for spot temperature calibration when the substrate rotation is stopped. Two DN16 ports are also required to be suitably placed for substrate work survey thermocouples. These shall be used for initial calibration when the substrate rotation is stopped.

Gas reaction chamber

Two thermocouples shall be available for the measurement and control of the substrate tray. The two thermocouples shall be in contact with the substrate tray. Thermocouple one shall control the system. Thermocouple two shall provide a comparison to thermocouple one and redundancy if thermocouple one fails. The system operator shall be able to switch control between the thermocouples. Two DN16 ports are also required to be suitably placed for substrate work survey thermocouples for initial calibration.

Data capture

System data should be captured to include but not limited to: -

- Temperature of all control, survey, and calibration thermocouples.
- Temperature set points.
- Pressure/vacuum of all gauges.
- RGA (Residual Gas Analyser) (4 masses minimum).
- Electron beam voltage and emission current.
- Pump data rotation frequency, motor current, temperature.
- Shutter and valve positions.
- Film thickness and rate data.

All data should be able to be readily displayed in a graphical form, with the ability to view the previous data by moving backwards and forwards through the data and zooming into selected data, i.e., the option to change the scale on the chart is desirable. A user-friendly graphical interface that provides retrospective inspection of the recorded data is desirable. Run data should be exportable in a Microsoft Excel compatible format. USB and Network data transfer shall be available for the movement of all captured data.

Vacuum and pressure

Evaporation chamber

The base pressure of the evaporation chamber shall be less than $5x10^{-9}$ mbar. The pressure of the evaporation chamber during the evaporation should be less than $5\ x10^{-8}$ mbar. The gas shall be passed through a 0.5-micron particulate filter before entering the system. during venting the flow of nitrogen should be controller to prevent particle movement inside the chamber.

Gas reaction chamber
The base pressure of the gas reaction chamber shall be less than $5x10^{-9}$ mbar. The nitrogen gas shall be passed through a 0.5-micron particulate filter before entering the chamber. This chamber shall allow the evaporated films to be reacted with pure hydrogen gas at up to a maximum pressure of 100 mbar. The hydrogen gas shall be purified using a reactive metal filter system. This shall be located as close as possible to the input of the gas reaction chamber. A suitable purifier system shall reduce the gas impurities (water, carbon monoxide, carbon dioxide and oxygen) in the hydrogen gas supplied to the side chamber to <100 ppt. Such a system shall be sized for the life of the system. The purifier system shall run at ambient temperature without any electrical input. Hot filament gauges shall be protected behind valves when hydrogen is admitted into the side chamber. A high accuracy (0.12%) or better heated pressure transducer shall be used to measure the pressure of the hydrogen gas in the side chamber. A robust process for preventing air and hydrogen mixing is required. Flow controllers are required to allow adjustment of the rate of flow of nitrogen and hydrogen gas into the side chamber.

Gas supply components
The nitrogen and hydrogen supply tubing to the system shall be instrument grade seamless stainless steel chemically cleaned and passivated to comply with ASTM G93 Level A and CGA 4.1. All components in the gas supply lines shall be suitable for high purity gas service.

A residual gas analyser (RGA) system shall be used for monitoring the vacuum environment of the evaporation chamber and for leak detection in both chambers. 0-100 AMU range is acceptable.

Vacuum pumps and valves

UHV vacuum pump shall be magnetically levitated turbo molecular pumps and UHV adapted cryogenic pumps (UHV replacement of Viton poppet over-pressure relief valve). Backing pumps shall be dry pumps. Robust systems and strong UK (United Kingdom) service support are required for these sub systems. The evaporation chamber pumping is preferred to be via a magnetically levitated turbo molecular and cryo-pump and the gas reaction chamber by a magnetically levitated turbo molecular pump.
Gate valves shall be of a reliable proven design, compatible with UHV and free of internal lubrication, metal bonnet sealing, welded metal bellow sealing for the feedthrough, cavity free Viton sealing for the gate, the leak rate of the body shall be $< 5 \times 10^{-10}$ mbar ls^{-1} and of the gate $< 1 \times 10^{-9}$ mbar ls^{-1}, cycles to first service shall be >= 50,000. Service kits shall be provided for all valves with the system where available.

Chambers

UHV components are preferred with metal sealing gaskets to ensure low leak rates. Easy exchange of the quartz crystals, mirrors and evaporation shielding shall be provided. Two sets of molybdenum evaporation shields shall be provided.
System bake-out jackets are required for both chambers. A bake out temperature of 150 °C or higher is desirable. The evaporation chamber walls may require cooling during the evaporation sequence.
Systems that have easy access to all flanges for maintenance are preferred.

Service

Removal of heavy (>30 Kg and or difficult for 2 persons to lift) system components for maintenance shall be aided by lifting equipment.
The clean room does not have a crane system so a portable solution such as a COTS manual mechanical stacker/forklift is required to be supplied with the system. Suitable accessories shall also be supplied to allow connection to system components. Suitable interface features shall be attached to all heavy system components where possible to facilitate easy manipulation via the lifting equipment. I.e., heavy flanges, pumps, compressors, e-beam components, etc.
Through life service proposals/options shall be included with the tender.

System control

Automatic control shall be provided for the deposition sequence, thermal profiles (PID (Proportional Integral Derivative Control)), pumps, gauges, and valve operation. Multiple recipes shall be able to be stored and recalled for use. Automatic control shall be provided for the gas reaction chamber thermal profile, gas admission and pump out. Manual movement of the substrates between the chambers is acceptable.

Safety

The evaporation chamber shall be supplied with vent gas below 0.5 bara to remove the requirement for PED (pressure equipment directive) compliance.
The gas reaction chamber shall be supplied with vent gas and hydrogen below 0.5 bara to remove the requirement for PED compliance.
Protection shall be provided against the scenario of a vented sealed chamber being heating and hence pressurised. A suitable pressure relief device may provide this protection for each chamber
Equipment shall comply with the requirements of the AWE ESMS (electrical safety management system).
An earth wand shall be provided with the electron beam system.
Implosion covers are required for all view ports. A spare set is to be provided with the system.
Any gas regulators supplied with the system shall contain metal diaphragms to provide a longer service life.
Interlocks and shielding shall be used as appropriate to provide electrical protection.

Testing

FAT (factory acceptance tests) and SAT (site acceptance tests) will comprise the following demonstrations: -
Demonstration of sequential evaporation.
Demonstration of co-evaporation.
Demonstration of sequential deposition onto a test sample substrate (silicon wafer). Several hundred nanometres of material 1 will be deposited. This will be immediately followed by a multi-micron deposition of material 2 (this will be a rare earth metal). Materials to be use in the tests will be agreed with AWE. Success will be measured by the pressure during deposition, successful application of the above minimum film thicknesses. Thickness uniformity of coating area, maximum to minimum less than 5% of minimum. Temperature uniformity.
Demonstration of crucible melt viewing system.
Demonstration of heavy component removal with lifting system.
Demonstration of sample movement between coating chamber and the gas reaction chamber.
Demonstration of the gas reaction sequence in the side chamber. Success will be measured by achieving the thermal uniformity, gas control to +/- 5% of target value, hydrogen and air mixing is prevented in a robust manner.
Demonstration of mirror exchange, shielding exchange, quartz crystal exchange, electron beam filament exchange.

Environment

The electron beam coater will be located in a class 1000 clean room. The system shall be compatible with this environment. A space of approximately 4.15 x 3.1 m is available for the system. Entry to the room is via a set of double doors and then an aperture of 2.08 x 1.46 m into the clean room. All services such as chilled water, nitrogen gas, hydrogen gas, exhaust, low impedance earth and electrical supply drop down from the ceiling void. The ceiling height is 2.7 m.