TECHNICAL SPECIFICATIONS
SILICON DEEP REACTIVE ION ETCH REACTOR (SIDRIE) WITH SINGLE WAFER SEMI-AUTOMATIC TRANSFER CHAMBER

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VERSION CONTROL SHEET

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2				
3				
4				

Contents

1. General

1.1. This specification describes the requirements for the Load Locked Silicon Deep Reactive Ion Etch Reactor (SiDRIE) for the Center for Integrated Nanotechnologies (CINT) at Sandia National Laboratories (SNL). System shall be configured for highly selective, precision etching of single crystal silicon and Silicon On Insulator (SOI) materials in support of Mid-Infrared Photonics, MEMS and advanced material research activities. Dual purpose Si etch capability, providing both high speed time-multiplexed, high aspect ratio/through wafer etch and plasma dicing, and also shallow etching of crystalline silicon structures in the sub-micron region with high precision. Objective is to aid in the development of discovery platforms in the fields of physics, chemistry, material science, microelectronics, quantum computing, and biology.

2. Principal Configuration of the SiDRIE Processing System

2.1. Ballroom configuration, Mainframe/load lock in operations area with support equipment located in adjacent chase within 10-15m of the mainframe. No bezel mounting. System power 208V, 60 Hz, 3-Phase.
2.2. Single wafer 100-200mm capable load lock with soft-rough/soft-vent, independent dry roughing pump.
2.3. Heated, Magnetically Levitated, Turbo Molecular pump with heated foreline, dry type process mechanical pump with associated cold traps/filters where applicable.
2.4. Reaction chamber shall have two powered electrodes to include an ICP (Inductively Coupled Plasma) unit with automatic impedance match and 5 kW (+/-1% of SP or +/-1W whichever is greater into 50-ohm resistive load). Both High Frequency (HF) and Pulsed Low Frequency (LF) water cooled (if available) solid state RF power supplies with automatic impedance matching for precision bias control 0-300 watts (+/-1% of SP or +/-1W whichever is greater into 50-ohm resistive load). Harmonic filtering where applicable. All RF system components must be properly rated for continuous operation at full output power at 6000’ ASL (Above See Level).
2.5. Reaction chamber to be heated with some form of resistive heating element array, heating blanket or a combination of the two, capable of sustained operation at maximum temperature for 12 hours.
2.6. Biasing electrode shall be field configurable to accommodate up to 200mm substrates with mechanical clamping mechanism and combination cryogenic-fluid-resistive cooling/heating units. Operating temperature range shall be -40 to 40°C continuous. Whenever possible, automatic adjustment of electrode temperature must recipe defined or set through the User Interface (UI).
2.7. Externally mounted gas module shall be configured to accommodate up to seven process gasses consisting with MFC/line heating for C_4F_8. At installation, process gasses to be O_2, N_2 Ar, CF_4, C_4F_8, SF_6 plus one spare.
2.8. Cathode/Substrate backside Helium cooling with pressure control.
2.9. Complete Optical Emissions Spectrometer endpoint detection systems with support computer where applicable.
2.10. The system shall meet all OSHA standards in force at the time of shipment. The system shall meet safety standards of a nationally recognized testing laboratory (NRTL).

2.11. Hardware shall be equipped with appropriate shielding to protect personnel from high energy electromagnetic radiation and thermal hazards.

2.12. The system shall be properly interlocked to protect against system damage resulting from facilities failure (electrical power, cooling water, scrubbed exhaust, etc.). The system shall operate in a failsafe mode such that the system shall automatically execute a power down to a safe state or enter a safe state such that restoration of failed facilities does not result in system damage.

2.13. The system shall be warranted to be free from defects in materials and workmanship for a period of one year following on-site acceptance.

2.13.1. The Contractor Service Division shall provide a 24 hour response to a notification to tool issue (either by phone, email, or on-site visit).

2.13.2. The Contractor Service Division shall begin onsite service/repairs within 72 hours (3 business days) from initial notification by SNL.

2.13.3. All partial repairs shall be completed at the next Preventative Maintenance Scheduled service or within 180 days of an initial Contractor response.

2.13.4. Partial repairs: Temporary remediation of an issue that allows the tool to otherwise operate until the system is fully restored to Contractor specifications.

2.13.5. If repairs are not completed within 90 days, then the Contractor shall offer an escalation plan in writing or an equitable adjustment as reasonably negotiated between both parties

3. Performance Requirement

3.1. **Processes**

3.1.1. Materials to be Etched – Silicon, Silicon On insulator, Silicon Dielectric Materials

3.1.2. <u>High Speed Deep Reactive Ion Etch 1</u> 525um depth (Through Wafer) 100mm substrate, Si ER >10um/minute (max speed), 5:1 aspect ratio, >200:1 Si:SiO2 etch selectivity, >100:1 Si:PR (Photoresist) etch selectivity, 90° +/-1° sidewall angle, sidewall scalloping < 500nm or better, center to edge. Targeting MEMS, Wafer thinning, Shadow Masks, small area Si Dry Dicing, fast anisotropic backside SOI handle/thru-wafer to BOx etch. **Test Conditions -** Etch mask material, 4um, low stress LPCVD (Low Pressure Chemical Vapor Deposition) SiO_2, 727°C, or Thermal SiO2 equivalent, 1050°C. SiO_2 backside stop layer. Supplier to provide details, including number of substrates needed, pattern area limitations (loading requirements) and type of geometry and pitch, 100mm diameter substrate, high speed, through wafer etch demonstration. Results from demonstration to be verified during tool qualifications. **Test Methods –** SEM (Scanning Electron Microscopy), Spectroscopic Reflectometry to assess etch selectivity.

3.1.3. <u>High Speed Deep Reactive Ion Etch 2</u>, 100um depth, 100mm substrate, Si ER >5um/minute, 70:1 aspect ratio, ultrasmooth sidewalls, 90 degree sidewall angle. >50:1 Si:SiO_2 etch selectivity, >30:1 Si:PR (Photoresist) etch selectivity, 90° +/-1° sidewall angle , sidewall scalloping < 50nm or better, center to edge. Surface morphology, <20Å average, maximum surface roughness. Targeting MEMs, SOI device layer etch, precision termination with no notching at the buried oxide layer. Shallow, precise time-multiplexed etch. **Test Conditions -** Etch mask material, photoresist MicroChemical AZ 10XT (220cP, 6μm), or equivalent 110°C, 180s SB. equivalent. Supplier to provide details, including number of substrates needed, pattern area limitations (loading requirements) and type of geometry and pitch, 100mm diameter substrate, lower speed, precision, time multiplexed etch demonstration. Results from demonstration to be

verified during tool qualifications. **Test Methods –** SEM (Scanning Electron Microscopy), Spectroscopic Reflectometry to assess etch selectivity, AFM (Atomic Force Microscopy), Profilometry.

3.1.4. Shallow Si Etch, Mixed or "Pseudo Bosch" Etch, 100mm substrate, 10um depth, 125nm CD, up to 80:1 aspect ratio (Ni Mask), >100:1 (Best Effort) Si:EB-R (Zion ZEP520 Ebeam Resist, 300nm) etch selectivity , 90° sidewall angle. Surface morphology, <10Å average, maximum surface roughness. Targeting SOI device layer, Shallow Si, Nanowires and Microneedles. **Test Conditions** – a) Etch mask material PVD (by Electron Beam) Cr/Ni, 5nm/50nm, 100mm substrate, 1 cm^2 pattern area centered, pillar array, 125nm CD with 500nm pitch. Supplier to provide details, including number of substrates required, pattern area limitations (loading requirements), high aspect ratio, submicron CD etch demonstration and then subsequent verification through tool qualifications. b) Same etch conditions as a), customer will also provide a ZEP patterned test wafer to etch to identify EB-R selectivity. **Test Methods –** SEM (Scanning Electron Microscopy), Spectroscopic Reflectometry to assess etch selectivity, AFM (Atomic Force Microscopy), Profilometry.

3.1.5. Etch Uniformity, 150mm, <+/-3% across the wafer, 10mm edge exclusion area, High Speed Deep Reactive Ion Etch 2 process. **Test Conditions -** Etch mask material, photoresist MicroChemical AZ 10XT (220cP, 6µm), or equivalent 110°C, 180s SB. equivalent. Supplier to provide details, including number of patterned substrates required, pattern area limitations (loading requirements), type of geometry and pitch in test region, 9-pt measurement, **Test Methods –** SEM (Scanning Electron Microscopy), Spectroscopic Reflectometry to assess etch selectivity, Profilometry.

3.1.6. SOI BOx Termination Verification, SEM images are sufficient that show zero notching processed on a similarly configured reactor to the reactor proposed and delivered.

3.2. **Reaction Chamber**

3.2.1. Two sets of process kits for field conversion of the biasing electrode for 100mm, 150mm and 200mm operation.

3.2.2. Two sets of chamber shields and non-biasing electrode process kit hardware.

3.2.3. Gas flow calibration. The Mass Flow Controllers (MFC) must read zero at a zero flow state, and that MFCs meet OEM specifications. Using the tool's flow calibration routine, all MFC calculated correction values must fall within 10% of 1.00 for gas specific calibrated MFCs or published gas flow Correction Factors for non-gas specific calibrated Thermal-based MFCs.

3.2.4. Shall be capable of high-speed, sub-1 second switching of gas flow, pressure and bias control component between two independent etch and deposition chemistries. Furthermore, pumping system components must be adequately sized to properly buffer significant variations in high/low atomic mass chemistries over short periods of time.

3.2.5. ICP RF Generator Calibration. The ICP generator shall meet OEM specifications for forward power output linearity into a 50-ohm resistive load and that the displayed power output valve on the User Interface (UI) registers a value within OEM specifications. (+/-1% of SP or +/-1W whichever is greater into 50-ohm resistive load)

3.2.6. ICP RF Reflected power at the output of generator shall be less than 10 watts and remain stable below that level at 80% of the generator's full power into the plasma, for a period of 30 minutes.

3.2.7. Bias RF Generator Calibration. The bias RF generator must meet OEM specifications for forward power output linearity into a 50-ohm resistive load and that the displayed power

output valve on the User Interface (UI) registers a value that meets OEM specifications. (+/-1% of SP or +/-1W whichever is greater into 50-ohm resistive load).

3.2.8. Bias RF Reflected power at the output of generator shall be less than 1 watt and remain stable below 1 watt, at 100% of the generator's full output power into the plasma, for a period of 30 minutes.

3.2.9. Substrate surface temperature rise and clamp stability. a) Under normal biasing/ICP conditions (Shallow Si Etch), the measured substrate surface temperature shall remain less than 45°C, with plasma, for a period of 15 minutes at an electrode temperature setpoint of 20°C. b) same test conditions, 100mm Si, AZ4330 photoresist coated Si substrate, soft baked 110°C, 90s, ten consecutive runs, visual analysis, no evidence of resist reticulation.

3.2.10. Reaction Chamber and Associated Mainframe Vacuum System Component Inboard Leak Integrity. a) helium mass spectrometer inboard leak rate shall be $<1E^{-7}$ mbar l/s, and b) system generated rate of rise <2mT/minute over a 10 minute test period.

3.2.11. Reactor's Gas Line/Gas System Inboard Leak Integrity. All process gas system components and hardware shall be helium leak checked using a He mass spectrometer. Leak rate of the system under test shall not exceed $5E^{-8}$ mbar l/s for non-toxic gasses, and $<1E^{-8}$ mbar l/s for all corrosive/toxic gasses.

3.2.12. Chamber wall heater control and performance. Chamber wall temperature setpoint to be UI definable and readable on the UI. Demonstrate ability to operate at maximum temperature for a period of 12 hours without user intervention. At the end of the test, re-verify reaction chamber leak integrity (ROR or He MS).

3.2.13. Pressure Control System. Pressure control valve, turbo molecular pump and process mechanical pumps shall operate throughout its configured pressure control range. No oscillations, measured value's adherence to process SP. Argon or N_2 gas flowing during test.

3.2.14. Optical Emissions Spectrometer hardware/software operation and accuracy must comply with instrument OEM standards.

3.3. **Transfer Mechanism/Load Lock**

3.3.1. Single wafer transfer system with tooling provided to accommodate small samples bonded to a 100mm contractor supplied carrier, or 100mm, 150mm or 200 mm semistandard dimension substrates.

3.3.2. System shall include four (4) process compatible, highly selective 100mm carriers to accommodate samples as small as 4mm x 4mm.

3.3.3. Verify wafer handler operation. Ten consecutive transfers into and out from the reaction chamber without intervention. Vent, pump, transfer, short 1:00 plasma, transfer out, vent, repeat. Resist coated 200mm wafer, AZ4330, 110°C bake, 90s.

3.3.4. Load Lock and Associated Mainframe Vacuum System Component Inboard Leak Integrity Verification. a) helium mass spectrometer inboard leak rate shall be $<1E^{-7}$ mbar l/s, and b) system generated rate of rise <2mT/minute over a 10 minute test period.

3.3.5. Load Lock Evacuation/Vent. Confirm slow/fast pump and vent operation, load lock must pump to a base pressure of less than 30mT in period of less than 5 minutes. Load lock must vent to atmosphere in a period of less than 5 minutes.

3.4. **Vacuum system**

3.4.1. Vacuum System Component Inboard Leak Integrity Verification. Helium mass spectrometer inboard leak rate shall be $<1E^{-7}$ mbar l/s for all vacuum system plumbing and components.
3.4.2. Process Mechanical Pump - Dry Pump only, set up and selected for corrosive and O_2 service.
3.4.3. Load Lock Pump – Dry Pump only, O_2 service.
3.4.4. Magnetically Levitated Turbo Molecular Pump, with a minimum 2300 l/s pumping capacity, heated base and fore line with N_2 purge

3.5. **Software and automation**

3.5.1. The system computer and control software shall use an MS Win7 or Win10 operating system.
3.5.2. PC and System software be able to operate standalone, disconnected from an external network of server for an undeterminable period.
3.5.3. The system control computer, peripherals, and system software shall provide capabilities and performance consistent with the specifications in this document
3.5.4. The tool shall be operated with user friendly software with open-source processing routines.
3.5.5. Routine operation shall be automated, but with the option to be run manually if necessary.
3.5.6. All system and subsystem parameters shall be able to be monitored and accessible from the UI.
3.5.7. Recipes and parameters shall be archivable to a thumb drive or mass storage media for records retention.
3.5.8. A backup of the UI and any other software required to quickly return the system to an operational state must be resident on the system's hard drive
3.5.9. Lifetime support for the system's UI and any other contractor proprietary software required to keep the system in an operational state.
3.5.10. Unless otherwise specified, all contractor provided software licenses are permanent and do not require a subscription service to maintain the tool in an operational state.

4. Optional Items

4.1. Atomic Layer Etch module if available.
4.2. Pumps – Edwards preferred, however based on availability Pfeiffer and DryTek are acceptable alternatives.
4.3. Advanced Energy, or Seren IPC RF Generators and impedance matching units preferred.
4.4. If an option, MKS mass flow controllers.
4.5. Recommended spare parts and consumables kits.

5. Power, Environment, and Safety

5.1. Contractor shall integrate Lockout/Tagout (LOTO) hardware support for all power systems.
5.2. Contractor shall provide the appropriate RF, Electrical and Pressure Safety Interlocks to protect the reactor and workers from common hazards.
5.3. System shall have proper shielding to protect and limit occupant exposure from ionizing/non-ionizing, electromagnetic radiation which includes RF, X-Ray and Ultraviolet radiation. Furthermore, system shall be properly shielded to protect/buffer sensitive electronics from strong Electromagnetic Fields generated by the tool or similar tools that are in close proximity.

5.4. Sapphire process chamber viewports shall be used with Lexan or Plexiglass cover. The OES viewport shall be sapphire with appropriate shielding to prevent workplace exposure to stray UV light.
5.5. Electrical power shall be 208 VAC, 3-phase (3 or 4 wire), 50-60 Hz
5.6. Provision for a remote shutdown command to place the reactor into a fail-safe condition should a fume exhaust failure occur. Typical safety loop through a series of facility equipment relay contacts. Isolated loop powered by reactor power supply, fail-safe open circuit, loop closes when all support systems are normal.
5.7. To prevent personal injury, damage to the equipment or facility, process must abort placing system into a fail-safe state should any of the following conditions occur. Loss of a) process cooling water flow, b) exhaust static pressure, c) pneumatic supply pressure or d) power anomaly.
5.8. Provisions must be provided for Emergency Power Off (EPO), operator reset/power up, of the reactor and all vendor supplied reactor support equipment. Switches shall be provided located in close proximity to the mainframe/load lock in the operations area, and within 5' of the support equipment in the chase. All EPO switches must be clearly marked and easily identified.
5.9. Contractor shall be responsible for all power feeds between the tool's main power distribution panel, mainframe and all contractor supplied support equipment. Properly shielded communications, control and instrumentation cables are to be provided.
5.10. Provisions for single point, low impedance earth ground (structural steel in our case) must be provided on the mainframe and any other subsystem components that may generate strong electromagnetic fields, are highly sensitive to Radio Frequency Interference (RFI) or other forms of transient induce Electromagnetic Interference (EMI).
5.11. SNL shall be responsible for process gas sourcing and delivery, power to main disconnect, process cooling water delivery to/from the system components, closed fume exhaust to pumps, gas cabinets, toxic gas monitoring and control.

6. CINT/SNL site-specific requirements

6.1. Facility Utility/Lab Specifications
  6.1.1. Lab Environment, Class 1000 operations area only, air return through chase. Temp 70 +/- 2°F, Humidity 40 +/-5%RH
  6.1.2. Process gas cabinets and house gas delivery to contractor's equipment. With exception to house nitrogen and select toxic, when available processes gasses are ULSI grade, filtered <0.003 um at 5N9 purity (purified to 9N9 when possible).
  6.1.3. House nitrogen, liquid source, filtered <0.003, better than 99.4% purity. Regulated POU, 90-110 psi maximum house pressure.
  6.1.4. Pneumatic Air Supply filtered <0.3um, Nitrogen, 90-110 psi maximum house pressure from liquid source.
  6.1.5. Main power to reactor's disconnect should be 208V-3P, 3 or 4 wire. (Y)
  6.1.6. Process cooling water delivery to/from the system components. Filtrated 10um nominal, conductivity <50 micromhos, pH 7-9, Total biological <1000 RLU. System's Al (2024) corrosion rate <0.5 mpy, Cu (CDA110) corrosion rate <0.35 mpy.
  6.1.7. Fume exhaust to pumps, gas cabinets, equipment heat exhaust, and any applicable abatement systems. >2.0" WC static pressure.
6.2. With this order, written documentation shall be provided verifying that the products ordered by the BSA based on the stated specifications, product descriptions, and performance statements, or associated supplier quotes have been supplied.

6.3. The items shall be provided with all needed installation requirements and instructions, and operating and maintenance instructions to ensure correct installation, usage, and maintenance. All documentation shall be provided in English.
6.4. Where applicable, documentation shall include the rated capacities and capabilities, accuracy, and uncertainty performance specifications of each device.
6.5. The Contractor shall furnish with each system a replacement parts listing giving the part number and serial or lot control number (if applicable) of each replacement part that may be necessary to maintain the system in a fully functional condition.
6.6. It is the Contractor's responsibility to meet all applicable US electrical and associated safety and health code requirements relative to the described equipment.
6.7. The system shall be tested/inspected at the Contractor's site to ensure that all technical requirements of the product specification have been met. SNL reserves the right to have a representative present during any manufacturing, assembly, test, inspection, or other activities associated with this system. Test/inspection results shall be documented and provided to SNL's representative prior to shipment of the system. SNL's representative shall be notified of planned testing at least ten working days prior to commencement.
6.8. Associated computer codes shall be validated and verified for correctness prior to release to the customer.
6.9. All deviations from the technical specification that were not approved prior to conduct of activities associated with these deviating conditions shall be classified as nonconformances. All nonconformance documentation shall be provided to the SNL's representative two weeks prior to shipment of the system. Shipment shall not take place until all nonconformances have been approved by SNL's representative.
6.10. Where applicable, documentation shall include the calibration status (calibrated or not calibrated) of each device and - if shipped in a calibrated condition - a description or reference to the method used to perform the calibrations at the time of shipment including the reference standard(s) used for this purpose.
6.11. Where applicable, documentation shall include instructions concerning the calibration of associated devices, instruments, or components to fully ensure the stated operating capabilities based on methods traceable to the US National Institutes for Standards and Technology.
6.12. The Contractor is responsible for all packing and shipping provisions to ensure that the products in this order arrive at the SNL's site in an undamaged, working condition.
6.13. Final acceptance of the described equipment shall be based on testing to the technical requirements of the specifications after completion of installation at the SNL's site.