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Specifications for a cryogen-free dilution refrigerator with pulse-tube cryocooler, superconductingmagnet, and coax wiring

Purpose: A dry cryogenic system, equipped with a pulse-tube cryocooler and compressor, and consisting of a superconducting magnet, is required for low temperature (between 10 mK and 1 K) transport measurements, with focus on quantum computing with electron spins in silicon. The system will be installed in the Physics department of Indian Institute of Technology, Bombay.

Detailed specifications:

1. The cryostat: (a) The vacuum enclosure and the radiation shields should be light weight and split in two parts, such that to gain access to the dilution unit, only the lower part need to be removed.
   (b) A turbomolecular pump separate from the one used for the ^{3}He circulation should be provided for vacuum pumping

2. The dilution refrigerator insert: (a) The insert should have all the necessary KF ports on the top flange, for (i) the pulse tube, (ii) the condensing line, (iii) the pumping line for the cryostat vacuum, (iv) the still pumping line, (v) the current leads for the superconducting magnet, and (vi) magnet diagnostic line. Additional KF ports allowing the necessary wiring (described later) should also be available on the top flange.
   (b) The dilution unit should be removable/replaceable without disturbing the experimental plates/wiring
   (c) The pulse tube unit should be replaceable without disturbing the dilution unit/experimental plates (d) The space beneath the mixing chamber should be wider than the bore of the superconducting magnet and sufficiently long to accommodate the same.

3. Base temperature/Cooling power: The base temperature should be 10 mK or lower. The cooling power should be (a) ⌑ $12\mu W$ at 20 mK (b) > 400 μW at 100 mK, and (c) > 600 μW at 120 mK, and (d) 2 W at 4.2 K with complete wiring and outside the mixing chamber.

4. Gas Handling system
   (a) The gas handling system (GHS) should provide the possibility of (i) computer-controlled fully automatic, as well as, (ii) completely manual control of the cool-down sequence, to reach the base temperature.
   (b) The gas handling system should be *completely oil-free*, using suitable pumps for ^{3}He circulation and other requirements.
   (c) The GHS should be provided with both internal and external liquid nitrogen cold trap.
   (d) Control valves, flowmeters, safety and pressure regulators, gauges and electronic units of the GHS should be of very high quality (sourced from well-established manufacturers with proven track-record of reliability) (e) Provision for robust electrical and mechanical isolation of the GHS from the cryostat using suitable clamps, spacers, and dampers should be provided.

(f) The turbomolecular pump for ^{3}He circulation should be separated from the one for vacuum pumping of the cryostat.

5. Diagnostic/Control Electronics: (a) The necessary electronic unit for control and monitoring of the resistance thermometers and heaters should be provided, along with the appropriate software to run the unit from a PC and through web interface.

6. Safe recovery in the event of power failure: The control unit should have the provision for putting the unit in a safe mode (including avoidance of quench of the superconducting magnet system).

7. Magnetic field: (a) The superconducting magnet should be capable of producing a field of minimum 9 Tesla, with a homogeneity better than (or equal to) *±0.1% DSV*.
   (b) The magnet should be easily removable from the bottom of the dilution unit.
   (c) The field stability must be better than 0.05% drift per hour.
   (d) The bore diameter should be equal to or larger than 4 inch, such that the sample space is minimum 90 mm. (e) The magnet should have a persistent mode switch offering field stability better than 50 ppm drift per hour at full field.
   (f) The magnet should have suitable quench protection mechanism.
   (g) The magnet should be provided with the necessary power supply, magnet temperature sensor and readout, and current leads. The power supply should be capable of "four-quadrant" operation and smooth zero crossing. No mechanical switching or glitch should occur when the magnetic field is ramped through zero value.
   (h) Ramp rate up to approximately 0.1Tesla/minute is required.
   (i) All the functions of the magnet supply should be accessible through an IEEE-488 (GPIB) interface.
   (j) Necessary accessories enabling use of the system without the magnet should be provided.

8. Wiring: Following experimental wiring should be provided.

DC lines: (a) 12 twisted pairs of Cu (AWG 35) wiring from 24-pin Fischer connector at room temperature to 4K, followed by 12 twisted pairs of CuNi or Ph-Br wiring from 4K to the mixing chamber plate, with micro-D break at 4 K.

(b) 12 twisted pairs of Cu (AWG 35) wiring from 24-pin Fischer connector at room temperature to 4K, followed by 12 twisted pairs of NbTi-CuNi wiring from 4K to the mixing chamber plate, with micro-D break at 4 K.

(c) 12 twisted pairs of CuNi or Ph-Br wiring from 24-pin Fischer connector at room temperature to mixing chamber plate, with micro-D break at 4 K.

(d) 12 twisted pairs of Cu wiring from 24-pin Fischer connector at room temperature to 4K, terminated by nano-D connector, with/without magnetic shielding.

RF lines: (a) Vacuum flanges with necessary feedthroughs and additional thermal anchoring flanges at 50 K and 4 K for the experimental wiring mentioned below should be provided.

(b) 1x 2.19 mm CuNi-SCuNi semi-rigid coax cable between RT and 4 K followed by 2.19 mm or 0.86 mm CuNi-SCuNi coax cable between 4 K and mixing chamber plate. All connectors should be of K 2.92 mm (40 GHz) type.

(c) 1x 2.19 mm CuNi-SCuNi semi-rigid coax cable between RT and 4 K followed by 2.19 mm or 0.86 mm NbTi-NbTi coax cable between 4 K and mixing chamber plate. All connectors should be of K 2.92 mm (40 GHz) type

(d) 1x 2.19 mm CuNi-SCuNi semi-rigid coax cable between RT and 4 K followed by 2.19 mm or 0.86 mm CuNi-SCuNi coax cable between 4 K and mixing chamber plate. All connectors should be of SMA (18 GHz) type.

(e) 1x 2.19 mm CuNi-SCuNi semi-rigid coax cable between RT and 4 K followed by 2.19 mm or 0.86 mm NbTi-NbTi coax cable between 4 K and mixing chamber plate. All connectors should be of SMA (18 GHz) type.

(f) 8 x CuNi-SCuNi semi-rigid coax cables, with graphite-coated FEP dielectric designed for 50 Ohm characteristic impedance, and provided with SMA (18 GHz) connectors, between RT and mixing chamber plate, with breakout at 4 K plate.

(g) 0dB attenuators at 50K, 4K, still, cold plate, and mixing chamber should be included.

9. Vibration isolation:

(a) The cryostat support frame must provide separation of the cryostat top and pulse tube ballast tanks and motor to minimize the vibration transfer to the cryostat from the pulse tube, e.g., a separate shelf for placing the pulse tube components.

(b) The cryostat must be isolated from the support frame and pulse tube components (ballast tanks and motors) via active (for example: using controlled spring action) vibration damping system (in the 1-200Hz range).

10. Essential accessories:

(a) Two fully shielded breakout boxes specialized for low-temperature experiments. The breakout should extend the Faraday cage of the cryostat, going from a 24-pin Fischer connector to a 24- channel BNC connector panel. All wiring inside the break-out box should be done in twisted pairs for best noise immunity. Switches to enable connection of each channel directly to ground or a common bus should be provided.

(b) A He leak detector system, capable of operating in vacuum and sniffing leak detection modes, with minimum He leak detection rates of 5 $\times 10^{-12}$ mbar l/s and 5$\times 10^{-9}$ mbar l/s, respectively, and supported by oil free pumping system, must be included in the quote.

(c) Tool kits for replacing, refurbishing experimental wiring.

(d) Tool kits for mounting/removing vacuum flanges and vacuum enclosures must be included.

(e) 2x gold-plated Be-Cu cold finger, as per the design provided by us should be included.

11. Warranties and contracts

(a) Comprehensive warranty for the entire system and essential accessories for minimum 36 months

12. Track record, presentations, and references

(a) Feedback of end-users (as obtained by us), specifically for semiconductor spin quantum computing research, will be critically considered.

(b) Proven track record of installation and service to customers based in India and/or elsewhere should be provided.

(c) The technical bid must contain point-by-point technical compliance data. If required, the bidder will make available for meetings for technical clarifications.

13. Installation, commissioning, and training should be provided by the vendor at our site. The cost towards this should be included in the quotation.