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| United States Patent | 12392695 |
| Kind Code | B2 |
| Date of Patent | August 19, 2025 |
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# Cryogenic analysis systems and methods

## Abstract

Switch assemblies for a cryogenic device analysis system are provided. The switch assembly can include: a cold source conductive member extending lengthwise to a cold source; and a cryogenic device conductive member extending lengthwise to a cryogenic device and at least partially overlapping at least a portion of the cold source conductive member. Methods for closing a conductive connection between a cold source and a cryogenic device within a cryogenic analysis system are provided. Methods for opening a conductive connection between a cold source and a cryogenic device within a cryogenic analysis system are provided. Cryogenic device analysis systems are also provided.

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**Appl. No.:** **18/771991**

**Filed:** **July 12, 2024**

## Prior Publication Data

| Document Identifier | Publication Date |
|---|---|
| US 20240369461 A1 | Nov. 07, 2024 |

## Related U.S. Application Data

continuation parent-doc US 17698764 20220318 US 11959845 20240416 child-doc US 18582621
continuation-in-part parent-doc US 18582621 20240220 US 12292366 child-doc US 18771991

us-provisional-application US 63164469 20210322

## Publication Classification

**Int. Cl.:** **G01N1/42** (20060101); **G01N25/14** (20060101)

**U.S. Cl.:**

CPC **G01N1/42** (20130101); **G01N25/145** (20130101);

## Field of Classification Search

**CPC:** G01N (1/42); G01N (25/145)

## References Cited

**U.S. PATENT DOCUMENTS**

| Patent No. | Issued Date | Patentee Name | U.S. Cl. | CPC |
|---|---|---|---|---|
| 4827736 | 12/1988 | Miura | 62/51.1 | F25D 19/006 |
| 5611207 | 12/1996 | Hess | 62/298 | B01L 1/02 |
| 11125664 | 12/2020 | Doherty | N/A | G01N 35/00 |
| 2007/0252090 | 12/2006 | van de Water | 250/429 | H01J 37/20 |
| 2013/0194703 | 12/2012 | Husband | 361/19 | H02H 9/023 |
| 2019/0170622 | 12/2018 | Doherty et al. | N/A | N/A |
| 2019/0170623 | 12/2018 | Doherty | N/A | F17C 3/085 |
| 2020/0279680 | 12/2019 | Mine | N/A | G01R 33/3804 |
| 2021/0262701 | 12/2020 | Stautner | N/A | G01R 33/3804 |

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## Background/Summary

CROSS REFERENCE TO RELATED APPLICATION (1) This application is a continuation-in-part of U.S. patent application Ser. No. 18/582,621 filed Feb. 20, 2024, entitled “Cryogenic Analysis Systems and Methods”, which is a continuation of U.S. patent application Ser. No. 17/698,764 filed Mar. 18, 2022, entitled “Cryogenic Analysis Systems and Methods”, now U.S. Pat. No. 11,959,845 which issued Apr. 16, 2024, which claims priority to and the benefit of U.S. Provisional Patent Application Ser. No. 63/164,469 filed Mar. 22, 2021, entitled “Cryogenic Analysis Systems and Methods”, the entirety of each of which is incorporated by reference herein.

TECHNICAL FIELD
(1) The present disclosure relates to cryogenic device analysis systems and methods.
BACKGROUND
(2) Cryogenics is a critical technology for the quantum information science and technology industry. Reaching stable, low temperatures near absolute zero is necessary to maintain qubit coherence, investigate quantum properties, and ultimately realize the potential of quantum

applications in computing, sensing, and networking. Quantum systems rely on cryogenic devices including electrical, optical, RF, and microwave components that must operate at low, cryogenic temperatures near absolute zero. Despite advances cryogenic devices can prove unreliable due to challenges in designing and manufacturing of components that can withstand low temperatures and multiple thermal cycles across a wide temperature range.

(3) Testing these devices can be cumbersome and tedious to perform because of the time necessary to cool a cryogenic device down to these very low operational temperatures. Today's closed-cycle cryostats can take more than 3 hours to cool a cryogenic device to 4K. This cryogenic device exchange time can limit the number of cryogenic devices that can be tested in a day and places a bottleneck on the pace of quantum discovery.

SUMMARY

(4) To reduce the cryogenic device exchange time of conventional cryostats by greater than 10×, a new cryostat architecture is provided herein in which the temperature and vacuum control of the cryogenic device can be controlled independently from the rest of the cryostat. Such an architecture would allow the cryogenic device to be warmed, vented to atmosphere, and exchanged-all while keeping the remaining large mass components, including the cryocooler, cold and under vacuum. Cryogenic device exchange time can be performed significantly faster, since only the mass of the cryogenic device is thermally cycled (cooled down and warmed up) during an exchange.

(5) It has been recognized that typical cryostats used to cool devices to cryogenic temperatures thermally engage to a cold source via a thermal conduit. In these typical systems the device and cold source are always thermally engaged and located within the same vacuum chamber. Despite the desire to thermally cycle just the cryogenic device, current systems require the entire system to be thermally cycled to exchange a cryogenic device. Current cryostat architectures utilizing solid conduction heat transfer cannot allow a cryogenic device to be exchanged any faster than the time required to cool down the cold source itself; typically 60-90 minutes for a 2-stage cryocooler for example. The cryogenic device is a fraction of the mass compared to that of the cold source, thermal conduit, and associated radiation shields such that the cryogenic device exchange time is significantly reduced when only the cryogenic device is thermally cycled.

(6) The systems of the present disclosure provide a new cryostat architecture that can include, in particular embodiments, thermal and vacuum control of the cryogenic device independent from the remainder of the analysis system. The cryogenic device and cold source are in separate vacuum spaces, and a thermal switch can be utilized to engage/disengage thermal communication between the cryogenic device and the cold source, thereby allowing for the cryogenic device to be thermally cycled and exchanged without having to thermally cycle the entire analytical system.

(7) Cryogenic device analysis systems are provided that can include: a cold source within a first vacuum chamber; a cryogenic device mount within a second vacuum chamber, wherein the first and second vacuum chambers are separated by a vacuum barrier; and a first thermal conduit extending from the cold source through the vacuum barrier to the sample mount.

(8) Methods for performing analysis of a cryogenic device are provided, the methods can include: providing a cold source within a first vacuum chamber; thermally connecting the cold source to a cryogenic device mount within a second vacuum chamber through a vacuum barrier between the first and second vacuum chambers; within the second vacuum chamber reducing a temperature of the cryogenic device with the cold source; performing analysis of the cryogenic device while the cryogenic device is both operational and at cryogenic temperature; and disengaging the cold source from the sample mount and replacing the cryogenic device with another cryogenic device for analysis.

(9) Embodiments of a switch assembly configured to connect/disconnect cold source conductive members from sample space conductive members in low pressure and/or low temperature environments are provided. Embodiments of the switch can include a structure, for example, a chassis, of higher coefficient of thermal expansion (CTE) than the conductive members.

Implementations can allow for higher force on a cold closed thermal contact joint than at warm temperatures. Additionally, embodiments allow for the use of smaller components and less powerful power sources to control actuators. This can provide the user with more cooling power, faster cooldown times, and lower cryogenic temperatures.
(10) Switch assemblies for a cryogenic device analysis system are provided. The switch assembly can include: a cold source conductive member extending lengthwise to a cold source; and a cryogenic device conductive member extending lengthwise to a cryogenic device and at least partially overlapping at least a portion of the cold source conductive member, wherein either or both of the conductive members are biased to define an insulative space between the conductive members at the overlap in an open orientation.
(11) Methods for closing a conductive connection between a cold source and a cryogenic device within a cryogenic analysis system are provided. The methods can include: providing sufficient mechanical force to either or both of a portion of a cold source conductive member or a portion of an overlapping cryogenic device conductive member to at least partially thermally engage the overlapping portions of the conductive members and thereby close a thermal connection between the conductive members.
(12) Methods for opening a conductive connection between a cold source and a cryogenic device within a cryogenic analysis system are provided. The methods can include providing sufficient thermal energy to an encompassing member to provide freedom of movement between the overlapping portions of the conductive members.
(13) Cryogenic device analysis systems are also provided. The systems can include: a pair of vacuum regions separated by a vacuum barrier; and a switch within either of the vacuum regions. The switch can include: a cold source conductive member extending lengthwise to a cold source within one vacuum region; a cryogenic device conductive member extending lengthwise to a cryogenic device within another vacuum region and at least partially overlapping at least a portion of the cold source conductive member, wherein either or both of the conductive members are biased to define an insulative space between the conductive members at the overlap in an open orientation; and at least one mechanical actuator operatively engaged with either of the portions of the conductive members.

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## Description

BRIEF DESCRIPTION OF DRAWINGS
(1) Embodiments of the disclosure are described below with reference to the following accompanying drawings.
(2) FIG. **1** is cryogenic device analysis system according to an embodiment of the disclosure.
(3) FIG. **2** is a vacuum system for use in a cryogenic device analysis system according to an embodiment of the disclosure.
(4) FIG. **3** is a cryogenic device analysis system according to one embodiment of the disclosure.
(5) FIG. **4** is a cryogenic device mount and radiation shield mount system for use in a cryogenic analysis system according to an embodiment of the disclosure.
(6) FIG. **5** is a cryogenic device analysis system according to one embodiment of the disclosure.
(7) FIG. **6** is a cryogenic device analysis system according to one embodiment of the disclosure.
(8) FIG. **7** is a depiction of a cryogenic device analysis system having a switch assembly in one configuration according to an embodiment of the disclosure.
(9) FIG. **8** is the system of FIG. **7** in another configuration according to an embodiment of the disclosure.
(10) FIG. **9**A is a more detailed view of portions of the switch assembly of FIGS. **7** and **8** in one configuration according to an embodiment of the disclosure.

(11) FIG. **9**B is a depiction of the portions of FIG. **9**A in another configuration according to an embodiment of the disclosure.
(12) FIG. **9**C is yet another configuration of the portions of FIGS. **9**A and **9**B according to an embodiment of the disclosure.
(13) FIG. **10** is another depiction of a switch assembly according to an embodiment of the disclosure.
(14) FIG. **11**A-F are different configurations of a switch assembly according to an embodiment of the disclosure.
(15) FIG. **12** is an isometric view of a switch assembly according to an embodiment of the disclosure.
(16) FIG. **13** is an elevational view of a switch assembly according to an embodiment of the disclosure.
(17) FIG. **14** is a cross-sectional view of the switch assembly of FIG. **13** according to an embodiment of the disclosure.
DESCRIPTION
(18) This disclosure is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article **1**, Section **8**).
(19) Cryogenic device analysis systems and methods will be described with reference to FIGS. **1-14**.
(20) Referring first to FIG. **1**, a cryogenic device analysis system **10** is depicted that can include a cold source **32** within a first vacuum chamber **40** which can be defined by first vacuum chamber housing **30**. A cryogenic device mount **16** can be within a second vacuum chamber **26** which can be defined by second vacuum chamber housing (walls) **12**. Second vacuum chamber **26** defines feedthrough openings (not shown) configured to receive electrical or optical cables **20** for operative coupling to a cryogenic device **18** upon device mount **16** within second vacuum chamber **26**. The feedthroughs can provide for electrical and/or optical access to cryogenic device **18**. Vacuum sealing interfaces and features may be provided as part or a portion of walls **30** and/or **12** to provide user access to the cryogenic device.
(21) First and second vacuum chambers are separated by a vacuum barrier **38**. A first thermal conduit **36** in combination with conduit **24** can extend from cold source **32** through vacuum barrier **38** to cryogenic device mount **16**. Vacuum barrier **38** can be a non-permeable physical barrier that can withstand a pressure differential of >15 psia. One portion of vacuum barrier **38** can be mounted or coupled to either or both of walls **30**/**12** and held at room temperature (295 K) while another portion is maintained at the cryogenic device temperature, for example 4K.
(22) Vacuum barrier **38** can be configured to be thermally resistive to reduce the conductive heat load within the system and particularly to cryogenic device **18**. For example, barrier **38** can be comprised of low thermally conductive materials including titanium, stainless steel, ceramic, and/or fiberglass components. Further reductions in conductive heat load can be reduced by configuring barrier **38** with low cross-sectional area and geometries that maximize the length of the conductive path. Additionally, vacuum barrier **38** can be constructed of vacuum compatible materials with minimal off-gassing and low leak rates, to support vacuum or UHV conditions. Barrier **38** may be composed of a single material, or potentially multi-material and joined using fasteners, epoxies, or various manufacturing techniques such as welding, brazing, 3D printing, and/or soldering (see U.S. Pat. No. 11,150,169 B2 issued Oct. 19, 2021, the entirety of which is incorporated by reference herein).
(23) Vacuum barrier **38** can be a non-permeable physical boundary that separates first vacuum chamber **40** from second vacuum chamber **26**. Vacuum barrier **38** may complete chamber walls of first vacuum chamber **40** and/or second vacuum chamber **26**. Barrier **38** may also be separate from either or both of the walls of first or second chambers **40** or **26**, for example as part of a conduit (not shown) extending between chambers **40** and **26** and configured to house thermal conduit **36**

and/or **24**. Barrier **38** separates the pressures within chambers **40** and **26**.

(24) A first thermal switch **34** can be operatively aligned along first thermal conduit **36** between cold source **32** and vacuum barrier **38**. Thermal switches can be configured to connect/disconnect thermal communication between cold source **32** and cryogenic device mount **16** and/or device **18** under test. With the thermal switch **34** closed, heat flows from the cryogenic device **18** to cold source **32**. When switch **34** is opened, heat flow between cryogenic device **18** and cold source **32** is significantly reduced if not disconnected altogether. Various types of thermal switches, also known as heat switches, have been developed and could be employed. Examples include thermal gas-gap diodes, heat exchangers, heat pipes, superconducting heat switches, mechanical switches, and magneto resistive heat switches. The specific type of thermal switch technology can be optimized for different applications, either for use in sub-**1**K with low heat transfer rates or designed for low power usage for space-based applications for example.

(25) Mechanical switches, which rely on the contact of two or more thermal conductors driven together by a mechanism, for example a screw driven by an electrical stepper motor, to close the switch may be utilized for 4K operation as it allows for thermal contact interface design freedom, ease of control using off-the-shelf force transducers, and motion components that support fully automated control. While shown to be within chamber **40**, in other embodiments thermal switch **34** can be located in chamber **26**.

(26) Device analysis system **10** can also include first thermally insulative cryogenic device mount supports **22** extending between cryogenic device mount **16** and walls **12** of second vacuum chamber **26**. Vacuum barrier **38** can be a portion of first vacuum chamber **40**. Vacuum barrier **38** can have be a portion of second vacuum chamber **26**. Vacuum barrier **38** can be a portion of both first and second vacuum chambers (**40**/**26**).

(27) In accordance with at least one example, cryogenic device **18** to be cooled is thermally engaged with cold source **32** via first and second thermal conduits **36**/**24**. Cryogenic device **18** resides in second vacuum chamber **26** and cold source **32** in first vacuum chamber **40**. Second vacuum chamber **26** and first vacuum chamber **40** can share walls. For example, chamber walls **30** may be contiguous with chamber walls **12** as shown. Alternatively, chamber walls **30** and chamber walls **12** may not be contiguous.

(28) Cryogenic device **18** is mounted to and thermally engaged with a cryogenic device mount **16**. Cryogenic device mount **16** is mechanically supported by a cryogenic device support structure that can include first thermally insulative cryogenic device mount supports **22** (thermally insulative supports) extending between cryogenic device mount **16** and walls of second vacuum chamber **26**.

(29) Thermally insulative supports can be a structure that mechanically supports substrates that are thermally coupled to cold source **32**, for example, cryogenic device **18** and/or cryogenic device mount **16**. Thermally insulative supports can be configured to minimize heat transfer from where the insulative support is mounted to the walls (substrate) of the vacuum chamber, typically at room temperature, to the cryogenic device. The supports can also be configured to reduce vibrations at the cryogenic device; the support can be a high-stiffness structure. The cryogenic device support structure **22** can be constructed of materials and in geometries resulting in a thermally resistive, stiff structure. For example, it may be composed of titanium, stainless steel, aluminum, ceramics, fiberglass components, G10, and/or PEEK materials.

(30) It could be composed of a single material, or potentially multi-material and joined using fasteners, epoxies, or various manufacturing techniques such as welding, brazing, 3D printing, and/or soldering.

(31) Conduits **36**/**24** transfer thermal energy (heat) between cryogenic device mount **16** and cold source **32** and, by example, to and from the cryogenic device **18** to cold source **32**. Thermal conduit **24** is in the second vacuum chamber **26** and thermal conduit **36** is in first vacuum chamber **40**. Thermal switch **34** is located between mount **16** and cold source **32** to engage/disengage thermal communication between cryogenic device **18** and cold source **32**.

(32) Cryogenic device **18** can be a device or component to be analyzed at a cryogenic temperature of interest. Device **18** can be, for example, an electronic or optical device used in a quantum computer, including for example an RF amplifier, that is tested and qualified for use prior to installation in a quantum computer. Device **18** can include or be supported by processing circuitry that can be operatively connected to a quantum computing system for operation at cryogenic temperatures. Accordingly, device **18** can be configured to be coupled to and operated with electrical or optical cables **20**, which, in example embodiments can be operationally coupled to processing circuitry (not shown) that can be utilized to monitor and/or operate device **18** during analysis using the systems of the present disclosure.
(33) Cold source **32** is a source of heat or cold energy that can be used to heat or cool cryogenic device **18**. Example cold source **32** can include a mechanical cryocooler, with either one or multiple cooling stages, or for example a dewar of fluid cryogen such as helium or nitrogen.
(34) Thermal conduits of the present disclosure can be a conduit that can transfer heat to and/or from cold source **32** to a cryogenic device **18** via sample mount **16**. The conduits can facilitate heat transfer via solid conduction through, for example, a copper bar or rod (not shown). The conduits can also include a fluid conduit that transfers fluid cryogens to or from a cold source to cryogenic device **18**.
(35) Chamber walls **30** and/or **12** can be a non-permeable structure capable of maintaining an interior vacuum pressure, for example <1E-7 Torr or possibly ultra-high-vacuum (UHV) conditions <1E-11 Torr. Walls **30** and/or **12** can be made of machined aluminum for example or a welded metal structure.
(36) System **10** can include vacuum systems **50** and/or **52** for example. These systems can be a single system and/or multiple systems that may operate independently of one another. For example, chambers **40** and **26** can be independently controlled using vacuum control components **100** that are connected to each of the vacuum chambers **26** and **40** via vacuum hoses **104** as shown in FIG. **2**. A vacuum control module **102** can include a vacuum pump, pressure gauges, valves, electronics, and software control to pull vacuum and vent either one or both of chambers **40**/**26**. The control of each pressure within the chambers can be independent, such that one chamber can be under vacuum conditions, <1E-7 Torr for example, while the other chamber is simultaneously vented to atmosphere.
(37) The temperature of cryogenic device **18** can be controlled with a thermometer and heater either attached to cryogenic device **18** and/or the cryogenic device mount **16**. The temperature can be controlled via a PID loop or other control logic that controls the heater output, for example by increasing current applied to a resistive heater, to achieve a desired cryogenic device temperature. Accordingly, systems of the present disclosure may be operatively controlled with processing circuitry not shown.
(38) In accordance with at least one example, when cryogenic device **18** and cold source **32** are cold and the vacuum chambers **26** and **40** are under vacuum, the process for cryogenically cooling a new cryogenic device can include: 1) Disengaging the thermal switch to stop or significantly reduce the heat transfer between the cryogenic device **18** and the cold source **32**. 2) Warming the cryogenic device **18** to room temperature by controlling cryogenic device heater (part of sample mount and not shown) and turning off the heater once it reaches room temperature. 3) Venting chamber **26** to atmosphere. 4) Exchanging cryogenic device **18** for alternative device for analysis. 5) Pulling vacuum to reduce the pressure within chamber **26**. 6) Engaging thermal switch **34** so cryogenic device **18** is thermally engaged with cold source **32**.
(39) Utilizing the systems of the present disclosure, a cryogenic device exchange can be performed much faster because only the cryogenic device—whose mass is typically a fraction of the cold source mass-must be thermally cycled during a cryogenic device exchange.
(40) FIG. **3** depicts another embodiment of the disclosure. In accordance with this embodiment, multiple thermal switches **222** and **232** are used to engage multiple components (shield mounts **204**

and sample mount **16**) within chamber **26**. In accordance with example implementations cold source **32** within chamber **40** can include at least two cold source stages **220** and **230** configured to provide different temperatures from each stage. Accordingly, the first thermal conduit **234** can extend from second stage **230** through vacuum barrier **38** to sample mount **16**.

(41) Within chamber **26** can be a thermal radiation shield **202** operatively aligned to shield either or both of cryogenic device **18** and/or device mount **16** from thermal radiation. At least one thermal radiation shield mount **204** supporting thermal radiation shield **202** can be provided. Thermally insulative shield mount supports **206** can be provided extending between the second mounts **204** and the walls of the vacuum chamber **26**. To facilitate thermal control of shield **202** and mounts **204**, thermal conduit **224/208** is provided extending from cold source stage 1 **220** to the thermal radiation shield mount **204**. System **200** can also include another thermal switch **222** along the thermal conduit **224/208** and operatively aligned between cold source **32** and vacuum barrier **38**.

(42) Accordingly, inside chamber **26** is radiation shield **202** that shields cryogenic device **16** from radiative heat loads from walls **12** of chamber **26** when maintained at room temperature. Cold source **32** is shown to have two stages, representing for example a Pulse Tube or Gifford-McMahon cryocooler with two stages operating at different temperatures: 40K on stage **220** for example and 4K on stage **230**. Cryogenic device **18** is in thermal communication with the stage **230** cold source via thermal conduits **234/208** in chambers **26** and **40**. Thermal switch **232** engages/disengages thermal communication between cryogenic device **18** and cold source stage **230**. Cryogenic device **18** is thermally engaged with cryogenic device mount **16** that is supported by a cryogenic device support structure **22**.

(43) Radiation shield **202** is in thermal communication with the stage **220** cold source via thermal conduits **224/208** in chambers **40** and **26**. Thermal switch **222** engages/disengages the thermal communication between radiation shield mount **204** and cold source stage **220** via the cold source stage thermal conduit **224/208**. Radiation shield **202** is thermally engaged with radiation shield mount **204** that is supported by a insulative radiation shield mount support structure **206**.

(44) Thermal switches **222/232** can be operated independently. For example, cryogenic device **18**, in thermal communication with cold source stage **230**, can be held at 4K for example. Radiation shield **202**, in thermal communication with cold source stage **220**, can be held at 40K for example. The temperature of cryogenic device **18** and radiation shield **202** can be independently controlled using heaters, thermometers, and processing circuitry (software) to control heater power to achieve desired temperature setpoints.

(45) Radiation shield support **206** and cryogenic device support **22** are separate components. In other embodiments, the supporting structure may be a single component that includes an integrated radiation shield mount and a cryogenic device mount.

(46) FIG. **4** shows an example embodiment of an example support structure. The structure can be mounted via fasteners to walls **12** of chamber **26**, held at room temperature, using the cryogenic device vacuum housing mount locations **304**. Thermally resistive supports **206** and **302** connect walls **12** to the radiation shield mount **204** and radiation shield mount to the cryogenic device mount, respectively. These supports are thermally resistive as to reduce conductive heat transfer through the supports to the radiation shield mount **204** and cryogenic device mount **16**. Cryogenic device **18** and radiation shield **202** can be mounted to cryogenic device mount **16** and radiation shield mount **204**, respectively, using fasteners.

(47) In other embodiments, radiation shield **202** and radiation shield mount **204** in FIG. **3** could be replaced with other components that are in thermal communication with cold source stage **220** and thermal switch **222**. For example, radiation shield mount **204** could be replaced with a thermal lagging component that is used to thermally lag electrical wires, optical fibers, gas tubes, RF coax, and etc. that enter the cryogenic device vacuum space via feedthroughs in walls **12** of chamber **26** and are used to monitor or control cryogenic device **18**. Thermally lagging such components, at cold source stage **220** temperature of the thermal lagging component can reduce the conductive

heat load such components add to the cryogenic device.
(48) In FIG. **1** and FIG. **3**, both cryogenic device mount supports **22** and the vacuum barrier **38** are combined to have portions that are thermally cycled when a cryogenic device exchange is performed. These components are arranged to facilitate both the support and cooling/heating of device **18**. Because each is mounted to the vacuum housing maintained at room temperature, both bring in heat loads that reduce the available cooling power to reduce the cryogenic device temperature, thereby increasing the time required to cooldown the cryogenic device. A faster cryogenic device cooldown, and therefore cryogenic device exchange, can be achieved by either reducing the mass of the components that must be thermally cycled and/or reducing the heat loads on the cryogenic device.
(49) Accordingly, FIG. **5** shows system **400** as another embodiment of the systems of the present disclosure, wherein the cryogenic device mount supports **22** and the vacuum barrier **38** components in FIG. **1** and FIG. **3** are combined in a single component **460**. Here, the vacuum barrier also serves as the physical support of the cryogenic device mount. By reducing the mass of the components that are thermally cycled during a cryogenic device exchange and the heat loads on the cryogenic device even further, the cryostat architecture in FIG. **5** can provide an even faster cryogenic device exchange time.
(50) System **500** is depicted in FIG. **6** to include an example vacuum barrier **510** between walls **502** of vacuum chambers **26** and **40**. Vacuum barrier **510** bridges a thermal gradient from 300K-4K while minimizing the heat load to cryogenic device **508**. Barrier **510** also supports and reduces vibrations of cryogenic device **508**. Accordingly, the vacuum barrier must be of a sufficiently high resonant frequency that the cryogenic device vibrations **504** are acceptable. Barrier **510** can provide thermal lagging/connections for a radiation shield and incoming electrical and/or optical connections to the cryogenic device. In isolating chamber **26**, vacuum barrier **510** can provide an attractive option for UHV in sample chamber **26**. To that end, the vacuum barrier may be designed and constructed of UHV compatible materials to enable use in future UHV applications. In accordance with example configurations, barrier **510** can include mounts **304**, **204**, and **506**. Mounts **204** and **506** can be operatively engaged with stages **220** and **230** respectively and/or switches **222** and **232**.
(51) Referring next to FIG. **7**, in accordance with example implementations and with reference to the orientation and placement of the thermal switches indicated above, system **600** is provided that is part of a cryogenic device analysis system and depicts a switch assembly in the open position. As shown, there can be a cold source **602** at one temperature that may be in a vacuum space different from a sample space **604** that can be at a higher temperature in this open position. Accordingly, a mechanical actuator **606** can be used to close the switch, and then provide the configuration shown in FIG. **8**. The mechanical actuator **606** can be coupled to an actuator drive. Both mechanical actuator **606** and the actuator drive **608** can be coupled to an actuator drive controller **610**. Actuator drive controller **610** and actuator drive **608** can be utilized to determine when the switch is in the open or closed position based on torque and/or temperature as well as rotations of the actuator drive as determined by the actuator drive controller **610**. As shown in FIG. **8**, the switch of system **600** is in the closed position, thereby allowing cold source **602** to be at the same temperature as sample space **604**.
(52) A current controlled drive can be used to provide more precise control of torque and therefore strain to the thermal switch than a mechanical torque drive system. This can assist with repeatability and dependable performance for each thermal cycle. In accordance with at least one embodiment, the switch assembly can include an encoder and/or torque measurement device as part of the drive controller.
(53) Referring next to FIGS. **9**A-**9**C, cold source conductive members and cryogenic device conductive members are shown overlapping one another at portions **708** and **706** to form an insulative space **710** therebetween. As shown, these members can extend to within vacuum spaces

**604** and **602** respectively. The entirety of the overlap of portions **708** and **706** may be on one vacuum space side; for example, the entirety can be on the side of the cold source barrier **702**, or the entirety can be on the side of the cryogenic device conductive or sample space barrier **704** respectively. The conductive materials of the present disclosure can be copper or aluminum for example.

(54) In accordance with example implementations, and with reference to FIG. **9**B, a force can be applied to pliable portion **706** to initiate thermal contact between **706** and **708**, thereby closing the switch and arranging thermal conduction between **602** and **604**. While shown as single application of force, this force may be applied to portion **708** as well or in the alternative to portion **708** alone. Accordingly, configurations include portions **706** and/or **708** that are sufficiently flexible, pliable, and/or moveable to be transitioned from a biased position (FIGS. **9**A and **9**C) to a thermal contact position (FIG. **9**B).

(55) With reference to FIG. **9**C, and in accordance with example implementations, to open the switch after conduction is established and thereby disconnect thermal connection between **602** and **604**, force (F) can be removed from portion **706** and/or thermal energy (T) provided to portion **708**, thereby causing portion **706** to revert to its biased configuration defining insulative space opening **710** therebetween and no thermal conductivity. While the thermal energy (T) is shown being provided to portion **708**, alternative embodiments can include providing the thermal energy to portion **706** as well or in the alternative to portion **706**, thus configurations can include removing force and providing thermal energy to the same portion.

(56) Referring next to FIG. **10**, in accordance with an alternative embodiment, a switch assembly can include overlapping portions **706** and **708**, and a heating element **712**, for example a thermal couple, operatively engaged with portion **708** of the cryogenic device conductive member. In accordance with example implementations, an actuator **606** can be operatively engaged with overlapping portion **706**, and to limit thermal contact between actuator **606** and overlapping portion **706**, having insulative portion **716**. In accordance with example implementations, to assist with the bias in the open position of portion **706** in relation to portion **708**, a biasing member **714** can be provided that mechanically connects portion **706** with another portion of the cryogenic device conductive member **604**.

(57) Referring next to FIG. **11**A, in accordance with another example implementation, overlapping portions **708** and **706** can be arranged with structure **720** operatively engaged with either portions **706** or **708** to fix one of the overlapping portions in relation to the structure but allow bias and movement of the other of the overlapping portions. Structure **720** can be an encompassing structure configured to encompass at least overlapping portions **708** and **706**. Accordingly, this configuration can assist with cold member dis-engagement and/or to minimize heat transfer to cold member when the switch is in the open position.

(58) Referring next to FIGS. **11**B-**11**F, multiple configurations of the thermal switch of the present disclosure are provided. Particularly with reference to FIG. **11**B, a completely open switch configuration is shown that has overlapping portions **706** and **708** encompassed by encompassing structure **720**, leaving a thermally disconnected space **722** therebetween. Referring next to FIG. **11**C, upon the application of force to either one or both of portions **706** or **708**, portions **706** and **708** are brought into contact to initiate a contact force **724** between the portions. In this configuration, the small contact force **724** is sufficient for the encompassing structure **720** to be in thermal engagement with both portions **706** and **708**. Upon engagement of encompassing structure **720**, encompassing structure **720** will constrict as shown in FIG. **11**D. In FIG. **11**D, this constriction brings a large contact force **726** between portions **706** and **708**. Referring next to FIG. **11**E, in accordance with example implementations, the switch can be opened by warming structure **720**. This reduces the contact force between the portions and allows at least one of the overlapping portions **708** or **706** freedom of movement. Upon achieving that freedom of movement, force can be applied in the opposite direction to one or both of the portions and provide a thermally

disconnected space **722** as shown in FIG. **11**F.
(59) In accordance with example implementations, when overlapping portions are not in thermal communication (i.e., at substantially different temperatures) structure **720** can also be thermally disengaged. When portions **708** and **706** are sufficiently proximate to have thermal engagement, structure **720** may likewise be thermally engaged. As a result of this engagement, structure **720** may constrict about portions **708** and **706** to completely thermally engage portions **708** and **706**. Structure **720** may be warmed to loosen constriction about portions **708** and **706** and thus allow for less thermal engagement between the portions. Mechanical driven withdrawal of the portions can then be provided to space the portions far enough apart to provide a thermal disconnect. These stages of opening and closing the thermal switch are shown by example in FIGS. **11**A to **11**F.
(60) Accordingly, heat application significantly reduces the force required to disengage the thermal switch. Structure **720** can be configured or referred to as a chassis component and/or comprise a material with a higher CTE than either of portions **706** and **708**. Accordingly, when **720** cools, it contracts more than **706** and **708**, thereby imparting a substantial contact force between **706** and **708** for low contact resistance and high heat transfer from one member to the other. Utilizing structure **720** in this way can reduce motor/actuator size, drive current and electronics, drive shaft, gears and linking components, thermal switch, reliability and cycling longevity, for example. More detailed evaluation of the materials of structure **720** are provided with reference to Table 1 below.
(61) TABLE-US-00001 TABLE 1 Torque to Torque to Additional Loosen Loosen Preload Force Total Force w/No Heat on w/Heat on Torque Preload due to when Cold Chassis Chassis Chassis Material (in * lbs) (lbf) CTE (lbf) (4K) (in * lbs) (in * lbs) Low CTE C101 4.7 100.00 262.00 362.00 5.7 ~4.7 Material Cu High CTE 6061 4.7 100.00 565.30 665.30 10.48 ~4.7 Material Al
(62) A low CTE and a high CTE structure **720** material is compared to illustrate the advantages provided by a high CTE material on Total Force and to illustrate why heating structure **720** is useful.
(63) A Preload Torque from a mechanical driver applies an initial Preload Force between the two conductive members. This can initiate cooling and allows the chassis (i.e., structure **720**) to begin cooling as well. As the chassis cools, additional force is applied by the constriction of the chassis to the conductive member interface. If the chassis is a low CTE material such as C101 Copper, then the additional force will amount to 262 lbf. If the chassis is made of a high CTE material such as 6061 Aluminum, then the additional force will be much higher, 565.3 lbf in this specific example.
(64) This results in a much higher Total Force when the system is at base temperature, 4 Kelvin in this example.
(65) Accordingly, the breakaway torque to loosen the connection of the portions is much higher for the High CTE Material due to the added load from CTE. To reduce the breakaway torque, heat can be applied to the chassis to warm it up and reduce the force applied due to the difference in CTE between the chassis and the conductive members (assumed to be C101 Copper in this example).
(66) With a heated chassis, the motor torque required to loosen the joint will be similar to the initial Preload Torque (although it will not match it exactly in reality, it will be similar). Therefore, by adding heat to the chassis this design allows for a lower torque motor, smaller thermal switch components, and less stress on the thermal switch assembly overall during the process of opening the switch. An encompassing structure **720** having a larger CTE than portions **706** and/or **708** and can exert a large mechanical force pushing the portions in contact **726**.
(67) Accordingly, structure **720** can be affixed to portion **708** while leaving portion **706** sufficiently moveable to be put into contact with overlapping portion **708**. In accordance with at least one embodiment, structure **720** is depicted as a chassis encompassing both portions; however, the structure can be affixed within the vacuum chamber of the system itself to a wall of the vacuum chamber, for example, and affixed thereto by insulative materials.
(68) In accordance with yet another embodiment of the disclosure, another switch assembly is shown in FIGS. **12-14**. This switch assembly is presented first in an isometric view in FIG. **12** that

includes overlapping portions **706** and **708** having a structure **720** thereabout, and heating element **712** that extend through **720** and into overlapping portion **708** while actuator coupling device **800** extends through structure **720** to mechanically engage overlapping portion **708** at insulative portion **716**. As shown, actuator coupling device **800** can be configured to receive a drive from the actuator. Device **800** can be constructed of insulative materials and engage insulative portion **716**.

(69) In accordance with example implementations and utilizing the systems and components shown herein, methods for closing conductive connection between a cold source and a cryogenic device within a cryogenic analysis system are provided. These methods can include providing a sufficient mechanical force to either or both of a portion of a cold source conductive member or a portion of an overlapping cryogenic device conductive member to thermally engage the overlapping portions of the conductive members and thereby close a thermal connection between the conductive members. This mechanical force as described can be provided from a mechanical actuator. This actuator can also be configured with an actuator drive coupled to an actuator drive controller. As a way of measuring and determining whether the connection between the conductive members is open or closed, the torque and/or rotations of the actuator can be measured using the drive controller.

(70) In an additional embodiment, the methods include disconnecting these conductive members utilizing heat provided to one or both of the overlapping portions. In accordance with example implementations, providing heat can return at least one of the portions to its biased position in relation to the other portion which provides an insulative space between the members. Additionally, to provide this space, the mechanical actuator can be withdrawn to remove force applied to at least one portion of an overlapping conductive member.

(71) In compliance with the statute, embodiments of the invention have been described in language more or less specific as to structural and methodical features. It is to be understood, however, that the entire invention is not limited to the specific features and/or embodiments shown and/or described, since the disclosed embodiments comprise forms of putting the invention into effect.

## Claims

1. A switch assembly for a cryogenic device analysis system, the assembly comprising: a cold source conductive member extending lengthwise to a cold source; and a cryogenic device conductive member extending lengthwise to a cryogenic device and at least partially overlapping at least a portion of the cold source conductive member, wherein either or both of the conductive members are biased to define an insulative space between the conductive members at the overlap in an open orientation.
2. The switch assembly of claim 1 wherein one or both of the overlapping portions of the conductive members are sufficiently flexible, wherein the application of mechanical force to either one or both closes the insulative space to provide thermal contact between the portions.
3. The switch assembly of claim 2 further comprising a mechanical actuator operatively engaged with at least one of the overlapping portions of the conductive members.
4. The switch assembly of claim 3 further comprising a mechanical actuator drive and controller operatively engaged with the mechanical actuator.
5. The switch assembly of claim 1 further comprising an encompassing structure about the overlapping portions.
6. The switch assembly of claim 5 further comprising a heater assembly operatively engaged with the encompassing structure, wherein application of heat from the heater assembly to the encompassing structure lessens the mechanical contact force between the portions.
7. The switch assembly of claim 2 further comprising insulative members between the at least one overlapping portion and the mechanical actuator.
8. The switch assembly of claim 1 further comprising an insulative biasing member extending

between the conductive members.
9. The switch assembly of claim 5 further comprising a structure operatively engaged about the overlapping portions and wherein the structure defines a collar or chassis.
10. A method for closing/opening a conductive connection between a cold source and a cryogenic device within a cryogenic analysis system, the method comprising providing sufficient mechanical force to either or both of a portion of a cold source conductive member or a portion of an overlapping cryogenic device conductive member to at least partially thermally engage the overlapping portions of the conductive members.
11. The method of claim 10 further comprising providing the mechanical force from a mechanical actuator.
12. The method of claim 11 further comprising operating the mechanical actuator using an actuator drive coupled to an actuator drive controller.
13. The method of claim 12 further comprising monitoring the torque provided to the mechanical actuator to determine the closing of the thermal connection.
14. The method of claim 12 further comprising monitoring the rotations of the mechanical actuator to determine the closing of the thermal connection.
15. The method of claim 10 further comprising constricting an encompassing structure about both the portion of the cold source conductive member and the portion of an overlapping cryogenic device conductive member to close the switch and thermally connect the members.
16. The method of claim 15 wherein the mechanical actuator is engaged to initiate the cooldown of the overlapping cryogenic device conductive member as well as the encompassing structure.
17. The method of claim 15 further comprising warming the encompassing structure to provide freedom of movement between the portion of the cold source conductive member and the portion of an overlapping cryogenic device conductive member.
18. The method of claim 17 further comprising providing sufficient mechanical force to thermally disconnect the portion of the cold source conductive member and the portion of an overlapping cryogenic device conductive member and open the switch.
19. The method of claim 15 further comprising using an insulative member operatively engaged between the portion of the cold source conductive member and the portion of an overlapping cryogenic device conductive member to bias the members to define an insulative space between the members.
20. The method of claim 10 further comprising operating a mechanical actuator to provide the mechanical force.
21. The method of claim 20 further comprising monitoring the torque provided to the mechanical actuator or rotations of the mechanical actuator to determine the opening of the thermal connection.
22. A cryogenic device analysis system, the system comprising: a pair of vacuum regions separated by a vacuum barrier; and a switch within either of the vacuum regions, the switch comprising: a cold source conductive member extending lengthwise to a cold source within one vacuum region; a cryogenic device conductive member extending lengthwise to a cryogenic device within another vacuum region and at least partially overlapping at least a portion of the cold source conductive member, wherein either or both of the conductive members are biased to define an insulative space between the conductive members at the overlap in an open orientation; and at least one mechanical actuator operatively engaged with either of the portions of the conductive members.