US 20080098752A1

(19) **United States**

(12) **Patent Application Publication**

Hohne

(10) **Pub. No.: US 2008/0098752 A1**

(43) **Pub. Date: May 1, 2008**

(54) **LOW TEMPERATURE CRYOSTAT**

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(21) Appl. No.: **11/720,354**

(22) PCT Filed: **Nov. 29, 2005**

(86) PCT No.: **PCT/EP05/56315**

§ 371 (c)(1), (2), (4) Date: **May 29, 2007**

(30) **Foreign Application Priority Data**

Nov. 29, 2004 (DE) 20 2004 018 469.9

Publication Classification

(51) **Int. Cl.**
F25D 3/10 (2006.01)

(52) **U.S. Cl.** **62/51.1**

(57) **ABSTRACT**

A low temperature cryostat is disclosed. The low temperature cryostat may include a cryostat vessel, a cooling device arranged in the cryostat vessel for producing a cooling temperature level, a microscopy device for examining a sample, and at least one thermal coupling for thermally and mechanically connecting the microscopy device to the cooling device. The cooling device may comprise a pulse tube cooling system.

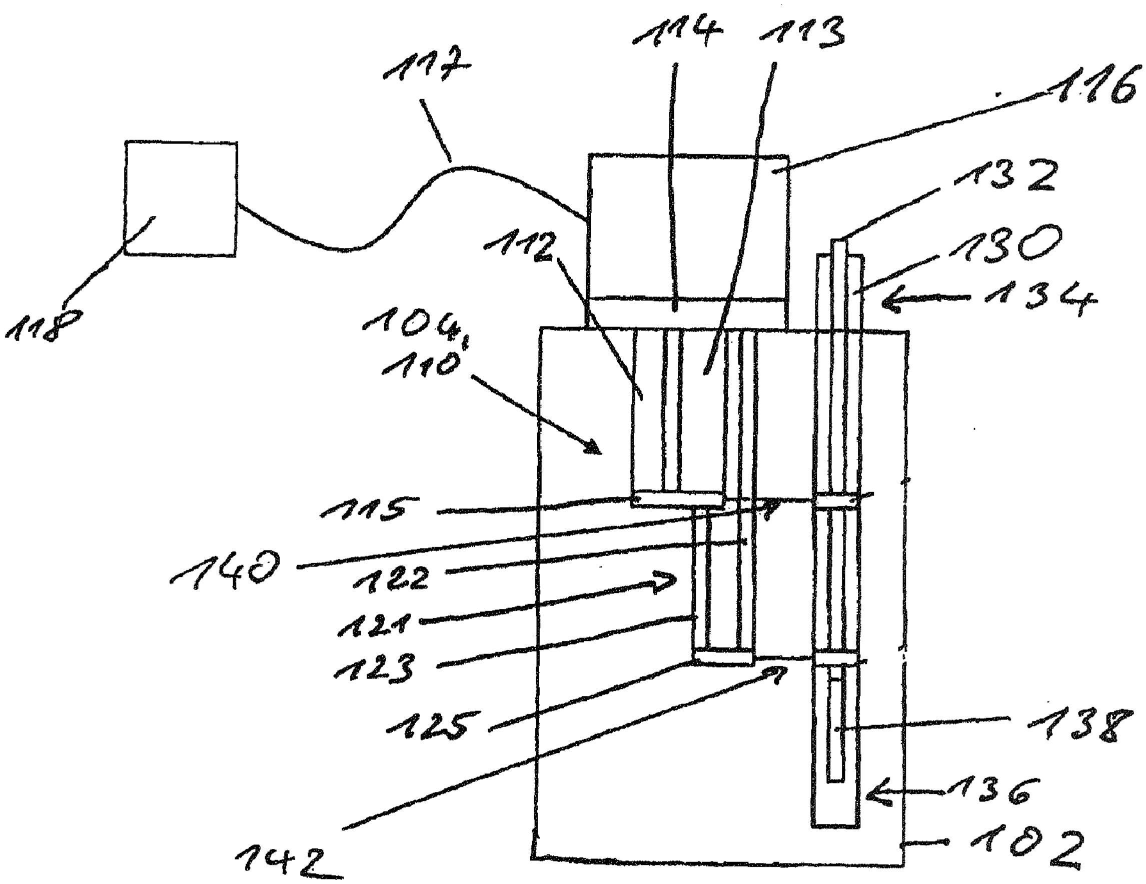


Fig. 1

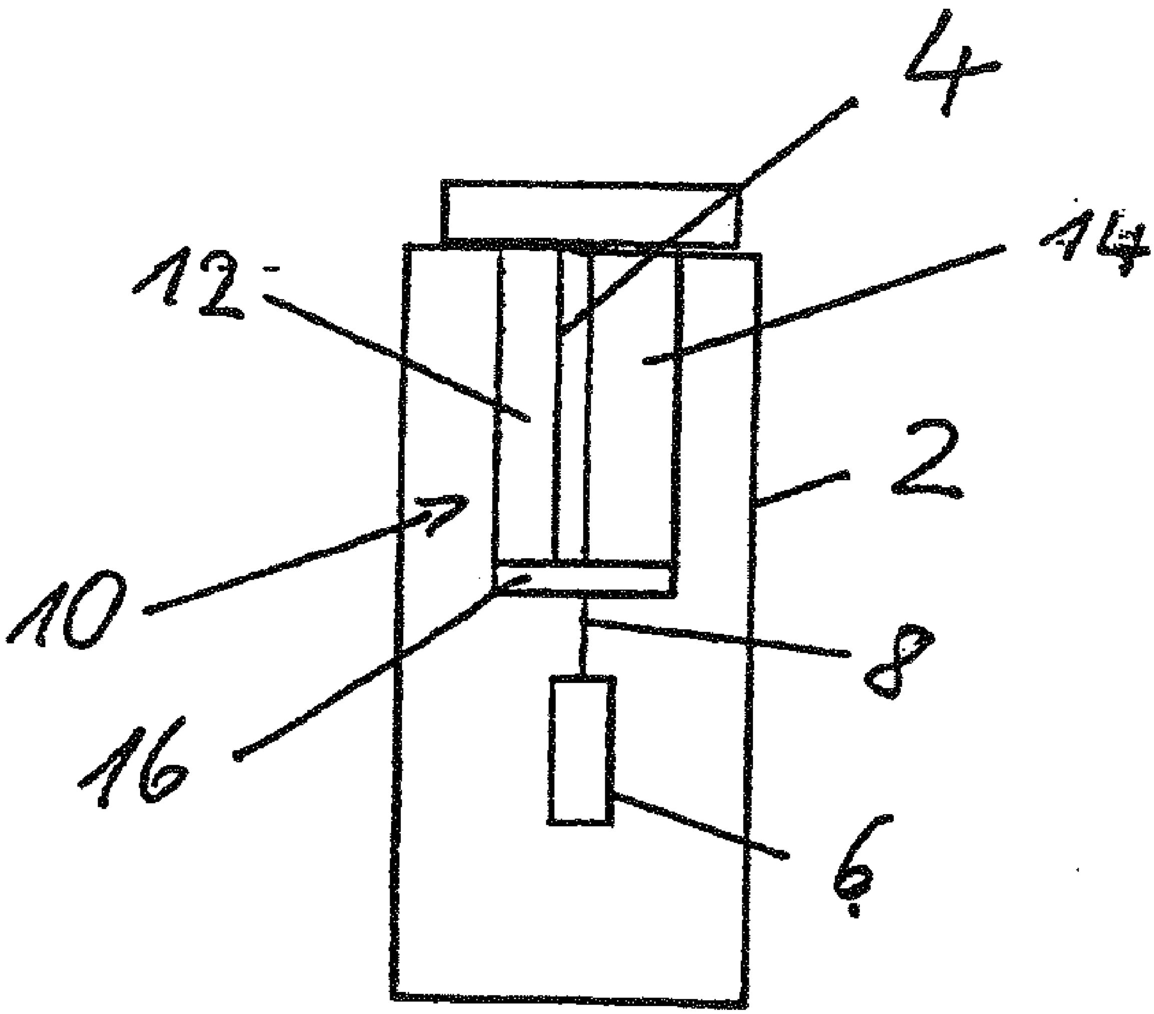
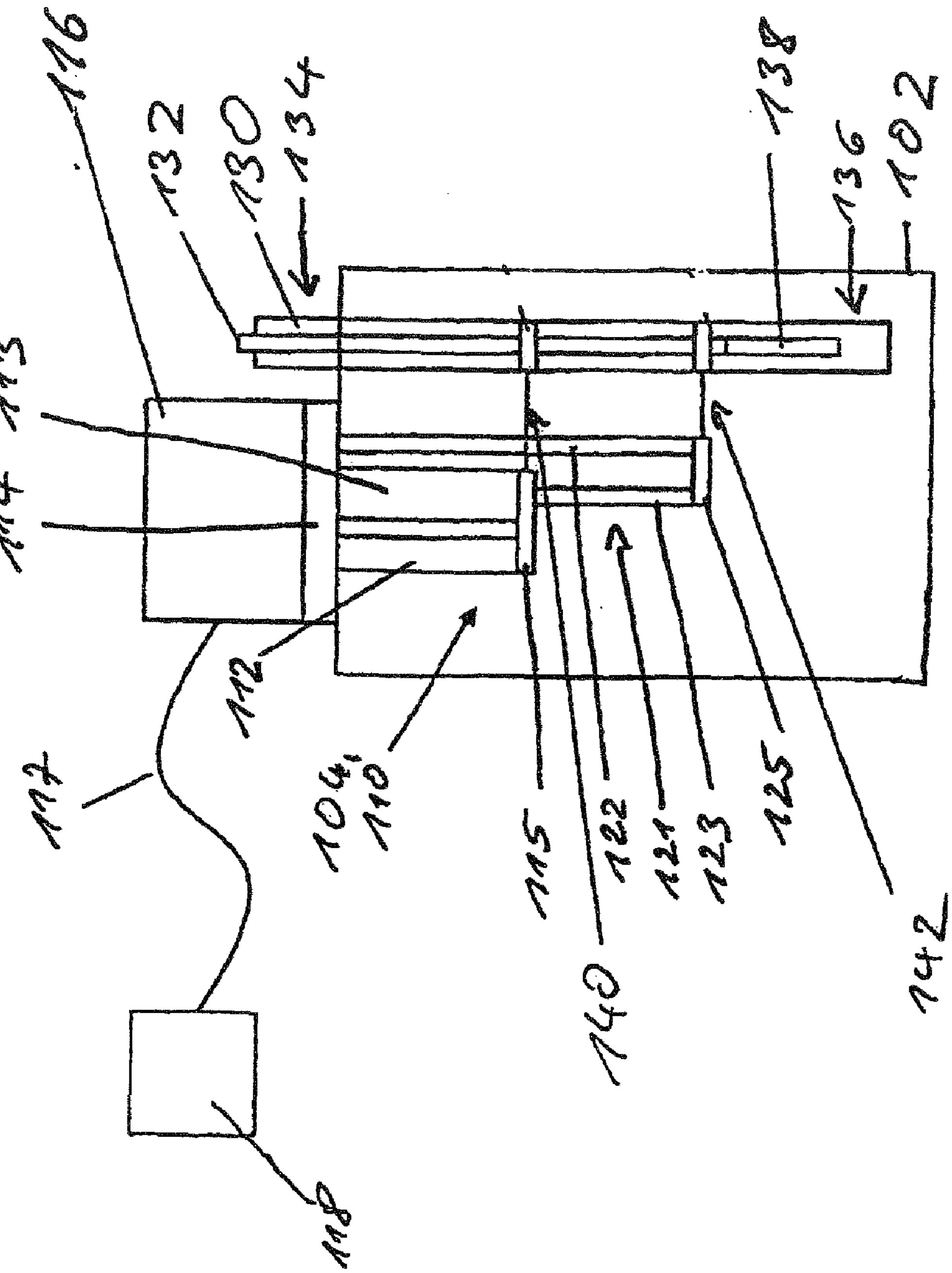


Fig. 2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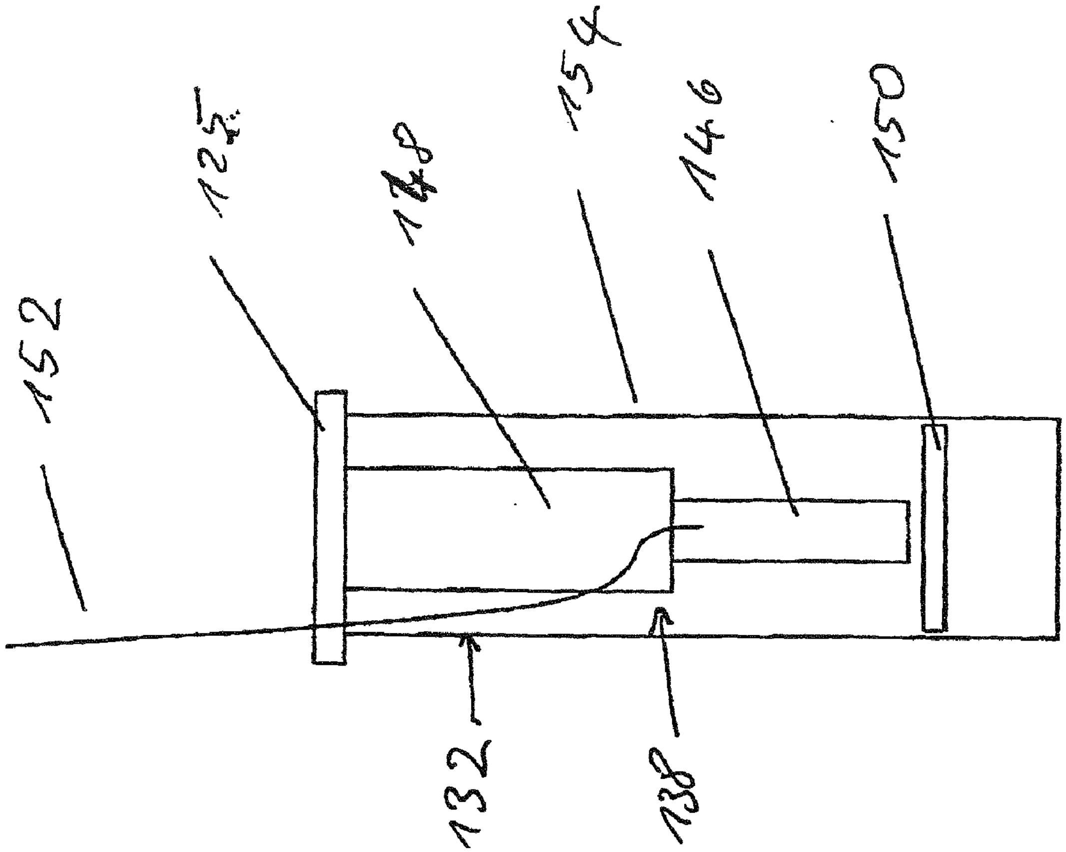


Fig. 3

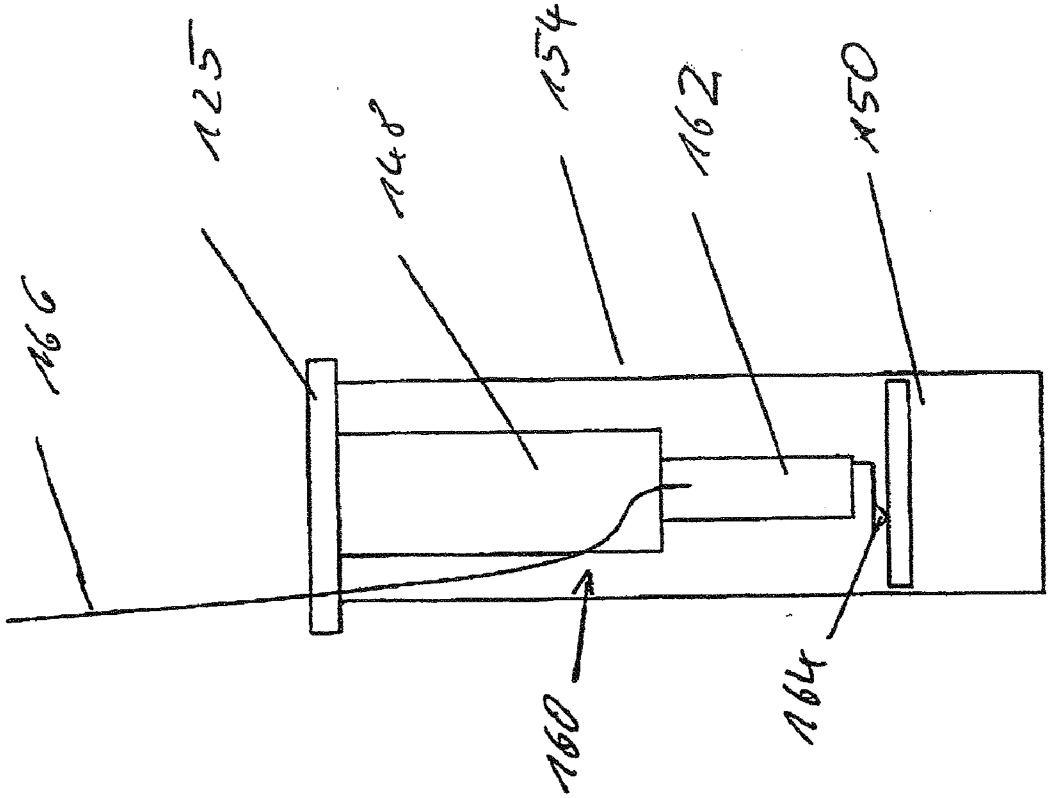


Fig. 4

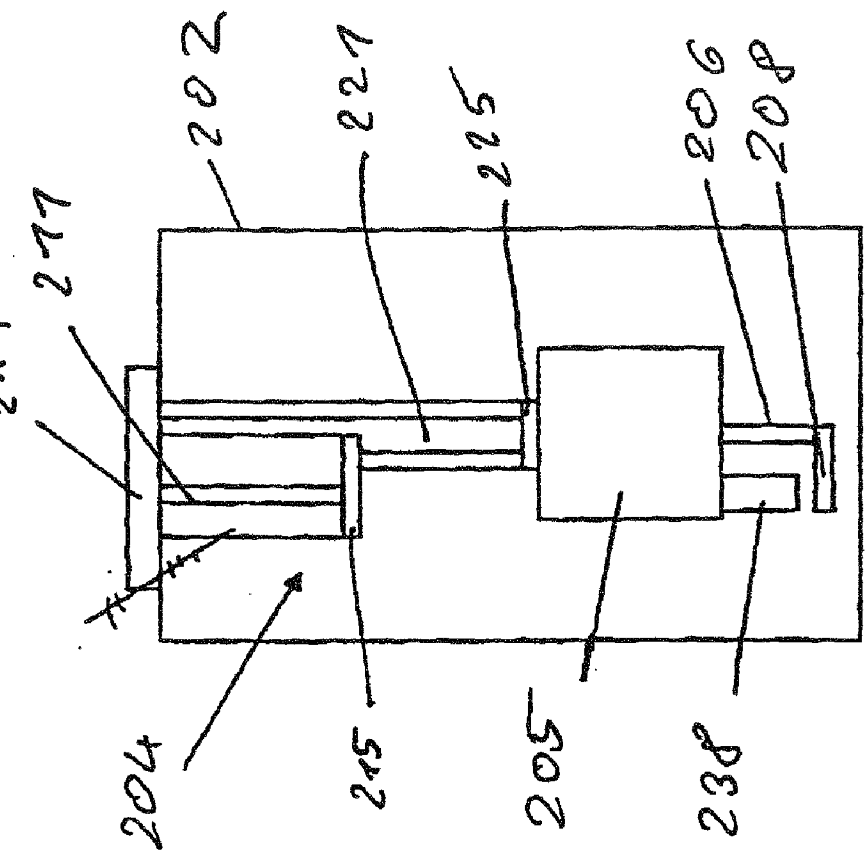
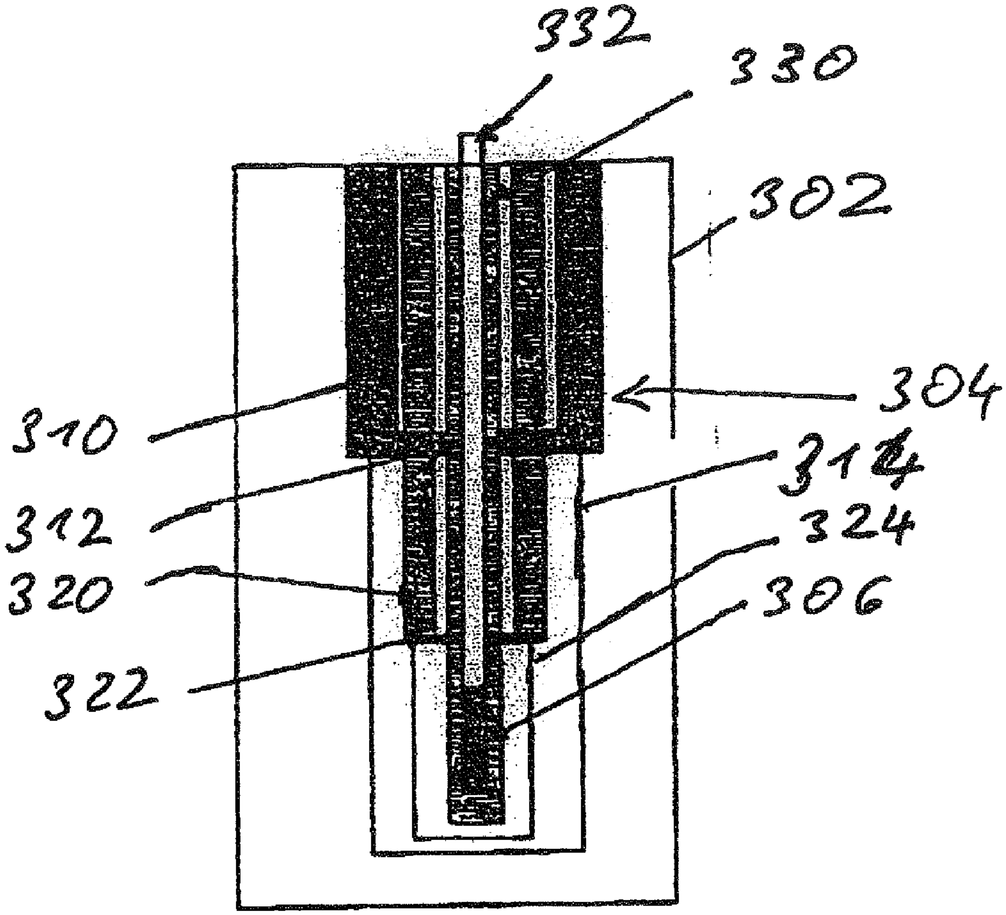


Fig. 5

Fig. 6



LOW TEMPERATURE CRYOSTAT

RELATED APPLICATION INFORMATION

[0001] This application claims priority to Patent Cooperation Treaty Application Number PCT/EP2005/056316 filed Nov. 29, 2005, which claims priority to German Application DE 20 2004 018 469.9 filed Nov. 29, 2004, both of which contents are incorporated herein by reference.

NOTICE OF COPYRIGHTS AND TRADE DRESS

BACKGROUND

[0003] 1. Field

[0004] This disclosure relates to a low temperature cryostat.

[0005] 2. Description of the Related Art

[0006] It is conventional to make use in low temperature microscopy of sample tubes in which the respective microscope is arranged. The sample tubes are inserted into 4K cryostats and cooled by means of liquid nitrogen (77K) and liquid helium (4K). A so-called dipstick with a sample to be examined and a microscope is inserted into the sample tube and cooled. The sample tube itself can in this case be evacuated or be filled with exchange gas for the purpose of better thermal coupling to the liquid nitrogen and the liquid helium.

[0007] FIG. **6** shows such a conventional arrangement having a cryostat vessel **302** that is evacuated. A cooling device **304** and a microscopy device **306** are arranged in the cryostat vessel **302**. The cooling device **304** comprises a nitrogen cooler **310** with liquid nitrogen as coolant. The nitrogen cooler **310** is connected to a 70K cold shield **314** via a thermal 70K coupling **312**. Arranged concentrically in the nitrogen cooler **310** with 70K cold shield **314** is a helium cooler **320** that is thermally coupled to a 4K cold shield **324** via a 4K coupling **322**. A sample tube **330** is arranged concentrically relative to the helium cooler **320** with 4K cold shield **322**, and relative to the nitrogen cooler **310** with 70K cold shield **314**. The thermal connection between the sample tube **330** and the nitrogen cooler **310** and/or the helium cooler **320** is performed by a mechanical, and therefore thermal connection of the sample tube **330** to the 70K coupling **314** and/or the 4K coupling **324**. A sample rod or dipstick **332** is inserted into the sample tube **330**, and a confocal microscope **334** is arranged at its lower end.

[0008] Cooling with the aid of liquid nitrogen and liquid helium is disadvantageous in this known apparatus, since handling liquid nitrogen and liquid helium is complicated and awkward. Moreover, the use of liquid helium is expensive.

[0009] It is therefore an object of the present invention to specify a low temperature cryostat that is easier to handle and more cost-effective in operation.

[0010] This object is achieved by means of a low temperature cryostat in accordance with the features of claim **1**.

[0011] Further details, features and advantages of the invention emerge from the following description of preferred embodiments of the invention with the aid of the drawings, in which:

DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1** shows a schematic of a first embodiment of the invention having a single-stage pulse tube cooler;

[0013] FIG. **2** shows a second embodiment of the invention having a two-stage pulse tube cooler;

[0014] FIG. **3** shows a detailed illustration of the confocal microscope of the second embodiment of the invention having a piezo positioning apparatus;

[0015] FIG. **4** shows a detailed illustration, corresponding to FIG. **3**, of a third embodiment of the invention having an atomic force or scanning tunneling microscope instead of the confocal microscope;

[0016] FIG. **5** shows a fourth embodiment of the invention having a ADR cooling stage, a 100 mK cooling stage and a confocal microscope;

[0017] FIG. **6** shows a low temperature cryostat according to the prior art.

DETAILED DESCRIPTION

[0018] Throughout this description, the embodiments and examples shown should be considered as exemplars, rather than limitations on the apparatus and methods disclosed or claimed.

[0019] Since it is impermissible in low temperature microscopy to transmit vibrations onto the sample, there has so far been no use of mechanical cooling devices such as compressors and pulse tube coolers. Compressor cooling devices have a broad spectrum of vibrations from the low frequency up to the high frequency range, and are therefore unsuitable as a replacement for nitrogen/helium coolers. Given appropriate design, pulse tube coolers can certainly be configured because of vibration, but their functionality dictates that they have vibrations in the low frequency **1** Hz range that cannot be eliminated. These vibrations originate from the oscillating gas column in the pulse tube cooler. These vibrations cause a deflection of the cold head of the pulse tube cooler in the □m region. The use of pulse tube coolers has so far been refrained from because of these vibrations that cannot be eliminated. However, it has been shown that when use is made of pulse tube coolers these low frequency vibrations are by far less disturbing than assumed. This is likely to be ascribed to the fact that the microscope device connected to the cold head covibrates synchronously because of the low frequencies, and this oscillation is therefore not disturbing.

[0020] In accordance with an advantageous refinement of the invention, the component of a pulse tube cooler that still most readily also generates high frequency vibrations in addition to the low frequency vibrations, specifically the turning valve, is arranged outside the cryostat vessel and is connected to the latter by means of a flexible hose line. This prevents the high frequency vibrations from impairing the mode of operation of the microscopy device, and at the same time the low frequency vibrations are reduced. Consequently, it is only the low frequency vibrations that still occur in the cryostat vessel on the basis of the oscillating gas.

[0021] In accordance with a further preferred refinement of the invention, the thermal coupling of the microscopy device to the pulse tube cooling system is designed in an elastic and vibration damping fashion. Consequently, the low frequency vibrations still occurring from the pulse tube cooling system are strongly damped and are therefore less able to have a disturbing effect on the microscopy device. Moreover, account is thereby taken of the unavoidable changes in length between ambient temperature and the temperature of the sample.

[0022] Such a low temperature cryostat can be used with a multiplicity of different microscopy devices such as confocal microscope, tunneling microscope, atomic force microscope, magnetic microscope, chemical microscope etc.

[0023] The remaining subclaims relate to further advantageous refinements of the invention.

[0024] FIG. **1** shows a schematic of the essential components of a first embodiment of the invention, in the case of which the basic concept of the invention is concerned. A cooling device **4** in the form of a single-stage pulse tube cooler **10** is arranged in a cryostat vessel **2**. The pulse tube cooler **10** comprises a pulse tube **12** and a regenerator **14** that are arranged between a cold head **16** and a valve head **18**. A microscopy device **6** is mechanically and thermally coupled to the cold head **16** by means of a thermal coupling **8**.

[0025] FIG. **2** shows a second embodiment having a cryostat vessel **102**, a cooling device **104**, arranged in the cryostat vessel **102**, in the form of a two-stage pulse tube cooling system **110**. The pulse tube cooling system **110** has a first pulse tube cooler **111** and a second pulse tube cooler **121**. The first pulse tube cooler **111** has a first pulse tube **112** and a first regenerator **113**. The first pulse tube **112** and the first regenerator **113** are arranged between a valve head **114** and a 60K cold head **115**. The second pulse tube cooler **121** has a second pulse tube **122** and a second regenerator **123**. The second pulse tube **122** is arranged between the valve head **114** and a 4K cold head **125**, and the second regenerator **123** is arranged between the 60K cold head **115** and the 4K cold head **125**. A ballast volume **116** is directly connected to the valve head **114** arranged outside the cryostat vessel **102**. The valve head **114** and the ballast volume **116** are connected to a turning valve **118** via a flexible hose **117**.

[0026] Arranged in the cryostat vessel **102** is a sample tube **130** that is accessible from the outside and into which a sample rod **132** can be inserted. The sample rod **132** has a warm end **134**, which projects from the cryostat vessel **102**, and a cold end **136**, which comes to lie in the interior of the cryostat vessel **102**. A confocal microscope **138** is arranged in the region of the cold end **136** of the sample rod **132**.

[0027] The sample tube **130**, and thus the sample rod **132** with the confocal microscope **138** are connected thermally to the 60K cold head **115** via a 60K coupling **140**, and to the 4K cold head **125** of the cooling device **104** via a 4K coupling **142**. The 60K coupling **140** is arranged closer at the warm end **134**, and the 4K coupling **142** is arranged in the region of the cold end **136**. The sample rod **132** is arranged concentrically in the sample tube **130**. The sample tube **130** has a hollow cladding **144** that can be evacuated or filled with exchange gas.

[0028] Owing to the spatially separated arrangement of the turning valve and its connection to the valve head via a flexible hose **117**, vibrations of the turning valve **118** are strongly damped, and scarcely any vibrations are transmitted onto the cryostat vessel. Owing to the configuration of the 60K coupling **140** and of the 4K coupling **142** in the form of an elastic strip made from material that effectively conducts heat, vibrations from the pulse tube cooling system are likewise strongly damped, and so scarcely any vibrations are transmitted onto the sample tube **130**, and thus onto the confocal microscope **138**. A braided ground strap made from electrolytic copper is well suited therefor.

[0029] FIG. **3** shows a detail of the third embodiment of the invention, specifically the cold end **136** of the sample rod **132** with the confocal microscope **138**. The confocal microscope **138** comprises a lens arrangement **146** that is thermally and mechanically connected to the 4K coupling **142** by means of a piezo positioning apparatus **148**. A sample **150** to be examined is arranged below the lens arrangement **146**. The light that originates from a light source (not illustrated), is reflected by the sample **150** and falls into the lens arrangement **146** is guided out of the cryostat vessel **102** via an optical fiber **152**. The viewing light is preferably likewise coupled in via the optical fiber **152**. The focusing of the lens arrangement **146** is performed by the piezo apparatus **148**. The lens arrangement **146** can be moved and positioned on three spatial axes relative to the sample **150** with the aid of the piezo positioning apparatus **148**. The entire arrangement is surrounded by a cladding **154** that is part of the sample rod **132**.

[0030] FIG. **4** shows a detail of a third embodiment of the invention, in the case of which instead of a confocal microscope an atomic force or scanning tunneling microscope **160** is provided in the cryostat design according to FIG. **2**. Components are correspondingly provided with the same reference numerals in FIGS. **3** and **4**. The third embodiment of the invention differs from the second embodiment only in that a carrier unit **162** for a scanning tip **164** is provided instead of the lens arrangement **146**, and an electric signal line **166** is provided instead of the light guide **152**.

[0031] FIG. **5** shows a fourth embodiment of the invention having a cryostat vessel **202** in which a cooling device **204** is accommodated. The cooling device **204** arranged in the cryostat vessel **202** comprises a two-stage pulse tube cooling system **210** having a first pulse tube cooler **211** with a first cold head **215**, and a second pulse tube cooler **221** with a second cold head **225**. The interface to the outside is provided via a valve head **214**. The remaining components such as turning valve and ballast volume, for example, are not illustrated. The two-stage pulse tube cooling system **210** comes close to the pulse tube cooling system from FIG. **2**. The two-stage pulse tube cooling system **210** precools an adiabatic demagnetization cooling stage or an ADR cooling stage **205**, having a magnet that is not, illustrated, to approximately 4K. The ADR stage **205** is thermally and mechanically coupled to the second cold head **225** of the two-stage pulse tube cooling system **210** The confocal microscope **238** with positioning apparatus (not illustrated) is arranged at the magnet (not illustrated) of the ADR cooling stage **205**. The confocal microscope **238** is thereby thermally coupled to the second cold head **225** and is cooled to approximately 4K. The ADR cooling stage **205** cools to approximately 100 mK. A sample **208** is thermally coupled to the ADR cooling stage **205** via a sample holder **206**, such that the sample is cooled to approximately 100 mK.

[0032] The above-described embodiments of the invention may also be combined with one another. It is likewise possible, for example, to arrange a number of different microscopes in the cryostat vessel.

LIST OF REFERENCE NUMERALS

[0033] **2** Cryostat vessel

[0034] **4** Cooling device

[0035] **6** Microscopy device
[0036] **8** Thermal coupling
[0037] **10** Pulse tube cooler
[0038] **12** Pulse tube
[0039] **14** Regenerator
[0040] **16** Cold head
[0041] **18** Valve head
[0042] **102** Cryostat vessel
[0043] **104** Cooling device
[0044] **110** Two-stage pulse tube cooling system
[0045] **111** First pulse tube cooler
[0046] **112** First pulse tube
[0047] **113** First regenerator
[0048] **114** Valve head
[0049] **115** 60K cold head
[0050] **116** Ballast volume
[0051] **117** Flexible hose
[0052] **118** Turning valve
[0053] **121** Second pulse tube cooler
[0054] **122** Second pulse tube
[0055] **123** Second regenerator
[0056] **125** 4K cold head
[0057] **130** Sample tube
[0058] **132** Sample rod
[0059] **134** Warm end of **132**
[0060] **136** Cold end of **132**
[0061] **138** Confocal microscope
[0062] **140** 60K coupling
[0063] **142** 4K coupling
[0064] **144** Cladding of **130**
[0065] **146** Lens arrangement
[0066] **148** Piezo apparatus
[0067] **150** Sample
[0068] **152** Optical fiber
[0069] **160** AFM or scanning tunneling microscope
[0070] **162** Carrier unit for **164**
[0071] **164** Scanning tip
[0072] **166** Electric signal line
[0073] **202** Cryostat vessel
[0074] **204** Cooling device
[0075] **205** ADR cooling stage
[0076] **206** Sample holder
[0077] **208** Sample
[0078] **210** Two-stage pulse tube cooling system
[0079] **211** First pulse tube cooler
[0080] **214** Valve head
[0081] **215** First cold head
[0082] **221** Second pulse tube cooler
[0083] **225** Second cold head
[0084] **238** Confocal microscope
[0085] **302** Cryostat vessel
[0086] **304** Cooling device
[0087] **306** Microscopy device
[0088] **310** Nitrogen cooler
[0089] **312** 70K coupling
[0090] **314** 70K cold shield
[0091] **320** Helium cooler
[0092] **322** 4K coupling
[0093] **324** 4K cold shield
[0094] **330** Sample tube
[0095] **332** Sample rod (dipstick)
[0096] Closing Comments

[0097] The foregoing is merely illustrative and not limiting, having been presented by way of example only. Although examples have been shown and described, it will be apparent to those having ordinary skill in the art that changes, modifications, and/or alterations may be made.

It is claimed:

1. A low temperature cryostat having
a cryostat vessel,
a cooling device, arranged in the cryostat vessel, for producing a cooling temperature level TK,
a microscopy device for examining a sample, and
at least one thermal coupling for thermally and mechanically connecting the microscopy device to the cooling device, wherein
the cooling device comprises a pulse tube cooling system.

2. The low temperature cryostat as claimed in claim **1**, wherein the pulse tube cooling system comprises a turning valve that is arranged outside the cryostat vessel and is connected to the cryostat vessel via a vibration damping line.

3. The low temperature cryostat as claimed in claim **2**, wherein the vibration damping line is a flexible connecting hose.

4. The low temperature cryostat as claimed in one of the preceding claims, wherein the pulse tube cooling system is a single-stage pulse tube cooler.

5. The low temperature cryostat as claimed in one of the preceding claims **1**, wherein the pulse tube cooling system comprises a multistage, in particular two-stage pulse tube cooler.

6. The low temperature cryostat as claimed in claim **1**, wherein the thermal coupling of the microscopy device to the pulse tube cooling system is designed in an elastic and vibration damping fashion.

7. The low temperature cryostat as claimed in claim **1**, wherein the microscopy device is arranged in a sample tube.

8. The low temperature cryostat as claimed in claim **7**, wherein the sample tube can be inserted into the cryostat vessel and can be thermally coupled to the cooling device via the thermal coupling.

9. The low temperature cryostat as claimed in claim **1**, wherein the cooling device comprises a first cooling stage in the form of said pulse tube cooling system, and a second cooling stage for a cooling temperature level in the range <4K, and wherein the second cooling stage is precooled by the first cooling stage.

10. The low temperature cryostat as claimed in claim **9**, wherein the second cooling stage has an adiabatic demagnetization device or a 3 He/4 He dilution cooler or a 3 He cooler or a mechanical cooling device such as a helium compressor cooler, or an electric cooling device such as a Peltier element or a superconducting tunnel diode such as an NIS diode.

11. The low temperature cryostat as claimed in claim **1**, wherein the microscopy device comprises a confocal microscope.

12. The low temperature cryostat as claimed in claim **1**, wherein the microscopy device comprises a scanning tunneling microscope.

13. The low temperature cryostat as claimed in claim **1**, wherein the microscopy device comprises an atomic force microscope.

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