US 20090071401A1

(19) United States

(12) Patent Application Publication

Clark et al.

(10) Pub. No.: US 2009/0071401 A1

(43) Pub. Date: Mar. 19, 2009

(54) **METHOD AND APPARATUS FOR RECYCLING INERT GAS**

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(21) Appl. No.: **12/292,009**

(22) Filed: **Nov. 10, 2008**

Related U.S. Application Data

(62) Division of application No. 11/176,305, filed on Jul. 8, 2005, now Pat. No. 7,465,476.

(30) **Foreign Application Priority Data**

Aug. 12, 2004 (GB) 0417936.2

Publication Classification

(51) **Int. Cl.**
B05C 11/00 (2006.01)

(52) **U.S. Cl.** **118/666**; 118/61

(57) **ABSTRACT**

A method for recycling an inert gas evacuated from a material deposition process chamber **10** comprises cooling the evacuated inert gas and recirculating a proportion of the cooled gas to the chamber **10** at a first temperature for use as a cooling gas in the material deposition process **12**, and recirculating a proportion of the cooled gas to the chamber **10** at a second temperature for use as a shielding gas in the material deposition process **12**, the second temperature being higher than the first temperature. Apparatus **22** for recycling an inert gas is also disclosed.

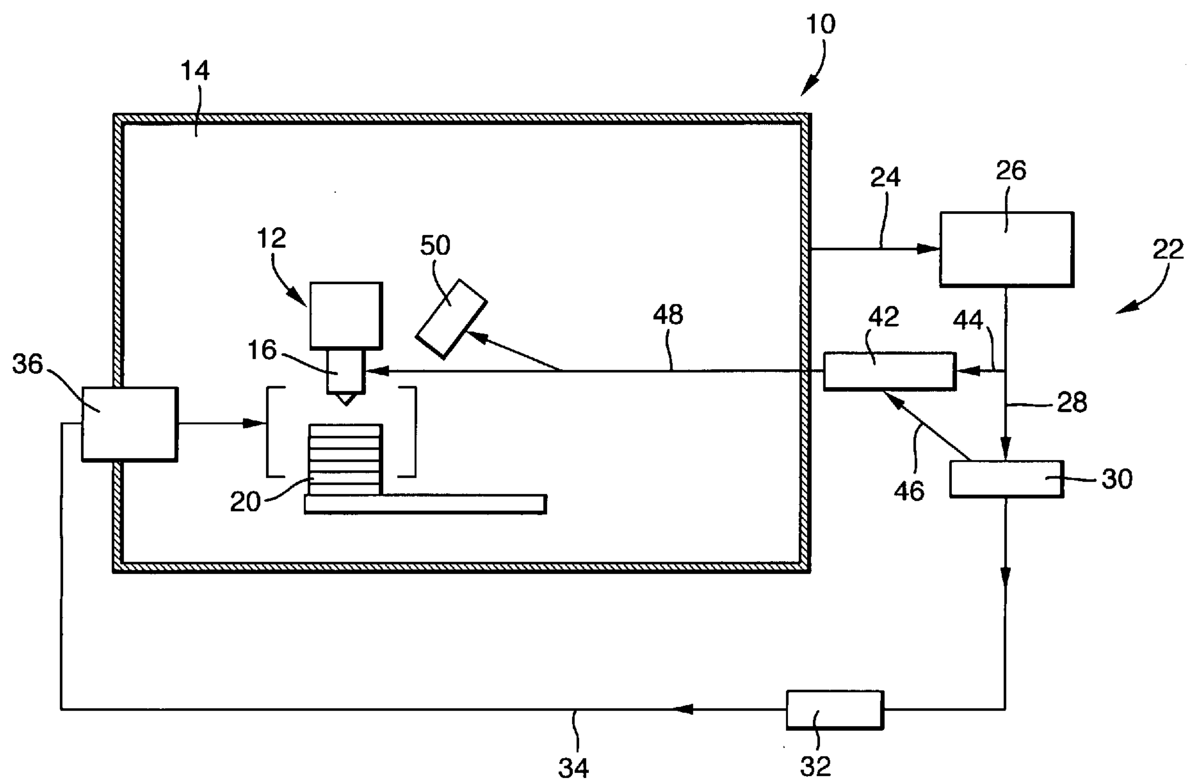


Fig.1.

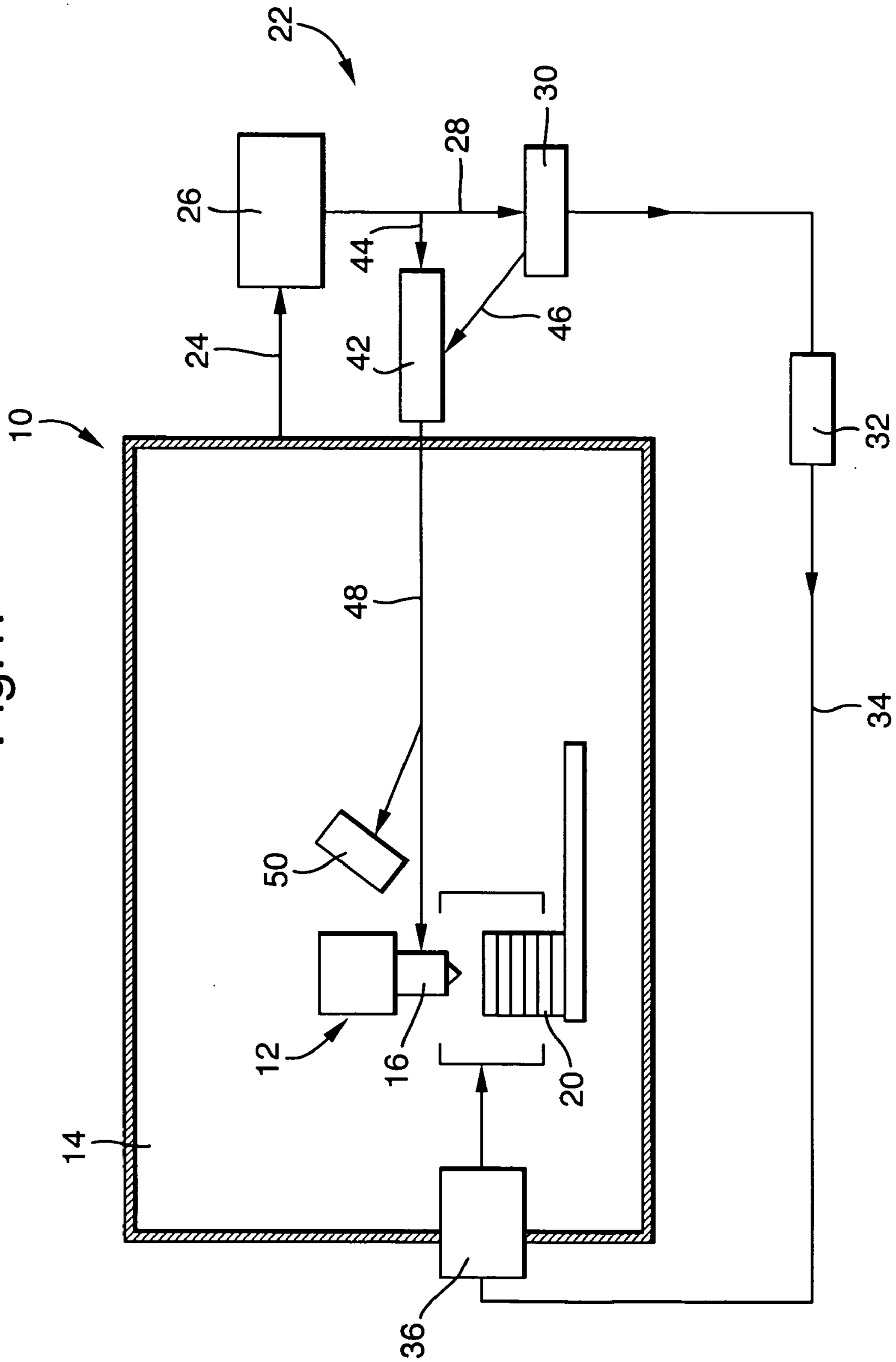
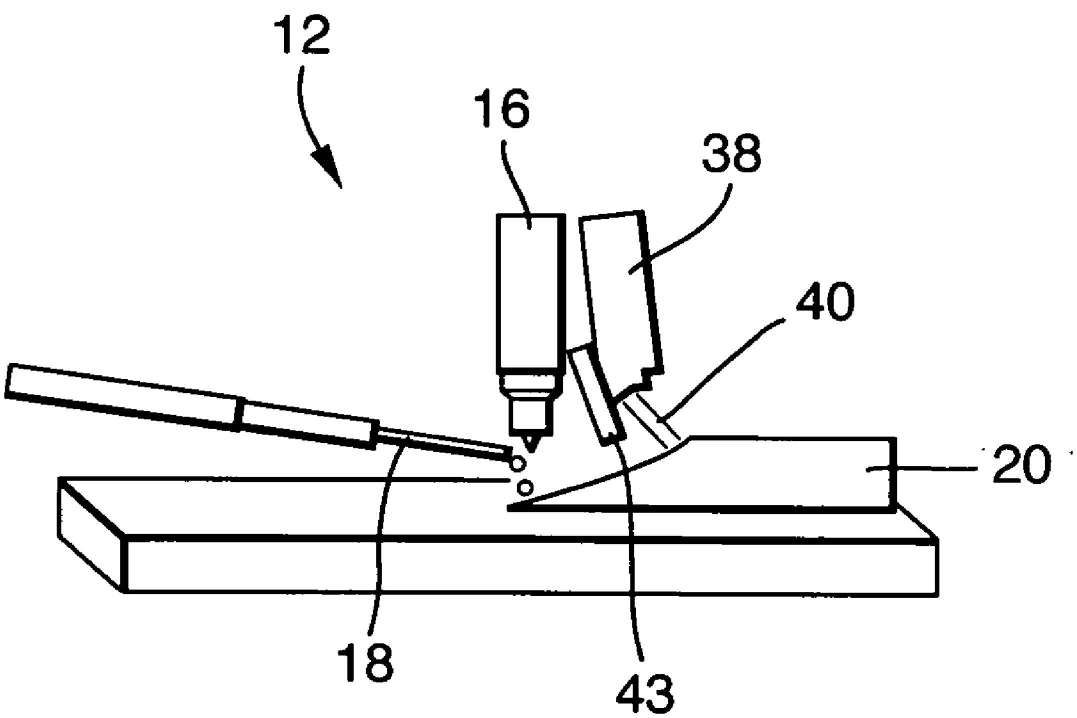


Fig.2.



METHOD AND APPARATUS FOR RECYCLING INERT GAS

[0001] The present invention relates to a method and apparatus for recycling an inert gas evacuated from a material deposition process chamber.

[0002] Material deposition processes, such as Shaped Metal Deposition (SMD) and Direct Laser Deposition (DLD), are carried out in an inert gas atmosphere to prevent oxidation of the deposited material. Such processes are normally carried out in a chamber, for example with a small internal over pressure, to which the inert gas is supplied.

[0003] Conventionally, the inert gas is supplied to the chamber and discarded after use such that a constant supply of the gas is needed. This is inefficient, especially when inert gases having a large specific heat capacity, such as helium, are used as these tend to be expensive.

[0004] It would therefore be desirable to reduce the disadvantages of the known process.

[0005] According to one aspect of the present invention, there is provided a method for recycling an inert gas evacuated from a material deposition process chamber, the method comprising:

[0006] after evacuation cooling the evacuated inert gas to provide a cooled gas;

[0007] recirculating a proportion of the cooled gas to the chamber at a first temperature for use as a cooling gas in the material deposition process; and

[0008] recirculating a proportion of the cooled gas to the chamber at a second temperature for use as a shielding gas in the material deposition process, the second temperature being higher than the first temperature.

[0009] According to another aspect of the present invention, there is provided apparatus for recycling an inert gas evacuated from a material deposition process chamber, the apparatus comprising means for cooling the evacuated inert gas to provide a cooled gas, means for recirculating a proportion of the cooled gas to the chamber at a first temperature for use as a cooling gas in the material deposition process, and means for recirculating a proportion of the cooled gas to the chamber at a second temperature for use as a shielding gas in the material deposition process, the second temperature being higher than the first temperature.

[0010] Preferred features of the invention are defined in the accompanying claims.

[0011] An embodiment of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:—

[0012] FIG. **1** is a schematic view of a method and apparatus for recycling inert gas according to the invention; and

[0013] FIG. **2** is a detailed view of the method and apparatus in use with a material deposition process.

[0014] FIG. **1** illustrates diagrammatically a material deposition process chamber **10** in which a material deposition process generally designated with the reference numeral **12** is carried out. The chamber **10** is in the form of a gas chamber to which an inert gas is supplied. The chamber **10** is sealed to a high standard and gas is supplied to the chamber **10** such that there is a small internal over pressure. The chamber **10** contains a minimal amount of oxygen and thus provides an inert gas atmosphere **14** in which the material deposition process **12** can be carried out.

[0015] Referring to FIG. **2**, one example of a material deposition process **12** carried out in the chamber **10** is shown. The material deposition process **12** is a conventional Shaped Metal Deposition (SMD) process in which a heat source, for example a tungsten inert gas (TIG) torch **16**, is used to create an arc and melt a filler wire **18**. When melted, the filler wire **18** is deposited onto an underlying layer of material and solidifies to form deposited material **20**. It will of course be appreciated that the material deposition process **12** can be carried out using any suitable heat source, other than a TIG torch **16**, which requires an inert atmosphere. Techniques such as laser and powder or wire deposition, low pressure electron beam, etc, may alternatively be employed.

[0016] In order to optimise the properties of the deposited material **20**, it is necessary to control the temperature and cooling rate at which the deposition process **12** is carried out. One method by which temperature and cooling rate can be controlled is to use an inert gas. The present invention provides apparatus **22** for recycling the inert gas used in the material deposition process **12** which enables the gas temperature to be carefully controlled, as will now be described.

[0017] Referring again to FIG. **1**, the apparatus **22** comprises a closed loop system for pumping inert gas from the chamber **10** and recirculating it to the chamber **10**. The apparatus **22** preferably operates to continuously pump inert gas and recirculate it to the chamber **10**. The apparatus **22** comprises a first path **24** along which gas is evacuated from the chamber **10** and supplied to a gas scrubber **26**. The gas scrubber **26** is operable to purify the gas evacuated from the chamber **10** by removing oxygen and moisture, and may remove other gases such as nitrogen and hydrogen. Any suitable gas scrubber **26** may be used, for example comprising a combination of heaters and catalysts to cause the evacuated gas to react and therefore to purify the gas.

[0018] A dehumidifier (not shown) may also be provided to remove moisture from the evacuated inert gas.

[0019] Upon exit from the gas scrubber **26**, a proportion of the purified gas, which may for example be at a temperature in the order of 20° C., is supplied along a second path **28** to a means for cooling the evacuated gas in the form of a gas cooler or chiller **30**. The gas cooler **30** is operable to cool the evacuated inert gas to a first temperature which may for example be in the order of −160° C. Means in the form of a pump **32** is provided for recirculating a proportion of the gas cooled to the first temperature to the chamber **14**. The gas is recirculated along a thermally insulated gas pipe **34** and is supplied into the chamber **14** using a valve **36** which has a suitably low coefficient of thermal expansion.

[0020] The cooled gas recirculated at the first temperature is used as a cooling gas in the material deposition process **12** and in particular enables the cooling rate of the deposited material **20** to be carefully controlled. Referring to FIG. **2**, according to one embodiment of the invention, the apparatus **22** includes a gas lens **38**, which may for example be a ceramic gas lens, for directing a jet **40** of the gas cooled to the first temperature directly towards the deposited material **20** to cool the deposited material **20**. Shielding means in the form of a shield or baffle **42** is mounted on the end of the gas lens **38** and is positioned between the end of the TIG torch **16** and the gas jet **40** to protect the arc formed by the TIG torch **16** from turbulence formed by the jet **43** in the immediate vicinity of the arc and also from the very low first temperature to which the gas is cooled. Exposure of the arc to such a low temperature may prevent proper melting of the filler wire **18** and thus hinder material deposition.

[0021] The flow rate of the gas forming the gas jet **40** is variable to enable the cooling rate of the deposited material **20** to be carefully controlled. Although only one gas jet **40** is illustrated, it is to be understood that any number of gas jets **40** may be provided according to the particular application. In this case, the flow rate of each gas jet **40** may be varied independently to control the cooling rate of the deposited material **20**.

[0022] When a plurality of gas jets **40** is provided, the temperature of the gas supplied by each jet **40** may be independently variable either as an alternative, or in addition, to the flow rate of the gas. This further contributes to the ability to control the cooling rate of the deposited material **20**.

[0023] Referring again to FIG. **1**, the apparatus **22** includes a gas mixing device in the form of a gas mixer **42**. A proportion of the uncooled gas from the gas scrubber **26** is fed along a third path **44** to the gas mixer **42**. Likewise, a proportion of the gas which has been cooled to the first temperature in the gas cooler **30** is fed along a fourth path **46** from the gas cooler **30** into the gas mixer **42**. The uncooled gas from the scrubber **26** and the gas cooled to the first temperature are mixed in the gas mixer **42** to thereby raise the temperature of the cooled gas from the first temperature to a second temperature, which is higher than the first temperature. For example, the second temperature may be in the order of 15-20° C.

[0024] Upon exit from the gas mixer **42**, the gas at the second temperature is recirculated into the chamber **10** along a fifth path **48**. Most of the gas at the second temperature is supplied to the TIG torch **16** where it acts as a shielding gas in the material deposition process **12**. A small proportion of the gas may also be directed towards equipment, such as a camera **50**, located in the chamber **10** to cool the equipment and prevent damage thereto.

[0025] In an exemplary embodiment, the cooling gas cooled to the first temperature may be recirculated to the chamber **10** along the pipe **34** at a volume flow rate in the order of, for example, between 1000 and 2000 litres per minute, whilst the shielding gas at the second temperature may be recirculated to the chamber **10** along the fifth path **48** at a volume flow rate in the order of, for example, between 15 and 100 litres per minute. It will however be appreciated any suitable flow rates may be selected and will be dependent upon the nature of the process, the required amount of cooling of the evacuated gas, and the desired cooling rate of the deposited material **20**.

[0026] As mentioned, gas is supplied to the chamber **10** such that there is a small internal over pressure, and this ensures that any leaks which may occur between the chamber **10** and the outside atmosphere are from the chamber **10** and not into the chamber **10**. The constant flow of gas around the closed loop system, and in particular the evacuation of the gas from the chamber **10** along the first path **24** via a constriction, ensures that a back pressure is established inside the chamber thereby maintaining the chamber **10** at a positive pressure. In the illustrated embodiment, the gas is evacuated from the chamber **10** through a constriction formed directly in a side wall of the chamber **10**. In another embodiment, a side wall of the chamber **10** may include a plurality of perforations over its entire area to thereby act as a reverse diffuser. This would ensure an even flow of gas substantially across the whole cross-section of the chamber **10**. It would still be necessary to provide a constriction before evacuating the gas along the first path **24** to establish back pressure and thereby maintain the chamber **10** at a positive pressure.

[0027] In order to enable optimisation of the cooling of the deposited material **20** and the deposition process shielding gas, the apparatus **22** includes a temperature monitoring system (not shown). The temperature monitoring system includes temperature sensors which are operable to monitor at least the first and second temperatures, and alternatively or in addition the temperature of the deposited material **20** and the arc temperature of the material deposition process **12**. The temperature monitoring system includes a controller which is operable to adjust the amount of cooling of the evacuated gas, for example by varying the flow rate of evacuated gas through the gas cooler **30**, to thereby vary the first and/or second temperatures. Additional means may also be provided to vary the gas temperature.

[0028] The apparatus **20** may also include a pressure monitoring system to enable the pressure within the chamber **10** to be carefully monitored and controlled.

[0029] There is thus provided a method and apparatus **22** for recycling an inert gas evacuated from a material deposition chamber **10**. The method and apparatus ensures that the inert gas used in the chamber **10** is continuously recycled and reused rather than being discarded after use. Use of the apparatus **22** is therefore particularly advantageous when the inert gas is an expensive gas, such as helium. This is because at the large volume flow rates required, it is uneconomic to use helium and discard the gas after use. The method and apparatus **22** may however be used to recycle any inert gas or any mixture of inert gases, for example a mixture of argon and helium.

[0030] Although embodiments of the invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that various modifications to the examples given may be made without departing from the scope of the present invention, as claimed. For example, the apparatus may comprise at least two gas coolers **30**, one for cooling a proportion of the evacuated gas to the first temperature and the other for cooling a proportion of the evacuated gas to the second temperature. Under these circumstances, the use of a gas mixer **42** may be unnecessary.

1-12. (canceled)

13. Apparatus for recycling an inert gas evacuated from a material deposition process chamber, the apparatus comprising means for cooling the evacuated inert gas to provide a cooled gas, means for recirculating a proportion of the cooled gas to the chamber at a first temperature for use as a cooling gas in the material deposition process, and means for recirculating a proportion of the cooled gas to the chamber at a second temperature for use as a shielding gas in the material deposition process, the second temperature being higher than the first temperature.

14. Apparatus according to claim **13**, wherein the means for cooling the evacuated inert gas comprises a gas cooler operable to cool the evacuated gas to the first temperature.

15. Apparatus according to claim **14**, wherein the means for recirculating the cooled gas at the first temperature comprises a pump device for recirculating the cooled gas directly from the gas cooler to the chamber at the first temperature.

16. Apparatus according to claim **14**, wherein the means for recirculating the cooled gas at the second temperature comprises a gas mixing device for mixing a proportion of the gas cooled to the first temperature with a proportion of the uncooled evacuated gas to raise the temperature of the gas to the second temperature, prior to recirculation to the chamber.

17. Apparatus according to claim **13**, wherein the apparatus further comprise a gas scrubber, located between the chamber and the means for cooling the evacuated gas, for removing impurities from the evacuated gas.

18. Apparatus according to claim **13**, wherein the apparatus comprises means for directing the cooled gas at the first temperature onto material deposited in the material deposition process to cool the deposited material.

19. Apparatus according to claim **18**, wherein the apparatus comprises shielding means between the directing means and a heat source used in the material deposition process.

20. Apparatus according to claim **13**, wherein the apparatus comprises a monitoring system for monitoring the first and second temperatures, the monitoring system including a controller for adjusting the recirculation rate to compensate for temperature variations.

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