

Pipe Heating

Field

The present invention relates to a temperature regulation device for controlling the temperature of pipework. The present invention also relates to a method for regulating the temperature of pipework with a temperature regulation device. The present invention also relates to the use of a temperature regulation device.

Background

Process pipework is used in many industries for conveying liquid and/or gas. In some applications, the pipework may require heating. For example, pipework may be heated to reduce the likelihood of the condensation or solidification of a substance being conveyed through the pipework.

In some current systems, by way of example, pipework may be heated by NiCr wire embedded or sewn into a substrate, or by etched metal foil embedded into an electrically insulative substrate, or by an inductive heat generation method. Each of these technologies may require designs to be tailored to meet specific voltage and power requirements. Additionally, temperature sensors must be included in the system to regulate the heat provided to the pipework. Temperature sensors typically measure the temperature of a single point of the pipework, and this may be used to regulate the temperature of a large area of pipework. In some applications, this may be unsuitable and may lead to a variety of problems.

In some instances, process pipework may be arranged such that two or more pipes run next to each other and/or are in contact. As a result of their proximity, the areas where the pipes are closest or touch may become hotter than other areas of the respective pipes. This may result in uneven heating of the contents of the pipework. In such instances, for ease of fitment and access the temperature sensor(s) may be positioned on the away from the contact point of the pipes. As the temperature sensor(s) is positioned away from the hotspot, it may not register the uneven temperature profile within the pipe.

Current systems may also be negatively impacted by environmental conditions. If the pipework is arranged outside, a wind may blow on one side of pipe whilst the other side of the pipe is shielded from the wind. Accordingly, the shielded side may become hotter than the wind-exposed side. In such systems, the positioning of the temperature sensor(s) is critical. If the temperature sensor(s) are poorly positioned and only measure the temperature on one side of the pipe, this may result in uneven heating of the contents of the pipework.

Overall, different areas of pipework may need be heated at different rates depending on the operating conditions during use. With currently available heating systems, it may be overly complex and expensive to provide a system that can account for the variable heating requirements. Process pipework of the prior art may have inconsistent heating, leading to
5 inconsistent thermal profiles of the contents of the pipework, and therefore potentially unsafe operation conditions.

There is a desire for improved temperature regulation devices for controlling the temperature of pipework.

The present invention aims to solve, at least in part, these and other problems associated with
10 the prior art.

Summary

The invention is defined in the appended claims.

In a first aspect, the present invention provides a temperature regulation device for controlling the temperature of pipework. The device comprises a plurality of electrically connected
15 positive temperature coefficient (PTC) heating elements arranged in thermal contact with a substrate layer. The substrate layer has a thermal conductivity greater than about $150 \text{ Wm}^{-1}\text{K}^{-1}$. The substrate layer is configured to thermally contact at least a portion of the pipework when in use. The device further comprises an electrical connector for connecting the positive temperature coefficient heating elements to a power source when in use.

20 The device may be used in substantially any application where temperature regulation of pipework and its contents is required. Typically, the pipework may convey liquid and/or gas when in use. By way of example, the pipework may be for conveying chemicals or an exhaust flow, particularly the pipework may be part of a semiconductor production process.

A positive temperature coefficient (PTC) heating element may be a thermo-sensitive device
25 that has a relatively high positive temperature coefficient of resistance when at or above a temperature (i.e. the Curie or transition temperature). If a constant voltage is applied, when the temperature of the positive temperature coefficient heating element is below the Curie temperature, the electrical resistance of the PTC heating element remains substantially unchanged. Over time, the temperature of the PTC heating element will increase as a result
30 of resistive heating. When the temperature of the positive temperature coefficient heating element increases to be greater than the Curie temperature, the resistance of the PTC heating element may increase at a faster rate. Thus, the current flow through the PTC heating element may be reduced and the PTC heating element may produce less heat.

By this mechanism, positive temperature coefficient heating elements may self-regulate their thermal output according to their temperature. At a given voltage, a PTC heating element may regulate its temperature to be substantially at the Curie temperature of said PTC heating element.

- 5 The resistance characteristics of each positive temperature coefficient heating element of the device may be selected according to the requirements of the application in which it is used. Specifically, positive temperature coefficient heating elements may be selected so that their respective Curie temperatures correspond to the thermal requirements of the application. Preferably, each positive temperature coefficient heating element may have substantially the
- 10 same Curie temperature. For example, the Curie temperature of each of the positive temperature coefficient heating elements of the device may be within about $\pm 10^{\circ}\text{C}$ of the Curie temperature of each of the other positive temperature coefficient heating elements of the device, more preferably within about $\pm 5^{\circ}\text{C}$, most preferably within about $\pm 1^{\circ}\text{C}$.

- In alternative embodiments, one or more positive temperature coefficient heating element of
- 15 the device may have a different Curie temperature to at least one other positive temperature coefficient heating element of the device. This may allow for thermal gradients to be maintained within the process pipework during use.

- By way of example, factors for consideration when selecting the positive temperature coefficient heating elements for a device according to the invention may include the desired
- 20 temperature of the contents of the pipework, the location of the pipework, and/or the arrangement of the pipework.

The substrate layer may be configured to transfer heat from the pipework to the positive temperature coefficient heating elements. The positive temperature coefficient heating elements may be spaced apart on the substrate layer in an array.

- 25 The substrate layer may have a thermal conductivity greater than about $200 \text{ Wm}^{-1}\text{K}^{-1}$, preferably from about $200 \text{ Wm}^{-1}\text{K}^{-1}$ to about $5000 \text{ Wm}^{-1}\text{K}^{-1}$, more preferably from about $3000 \text{ Wm}^{-1}\text{K}^{-1}$ to about $5000 \text{ Wm}^{-1}\text{K}^{-1}$. Advantageously, this may enable the substrate layer to provide efficient heat transfer between the pipework and the positive temperature coefficient heating elements of the device, and vice versa. Preferably, the substrate layer may have a
- 30 thermal conductivity greater than about three times the thermal conductivity of the material of pipework or more. Preferably, the substrate layer may have a thermal conductivity of from about three times to about five hundred times the thermal conductivity of the material of the pipework.

The electrical connector may be wiring. In addition to providing connection to the power source, the electrical connector may electrically connect the positive temperature coefficient heating elements.

Advantageously, the temperature regulation device may be self-regulating. In other words, the device may not require temperature sensors in addition to the positive temperature coefficient heating elements. The positive temperature coefficient heating elements may be operable without needing feedback controls and/or external diagnostics. When in use, each of the positive temperature coefficient heating elements of the device may function as both a heating element and as a temperature sensor.

When in use, the device may be configured to provide auto-regulated thermal output both axially along and circumferentially about the pipework. If there is a hotter or cooler region of the pipework, the positive temperature coefficient heating element(s) of the device near that region may automatically regulate their thermal output to compensate for the temperature difference. This may improve the uniformity of the temperature profile of the pipework. This may provide simpler and safer operating conditions in comparison to heating devices of the prior art.

The device may be configured to be wrapped about an outer surface of the pipework such that the substrate layer and thereby the positive temperature coefficient heating elements are in thermal contact with the pipework. The device may be a wraparound device. When installed, the substrate layer may provide a sleeve substantially surrounding the pipework. Preferably, the substrate layer may be in direct contact with an outer surface of the pipework. This may allow heat transfer therebetween.

The device of the present invention may be configured to operate at a wider voltage range than devices of the prior art. For example, the device may be operable from about 12V to about 400V alternating current.

Typically, the Curie temperature of one or more, preferably all, of the positive temperature coefficient heating elements of the device may be from about 60 °C to about 300 °C, preferably from about 60 °C to about 240 °C. However, it will be appreciated that the Curie temperature of the positive temperature coefficient heating element(s) may be selected according to the condensation temperature of the chemicals being conveyed through the pipework.

In some embodiments, a high resistive PTC design can be used. Such embodiments may advantageously reduce the surge current at high voltages. This may reduce the current drawn by the device when initially connected to a power source. In such embodiments, one or more of the positive temperature coefficient heating elements of the device may have a relatively

high resistance in comparison to one or more further positive temperature coefficient heating elements of the device.

Typically, the positive temperature coefficient heating elements may be electrically connected in parallel. Advantageously, this may ensure that, should a single positive temperature coefficient heating element fail, then power would continue to be supplied to the remaining positive temperature coefficient heating elements and the device would continue to operate. This may improve the operating performance of the device, as the device may continue to regulate the temperature of the pipework, and thereby the contents conveyed therein.

Typically, the device may comprise from about 2 to about 200 positive temperature coefficient heating elements. The number of positive temperature coefficient heating elements may be selected according to the application. The number of positive temperature coefficient heating elements of the device may depend on factors including the dimensions of the pipework to be heated, the desired temperature of the contents of the pipework, the environmental conditions surrounding the pipework.

The positive temperature coefficient heating elements may be arranged in an array on the substrate layer. The positive temperature coefficient heating elements may be arranged in a repeating array on the substrate layer. Preferably, the positive temperature coefficient heating elements may be substantially evenly spaced on the substrate layer. Modelling may be performed to determine an appropriate number and arrangement of the positive temperature coefficient heating elements on the substrate layer for a given application.

Typically, the positive temperature coefficient heating elements are PTC pad heaters, PTC rope heaters, and/or ceramic PTC heaters. The type of positive temperature coefficient heating element may be selected according to the application. In some embodiments, the device may comprise a plurality of the same type of positive temperature coefficient heating elements.

The device may further comprise an insulation layer configured to reduce thermal conduction in a direction away from the pipework when in use. Preferably, in use, the substrate layer may be arranged between the pipework and the insulation layer.

Typically, the device may further comprise at least one switch configured to limit current flow. In use, operation of the switch may enable conductance to be limited to at least one of the positive temperature coefficient heating elements of the device.

Preferably, the switch may be arranged between the positive temperature coefficient heating element arranged closest to the electrical connector and the next closest positive temperature coefficient heating element. In this arrangement, the switch may allow conductance to the first

positive temperature coefficient heating element (i.e. the PTC element closest to the power source), whilst substantially preventing conductance to the remaining positive temperature coefficient heating elements.

When power is initially supplied, the positive temperature coefficient heating elements of the device may initially draw a large current (i.e. surge current) as the positive temperature coefficient heating elements are cold and therefore have a relatively low resistance. Advantageously, use of the switch may allow the first positive temperature coefficient heating element to heat up and compensate for the surge current when power is first supplied to the device. The heating caused by the surge current may thereby be limited to the first positive temperature coefficient heating element, and not occur in the remaining positive temperature coefficient heating elements of the device.

In some embodiments, the device may comprise a plurality of switches. Preferably, each switch may correspond to one or more positive temperature coefficient heating element. In other words, each switch may be configured to limit the conductance to one or more positive temperature coefficient heating element(s). This may enable further control over the operation of the device. Advantageously, in such embodiments a sequential start up process may be used by sequentially operating the switches whilst turning the device on. This may limit the total startup current.

The device may comprise one or more positive temperature coefficient heating elements having a first Curie temperature, and one or more further positive temperature coefficient heating elements having a second Curie temperature. In some embodiments, the positive temperature coefficient heating element(s) having the first Curie temperature may have a separate electrical connector (i.e. wiring) to a power source to the positive temperature coefficient heating element(s) having the second Curie temperature. In some embodiments, the positive temperature coefficient heating element(s) having the first Curie temperature may be connected to a separate power source to the positive temperature coefficient heating element(s) having the second Curie temperature.

Advantageously, this may allow for the device to provide variable thermal output, which may be required for certain applications.

The device may comprise one or more additional positive temperature coefficient heating elements having a third or further Curie temperature.

Typically, the device may further comprise a bracket configured to connect at least one positive temperature coefficient heating element to the substrate layer. Preferably, each positive temperature coefficient heating element may connect to the substrate layer via a

bracket. Each positive temperature coefficient heating element may have a corresponding bracket.

Advantageously, the bracket may maintain the position of the PTC element relative to the substrate layer and within the desired array. Furthermore, the bracket may provide wire strain
5 relief.

Preferably, the or each bracket comprises a first portion coupled to a second portion. The positive temperature coefficient heating element and the substrate layer are arranged between said first and second portions. The first portion and second portion may be arranged to clamp the positive temperature coefficient heating element and substrate layer therebetween. The
10 bracket may comprise one or more rivets, bolts, or other fixings configured to clamp the first portion to the second portion.

Additionally, or alternatively, at least one positive temperature coefficient heating element may be connected to the substrate layer by, for example, resistance welding or adhesive. In some embodiments, the resistance welds may substantially surround the positive temperature
15 coefficient heating element whilst avoiding the electrical connector.

The substrate layer may comprise a metallic foil or graphene. Preferably, the substrate layer may comprise copper foil stock or aluminium foil stock.

Typically, the temperature regulation device may further comprise a protective layer. The positive temperature coefficient heating elements may be arranged between the substrate
20 layer and the protective layer. Preferably, the protective layer may be the same material as the substrate layer. Preferably, the protective layer comprises a metallic foil or graphene. The protective layer may be the insulating layer as discussed hereinbefore.

The first and second portion of each bracket may be arranged to secure the substrate layer, a positive temperature coefficient heating element and the protective layer therebetween.

25 In a further aspect, the present invention provides a method for regulating the temperature of pipework. The method comprises the steps of:

- a) providing a temperature regulation device according to any embodiment of the preceding aspect,
- b) connecting the temperature regulation device to the pipework, such that the
30 substrate layer is in contact with the pipework,
- c) connecting the temperature regulation device to a power source.

In embodiments wherein the temperature regulation device comprises one or more positive temperature coefficient heating elements having a first Curie temperature, and one or more further positive temperature coefficient heating elements having a second Curie temperature, the method may further comprise the step of connecting the positive temperature coefficient heating elements having a second Curie temperature to a separate electrical power source (e.g. mains power supply, a battery) to those having a first Curie temperature. This step may be performed at the same time as step (c). Alternatively, the positive temperature coefficient heating elements having the second Curie temperature may be connected to a separate power source selectively according to the requirements of the application. The skilled person will appreciate that this step may be repeated for further positive temperature coefficient heating element(s) having third or further Curie Temperatures.

Typically, the method may further comprise the step of, upon startup, limiting the current flow to one or more positive temperature coefficient heating elements via one or more switches. Preferably, the switch may be positioned between the positive temperature coefficient heating element closest to the power source, and the next closest positive temperature coefficient heating element. Advantageously, this may compensate for the surge current upon connection to the power source.

The temperature regulation of the pipework according to the method of the invention may be substantially automatic.

Further features of the device used in the method of this aspect may be as defined elsewhere herein.

In a further aspect, the present invention provides the use of a temperature regulation device according to any embodiment of an aspect described herein for regulating the temperature of pipework in a semiconductor wafer processing device. Preferably, the temperature regulation device may be used for regulating the temperature of a fore line or exhaust line of semiconductor processing equipment. Advantageously, this may provide safe, efficient temperature regulation.

For the avoidance of doubt, all aspects and embodiments described herein may be combined mutatis mutandis. It is also to be understood that this invention is not limited to the embodiments and aspects set forth in the following detailed description or illustrated in the drawings. The invention may be implemented in various other embodiments and is capable of being implemented in alternative ways not expressly disclosed herein.

Also, it is to be understood that the phraseology and terminology used herein are for the purpose of description and should not be regarded as limiting. The use of "including" and

“comprising” and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items and equivalents thereof. Further, enumeration may be used in the description of various embodiments. Unless otherwise expressly stated, the use of enumeration should not be construed as limiting the invention to any specific order or number of components. Nor should the use of enumeration be construed as excluding from the scope of the invention any additional steps or components that might be combined with or into the enumerated steps or components.

Brief Description of Figures

Preferred features of the present invention will now be described, by way of example, with reference to the accompanying figures, in which:

Figure 1 shows a temperature regulation device according to an embodiment of the present invention;

Figure 2 shows a view of the interior electrical parts of a temperature regulation device according to an embodiment of the present invention;

Figure 3 shows a temperature regulation device according to an embodiment of the present invention when in situ on pipework;

Figure 4 shows a cross-sectional view of a portion of a temperature regulation device according to an embodiment of the present invention;

Figure 5 shows a bracket portion for use in a temperature regulation device according to the present invention;

Figure 6 shows a flow diagram of a method according to an embodiment of the present invention.

Detailed Description of Figures

Figure 1 illustrates a temperature regulation device (1) according to an embodiment of the present invention.

The device (1) comprises a plurality of positive temperature coefficient heating elements (2). The positive temperature coefficient heating elements (2) are electrically connected by wiring (3). The positive temperature coefficient heating elements (2) are arranged in thermal contact with a substrate layer (4). In this embodiment, the substrate layer (4) comprises a copper foil.

The wiring (3) is configured to be connected to a power source when in use.

Each of the positive temperature coefficient heating elements (2) are coupled to the substrate layer (4) by a bracket (5). The bracket (5) secures the positive temperature coefficient heating elements (2) to the substrate layer (4). The bracket (5) also provides wire strain relief.

5 The positive temperature coefficient heating elements (2) are arranged in an array on the substrate layer (4). The positive temperature coefficient heating elements (2) are substantially evenly spaced on the substrate layer (4).

In use, the device (1) is configured to be wrapped about an outer surface of the pipework such that the substrate layer (4) and the positive temperature coefficient heating elements (2) are in thermal contact with the pipework.

10 Figure 2 illustrates a view of the interior electrical parts of a temperature regulation device according to an embodiment of the present invention. The arrangement may correspond to the interior electrical parts of the embodiment of Figure 1.

In use, the interior electrical parts may be arranged between a substrate layer (not shown) and a protective layer (not shown).

15 The positive temperature coefficient heating elements (2) are connected by wiring (3). The positive temperature coefficient heating elements (2) may be electrically connected to a switch (6). The switch (6) may be configured to limit conductance to the positive temperature coefficient heating elements (2) during operation.

20 Figure 3 illustrates a temperature regulation device (7) according to an embodiment of the present invention when in situ on pipework (8). The temperature regulation device (7) is wrapped about the external surface of the pipework (8).

The substrate layer (9) of the temperature regulation device (7) is in thermal contact with the external surface of the pipework (8). In this embodiment, the array of positive temperature coefficient heating elements (10) are substantially evenly spaced about the external surface
25 of the pipework (8). Accordingly, in use, the device (7) may automatically regulate the temperature of the pipework (8), and thereby the temperature of the contents conveyed therein.

Figure 4 illustrates a cross-sectional view of a portion of a temperature regulation device according to an embodiment of the present invention.

30 The positive temperature coefficient heating element (11) is arranged between the substrate layer (12) and the protective layer (13). The positive temperature coefficient heating element (11) is connected to other positive temperature coefficient heating elements of the array (not

shown) by wiring (14). All of the positive temperature heating elements (11) and the connecting wiring (14) are arranged between the substrate layer (12) and the protective layer (13).

The bracket (15) connects the positive temperature coefficient heating element (11) to the substrate layer (12) and the protective layer (13). The bracket (15) retains the position of the positive temperature coefficient heating element (11) in the array (not shown). The bracket (15) comprises a first portion (16) arranged generally on a first side of the device. The bracket (15) further comprises a second portion (17) arranged generally on a second side of the device. As will be described in greater detail in relation to Figure 5, the bracket (15) is configured to at least partially surround the positive temperature coefficient heating element (11) is arranged.

The bracket (15) compresses the wiring (14) providing strain relief. The substrate layer (12) and the protective layer (13) are also compressed between the first portion (16) and the second portion (17). In this embodiment, the first portion (16) and the second portion (17) are connected by rivets (18).

Figure 5 illustrates an embodiment of a bracket portion (19) for use in a temperature regulation device according to the present invention. The bracket portion may be the first portion (16) or the second portion (17). Preferably, the first portion (16) and the second portion (17) may be substantially the same dimensions.

The bracket portion (19) comprises a rim (20). In use, the positive temperature coefficient heating element is configured to be arranged within the rim (20), such that the rim (20) surrounds the positive temperature coefficient heating element. In other words, the bracket portion may have an aperture (21) in which the positive temperature coefficient heating element may be arranged when in use. In this embodiment, the aperture (21) is generally rectangular. The aperture (21) may have substantially the same shape as the positive temperature coefficient heating element that it is configured to surround. This may aid in maintaining the position of the positive temperature coefficient heating element.

The bracket portion (19) further comprises conduits (22). When in use, a rivet or other fixing may be inserted through each conduit (22) to maintain the position of the positive temperature coefficient heating element in the device.

Figure 6 illustrates a flow diagram of a method according to an embodiment of the present invention.

The method comprises the steps of providing a temperature regulation device according to any embodiment described herein (23), connecting the temperature regulation device to

process pipework such that the substrate layer of the device is in thermal contact with the pipework (24), and connecting the temperature regulation device to a power source (25).

For the avoidance of doubt, features of any aspects or embodiments recited herein may be combined mutatis mutandis. It will be appreciated that various modifications may be made to the embodiments shown without departing from the spirit and scope of the invention as defined by the accompanying claims as interpreted under patent law, including the doctrine of equivalents. Any reference to claim elements in the singular, for example, using the articles “a”, “an”, “the” or “said”, is not to be construed as limiting the element to the singular.

Reference Key

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| 10 | 1. Temperature regulation device |
| | 2. Positive temperature coefficient heating element |
| | 3. Wiring |
| | 4. Substrate layer |
| | 5. Bracket |
| 15 | 6. Switch |
| | 7. Temperature regulation device |
| | 8. Pipework |
| | 9. Substrate layer |
| | 10. Positive temperature coefficient heating element |
| 20 | 11. Positive temperature coefficient heating element |
| | 12. Substrate layer |
| | 13. Protective layer |
| | 14. Wiring |
| | 15. Bracket |
| 25 | 16. First portion |
| | 17. Second portion |
| | 18. Rivets |
| | 19. Bracket portion |
| | 20. Rim |
| 30 | 21. Aperture |
| | 22. Conduit |
| | 23. Method step |
| | 24. Method step |
| | 25. Method step |

Claims

1. A temperature regulation device for controlling the temperature of pipework, the device comprising:
a plurality of electrically connected positive temperature coefficient heating elements
5 arranged in thermal contact with a substrate layer;
the substrate layer having a thermal conductivity greater than about $150 \text{ Wm}^{-1}\text{K}^{-1}$ and
being configured to thermally contact at least a portion of the pipework when in use;
and
an electrical connector for connecting the positive temperature coefficient heating
10 elements to a power source when in use.
2. The temperature regulation device according to claim 1, wherein the positive temperature coefficient heating elements are electrically connected in parallel.
- 15 3. The temperature regulation device according to claim 1 or 2, comprising from about 2 to about 200 positive temperature coefficient heating elements.
4. The temperature regulation device according to any preceding claim, wherein the positive temperature coefficient heating elements are PTC pad heaters, PTC rope
20 heaters, and/or ceramic PTC heaters.
5. The temperature regulation device according to any preceding claim, further comprising at least one switch configured to limit current flow, preferably wherein the switch is arranged between the positive temperature coefficient heating element
25 arranged closest to the electrical connector and the next closest positive temperature coefficient heating element.
6. The temperature regulation device according to claim 5, comprising a plurality of switches, preferably wherein each switch corresponds to a positive temperature
30 coefficient heating element.
7. The temperature regulation device according to any preceding claim comprising one or more positive temperature coefficient heating elements having a first Curie temperature, and one or more further positive temperature coefficient heating
35 elements having a second Curie temperature.

8. The temperature regulation device according to any preceding claim, further comprising a bracket configured to connect at least one positive temperature coefficient heating element to the substrate layer, preferably wherein each positive temperature coefficient heating element is connected to the substrate layer via a bracket.
9. The temperature regulation device according to claim 8, wherein the bracket comprises a first portion coupled to a second portion, and wherein the positive temperature coefficient heating element and the substrate layer are arranged between said first and second portions.
10. The temperature regulation device according to any preceding claim, wherein the substrate layer comprises a metallic foil or graphene, preferably wherein the substrate layer comprises copper foil stock or aluminium foil stock.
11. The temperature regulation device according to any preceding claim, further comprising a protective layer, wherein the positive temperature coefficient heating elements are arranged between the substrate layer and the protective layer, preferably wherein the protective layer comprises a metallic foil or graphene.
12. A method for regulating the temperature of pipework comprising:
a) providing a temperature regulation device according to any preceding claim,
b) connecting the temperature regulation device to the pipework, such that the substrate layer is in contact with the pipework,
c) connecting the temperature regulation device to a power source.
13. The method according to claim 12, further comprising the steps of, upon startup, limiting the current flow to one or more positive temperature coefficient heating elements via one or more switches.
14. The method according to claim 12 or 13, wherein the temperature regulation is automatic.
15. The use of a temperature regulation device according to any of claims 1 to 11 for regulating the temperature of pipework in a semiconductor wafer processing device, preferably a fore line or exhaust line of semiconductor processing equipment.