APPARATUS AND PROCESS FOR SENSING TARGET GAS SPECIES IN SEMICONDUCTOR PROCESSING SYSTEMS

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates generally to a device and a method for sensing a target gas species, which have utility for monitoring of gaseous compounds and ionic species in semiconductor process operations.

Description of the Related Art

[0002] In the manufacture of semiconductor devices, the deposition of silicon (Si) and silicon dioxide (SiO_2), and subsequent etching, are vital operational steps that currently comprise 8 - 10 steps or roughly 25% of the total manufacturing process. Each deposition tool and etch tool must undergo a periodic cleaning procedure, sometimes as often as every run, in order to ensure uniform and consistent film properties.

[0003] Currently, in etching operations, etch endpoints are reached when a prescribed amount of time has elapsed. Over etch, in which the process gas continues to flow into the reactor chamber after the cleaning etch is finished, is common and leads to longer process cycles, reduced tool lifetimes, and unnecessary global-warming-gas losses to the atmosphere (Anderson, B.; Behnke, J.; Berman, M.; Kobeissi, H.; Huling, B.; Langan, J.; Lynn, S-Y., *Semiconductor International,* October (1993)).

[0004] Similar issues are present in the etching of silicon nitride materials when SiN is utilized in semiconductor device structures.

[0005] Various analytical techniques, such as FTIR, Optical Emission Spectroscopy, and Ionized Mass Spectroscopy, can be used to monitor the etch process. However, these techniques tend to be expensive, and often require a dedicated operator due to their complexity.

[0006] It would therefore be a significant advance in the art to provide a reliable, low-cost gas-sensing capability that will serve to improve the throughput and chemical efficiency of the equipment used for the deposition and etching of silicon-containing materials, including silicon, silicon nitride and silicon dioxide, by reducing and optimizing clean and etch times, and hence reducing chemical usage, lengthening equipment operating life, and decreasing equipment down time.

[0007] U.S. Patent Application No. 10/273,036 filed October 17, 2002 for "APPARATUS AND PROCESS FOR SENSING FLUORO SPECIES IN SEMICONDUCTOR PROCESSING SYSTEMS" discloses an apparatus and method for sensing solid-state fluoro species, using a fluoro-reactive metal filament weaved around metal packaging posts or Vespel® polyimide blocks on a KF flange. Detection of the fluoro species using such metal filament-based sensors relies on monitoring the resistance changes in the metal filaments caused by their reactions with the fluorine-containing compounds. In order to ensure acceptable sensitivity and signal-to-noise ratio for such metal filament-based sensors, the dimensions and the positions of the metal filaments are controlled and optimized via uses of the metal packaging posts or the Vespel® polyimide blocks, to provide an absolute resistance that is adequate for endpoint detection.

[0008] There is a continuing need to discover and develop improved filament-based sensors, by employing new compositions and structures to further enhance the sensitivity, signal-to-noise ratio, and mechanical reliability of such gas sensors, as well as to further reduce the response time and the manufacturing costs thereof.

SUMMARY OF THE INVENTION

[0009] The present invention relates generally to apparatus and method for sensing a target gas species, especially a fluoro gas species, in an environment susceptible to the presence of such

gas species, such as an ambient environment, a gaseous effluent stream from a semiconductor manufacturing process, etc.

[0010] In one aspect, the invention relates to a gas sensor assembly comprising a gas-sensing filament comprising nickel or nickel alloy.

[0011] Another aspect of the invention relates to a gas sensor assembly comprising a gas-sensing filament comprising a coating structure encapsulating a core structure, wherein such coating structure comprises nickel or nickel alloy, wherein such core structure is characterized by an electrical resistivity that is higher than that of the coating structure and a heat capacity that is lower than that of the coating structure.

[0012] Preferably, such core structure is characterized by an electrical resistivity that is at least fifty (50) times larger than that of the coating structure, and a heat capacity that is less than three fourth (3/4) of that of the coating structure. More preferably, such core structure is characterized by an electrical resistivity that is at least one thousand (1000) times larger than that of the coating structure, and a heat capacity that is less than one half (1/2) of that of the coating structure. Most preferably, such core structure is characterized by an electrical resistivity that is at least 10 $m\Omega \cdot cm$ and a heat capacity that is less than 2.5 $J/K \cdot cm^3$. In a particularly preferred embodiment of the invention, the core structure comprises silicon carbide. In another preferred embodiment of the invention, the core structure further comprises a composite structure formed by coating a carbon core fiber with silicon carbide.

[0013] Yet another aspect of the invention relates to a gas sensor assembly comprising a gas-sensing filament comprising nickel or nickel alloy, wherein such gas-sensing filament is fabricated by electrochemical thinning techniques and is therefore characterized by an average diameter of not more than 50 microns, preferably not more than 25 microns, more preferably not more than 10 μm, and most preferably within a range of from about 0.1 μm to about 5 μm.

[0014] The invention in a corresponding aspect relates to a method for fabricating a gas sensor assembly comprising a nickel-containing gas-sensing filament that is characterized by an average diameter of not more than 50 microns, comprising the step of: (1) providing a gas sensor assembly comprising a nickel-containing gas-sensing filament having an average

diameter that is more than 50 microns; and (2) electrically thinning such nickel-containing gas-sensing filament for a sufficient period of time so as to reduce the average diameter of such nickel-containing gas-sensing filament to 50 microns or less.

[0015] A further aspect of the present invention relates to a gas sensor assembly comprising a gas-sensing filament comprising nickel-copper alloy. Preferably, such nickel-copper alloy contains from about 10% to 90% nickel by weight, and from about 10% to about 90% copper by weight. More preferably, such nickel-copper alloy further comprises aluminum in the amount of from about 10% to about 90% by weight. Such nickel-copper alloy may also comprise other fluoro-resistant metal components, including but not limited to Ti, V, Cr, Mn, Nb, Mo, Ru, Pd, Ag, Ir, and Pt.

[0016] A still further aspect of the present invention relates to a gas sensor assembly comprising a nickel-containing gas-sensing filament having a porous surface having about 20% to about 80% total porosity, and more preferably 60% total porosity. Preferably, such porous surface of such gas-sensing filament is characterized by open pore structures.

[0017] Another aspect of the invention relates to a gas sensor assembly as described hereinabove, which further comprises means coupled with the gas-sensing filament for detecting a change in at least one property of such gas-sensing filament upon contact with a target gas species and responsively generating an output signal indicative of the presence of such target species.

[0018] Another aspect of the invention relates to a gas sensor assembly comprising an above-described gas-sensing filament and a support structure, wherein the gas-sensing filament is mounted on such support structure in a free-standing manner.

[0019] Yet another aspect of the present invention relates to a gas sensor assembly as described hereinabove, arranged in sensing relationship to a process chamber that is susceptible to presence of one or more target fluoro species, wherein the gas-sensing filament is mounted on a fluoro-resistant support structure and coupled to means for detecting a change in at least one property of such gas-sensing filament upon contact with the target fluoro species

and responsively generating an output signal indicative of the presence of said target fluoro species.

[0020] The invention in a further aspect relates to a gas sensor assembly as described hereinabove, which is constructed and arranged to monitor an effluent from a semiconductor manufacturing plant or a fluid derived from the effluent, wherein the effluent or fluid derived therefrom is susceptible of comprising a fluoro species, and wherein such gas sensor assembly further comprises means for detecting a change in at least one property of the gas-sensing filament upon contact with the fluoro species and responsively generating an output signal indicative of the presence of such fluoro species.

[0021] A still further aspect of the invention relates to a method of monitoring a fluid locus for the presence of a target gas species therein, said method comprising:

> exposing fluid at said fluid locus to a gas-sensing assembly as described hereinabove;
>
> monitoring at least one property of the gas-sensing filament of such gas-sensing assembly; and
>
> responsively generating an output signal when the gas-sensing filament exhibits a change in the at least one property thereof, indicating the presence of the target gas species in the fluid locus, or a change in concentration of the target gas species in the fluid locus.

[0022] Yet another aspect of the present invention relates to an elongated gas sensor element formed by one or more gas-sensing filaments, such elongated gas sensor element comprising two electrical connection terminals and a longitudinal axis, wherein the longitudinal axis of the sensor element is substantially perpendicular to a line defined by the two electrical connection terminals thereof.

[0023] Such elongated gas sensor element may comprise any number of gas-sensing filaments and has any suitable shape or conformation, as long as its longitudinal axis is substantially

perpendicular to the line defined by its two electrical connection terminals. In a preferred embodiment of the present invention, the elongated gas sensor element is formed of two gas-sensing filament attached together at first ends thereof and has a wishbone shape.

[0024] Such elongated gas sensor element preferably, but not necessarily, comprises a gas-sensitive coating that encapsulates a core structure, wherein the core structure has an electrical resistivity that is higher than that of the gas-sensitive coating and a heat capacity that is lower than that of the gas-sensitive coating. Nickel-containing coating is particularly sensitive to fluoro gas species, and therefore in a particularly preferred embodiment of the present invention, the elongated gas sensor element comprises a nickel-containing coating encapsulating a core structure, such core structure being characterized by a higher electrical resistivity and a lower heat capacity than those of such nickel-containing coating.

[0025] Another aspect of the present invention relates to a gas-sensing assembly, which comprises at least one of the above-described elongated gas sensor element mounted on a support structure, wherein such support structure comprises a surface for mounting the two electrical connection terminals of the elongated gas sensor element.

[0026] The invention in a further aspect relates to a method for monitoring a fluid locus for the presence of a target gas species therein, said method comprising the steps of:

exposing fluid at said fluid locus to a gas-sensing assembly as described hereinabove;

monitoring at least one property of the elongated gas sensor element of such gas-sensing assembly; and

responsively generating an output signal when the elongated gas sensor element exhibits a change in the at least one property thereof, indicating the presence of the target gas species in the fluid locus, or a change in concentration of the target gas species in the fluid locus.

[0027] A still further aspect of the present invention relates to a method for fabricating an elongated gas sensor element having a wishbone shape, comprising the steps of:

(a) aligning a pair of gas-sensing filaments side by side; and

(b) connecting such pair of gas-sensing filaments at first ends thereof, while leaving the opposite, second ends of said pair of gas-sensing filaments separated from each other, wherein the separated opposite, second ends of such pair of gas-sensing filaments form the two electrical connection terminals of the wishbone-shaped gas sensor element.

[0028] Alternatively, such wishbone-shaped gas sensor element can be formed by a method comprising the steps of:

(a) aligning a pair of filaments side by side;

(b) connecting such pair of filaments at first ends thereof, while leaving the opposite, second end of such pair of filaments separated from each other, so as to form a wishbone-shaped precursor structure; and

(c) forming a gas-sensitive coating over such wishbone-shaped precursor structure.

[0029] Yet another aspect of the present invention relates to a gas-sensing assembly arranged in sensing relationship to a process chamber that is susceptible to presence of one or more target fluoro gas species, wherein such gas-sensing assembly comprises a nickel-containing gas sensor element mounted on a surface of a support structure and coupled to means for detecting a change in at least one property of such gas sensor element upon contact with the target fluoro gas species and responsively generating an output signal indicative of the presence of the target fluoro gas species, wherein such nickel-containing gas sensor element has a longitudinal axis that is oriented perpendicular to or substantially perpendicular to the mounting surface of the support structure.

[0030] As used herein, the term "fluoro species" is intended to be broadly construed to encompass all fluorine-containing materials, including without limitation, gaseous fluorine compounds, fluorine *per se* in atomic and diatomic (F_2) forms, fluorine ions, and fluorine-containing ionic species. The fluoro species may for example include species such as NF_3, SiF_4, C_2F_6, HF, F_2, COF_2, ClF_3, IF_3, etc., and activated fluorine-containing species (denoted collectively as $F^{\bullet}$) thereof, including ionized fragments, plasma forms, etc.

[0031] Other aspects, features and embodiments of the invention will be more fully apparent from the ensuing disclosure and appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] FIG. 1 illustratively depicts the cross-sectional view of a gas-sensing filament comprising a Monel coating structure encapsulating a silicon carbide core structure, according to one embodiment of the present invention.

[0033] FIG. 2 shows a partial cross-section view of a composite core structure, according to one embodiment of the present invention.

[0034] FIG. 3 shows the output signals produced over time by a gas sensor assembly that employs a nickel-coated silicon carbide filament, in comparison with the output signals produced over time by a residual gas analyzer (RGA) unit.

[0035] FIG. 4 shows the output signals produced over time by a gas sensor assembly that employs a nickel filament, in comparison with the output signals produced over time by a residual gas analyzer (RGA) unit.

[0036] FIG. 5 shows a perspective view of a nickel filament comprising a neck portion that is electrochemically thinned, according to one embodiment of the present invention.

[0037] FIG. 6. illustratively depicts the cross-sectional view of a gas-sensing filament comprising a porous nickel coating, according to one embodiment of the present invention.

[0038] FIG. 7 is a SEM micrograph of a gas-sensing filament comprising a porous nickel coating formed on a dense substrate, according to one embodiment of the present invention.

[0039] FIG. 8. is a SEM micrograph of a gas-sensing filament comprising a porous nickel coating characterized by an open pore structure, according to one embodiment of the present invention.

[0040] FIGS. 9A and 9B show a gas-sensing assembly comprising two nickel-coated silicon carbide filament suspended by press fit electrical pins over a KF flange.

[0041] FIG. 10 shows a wishbone-shaped gas sensor element formed by two gas-sensing filaments, according to one embodiment of the present invention.

[0042] FIG. 11-13 show elongated gas sensor elements of various shapes and configurations.

[0043] FIG. 14 shows a wishbone-shaped gas sensor element that is vertically mounted on a support structure, according to one embodiment of the present invention.

[0044] FIG. 15 shows the signal responses produced over time by a vertically mounted wishbone-shaped gas-sensing element (WISHBONE), in comparison with the signal responses produced over time by a horizontally mounted straight nickel-coated SiC carbon fiber (XENA) under the same testing conditions.

DETAILED DESCRIPTION OF THE INVENTION, AND PREFERRED EMBODIMENTS THEREOF

[0045] The contents of U.S. Patent Application No. 10/273,036 filed October 17, 2002 for "APPARATUS AND PROCESS FOR SENSING FLUORO SPECIES IN SEMICONDUCTOR PROCESSING SYSTEMS" and U.S. Patent No. 6,265,222 issued July 24, 2001 for "MICRO-MACHINED THIN FILM HYDROGEN GAS SENSOR, AND METHOD OF MAKING AND USING THE SAME" are incorporated herein by reference in their entirety for all purposes.

[0046] While the invention is described more fully hereinafter with specific reference to applications in semiconductor process control, it is to be appreciated that the utility of the invention is not thus limited, but rather extends to a wide variety of other uses and applications, including, without limitation, deployment in life safety systems, room or ambient environment monitoring operations, and other industrial as well as consumer market gas-sensing applications.

[0047] As is well known, fluoro species react with most metals to form compounds that have a high, and sometimes, mixed oxidation state (Inorganic Solid Fluorides, Chemistry and Physics.

Academic Press, 1985, Ed P. Hagenmuller). Many of the transition metals and noble metals (including, for example, but not limited to Ni, Cu, Al, Ti, V, Cr, Mn, Nb, Mo, Ru, Pd, Ag, Ir, and Pt) readily form various non-volatile fluorinated compounds in contact with such fluoro species.

[0048] The present invention therefore employs fluoro-reactive metal filaments. By monitoring changes in the properties of such metal filaments as caused by their reaction with fluoro species, one can determine the presence and/or concentration of one or more target fluoro species in a particular gaseous environment, such as a effluent gas stream discharged by a semiconductor chamber clean process.

[0049] Specifically, the electrical resistance increase observed for a fluoro-reactive metal filament, when placed in a gaseous environment susceptible to contamination by a fluoro species, has been found to be a good indicator of the presence and concentration of such fluoro species in the environment. Because the metal filament possesses higher thermal conductivity than the gaseous environment, a significant portion of the heat generated by the exothermic reactions between the metal filament and the fluoro species is channeled to the metal filament, causing temperature increase in such metal filament, which in turn raises the electrical resistance of such metal filament.

[0050] Specifically, the present invention relates to the uses of nickel-containing filaments, which contains either pure nickel or nickel alloys, in gas-sensing assembly for detection of target fluoro species.

[0051] One preferred embodiment of the invention employs a gas-sensing filament comprising a fluoro-reactive coating structure that contains nickel or nickel alloy, while such coating structure encapsulates a high resistivity, low thermal mass core structure, which is characterized by an electrical resistivity that is higher than that of the coating structure and a heat capacity (i.e., the product of specific heat C_p and density D) that is lower than that of the coating structure.

[0052] Preferably, such core structure is characterized by an electrical resistivity that is at least fifty (50) times larger than that of the coating structure, and a heat capacity that is less than

three fourth (3/4) of that of the coating structure. More preferably, such core structure is characterized by an electrical resistivity that is at least one thousand (1000) times larger than that of the coating structure, and a heat capacity that is less than one half (1/2) of that of the coating structure. Most preferably, such core structure is characterized by an electrical resistivity that is at least 10 $m\Omega \cdot cm$ and a heat capacity that is less than 2.5 $J/K \cdot cm^3$.

[0053] Many combinations of materials are available for forming such coating and core structures. Without limiting the broad scope of the present invention, examples of materials suitable for forming the coating and core structures are herein provided, which include: (1) pure nickel for the coating and a nickel alloy (such as Monel, a nickel-copper alloy) for the core; (2) pure nickel or nickel alloy for the coating and silicon carbide for the core; (3) pure nickel or nickel alloy for the coating and carbon for the core, etc.

[0054] Silicon carbide is particularly preferred for forming the core structure in the present invention, because the high electrical resistivity (usually greater than 10 $m\Omega \cdot cm$) and low heat capacity (usually less than 2.5 $J/K \cdot cm^3$) of silicon carbide further enhances the signal strength and responsiveness of the nickel-containing filament sensor, without inducing significant heat loss. Moreover, silicon carbide is resistant to attack by the corrosive fluorine plasma, which, although is not a necessary feature of the encapsulated core structure, advantageously improves the mechanical robustness and reliability of the filament sensor when used in corrosive gaseous environment for detecting fluoro species.

[0055] Figure 1 illustratively shows the cross-sectional view of a gas-sensing filament **1** according to one embodiment of the invention, which comprises a core structure **6** made of β-silicon carbide encapsulated by a coating **2** fabricated by using the nickel-copper alloy, Monel.

[0056] Composite structures comprising multiple layers of high resistivity, low thermal mass materials can also be used to form the core structure for the filament sensors of the present invention. Various combinations and configurations of suitable core materials can be employed to further improve the performance of the filament sensors. In one instance of the present invention, silicon carbide fibers can be used, upon which a thin layer of nickel is formed as the gas-sensing layer.

[0057] Figure 2 shows a partial cross-sectional view of a silicon carbide fiber **10**. Such silicon carbide has an overall diameter of from about 78 microns to about 140 microns, which includes a carbon core **12** enclosed in a β-SiC sheath **16** with a carbon rich surface **18**. The SCS silicon carbide fibers have a heat capacity (C_p times D) that is about one half of that of nickel, and are resistant to fluoro species.

[0058] For quantitatively determining the signal strength and responsiveness of gas-sensing assemblies that contain the nickel-containing filaments as described hereinabove, effluent gas containing fluoro species from a semiconductor cleaning chamber is first contacted with such gas-sensing assemblies that contain nickel-containing filaments, to generate a set of sensor signal outputs. Such effluent gas is then passed through a residual gas analyzer (RGA) unit, to generate a set of control outputs. The graphical outputs produced by the gas-sensing assemblies of the invention and the control outputs produced by the RGA unit can be superposed as a function of time, to visualize the relative signal strength and responsiveness of such gas-sensing assemblies of the invention.

[0059] Figure 3 shows in the upper portion thereof, the signal outputs generated over time by a gas-sensing assembly comprising a nickel-coated SiC fluoro-sensitive filament, and the control outputs produced over time by a RGA unit are shown in the lower portion of Figure 3.

[0060] Figure 4, on the other hand, shows the signal outputs over time from a gas-sensing assembly that employs a nickel filament, in comparison with the control outputs produced over time by a RGA unit. Both gas-sensing assemblies demonstrate high sensitivity and high responsiveness, although the gas-sensing assembly containing the nickel-coated SiC filament shows better sensitivity and shorter response time than the one employing nickel filament.

[0061] To further enhance the performance of the nickel-containing filament sensors of the present invention, a high A_s/A_c ratio is desired, according to equation (19) provided hereinabove.

[0062] High A_s/A_c ratio can be effectively achieved by configuring the nickel-containing filaments at average outer diameters of less than 500 microns, more preferably less than 150 microns or less than 50 microns, and most preferably in a range of from about 0.1 micron to

about 30 microns, and average lengths of more than 1 cm, more preferably more than 5 cm, and most preferably more than 10 cm, as a balance between performance and ease of fabrication.

[0063] However, filaments having a diameter of about or less than 50 microns are extremely fragile and difficult to handle, rendering the fabrication of a gas-sensing assembly with such small filaments nearly impossible.

[0064] The present invention provides a solution to such problem, by first fabricating a gas-sensing assembly using a nickel-containing gas-sensing filament that has an average diameter larger than 50 microns, and then electrochemically thinning such gas-sensing filament to reduce its average diameter to increase the A_s/A_c ratio. In this event, the thinning process is carried out on a gas-sensing filament that has already been incorporated into the gas-sensing assembly, and no further handling of the gas-sensing filament is necessary after thinning, therefore significantly reducing the risk of damaging the ultra-thin filament.

[0065] Figure 5 shows a partially thinned nickel filament **22**, which has an original average diameter of about 100-110 microns. After electrochemical thinning at a portion of such filament **22**, the average diameter is effectively reduced to about 35-45 microns.

[0066] High A_s/A_c ratio can also be achieved by forming a nickel-containing filament having a porous surface, which functions to increase the surface area A_s of the filament sensor without comprising the cross-sectional area A_c thereof.

[0067] Figure 6 illustratively shows a nickel-containing filament **25** that comprises a relatively dense core **26** and a porous surface **28**. The porous surface of the nickel-containing filament may be provided by a two-stage plating process, wherein at an initial seeding stage, the plating of nickel or nickel alloy on a substrate (such as a core structure) is carried out at a relatively low speed, so as to allow improved bonding between the layer of nickel or nickel alloy plated and the underlying substrate, and wherein at the subsequent growth stage, the plating is conducted at a significantly faster rate, so as to form rough plating surface with microporosity or nanoporosity. Figure 7 shows a SEM micrograph of a nickel coating **34** of nanoporosity formed on a non-porous, dense substrate **32**.

[0068] Alternatively, porous nickel coating can be formed by using liquid crystal templates from proper surfactants. This technique is particularly suitable for forming open pore structures, which maximizes the fluoro-accessible surface area of the porous nickel coating and therefore further improves the sensitivity of the filament sensor. Figure 8 shows a SEM micrograph of a porous nickel coating **44** characterized by open pore structures and having a thickness of about 4.93 microns, formed on a dense silicon carbide substrate **42**. The porous nickel coating may be characterized by, for example, a total porosity of 60%, as determined by X-ray fluorescence analysis.

[0069] The performance of the nickel-containing gas-sensing filaments of the present invention can be further enhanced, by using various nickel-copper alloys, such as Monel, which are characterized by electrical resistance that are even higher than the pure nickel.

[0070] Preferably, such nickel-copper alloy contains from about 10% to 90% nickel from about 10% to about 90% copper by weight. Such nickel-copper alloy may further comprise other fluorine-resistant metals such as Al, Ti, V, Cr, Mn, Nb, Mo, Ru, Pd, Ag, Ir, and Pt.

[0071] The above-described various embodiments of the invention can be either independently implemented, or jointly employed, to provide a group of gas-sensing filaments with diverse material and structural characteristics that suit the requirements of various systems and applications. It will be recognized that the choice of a specific material and configuration for the fluoro species sensing element of the invention may vary according to the character of the stream being monitored for the presence of fluoro species, and particularly according to the concentration of the target gas species being monitored or otherwise present in the monitored gas.

[0072] The gas-sensing filaments of the invention can be readily mounted in any manner to form a gas-sensing assembly, which may also comprise means for detecting changes in such gas-sensing filament upon contact thereof with a target gas species, and means for responsively generating an output signal indicative of such changes. Specifically, a gas-sensing filament may be mounted in various free-standing manners to a fluoro-resistant support structure, as disclosed by U.S. Patent Application No. 10/273,036 filed October 17, 2002 for

"APPARATUS AND PROCESS FOR SENSING FLUORO SPECIES IN SEMICONDUCTOR PROCESSING SYSTEMS," the contents of which are incorporated herein by reference in their entirety. The free-standing gas-sensing filaments can be integrated as part of a device package in any suitable manner, and additional protection or insulation layers may be applied to such device package, for enhancing the resistance of the overall device package to corrosions by the fluorine-containing target compounds.

[0073] The ability to integrate the free-standing gas-sensing filaments into a standard microelectronic device package such as a chip carrier package, enables the gas sensor apparatus of the invention to be variously configured as a single-element device structure, or alternatively as a multi-element array, e.g., using varied metal structures, different geometries, or redundant structures operating at different temperatures, to enhance the gas detection capability of the overall sensing device.

[0074] In a preferred embodiment, the gas-sensing filament of the present invention is supported on a fluoro-resistant flange material, e.g., a KF flange formed of Vespel® polyimide, aluminum, or nickel. Vespel® polyimide is a preferred polyimide material of construction in various embodiments of the invention, but it will be recognized that other polyimide or polymeric (e.g., polysulfone) materials of construction may alternatively be used.

[0075] FIGS. 9A and 9B depict a gas sensor array **70** including a Vespel® polyimide flange **74** supporting a Vespel® polyimide block **76**, and two sets of nickel-coated press-fit electrical pins **78** thereon, for suspending two nickel-coated SiC gas-sensing filaments **72**, which may or may not be the same in structure.

[0076] The free-standing architecture of the nickel-coated SiC filaments allow them to be used both as the fluoro-sensing elements and the heat sources (e.g., susceptible to electrical resistance heating or other mode of heating), as well as maximizing the sensing area, as a result of the high surface-to-volume character of such filaments. The integrated design of the gas-sensing filaments and associated packaging obviates the problem of chemical attack by aggressive fluorinated gas species in the sensing environment, thereby achieving a fundamental advance in the art over standard silicon MEMS structures.

[0077] The present invention thus in one aspect provides a group of novel solid-state filament gas sensors that can be coupled in sensing relationship to a process chamber, e.g., a semiconductor process chamber, and can achieve various degrees of sensitivity and responsiveness, by appropriate selection of materials and structures for such filament sensors.

[0078] The present invention in another aspect provides a new filament-based gas sensor element, which is elongated in shape and has two electrical connection terminals and a longitudinal axis. The two electrical connection terminals of such gas sensor element define a line, to which the longitudinal axis of the gas sensor element is substantially perpendicular.

[0079] For a filament-based gas sensor of given composition, the aspect ratio between its longitudinal dimension (L) and its lateral dimension (D) has significant influences on its signal strength and response time. Generally speaking, the larger the L/D ratio, the higher the signal strength and the shorter the response time.

[0080] Since the longitudinal axis of the new gas sensor element of the present invention is substantially perpendicular to the lateral line defined by the two electrical connection terminals, the longitudinal dimension of such gas sensor element (i.e., the dimension along its longitudinal axis) is not limited by the lateral distance between its electrical connection terminals, and it therefore can be increased to maximize the L/D ratio, which in turn improves signal strength and reduces response time.

[0081] For illustration purposes, Figure 10 shows an elongated gas sensor element **110**, according to a preferred embodiment of the present invention. The elongated gas sensor element **110** has a wishbone-shape and is formed by attaching two gas-sensing filaments **111** and **112** together at their upper ends, while leaving the lower ends of such filaments separated from each other. The separated lower ends of the filaments **111** and **112** therefore form two electrical connection terminals **110A** and **110B**, by which an electrical current can be passed through the elongated gas sensor element **110** for gas-sensing at elevated temperatures. The longitudinal axis **110C** of the gas sensor element **110** (as shown by the vertical dotted line) is oriented perpendicular to the line (as shown by the horizontal dotted line) defined by the two electrical connection terminals **110A** and **110B**.

[0082] In such manner, the elongated gas sensor element **110** has a longitudinal dimension that is not limited by the distance between the two electrical connection terminals. As a result, the longitudinal dimension of such elongated gas sensor element **110** can be increased significantly for improving signal strength and reducing response time required for gas-sensing, without having to increase the lateral dimension thereof (i.e., either the dimension along the line defined by the two electrical connection terminals or the distance between the two electrical connection terminals).

[0083] Figure 11 shows another elongated gas sensor element **120**, according to an alternative embodiment of the present invention. The elongated gas sensor element **120** has a keyhole-shape and is formed by bending and shaping a single gas-sensing filament. The two ends of such bent/shaped gas-sensing filament form the two electrical connection terminals **120A** and **120B** of the gas sensor element **120**, and an electrical current therefore can be passed through the elongated gas sensor element **120** via such electrical connection terminals **120A** and **120B** for gas-sensing at elevated temperatures. The longitudinal axis **120C** of the gas sensor element **120** (as shown by the vertical dotted line) is oriented perpendicular to the line (as shown by the horizontal dotted line) defined by the two electrical connection terminals **120A** and **120B**.

[0084] Figure 12 shows another elongated gas sensor element **130**, which has an open hairpin-shape and is formed by bending a single gas-sensing filament. The two ends of the bent gas-sensing filament form the two electrical connection terminals **130A** and **130B** of the gas sensor element **130**, and an electrical current therefore can be passed through the elongated gas sensor element **130** via such electrical connection terminals **130A** and **130B** for gas-sensing at elevated temperatures. The longitudinal axis **130C** of the gas sensor element **130** (as shown by the vertical dotted line) is oriented perpendicular to the line (as shown by the horizontal dotted line) defined by the two electrical connection terminals **130A** and **130B**.

[0085] Figure 13 shows another elongated gas sensor element **140**, which has an M-shape and is formed by attaching four gas-sensing filaments **141**, **142**, **143**, and **144** in a zigzagged manner at respective ends. One end of filament **141** and one end of filament **144** form the two electrical connection terminals **140A** and **140B** for the gas sensor element **140**, and an electrical current therefore can be passed through the elongated gas sensor element **140** via such electrical connection terminals **140A** and **140B** for gas-sensing at elevated temperatures.

The longitudinal axis **140C** of the gas sensor element **140** (as shown by the vertical dotted line) is oriented perpendicular to the line (as shown by the horizontal dotted line) defined by the two electrical connection terminals **140A** and **140B**.

[0086] Note that many other shapes and configurations of the elongated gas sensor element are available and can be employed for practice of the present invention, but for illustration purposes, only a few exemplary embodiments are shown in Figures 10-13 herein. A person ordinarily skilled in the art can readily modify the shapes and configurations of the elongated gas sensor elements as shown in Figures 10-13, consistent with the disclosure provided herein and without undue experimentation, and any such modifications are within the broad scope of the present invention.

[0087] To achieve high gas sensitivity and minimum response delay, the L/D ratio of the elongated gas sensor element of the present invention is preferably larger than 3, and more preferably larger than 10, and most preferably larger than 50.

[0088] The elongated gas sensor element as described hereinabove can be mounted on a support structure, to form a gas-sensing assembly that can be placed at a fluid locus for detecting the presence of a target gas species. Such gas-sensing assembly may also comprise means for detecting changes in such gas sensor element upon contact thereof with the target gas species, and means for responsively generating an output signal indicative of such changes.

[0089] In a preferred embodiment, the support structure comprises a fluoro-resistant flange material, e.g., a KF flange formed of Vespel® polyimide or aluminum. Vespel® polyimide is a preferred polyimide material of construction in various embodiments of the invention, but it will be recognized that other polyimide or polymeric (e.g., polysulfone) materials of construction may alternatively be used.

[0090] Such support structure provides physical support as well as electrical connection to the gas sensor element via the two electrical connection terminals, and the supporting or mounting surface of the support structure therefore must be able to accommodate at least the two electrical connection terminals of the gas sensor element. In order to minimize the surface area or footprint of the support structure, the gas sensor element of the present invention is

arranged and configured so that its longitudinal axis is substantially perpendicular to the supporting or mounting surface of the support structure. In such manner, the footprint of the support structure is reduced without affecting or comprising the L/D ratio of the gas sensor element.

[0091] Figure 14 shows a gas-sensing assembly **150** comprising a support structure **152** with a planar supporting or mounting surface **154**. The mounting surface **154** comprises two press-fit pints **153** for mounting the two electrical connection terminals **151A** and **151B** of the wishbone-shaped gas sensor element **151**. In such manner, the gas sensor element **151** is mounted to the support structure **152** in a "vertical" manner, i.e., having its longitudinal axis **151C** oriented perpendicular to or substantially perpendicular to the mounting surface **154** of the support structure **152**.

[0092] Because the longitudinal axis of the gas sensor element is substantially perpendicular to the mounting surface of the support structure, the longitudinal dimension of the gas sensor element can be increased significantly for improving signal strength and reducing response time, but without having to increase the area of the mounting surface. Therefore, the gas-sensing assembly of the present invention advantageously provides enhanced gas-sensing capacity with reduced footprint.

[0093] Further, vertical mounting of the gas sensor element provides flexibility to accommodate thermal expansion and contraction of such gas sensor element along its longitudinal axis.

[0094] Therefore, the present invention achieves significant advancement in the gas-sensing field, by providing an elongated gas sensor element as described hereinabove, which can be vertically mounted on a support structure.

[0095] For detection of fluoro gas species, the present invention preferably employs fluoro-reactive metal filaments, such as the nickel-containing filaments as described hereinabove, to form such elongated gas sensor element. By monitoring changes in the properties of the metal filaments as caused by their reaction with fluoro species, one can determine the presence

and/or concentration of one or more target fluoro species in a particular gaseous environment, such as an effluent gas stream discharged by a semiconductor chamber clean process.

[0096] Specifically, a pair of nickel-coated SiC carbon fibers can be aligned side by side and then attached at one ends thereof, while leaving the opposite ends of such nickel-coated SiC carbon fibers unattached and separated from each other, to form a wishbone-shaped gas sensor element as described hereinabove with two electrical connection terminals.

[0097] Alternatively, such wishbone-shaped gas sensor element may be formed by aligning a pair of uncoated SiC carbon fibers and attaching them at one ends thereof, so as to form a wishbone-shaped precursor structure, which can be subsequently coated with a layer of gas-sensitive material, such as nickel or nickel alloy.

[0098] For quantitatively determining the signal strength and responsiveness of the gas sensor element of the present invention, effluent gas containing fluoro species from a semiconductor cleaning chamber was concurrently contact with a first gas-sensing assembly comprising a vertically mounted wishbone-shaped gas sensor element (WISHBONE) and a second gas-sensing assembly comprising a horizontally mounted straight nickel-coated SiC carbon fiber, both of which generated a set of sensor signal outputs. The signal outputs produced by the vertically mounted wishbone-shaped gas sensor element of the invention and by the horizontally mounted straight nickel-coated SiC carbon fiber were then superposed as a function of time, to visualize the relative signal strength and responsiveness thereof.

[0099] Figure 15 shows in the solid line the signal outputs generated over time by the gas-sensing assembly comprising the vertically mounted wishbone-shaped gas sensor element, which was formed by two nickel-coated SiC carbon fibers. The signal outputs generated over time by the gas-sensing assembly comprising the horizontally mounted straight nickel-coated SiC carbon fiber is shown thereby in dotted lines. It is clear that the wishbone-shaped gas sensor element provides faster responses and stronger signals in comparison with those provided by the straight nickel-coated SiC carbon fiber sensor.

[0100] The fluoro sensor assembly of the invention may include a single gas-sensing filament or a single elongated gas-sensing element in any of the numerous suitable forms described

hereinabove, or a plurality of such gas-sensing filaments and/or gas-sensing elements, wherein the multiple filaments and/or sensor elements provide redundancy or back-up sensing capability, or in which different ones of the multiple filaments and/or sensor elements are arranged for sensing of different target gas species in the stream or gas volume being monitored.

[0101] Further, the filaments and/or sensor elements in the array can be operated in different modes or in interrelated modes, which include, but are not limited to, constant current (CC) modes and constant resistance (CR) modes, for production of respective signals that are algorithmically manipulated, e.g., subtractively, to generate a net indicating signal, or alternatively, additively to produce a composite indicating signal, or in any other suitable manner in which the multiplicity of filaments and/or sensor elements is efficaciously employed to monitor the flow of target gas species in the stream or fluid volume of interest, for generation of correlative signal(s) for monitoring or control purposes.

[0102] In instances where multiple gas-sensing filaments and/or sensor elements are provided, different ones of the multiple gas-sensing filaments and/or sensor elements may be constructed and arranged for sensing of different gas species in the fluid environment being monitored, and/or same gas species at different temperatures, and different geometries and configurations of the filaments and/or sensor elements may be employed for redundancy and/or ensuring accuracy, etc.

[0103] In connection with the use of arrays of gas-sensing filaments and/or gas-sensing elements, advanced data processing techniques can be used to enhance the output of the sensor system. Examples of such techniques include, but are not limited to, the use of compensating signals, the use of time-varying signals, heater currents, lock-in amplifying techniques, signal averaging, signal time derivatives, and impedance spectroscopy techniques. In addition, advanced techniques that fall into the category of chemometrics may also be applied. These techniques include least squares fitting, inverse least squares, principal component regression, and partial least square data analysis methods.

[0104] The gas-sensing filament(s) and/or gas-sensing element(s) of the invention may therefore be coupled in a suitable manner, within the skill of the art, to transducers,

computational modules, or other signal processing units, to provide an output indicative of the present or change in amount of one or more target gas species in the fluid environment being monitored.

[0105] It will be recognized that micro-hotplate structures of a type adaptable to the practice of the present invention may be employed in the gas sensor assemblies of the present invention, as more fully described in U.S. Patent No. 6,265,222 issued July 24, 2001 in the names of Frank DiMeo, Jr. and Gautam Bahndari, the disclosure of which hereby is incorporated herein by reference in its entirety.

[0106] Although the invention has been variously described herein with reference to illustrative embodiments and features, it will be appreciated that the embodiments and features described hereinabove are not intended to limit the invention, and that other variations, modifications and other embodiments will readily suggest themselves to those of ordinary skill in the art, based on the disclosure herein. The invention therefore is to be broadly construed, consistent with the claims hereafter set forth.

THE CLAIMS

What is claimed is:

1. A gas sensor assembly comprising a gas-sensing filament comprising nickel or nickel alloy, and means for detecting a change in at least one property of said gas-sensing filament upon contact with a target gas species and responsively generating an output signal indicative of presence of said target gas species.

2. The gas sensor assembly of claim 1, wherein the target gas species comprises a fluoro species selected from the group consisting of NF_3, SiF_4, C_2F_6, HF, F_2, COF_2, ClF_3, IF_3, and activated species thereof.

3. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by an average diameter of less than about 500 microns.

4. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by an average diameter of less than about 150 microns.

5. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by an average diameter of less than about 50 microns.

6. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by an average diameter in a range of from about 0.1 micron to about 30 microns.

7. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by a length of more than about 1 cm.

8. The gas sensor assembly of claim 1, wherein said gas-sensing filament is characterized by a length of more than about 5 cm.

9. The gas sensor assembly of claim 1, wherein said gas-sensing filament comprises a coating structure encapsulating a core structure, wherein said coating structure comprises nickel or

nickel alloy, and wherein said core structure has an electrical resistivity that is higher than that of the coating structure and a heat capacity that is lower than that of the coating structure.

10. The gas sensor assembly of claim 9, wherein the electrical resistivity of the core structure is at least about fifty times higher than that of the coating structure, and wherein the heat capacity of said core structure is less than three fourth of that of the coating structure.

11. The gas sensor assembly of claim 9, wherein the electrical resistivity of the core structure is at least about a thousand times higher than that of the coating structure, and wherein the heat capacity of said core structure is less than one half of that of the coating structure.

12. The gas sensor assembly of claim 9, wherein the electrical resistivity of the core structure is at least about 10 $m\Omega \cdot cm$, and wherein the heat capacity of said core structure is less than 2.5 $J/K \cdot cm^3$.

13. The gas sensor assembly of claim 9, wherein said core structure comprises a nickel-copper alloy, and wherein said coating structure consists essentially of nickel.

14. The gas sensor assembly of claim 9, wherein said core structure comprises silicon carbide.

15. The gas sensor assembly of claim 9, wherein said core structure comprises a composite fiber having multiple layers of different materials.

16. The gas sensor assembly of claim 9, wherein said core structure comprises a composite fiber having a carbon core fiber coated with a silicon carbide layer.

17. The gas sensor assembly of claim 1, wherein the gas-sensing filament is electrochemically thinned after fabrication of said gas sensor assembly and is characterized by an average diameter of not more than 50 microns.

18. The gas sensor assembly of claim 17, wherein the gas-sensing filament is characterized by an average diameter of not more than 25 microns.

19. The gas sensor assembly of claim 17, wherein the gas-sensing filament is characterized by an average diameter of not more than 10 microns.

20. The gas sensor assembly of claim 17, wherein the gas-sensing filament is characterized by an average diameter in a range of from about 0.1 micron to about 5 microns.

21. The gas sensor assembly of claim 1, wherein the gas-sensing filament comprises a nickel-copper alloy containing from about 10% to about 90% nickel and from about 10% to about 90% copper by total weight of said alloy.

22. The gas sensor assembly of claim 21, wherein said nickel-copper alloy further comprises from about 10% to about 90% aluminum by total weight of said alloy.

23. The gas sensor assembly of claim 22, wherein said nickel-copper alloy further comprises one or more metals selected from the group consisting of Ti, V, Cr, Mn, Nb, Mo, Ru, Pd, Ag, Ir, and Pt.

24. The gas sensor assembly of claim 1, wherein said gas-sensing filament comprises a porous coating of nickel or nickel alloy.

25. The gas sensor assembly of claim 24, wherein said porous coating is characterized by open pore structures.

26. The gas sensor assembly of claim 1, further comprising a support structure for suspending said gas-sensing filament.

27. The gas sensor assembly of claim 26, wherein said support structure comprises a material that is resistant to said target gas species.

28. The gas sensor assembly of claim 26, wherein the target gas species comprises a fluoro species selected from the group consisting of NF_3, SiF_4, C_2F_6, HF, F_2, COF_2, ClF_3, IF_3, and activated species thereof, and wherein the support structure comprises a material selected from the group consisting of polyimide, aluminum, or nickel.

29. A method for monitoring a fluid locus for the presence of a target gas species therein, said method comprising:

exposing fluid at said fluid locus to a gas-sensing assembly as in claim 1;

monitoring at least one property of the gas-sensing filament of such gas-sensing assembly; and

responsively generating an output signal when the gas-sensing filament exhibits a change in the at least one property thereof, indicating the presence of the target gas species in the fluid locus, or a change in concentration of the target gas species in the fluid locus.

30. The method of claim 29, wherein said at least one property of the gas-sensing filament being monitored is the electrical resistance thereof.

31. A gas sensor assembly comprising a gas-sensing filament comprising a coating structure encapsulating a core structure, wherein said coating structure comprises a gas-sensitive material that exhibit a detectable change upon contact with a target gas species, and wherein said core structure is characterized by an electrical resistivity that is higher than that of the coating structure and a heat capacity that is lower than that of the coating structure.

32. A gas sensor assembly comprising a gas-sensing filament comprising a coating structure and a core structure, wherein said coating structure comprises nickel or nickel alloy, and wherein said core structure comprises silicon carbide.

33. A gas sensor assembly comprising a gas-sensing filament comprising a coating structure and a core structure, wherein said coating structure comprises nickel or nickel alloy, and wherein said core structure comprises a carbon center and a sheath of silicon carbide.

34. A gas sensor assembly comprising an electrochemically-thinned gas-sensing filament comprising nickel or nickel filament, wherein said filament is characterized by an average diameter of not more than 50 microns.

35. A method for forming the gas sensor assembly of claim 34, comprising the steps of:

(a) providing a gas sensor assembly precursor comprising a gas-sensing filament comprising nickel or nickel filament, wherein said filament has an average diameter of more than 50 microns;

(b) electrochemically thinning said gas-sensing filament for a sufficient period of time, so as to reduce the average diameter thereof to not more than 50 microns.

36. A method for forming a gas sensor assembly, comprising the steps of:

(a) providing a gas sensor assembly precursor comprising a gas-sensing filament comprising nickel or nickel filament;

(b) electrochemically thinning said gas-sensing filament for a sufficient period of time, so as to reduce the average diameter thereof.

37. A gas sensor assembly comprising a gas-sensing filament comprising a nickel-copper alloy.

38. A gas sensor assembly comprising a gas-sensing filament comprising a nickel-copper-aluminum alloy.

39. The gas sensor assembly of claim 38, wherein said nickel-copper-aluminum alloy comprises from about 10% to about 90% of nickel, from about 10% to about 90% of copper, and from about 10% to about 90% of aluminum, by total weight of said alloy.

40. A gas sensor assembly comprising a nickel-containing gas-sensing filament having a porous surface.

41. The gas sensor assembly of claim 40, wherein said porous surface is characterized by open pore structures.

42. A gas sensor assembly comprising a support structure for suspending a free-standing nickel-containing gas-sensing filament.

43. The gas sensor assembly of claim 42, wherein said support structure comprises a material that is resistant to fluoro species.

44. The gas sensor assembly of claim 42, wherein said support structure comprises a material selected from the group consisting of polyimide, aluminum, and nickel.

45. A gas sensor assembly arranged in sensing relationship to a process chamber that is susceptible to presence of one or more target fluoro species, wherein said gas sensor assembly comprises a gas-sensing filament containing nickel or nickel-alloy, as mounted on a fluoro-resistant support structure and coupled to means for detecting a change in at least one property of said gas-sensing filament upon contact with the target fluoro species and responsively generating an output signal indicative of the presence of said target fluoro species.

46. An elongated gas sensor element formed by one or more gas-sensing filaments, said elongated gas sensor element comprising two electrical connection terminals and having a longitudinal axis, wherein the longitudinal axis of the sensor element is substantially perpendicular to a line defined by the two electrical connection terminals thereof.

47. The elongated gas sensor element of claim 46, wherein said one or more gas-sensing filaments are characterized by an average diameter of less than about 500 microns.

48. The elongated gas sensor element of claim 46, wherein said one or more gas-sensing filaments are characterized by an average diameter of less than about 150 microns.

49. The elongated gas sensor element of claim 46, wherein said one or more gas-sensing filaments are characterized by an average diameter of less than about 50 microns.

50. The elongated gas sensor element of claim 46, wherein said one or more gas-sensing filaments are characterized by an average diameter in a range of from about 0.1 micron to about 30 microns.

51. The elongated gas sensor element of claim 46, characterized by a length of more than about 1 cm along its longitudinal axis.

52. The elongated gas sensor element of claim 46, characterized by a length of more than about 10 cm along its longitudinal axis.

53. The elongated gas sensor element of claim 46, characterized by a length of more than 20 cm along its longitudinal axis.

54. The elongated gas sensor element of claim 46, characterized by a wishbone shape.

55. The elongated gas sensor element of claim 46, comprising a nickel-containing coating that encapsulates a core structure, wherein said core structure has an electrical resistivity that is higher than that of the nickel-containing coating and a heat capacity that is lower than that of the nickel-containing coating.

56. The elongated gas sensor element of claim 55, wherein the electrical resistivity of the core structure is at least about fifty times higher than that of the nickel-containing coating, and wherein the heat capacity of said core structure is less than three-fourths of that of the nickel-containing coating.

57. The elongated gas sensor element of claim 55, wherein the electrical resistivity of the core structure is at least about a thousand times higher than that of the nickel-containing coating, and wherein the heat capacity of said core structure is less than one-half of that of the nickel-containing coating.

58. The elongated gas sensor element of claim 55, wherein the electrical resistivity of the core structure is at least about 10 $m\Omega \cdot cm$, and wherein the heat capacity of said core structure is less than 2.5 $J/K \cdot cm^3$.

59. The elongated gas sensor element of claim 55, wherein said core structure comprises a nickel-copper alloy, and wherein said nickel-containing coating consists essentially of nickel.

60. The elongated gas sensor element of claim 55, wherein said core structure comprises silicon carbide.

61. The elongated gas sensor element of claim 55, wherein said core structure comprises a composite fiber having multiple layers of different materials.

62. The elongated gas sensor element of claim 55, wherein said core structure comprises a composite fiber having a carbon core fiber coated with a silicon carbide layer.

63. The elongated gas sensor element of claim 46, comprising a nickel-copper alloy.

64. The elongated gas sensor element of claim 46, comprising a nickel-copper-aluminum alloy.

65. The elongated gas sensor element of claim 64, further comprising one or more metals selected from the group consisting of Ti, V, Cr, Mn, Nb, Mo, Ru, Pd, Ag, Ir, and Pt.

66. The elongated gas sensor element of claim 46, comprising a porous coating of nickel or nickel alloy.

67. The elongated gas sensor element of claim 66, wherein said porous coating is characterized by open pore structures.

68. A gas-sensing assembly comprising the elongated gas sensor element of claim 46 mounted on a support structure, wherein said support structure comprises a surface for mounting the two electrical connection terminals of the elongated gas sensor element.

69. The gas-sensing assembly of claim 68, further comprising means for detecting a change in at least one property of said elongated gas sensor element upon contact with a target gas species and responsively generating an output signal indicative of presence of said target gas species.

70. The gas-sensing assembly of claim 69, wherein the target gas species comprises a fluoro species selected from the group consisting of NF_3, SiF_4, C_2F_6, HF, F_2, COF_2, ClF_3, IF_3, and activated species thereof.

71. The gas-sensing assembly of claim 70, wherein the support structure comprises a material that is resistant to said target gas species.

72. The gas-sensing assembly of claim 70, wherein the support structure comprises polyimide or aluminum.

73. The gas-sensing assembly of claim 70, wherein said one or more gas-sensing filaments of the elongated gas sensor element contain nickel or nickel alloy.

74. The gas-sensing assembly of claim 73, wherein said one or more gas-sensing filaments of the elongated gas sensor element are electrochemically thinned after fabrication of said assembly to achieve an average diameter of not more than 50 microns.

75. The gas-sensing assembly of claim 73, wherein said one or more gas-sensing filaments of the elongated gas sensor element are characterized by an average diameter of not more than 25 microns.

76. The gas-sensing assembly of claim 73, wherein said one or more gas-sensing filaments of the elongated gas sensor element are characterized by an average diameter of not more than 10 microns.

77. The gas-sensing assembly of claim 73, wherein said one or more gas-sensing filaments of the elongated gas sensor element are characterized by an average diameter in a range of from about 0.1 micron to about 5 microns.

78. A method for monitoring a fluid locus for the presence of a target gas species therein, said method comprising:

exposing fluid at said fluid locus to a gas-sensing assembly as in claim 68;

monitoring at least one property of the elongated gas sensor element of such gas-sensing assembly; and

responsively generating an output signal when the elongated gas sensor element exhibits a change in the at least one property thereof, indicating the presence of the target gas

species in the fluid locus, or a change in concentration of the target gas species in the fluid locus.

79. The method of claim 78, wherein said at least one property of the elongated gas sensor element being monitored is the electrical resistance thereof.

80. A method for fabricating the elongated gas sensor element of claim 54, comprising the steps of:

(a) aligning a pair of gas-sensing filaments side by side; and

(b) connecting said pair of gas-sensing filaments at first ends thereof, while leaving the opposite, second ends of said pair of gas-sensing filaments separated from each other, wherein the separated opposite, second ends of said pair of gas-sensing filaments form the two electrical connection terminals of the elongated gas sensor element.

81. The method of claim 80, wherein each of said gas-sensing filaments is formed by coating a filament with a gas-sensitive material.

82. A method for fabricating the elongated gas sensor element of claim 54, comprising the steps of:

(a) aligning a pair of filaments side by side;

(b) connecting said pair of filaments at first ends thereof, while leaving the opposite, second end of said pair of filaments separated from each other, so as to form a wishbone-shaped precursor structure; and

(c) forming a gas-sensitive coating over said wishbone-shaped precursor structure.

83. A gas-sensing assembly arranged in sensing relationship to a process chamber that is susceptible to presence of one or more target fluoro gas species, wherein said gas-sensing assembly comprises a nickel-containing gas sensor element mounted on a surface of a support structure and coupled to means for detecting a change in at least one property of said gas sensor element upon contact with the target fluoro gas species and responsively generating an output signal indicative of the presence of said target fluoro gas species, wherein said nickel-containing gas sensor element has a longitudinal axis that is oriented perpendicular to or substantially perpendicular to the mounting surface of the support structure.