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(54) **ION-MOBILITY SPECTROMETRY SENSOR FOR NOX DETECTION**

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(57) **ABSTRACT**

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A sensor and detection methods are provided for detecting nitric oxides (NO_x) in an exhaust gas based upon ion mobility spectrometry (IMS) technique. An ionization chamber having an interior electrically conductive shell receives exhaust gas. A spark electrode having a needle tip extends into the ionization chamber. A shutter grid is coupled between the ionization chamber and an ion drift tube. A substantially continuous spark discharge is established between the electrically conductive shell and the needle tip of the spark electrode for ionization of the exhaust gas. Negative NO₂ ions are kept inside the chamber by biasing the electrically conductive shell and the shutter grid at a negative voltage. Then a positive pulse is applied to the shutter grid to cause the shutter to open for negative NO₂ ions to exit into the ion drift tube. The IMS sensor is small-sized, low-cost, robust, and reliable.

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 33 days.

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(51) Int. Cl.⁷ **H01J 49/26; G01N 23/00**

(52) U.S. Cl. **250/288; 250/286; 313/231.41; 315/111.21; 422/83; 436/116**

(58) Field of Search **250/288, 286; 313/231.41; 315/111.21; 422/83; 436/116**

(56) **References Cited**

U.S. PATENT DOCUMENTS

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* cited by examiner

20 Claims, 3 Drawing Sheets

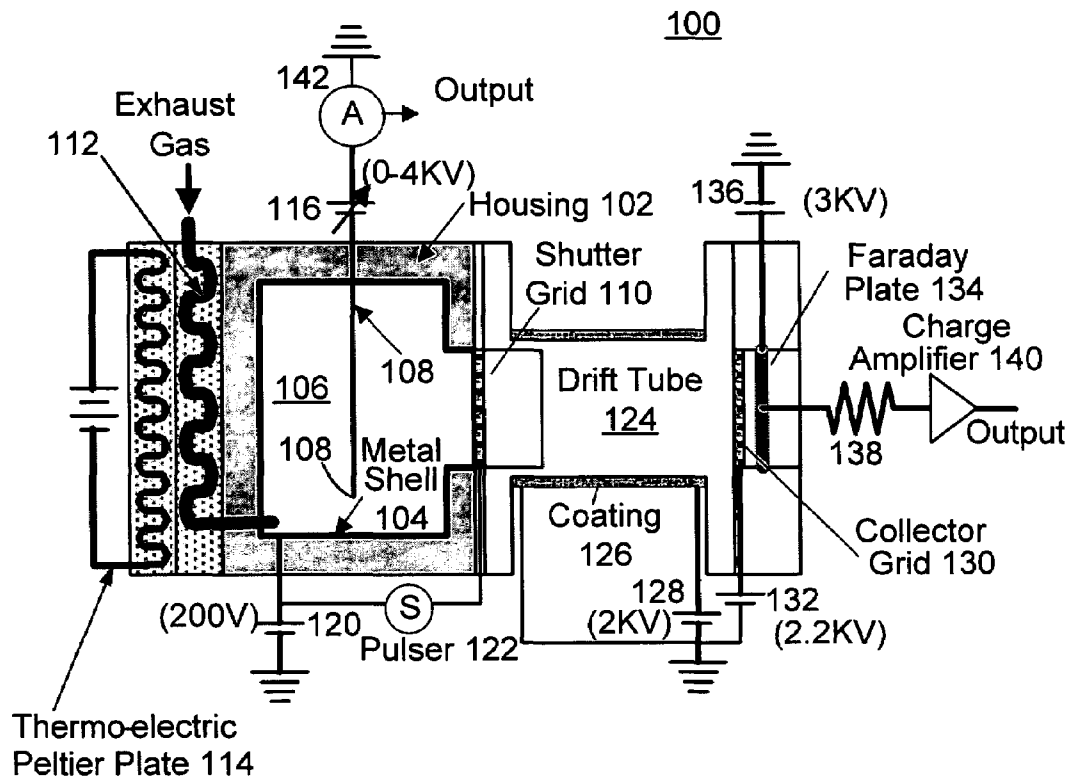


FIG. 1

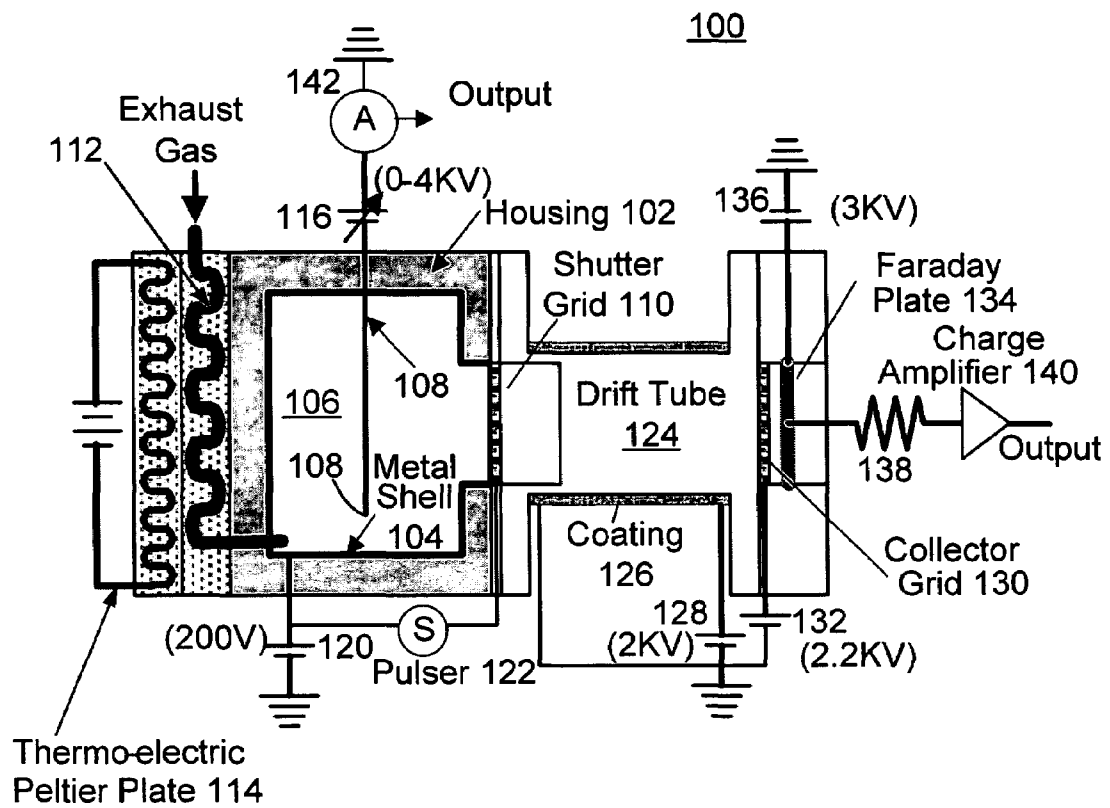


FIG. 2

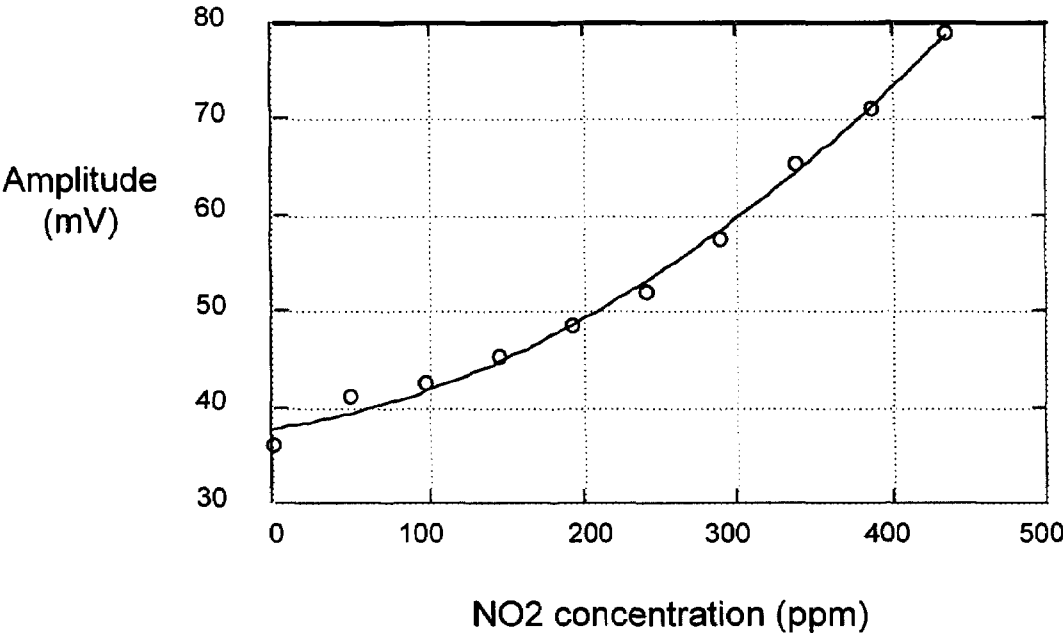
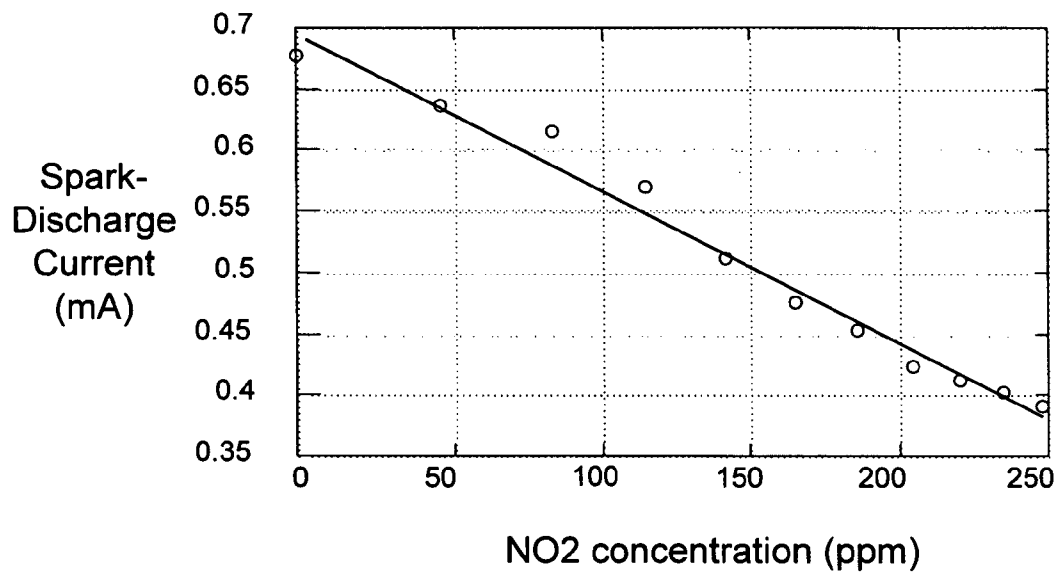


FIG. 3



ION-MOBILITY SPECTROMETRY SENSOR FOR NOX DETECTION

The United States Government has rights in this invention pursuant to Contract No. W-31-109-ENG-38 between the United States Government and Argonne National Laboratory.

FIELD OF THE INVENTION

The present invention relates to a sensor and detection methods for detecting nitric oxides (NOx), and more particularly to a Nox detection sensor based upon ion mobility spectrometry (IMS) technique.

DESCRIPTION OF THE RELATED ART

A typical IMS instrument consists of an ionization source, an ion drift tube and an ion detector. The instrument produces an ion spectrum from which ion drift time and peak amplitude are measured and related to ion characteristics. Commercial IMS instruments use a radioactive ionization source, typically ^{63}Ni , and require a vacuum in the drift tube, making the instrument impractical and expensive. Thus the current IMS instrument cannot be used as an automobile exhaust emission sensor.

Today, the need of NOx emission sensor is pronounced and urgent. Low-cost semiconductor NOx sensors generally suffer from (1) difficulty to function in a harsh environment, including for example, high temperature, pressure, and humidity, (2) problems of long-term stability, and (3) slow response and recovery times.

A principal object of the present invention is to provide an improved sensor and detection methods for detecting nitric oxides (NOx).

Other objects of the present invention are to provide such improved sensor and detection methods for detecting nitric oxides (NOx) substantially without negative effect and that overcome some disadvantages of prior art arrangements.

SUMMARY OF THE INVENTION

In brief, a sensor and detection methods are provided for detecting nitric oxides (NOx) in an exhaust gas based upon ion mobility spectrometry (IMS) technique. The IMS sensor includes an ionization chamber receiving the exhaust gas. The ionization chamber includes an interior electrically conductive shell. A spark electrode having a needle tip extends into the ionization chamber. A shutter grid is coupled between the ionization chamber and an ion drift tube. A substantially continuous spark discharge is established between the electrically conductive shell of the ionization chamber and the needle tip of the spark electrode.

In accordance with features of the invention, during a negative mode of operation, negative NO_2 ions produced in the discharge region are kept inside the chamber by biasing the electrically conductive shell of the ionization chamber and the shutter grid at a negative voltage. Then a positive pulse is applied to the shutter grid to cause the shutter to open for negative ions to exit into the ion drift tube. The pulse frequency is selected so that equilibrium between ion production and extraction is established. To detect positive NO ions, a positive mode of operation is used. In the positive mode of operation, opposite polarity voltages are applied as compared to the negative mode of operation.

In accordance with features of the invention, the IMS sensor is small-sized, low-cost, robust, and reliable. A ther-

moelectric Peltier plate optionally is used to condition the exhaust gas. The Peltier plate removes moisture from the gas stream and condenses large hydrocarbon molecules. The ion drift tube is a ceramic tube whose external surface is coated by a layer of conductive composites to maintain a uniform DC field. An IMS Faraday plate output current and a spark discharge current can be used to quantify the NOx concentration.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention together with the above and other objects and advantages may best be understood from the following detailed description of the preferred embodiments of the invention illustrated in the drawings, wherein:

FIG. 1 is a schematic and block diagram illustrating an exemplary ion mobility spectrometry (IMS) sensor for detecting nitric oxides (NOx) in accordance with the present invention;

FIG. 2 is a diagram illustrating an exemplary IMS Faraday plate output current of the ion mobility spectrometry (IMS) sensor of FIG. 1 relative to NO_2 concentration, measured in presence of simulated exhaust gas and at 5 nA/V sensitivity, in accordance with the present invention; and

FIG. 3 is a diagram illustrating an exemplary spark discharge current of the ion mobility spectrometry (IMS) sensor of FIG. 1 relative to NO_2 concentration in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Having reference now to the drawings, in FIG. 1 there is shown an exemplary ion mobility spectrometry (IMS) sensor for detecting nitric oxides (NOx) in accordance with the present invention generally designated by reference character **100**.

In accordance with features of the invention, IMS sensor **100** is small-sized, low-cost, robust, and reliable. IMS sensor **100** can be operated in both positive and negative modes. The negative mode of operation measures NO_2 in the gas stream and the positive mode of operation provides a measure of NO concentration. Control electronics provide the mode switching capability so that the total NOx concentration can be determined, where the total NOx concentration includes the negative NO_2 ions and positive NO ions. IMS sensor **100** can function in a harsh environment and provide a fast response.

IMS sensor **100** includes a housing **102** containing or substantially surrounding an electrically conductive cylinder or metallic shell **104** defining an ionization chamber **106**. The housing **102** preferably is formed of a ceramic material, or of a ceramic and Teflon material. The ionization chamber **106** includes a spark electrode **108**, such as a needle type electrode **108**, the metallic shell **104**, and a shutter grid **110**.

IMS sensor **100** includes an exhaust gas inlet path **112** positioned proximate a thermoelectric Peltier plate generally designated by reference character **114**. The thermoelectric Peltier plate **114** is used to condition the exhaust gas. The Peltier plate **114** removes moisture from the gas stream and condenses large hydrocarbon molecules.

IMS sensor **100** includes a variable voltage source **116** connected to needle electrode **108** that is used to establish a continuous spark discharge between a tip **118** of the needle electrode **108** and the metallic shell **104**. A voltage source **120**, such as a 200 Volt voltage source, is coupled to the

metallic shell **104** and to the shutter grid **110**. Also a pulser **122** is coupled to the shutter grid **110**.

During operation, a continuous spark discharge is established between the tip **118** of the needle electrode **108** and the metallic shell **104**. The negative NO₂ ions produced in the discharge region are kept inside the ionization chamber **106** by biasing the metallic shell **104** and the shutter grid **110** at a negative voltage. The positive pulse is applied to the shutter grid **110** to cause the shutter open for negative NO₂ ions to exit into an ion drift tube **124**. The pulse frequency of the pulser **122** is selected so that equilibrium between ion production and extraction is established.

To detect positive NO ions, a positive mode of operation is used. In the positive mode of operation, opposite polarity voltages are applied as compared to the negative mode of operation. The positive NO ions produced in the discharge region are kept inside the ionization chamber **106** by biasing the metallic shell **104** and the shutter grid **110** at a positive voltage. The negative pulse is applied to the shutter grid **110** to cause the shutter open for positive NO ions to exit into an ion drift tube **124**.

In accordance with features of the invention, the drift tube **124** is a ceramic tube whose external surface is coated by a layer **126** of conductive composites or resistive material to maintain a substantially uniform DC field. A voltage supply **128**, such as a 2 KV voltage supply, is coupled to the layer **126** carried by the drift tube **124**.

IMS sensor **100** includes a collection grid **130** connected to a voltage supply **132**, such as a 2.2 KV voltage supply. A Faraday plate **134** connected to a voltage supply **136**, such as a 3 KV voltage supply, is coupled via a resistor **138** to a charge amplifier **140**. An output of the charge amplifier **140** corresponds to an IMS Faraday plate output current can be used to quantify the NOx concentration. Also a spark discharge current detected by a second detector **142** coupled between the voltage supply **116** and ground, can be used to quantify the NOx concentration.

FIGS. **2** and **3** respectively illustrate IMS Faraday plate output current and a spark discharge current of the IMS sensor **100**. FIG. **2** illustrates a peak amplitude output vs. NO₂ concentration, measured in presence of simulated exhaust gas and at 5 nA/V sensitivity. FIG. **2** illustrates the spark-discharge current output vs. NO₂ concentration.

While the present invention has been described with reference to the details of the embodiments of the invention shown in the drawing, these details are not intended to limit the scope of the invention as claimed in the appended claims.

What is claimed is:

1. An ion mobility spectrometry (IMS) sensor for detecting nitric oxides (NOx) in an exhaust gas comprising:

an ionization chamber for receiving the exhaust gas; said ionization chamber includes an interior electrically conductive shell;

a spark electrode having a needle tip extending into said ionization chamber;

a shutter grid coupled between said ionization chamber and an ion drift tube;

means for establishing a substantially continuous spark discharge between said electrically conductive shell of the ionization chamber and said needle tip of the spark electrode for ionization of the exhaust gas.

2. An IMS sensor as recited in claim **1** includes a voltage source coupled to said electrically conductive shell of said ionization chamber and said shutter grid for biasing said electrically conductive shell and said shutter grid at a negative voltage.

3. An IMS sensor as recited in claim **1** includes a pulse generator for applying a positive pulse to said shutter grid to open said shutter grid for negative NO₂ ions to exit from said ionization chamber into said ion drift tube.

4. An IMS sensor as recited in claim **1** includes a collection grid and a Faraday plate coupled to said ion drift tube for detecting negative NOx ions and positive NO ions.

5. An IMS sensor as recited in claim **4** includes an output current of said Faraday plate used to quantify a NOx concentration.

6. An IMS sensor as recited in claim **1** includes a voltage source coupled to said electrically conductive shell of said ionization chamber and said shutter grid for biasing said electrically conductive shell and said shutter grid at a positive voltage.

7. An IMS sensor as recited in claim **1** includes a pulse generator for applying a negative pulse to said shutter grid to open said shutter grid for positive NO ions to exit from said ionization chamber into said ion drift tube.

8. An IMS sensor as recited in claim **1** wherein said ion drift tube is a ceramic tube having external surface coated by a layer of conductive material.

9. An IMS sensor as recited in claim **8** wherein a voltage source is coupled to said layer of conductive material to maintain a uniform DC field.

10. An IMS sensor as recited in claim **8** wherein said thermoelectric Peltier plate removes moisture from the gas stream and condenses large hydrocarbon molecules.

11. An IMS sensor as recited in claim **1** includes a thermoelectric Peltier plate for conditioning the exhaust gas received into said ionization chamber.

12. An IMS sensor as recited in claim **1** includes a spark discharge current used to quantify a NOx concentration.

13. An IMS sensor as recited in claim **1** includes a housing containing said ionization chamber and said interior electrically conductive shell.

14. An IMS sensor as recited in claim **1** wherein said housing is formed of a ceramic material.

15. A method for detecting nitric oxides (NOx) in an exhaust gas comprising the steps of:

providing an ion mobility spectrometry (IMS) sensor having an ionization chamber for receiving the exhaust gas; said ionization chamber includes an interior electrically conductive shell; a spark electrode having a needle tip extending into said ionization chamber; a shutter grid coupled between said ionization chamber and an ion drift tube;

establishing a substantially continuous spark discharge between said electrically conductive shell of the ionization chamber and said needle tip of the spark electrode for ionization of the exhaust gas;

biasing said electrically conductive shell and said shutter grid at a negative voltage; and

applying a positive pulse to said shutter grid to open said shutter grid for negative NOx ions to exit from said ionization chamber into said ion drift tube.

16. A method for detecting nitric oxides (NOx) in an exhaust gas as recited in claim **15** further includes biasing said electrically conductive shell and said shutter grid at a positive voltage; and

applying a negative pulse to said shutter grid to open said shutter grid for positive NO ions to exit from said ionization chamber into said ion drift tube.

17. A method for detecting nitric oxides (NOx) in an exhaust gas as recited in claim **15** wherein said biasing step

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includes providing a voltage source coupled to said electrically conductive shell of said ionization chamber and said shutter grid.

18. A method for detecting nitric oxides (NOx) in an exhaust gas as recited in claim **15** wherein said applying step includes providing a pulse generator coupled to said shutter grid for applying said positive pulse to said shutter grid.

19. A method for detecting nitric oxides (NOx) in an exhaust gas as recited in claim **15** includes providing a

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Faraday plate coupled to said ion drift tube and detecting an output current of said Faraday plate to quantify a NOx concentration of the exhaust gas.

20. A method for detecting nitric oxides (NOx) in an exhaust gas as recited in claim **15** includes detecting a spark discharge current to quantify a NOx concentration of the exhaust gas.

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