HIGH-SENSITIVITY, SILICON-BASED, MICROCALORIMETRIC GAS SENSOR

TECHNICAL FIELD

The invention relates to electronic controls, particularly internal combustion engine controls and engine diagnostic systems, and to improvements in a catalytic microcalorimeter for detecting gas constituents.

BACKGROUND OF THE INVENTION

Electronic engine control and diagnostic strategies for internal combustion engines for automotive vehicles require sensors for detecting and measuring engine operating variables and for developing appropriate sensor inputs for a microprocessor controller that responds to the variables by calculating air/fuel ratios and engine ignition timing for optimum engine performance and fuel economy. These known engine control strategies may rely on sensors to detect combustible exhaust gas constituents and to develop a signal that may be used to quantify those constituents, even in low concentrations such as 10 ppm.

Calorimeters, which are representative of one class of these sensors, may be used to measure the combustible gas concentrations by detecting and measuring temperature rise produced by the heat of combustion of a combustible constituent as it reacts with a catalyst located on a wire thermometer that forms a part of the sensor. A well known calorimetric sensor that is commercially available is the Pellistor, which consists of a ceramic body, impregnated with a noble metal catalyst, and a platinum resistance thermometer embedded in it. In order to compensate for ambient temperature fluctuations in the exhaust gas stream, a pair of sensor elements is used in tandem so that the increase in temperature of combustion of the flammable constituents is measured relative to a reference temperature, which is the exhaust gas temperature in an internal combustion engine environment. The reference temperature and the increase in temperature due to oxidation of the combustible constituents are measured independently by the paired elements, only one of which is influenced by the catalyst. The temperature is measured by resistors on each of the two elements. The resistance value of each resistor can be used as an indication of the temperature of that element.

Engine exhaust gases typically consist of a mixture of combustible gases including various hydrocarbons, carbon monoxide and hydrogen. Calorimetric gas sensors have different sensitivities to these combustible gases according to the characteristics of the catalyst and the operating conditions as well as other factors.

Catalytic calorimetric gas sensors may include electric heaters adjacent the temperature sensing resistance on a common substrate so that the operating temperature for the sensor elements may be kept higher than the temperature of the exhaust gas stream. The sensor output is roughly proportional to the number of carbon atoms in a molecule of a particular gas constituent because the heat of combustion for a hydrocarbon is roughly proportional to the carbon content of its molecules. It is possible, for example, to detect hydrocarbons in the exhaust gas that may contain carbon monoxide as well as other constituents since hydrocarbon molecules contain more carbon atoms.

An example of a calorimetric gas sensor based on silicon is described in a publication entitled "*Sensors and Actuators*", by M. Gall, published in 1991 by Elsevier Sequoia, The Netherlands, pp. 533–538. This publication describes a metallic resistor that serves as a heater and a temperature sensor. The sensor element includes a silicon frame holding a silicon nitride membrane. The membrane is obtained by selectively etching the underlying bulk silicon with a potassium hydroxide (KOH) solution. The metallic material of the resistor is deposited by evaporation to form a metallic layer on one side of the silicon nitride layer, and photolithography and etching are used to shape the metallic layer. The silicon nitride layer serves as a thermal insulator between the sensor metallic resistor and the silicon material. If compensation for environmental temperature fluctuations is desired, dual sensor elements can be used to establish a reference temperature in the exhaust gas stream. Micromachining techniques are used in fabricating this prior art device to shape the silicon during the manufacture of the paired elements. Concentration of combustible exhaust gas constituents then can be measured by detecting the temperature difference between the paired elements.

Reference patent U.S. Pat. No. 5,265,417 describes a catalytic calorimetric gas sensor to detect hydrocarbons in the vehicle exhaust. It comprises a silicon frame on which is mounted paired sensor elements, each element comprising a membrane on which is mounted resistor elements. One resistor element is used to measure the temperature of the surrounding gas. The other element includes a catalytic layer deposited on a dielectric layer that covers both resistors. The resistor for the element that contains a catalyst measures the temperature rise generated by the oxidation of the combustible gases as in the Gall device mentioned above. The membrane portion that supports one element is thermally isolated from the membrane portion that supports the other element. This thermal isolation is achieved because of the low thermal conductivity of the membrane portions and the ability of the silicon substrate to act as a heat sink.

The membranes of the device described in the '417 patent, unlike other prior art designs, comprise a composite of silicon nitride and silicon oxide layers to compensate in part for residual stresses and to obtain thicker, more robust substrates.

BRIEF DESCRIPTION OF THE INVENTION

The improved gas sensor of our invention makes it possible to achieve high sensitivity with improved reliability. This is accomplished by incorporating mechanically stable, robust, polysilicon plates that support the paired resistors of the sensor, one of the plates also supporting a thick catalyst layer. It is characterized by a reduced temperature gradient across the plates that support the resistors. It is characterized also by its durability in the harsh environment of an engine exhaust system where it is subjected to vibration, particle impingement and thermal shock.

Each of the paired elements of the sensor includes long, strategically-shaped, polysilicon arms that support the resistors and the substrate for the resistors, thereby reducing heat conduction to a surrounding silicon frame. Each of the paired elements of the sensor includes a low-power heating element to raise the temperature of the paired elements above the temperature of the exhaust gas stream. By using polysilicon, which has high thermal conductivity, and by positioning the