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ScienceDirect

Procedia Engineering 5 (2010) 1232–1235

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXIV, September 5-8, 2010, Linz, Austria

A new detection method of sevoflurane utilizing cataluminescence of γ-Al_2O_3 activated with Tb^{3+}

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Abstract

We propose a new sevoflurane sensor utilizing cataluminescence (CTL) of γ-Al_2O_3 catalyst activated with Tb^{3+}. Sevoflurane is a typical anesthetic agent used on patients during their surgery. The CTL is a kind of chemiluminescence emitted during the catalytic oxidation of combustible gas. The reproducible CTL is observed during the catalytic oxidation of sevoflurane vapor in the air for γ-Al_2O_3:Tb^{3+} catalyst at 600°C. The CTL intensity is proportional to the square root of the flow velocity of air containing sevoflurane vapor ranging in flow velocity from 8 to 26.5 cm/s at 600°C in catalyst temperature. The CTL intensity is nearly proportional to the sevoflurane concentration in the range of about 5 to 20 ppm.

Keywords: sevoflurane; anesthesia; anesthetic agent; cataluminescence; chemiluminescence; gas sensor

1. Introduction

Sevoflurane is a typical anesthetic agent which is used for patients during their surgical operation. As sevoflurane is liquid at room temperature, the sevoflurane vapor is prepared by vaporizing sevoflurane with oxygen using a vaporizer during the operation. The required concentration of the sevoflurane vapor is obtained by controlling the mixing ratio of the oxygen containing sevoflurane vapor and a carrier gas of pure oxygen. An accident might happen if the appropriate fill ration of sevoflurane liquid is not maintained in the vaporizer. In fact, it has been reported that in a case of the sevoflurane liquid with a fill ration that was lower, the concentration of sevoflurane vapor rapidly decreased under the conditions of a high flow rate and a high concentration above 8% [1]. Today, almost all of the anesthetic devices have no monitoring system of the anesthetic agent, and only feed-forward control can be done by controlling the mixing-ratio of the anesthetic vapor and the carrier gas. A convenient anesthetic monitor measuring the concentration continuously is expected to prevent such anesthetic accidents.

Cataluminescence (CTL) is a kind of chemiluminescence emitted during the catalytic oxidation of combustible

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1877-7058 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2010.09.335

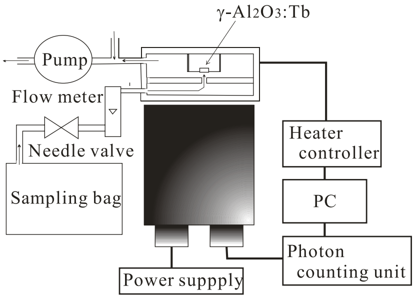

Fig. 1. Schematic illustration of the experimental setup.

gas. We have investigated the luminous mechanism of CTL, and applied it to gas sensors [2-7]. Some detection methods of sevoflurane have been proposed using microelectrode substrate [8], polypyrrole film [9] and modified multiwalled carbon nanotubes and polypyrrole [10]. However, CTL-based sensing for sevoflurane has not been reported except for the report that no CTL was observed for sevoflurane on a nanosized $ZnWO_4$ catalyst [11].

We found that CTL is emitted in air containing sevoflurane for γ-Al_2O_3 catalyst activated with Tb^{3+}. In this paper, the sensing mechanism and the characteristics of the sensor will be discussed.

2. Experimental

Figure 1 shows a schematic illustration of the experimental setup. A sampling bag (50L) made of PVF was used for preparing an air containing sevoflurane of a certain concentration. A precise amount of liquid sevoflurane was dropped into the bag and was vaporized by a precise amount of lab-air injected into the bag. γ-Al_2O_3 catalyst activated with Tb (1 mol%) was prepared by calcinations (900°C, 1h) of γ-Al_2O_3 powder after mixed with an aqueous solution of $Tb(NO_3)_3$. The γ-Al_2O_3:Tb powder was mixed with organic binder, and was screen-printed on a ceramic substrate (3 x 3 x 0.15 mm^3) which has a printed Pt-heater layer to form a CTL-based gas sensor. The sensor was heated in a light-tight vessel and sample gas was blown over the catalyst layer of the sensor through a hole (2 mm in diameter) placed 2 mm away from the sensor surface. The CTL emitted from the catalyst was passed through a band-pass filter of 488 nm and a hot-mirror and was measured by a photon counting method with a photomultiplier module. The flow velocity of the sevoflurane vapor was controlled by combination of an air pump and a flow meter with needle valve. The details of the sensor system will be given elsewhere [7].

3. Results and discussion

Figure 2 shows the CTL response to the injection of air containing sevoflurane vapor of 5 ppm measured using γ-Al_2O_3 catalyst activated with Tb^{3+}. In this figure, the CTL intensity was estimated by subtracting intensity of the thermal radiation emitted from the heated catalyst. When air and air containing sevoflurane vapor are blown over the sensor alternatively at a flow velocity of 26.5 cm/s, corresponding CTL emission is observed. This is the first observation of the CTL by a non-flammable fluorinated compound such as sevoflurane. On the other hand, CTL by ether which has hydrocarbon radicals was observed but CTL by sevoflurane was not observed for the nanosized $ZnWO_4$ catalyst [11]. This may because the latter catalyst does not containing an activator such as Tb.

Two CTL emission mechanisms are known; the first one is the chemiluminescence emission from excited intermediates such as formaldehyde which is produced in the course of catalytic oxidation [2], and the second one is the recombination radiation of electron-hole pairs which originated from adsorbed species produced during catalytic oxidation through energy levels of a rare-earth activator doped into the catalyst [4]. Excited intermediates to emit chemiluminescence might not be produced on the nanosized $ZnWO_4$ catalyst but the electron-hole pairs to emit recombination radiation might be produced on γ-Al_2O_3 catalyst activated with Tb^{3+}.

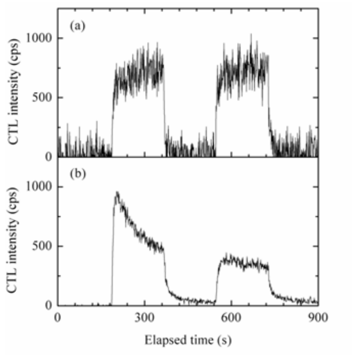

Fig. 2. Response of the CTL intensity to the injection of air containing sevoflurane vapor of 5 ppm under the flow velocity of 26.5 cm/s for γ-Al_2O_3:Tb catalyst at (a) 600°C and (b) 250°C.

In Fig. 2, the CTL response at 600°C is reproducible and stable in air containing sevoflurane of steady concentration, but that at 250°C was not reproducible. In order to investigate the reason for this result, we measured the flow velocity dependence of the CTL intensity.

Figure 3 shows the flow velocity dependence of the CTL in air containing sevoflurane vapor of 5 ppm at the catalyst temperatures of 600 and 250°C, respectively. In this figure, we measured and plotted the CTL intensities at 1 hour after introduction of sevoflurane vapor to obtain the nearly steady-state value of CTL intensity.

The CTL intensity I at 600°C depends on a flow velocity v, and I is in proportional to, but I at 250°C is independent on v. This result directly shows that the rate of catalytic reaction emitting CTL is under the diffusion controlled conditions at 600°C and is under the reaction controlled conditions at 250°C [2]. The CTL intensity is proportional to the rate of catalytic oxidation, which is limited by the rate of transfer of sevoflurane vapor from the gas phase to the catalyst surface under the diffusion controlled conditions at 600°C, so that the CTL intensity depends on the flow velocity around the catalyst. On the other hand, CTL intensity is limited by the rate of chemical reaction on the catalyst surface and is not dependent on the flow velocity under the reaction controlled conditions at 250°C [2]. Thus, stable and reproducible CTL may result from catalytic oxidation under the diffusion controlled conditions at 600°C, and unstable CTL may result from the inhibition of the catalytic oxidation by undesorbed species produced on the catalyst surface by the catalytic oxidation under the reaction controlled conditions at 250°C.

We measured the concentration dependence of the CTL intensity for air containing sevoflurane vapor under the stable diffusion controlled conditions at 600°C and at the flow velocity of 26.5cm/s. The result is plotted on log-log graph in Fig.4. The plots do not fit into a straight line, but nearly linear characteristics are observed in the range between 5 and 20 ppm. The sub-linear characteristics at the higher concentration region may result from the complex catalytic oxidation process of sevoflurane.

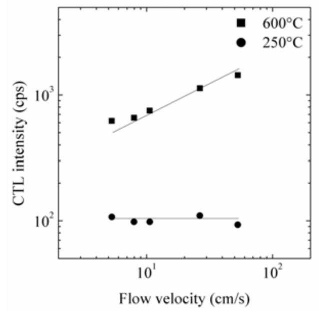

Fig. 3. Flow velocity dependence of the CTL intensity in air containing sevoflurane of 5 ppm at the catalyst temperature of 600 and 250 °C.

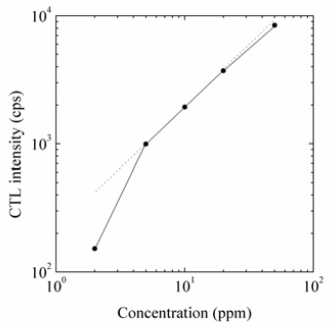

Fig. 4. The Concentration dependence of CTL intensity for air containing sevoflurane vapor under the flow velocity of 26.5 cm/s at the catalyst temperature of 600 °C.

4. Conclusion

We observed the CTL of sevoflurane by using a γ-Al_2O_3 catalyst activated with Tb^{3+}. The flow velocity dependence of the CTL intensity was proportional to the square root of the flow velocity ranging from 8 to 26.5 cm/s at 600°C, and stable and reproducible CTL was observed under the diffusion controlled conditions. The CTL-based sensor working under these conditions showed a nearly linear concentration dependence for the sevoflurane vapor in the range of 5 to 20 ppm. Oxygen containing sevoflurane-vapor of ca. 1 to 5% is used during surgery, so we will be able to measure the vapor of this concentration region by means of a dilution-technique of the sample gas with air.

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