

Particulate Matter Sensor for On Board Diagnostics (OBD) of Diesel Particulate Filters (DPF)

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ABSTRACT

The emissions legislation in the US and Europe introduce the need for the application of diesel particulate filters (DPF) in most Diesel vehicles. In order to fulfill future OBD legislations, which include more stringent requirements on monitoring the functionality of those particulate filters, new sensors besides the differential pressure sensor are necessary. The new sensors need to directly detect the soot emission after DPF and withstand the harsh exhaust gas environment. Based on multi layer ceramic sensor technology an exhaust gas sensor for particulate matter (EGS-PM) has been developed. The soot particle sensing element consists of two inter-digitated comb-like electrodes with an initially infinite electrical resistance. During the sensor operation soot particles from the exhaust gas are collected onto the inter-digital electrodes and form conductive paths between the two electrode fingers leading to a drop of the electrical resistance. A controlled regeneration of the soot detecting electrodes is conducted by heating the sensing element and burning off the deposited soot at temperatures above 600°C.

The concept and the performance of the EGS-PM as well as a new concept for the OBD of diesel particulate filters using the EGS-PM are presented.

INTRODUCTION

The need for a PM-sensor results from more stringent upcoming OBD-legislation on DPF-monitoring. Future OBD-thresholds will be below the effective detection limits that can be achieved with the differential pressure method currently used for detecting DPF-malfunctions.

For US-applications legislation has been finalized by CARB [1]. The need for a PM-sensor is foreseen for the model year

2013 when the OBD-limit for passenger cars/light duty vehicles drops to 17.5 mg/mi (1.75 $\otimes$ certification limit).

The EU-legislation is not finalized yet, but the EU-Commission has published a draft proposal on passenger car legislation [2]. The need for a PM-sensor is foreseen for September 2014 when the recommended PM-mass limit drops to 9 mg/km (2 $\otimes$ certification limit).

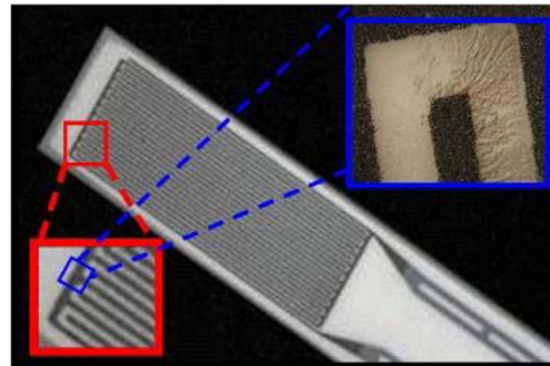
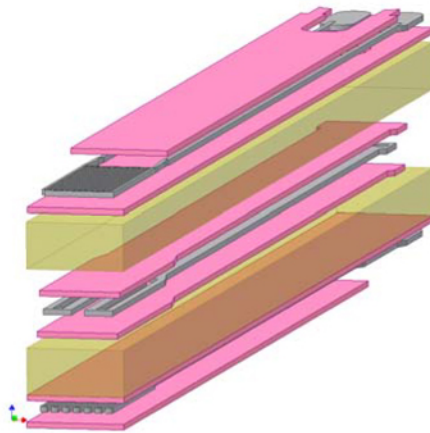


Figure 2. Schematic drawing of a resistive sensor element, consisting of an inter-digital electrode (IDE), a heater and an element for temperature measurement (left, color code: magenta: electrical isolating layers; grey: Pt-based conductive circuits; yellow: zirconia) and a top-view of the IDE including a magnified image of the soot deposit between the electrodes (right).

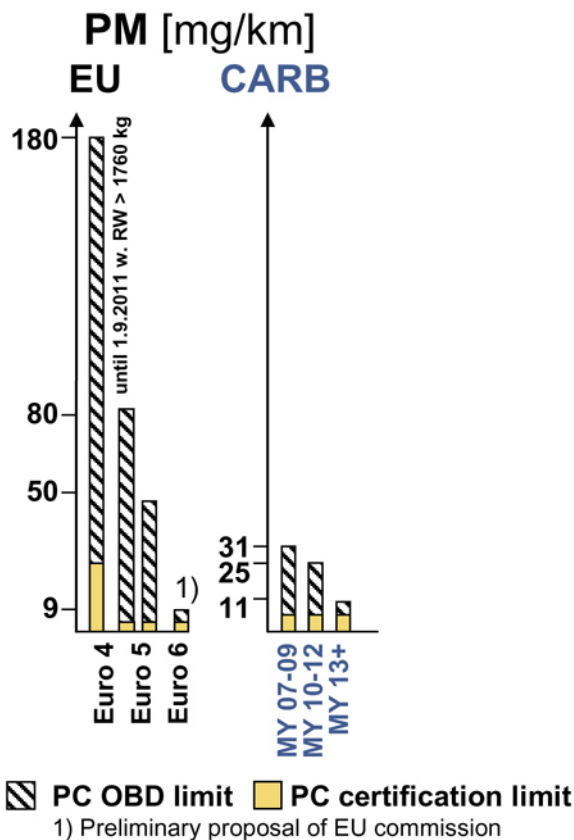


Figure 1. DPF-monitoring-limits according to OBD-legislation (CARB/EU).

PARTICULATE MATTER SENSOR

SENSOR FUNCTION

The resistive soot sensor concept was chosen based on industrial feasibility and especially under the aspect of

functionality, costs and durability. The collecting sensing element is based on existing multi layer ceramic sensor technology used for example for the Lambda sensor. The sensing element consists of two inter-digitated comb-like electrodes (IDE) with an infinite electrical resistance, an internal heater, and a temperature measuring element as shown in Figure 2.

<figure 2 here>

During the deposition of soot particles from the exhaust gas, an electrical contact is formed between the electrodes so that the electrical resistance starts to decrease. After a certain time of collection a pre-defined current threshold is reached and the heater element incorporated in the sensor element is used for heating the sensor above soot ignition temperatures $>600^{\circ}\text{C}$ for burning off the adsorbed soot. The time between the start of the measurement and the start of regeneration is defined as the response time. In order to guarantee a controlled regeneration of the sensing element the integrated temperature sensing element is used to control the temperatures reached during regeneration (see Figure 3).

<figure 3 here>

To understand the correlation between the sensor signal and the actual exhaust gas soot concentration it is necessary to understand the mechanisms involved in the soot particle deposition and the forming of conductive bridges between the IDE electrodes as shown in Figure 4. The following steps contribute to the sensor signal

- The sensor element is mounted in a housing as shown in Figure 4 and positioned in the exhaust gas line downstream of a diesel particulate filter (DPF).
- The exhaust gas is sampled using a shielding cap, specially developed for the particulate matter sensor.

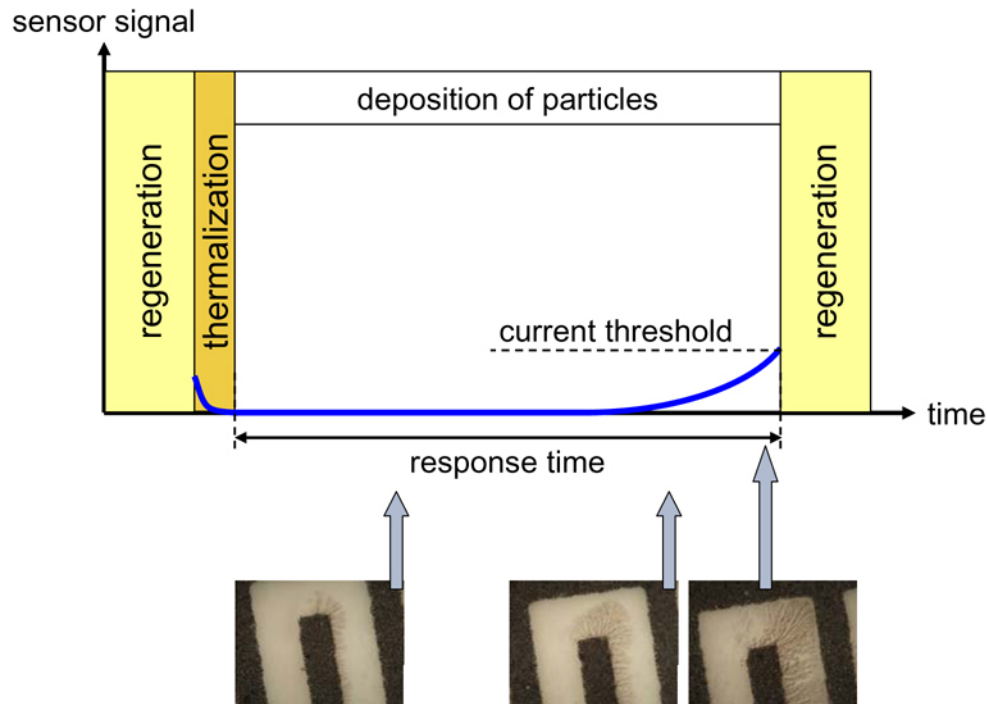


Figure 3. Signal characteristics of the resistive particulate matter sensor (the blue line represents the sensor current between the electrodes during the soot particle deposition) and corresponding images of the deposited soot between the electrodes (dark areas: electrodes; white areas: isolating aluminum oxide). A dendritic growth of a soot layer between the electrodes can be observed. The left image shows the dendrites at the beginning of the measurement where no connections between the electrodes are formed, whereas, a connection between the electrodes due to soot dendrites can be observed in the right picture.

- The sampled exhaust gas flow containing the soot particles is directed by the protection tube and flows across the sensing electrode structure. Soot particles are deposited onto the electrodes.
- Soot particle bridges are formed between the electrodes which lead to a “short-circuited” IDE and, hence, a measurable current between the electrodes.
- A subsequent regeneration process of the sensor element burns the soot bridges and the next measuring cycle starts.
- The actual sensor signal, representative for the soot concentration in the exhaust gas, is the time between the regeneration and the reaching of the threshold current, described as “response time” of the sensor.

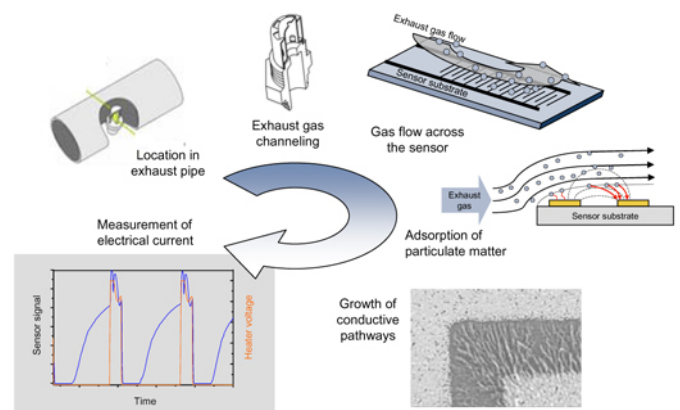


Figure 4. Schematic drawing of the mechanisms involved in the soot particle deposition and the forming of the sensor signal. The sensor element incorporated in a housing is positioned in the exhaust gas stream. The shielding cap samples a certain amount of exhaust gas and guides it across the IDE, where the particles are adsorbed. Soot particle bridges are formed between the IDE electrodes and a current can be measured. After reaching a predefined threshold the internal heater burns the deposited soot and the measurement cycles start over.