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(54) Title: CATALYST FEATURING SILICONE DIOXIDE BASED SUPPORT MATERIAL FOR THE PURIFICATION OF EXHAUST GASES

(57) Abstract: The present invention relates to a catalyst for the purification of exhaust gases from an internal combustion engine, which comprises a catalytically active coating on an inert ceramic or metal honeycomb body, said coating comprising at least one platinum group metal selected from the group consisting of platinum, palladium, rhodium and iridium on a fine, oxidic support material. As an oxidic support material, the catalyst comprises a low-porosity material on the basis of silicon dioxide that comprises aggregates of essentially spherical primary particles having an average particle diameter of between 7 and 60 nm.

Catalyst for the purification of exhaust gases from an internal combustion engine

25 The present invention relates to a catalyst (catalytic converter) for the purification of
exhaust gases from an internal combustion engine, which comprises a catalytically
active coating on an inert ceramic or metal honeycomb body, said coating comprising at
least one of the platinum group metals platinum, palladium, rhodium and iridium on a
fine, oxidic support material. The catalyst is especially suitable for the oxidative
30 purification of exhaust gases from diesel engines since it exhibits a good resistance to
poisoning by the sulfur components in diesel fuel.

Diesel engines are operated with so-called lean air/fuel mixtures, which means that the
air/fuel mixture fed to the engine contains more oxygen than is needed for the complete
combustion of the fuel. In addition to unburned hydrocarbons (HC) and carbon
35 monoxide (CO), the exhaust gases from diesel engines also contain nitrogen oxides
(NO_x) and soot particles. Another pollutant contained in the exhaust gas is sulfur
dioxide, which stems from the sulfur contained in diesel fuel.

For purifying the exhaust gases from diesel engines, use is often made of so-called diesel oxidation catalysts, which convert the hydrocarbons and the carbon monoxide in the exhaust gas into harmless components. Furthermore, these catalysts reduce the mass of the particles by oxidizing the organic compounds adsorbed on the particles.

- 5 Typical catalysts of this kind comprise a coating of one or more support oxides (for example aluminum oxide, silicon dioxide, titanium dioxide, cerium oxide as well as mixtures thereof), one or more zeolites as well as platinum as a catalytically active component on a ceramic or metal honeycomb body. The employed support oxides or support materials have a large surface area, i.e. their specific surface area (BET surface
10 measured according to the German Industrial Standard DIN 66131) is more than $10 \text{ m}^2/\text{g}$, preferably more than $50 \text{ m}^2/\text{g}$. The specific surface area should remain stable up to exhaust gas temperatures of about $800 \text{ }^\circ\text{C}$. In order to achieve a high degree of catalytic activity, the platinum is distributed very finely on the support oxides.

- The majority of the hydrocarbon emissions are emitted during the cold start phase since
15 the catalyst has not yet reached its operating temperature during this phase. In order to reduce hydrocarbon emissions during the cold start phase, zeolites are added to the catalysts. Zeolites are specific aluminosilicates with a defined pore structure. The pore sizes are in the order of magnitude of small organic molecules. At low temperatures, the zeolites store the hydrocarbons, while at higher temperatures, when the catalyst is
20 active, the hydrocarbons are released again (desorbed) and are then converted at the platinum crystallites of the catalyst.

- Such a catalyst is for example described in U.S. Patent No. 5,157,007. On an inert honeycomb carrier, the catalyst comprises a catalytically active coating, which comprises aluminum oxide, titanium oxide, silicon dioxide, zeolites or mixtures thereof
25 as oxidic support materials for the catalytically active platinum group metals. So-called precipitated silica is used as silicon dioxide. Precipitated silica exhibits a large specific surface area. Their pH value in 5% aqueous dispersion is more than 6 (Schriftenreihe Pigmente Nummer 31: "*Synthetische Kieselsäuren als Fließhilfsmittel und als Trägersubstanz*" [Technical Bulletin Pigments No. 31: "Synthetic silica as free flow
30 agent and support substance"]; company brochure of the company Degussa AG; 6th edition, November 1995). A pyrogenic titanium oxide with a specific surface area of $51 \text{ m}^2/\text{g}$ is used *inter alia* as titanium oxide.

U.S. Patent No. 5,928,981 describes a catalyst for purifying the exhaust gases from diesel engines, the catalyst comprising a mixture of several zeolites. As a support material for the catalytically active platinum group metals the catalyst furthermore comprises at least one material selected from the group consisting of aluminum silicate, aluminum oxide and titanium oxide. Pyrogenic titanium oxide obtained via flame hydrolysis and having a specific surface area of 50 m²/g, which is composed of 70 wt.-% of anatase and 30 wt.-% of rutile is said to be suitable as titanium oxide.

In the last few years, there has been considerable progress in the development of economical diesel engines. Due to their improved efficiency, modern diesel engines exhibit very low exhaust gas temperatures, which may be below 150°C during urban driving conditions. These temperatures create completely new demands on the durability of diesel catalysts. Due to the low exhaust gas temperatures, the purification of the exhaust gases from such diesel engines leads to an increased adsorption of the hydrocarbons, which clog the pores of the catalyst. This entails a reduction in catalytic activity. The catalyst may even break down completely, causing an engine failure due to the high exhaust-gas backpressure.

Alternating modes of operation consisting of longer drives under a low load followed by steep acceleration to maximum load is also critical. These alternating modes of operation can cause thermal damage to the catalyst when long drives under a low load lead to an adsorption of large amounts of hydrocarbons on the catalyst which upon change to maximum load operation are burned quickly. The released reaction heat can lead to temperatures of up to 1000 °C on the catalyst surface and cause thermal damage to the catalyst.

Another problem encountered by catalysts for the purification of exhaust gases from diesel engines is the sulfur content of the diesel fuel, which is emitted from the engine in the form of sulfur dioxide and adsorbed by the catalyst in the form of sulfates that damage the catalyst. In order to reduce damage caused by sulfur components it has been known to use acidic support oxides for the catalytically active precious metals, which only adsorb sulfur to a low degree.

Figures 1 and 2 show:

Figure 1 Photograph of the structure of platinum on aluminum silicate (support material no. 3 of Table 1), taken with a transmission electron microscope.

5 **Figure 2** Photograph of the structure of platinum on pyrogenic silicon dioxide (support material no. 6 of Table 1), taken with a transmission electron microscope.

There is a demand for diesel oxidation catalysts that exhibit an improved resistance to aging as well as a reduced propensity to be poisoned by sulfur components compared to known catalysts.

10 The present invention provides a catalyst for the purification of exhaust gases from an internal combustion engine, which comprises a catalytically active coating on an inert ceramic or metal honeycomb body, said coating comprising at least one platinum group metal selected from the group consisting of platinum, palladium, rhodium and iridium on a fine, oxidic support material. The oxidic support material is a low-porosity material on the basis of silicon dioxide and comprises aggregates of essentially spherical primary
15 particles having an average particle diameter of between 7 and 60 nm.

According to the present invention, a specific silicon dioxide is used as support material, which comprises aggregates of essentially spherical primary particles. In the present invention, the term "essentially spherical" denotes the form of a particle that exhibits a smooth surface and whose geometrical shape approximates a sphere.
20 However, this definition also encompasses drop-shaped primary particles or irregularly shaped primary particles with a smooth surface having a shape similar to a sphere. One characteristic of this material is the fact that its specific surface area is largely based on the geometrical surface (outer surface) of the primary particles, i.e. the material exhibits almost no pores. It is essentially non-porous.

25 The material to be used according to the present invention can easily be distinguished from usual, porous silicon dioxide materials by means of an electron microscope. The electron microscopic examinations clearly show the non-porous structure of the primary particles and allow the determination of their average particle diameter. These examinations can even be conducted with samples of the finished catalytic coating and
30 allow identification of the material.

The non-porous silicon dioxide can for example be prepared by subjecting silicon tetrachloride to a so-called flame hydrolysis (see for example "Schriftenreihe Pigmente" of the company Degussa AG, Number 11, 5th edition, August 1991: "*Grundlagen von Aerosil*[®]" [Technical Bulletin Pigments No. 11: The basics of Aerosil[®]]). For this purpose, silicon tetrachloride is brought into the gas phase and subsequently reacts quantitatively with water within an oxyhydrogen flame, thus forming the desired silicon dioxide. However, such materials can also be obtained in an arc and in plasma. In the following, silicon dioxide obtained from flame hydrolysis is also referred to as pyrogenic silicon dioxide.

10 Due to their solidification from a melt, the resulting primary particles are essentially spherical. They attach themselves to other primary particles and form what is referred to as aggregates, which generally cannot be broken up again into individual primary particles.

15 The size of the primary particles can be adjusted to about 7 to 60 nm by modifying the process parameters of the flame hydrolysis. In the catalyst according to the present invention, it is preferred that a material be used that has an average primary particle size of more than 15 nm and a specific surface area of upto about 150 m²/g. It is particularly preferred that the support material has an average primary particle size of between 20 and 50 nm and a specific surface area of between 90 and 40 m²/g.

20 The pyrogenic silicon dioxide is essentially non-porous and preferably has a pore volume of less than 0.2 ml/g of pore diameters less than 30 nm. Its maximum of the pore radius diameter is usually above 20 nm. The material is preferably acidic, i.e. its pH value in a 4 weight-% dispersion is less than 6, more preferably less than 5.5.

25 In order to increase its thermal stability, the support material can be doped with one or more oxides selected from the group consisting of aluminum oxide, zirconium oxide, alkaline-earth metal oxides and rare earth oxides. The weight of all doping elements should lie between 0.01 and 20 wt.-%, based on the total weight of the support material. The doping of the silicon dioxide is preferably carried out with the help of an aerosol, as described in EP-A-995 718. According to this application, doping is carried out by
30 introducing an aerosol into a flame as used for the pyrogenic preparation of silica by means of flame oxidation or flame hydrolysis, the aerosol containing salts or salt mixtures of the doping element or the element itself in dissolved or suspended form or mixtures thereof. After the reaction in the flame, the doped silicon dioxide is separated

from the gas flow. Preferably, a support material is used that is doped with aluminum oxide in an amount of between 0.05 and 1 wt.-%.

Since the silicon dioxide to be used in the catalytically active coating according to the present invention has a low porosity, adsorption of the hydrocarbons, which is
5 responsible for the primary poisoning ("the clogging of pores"), is largely suppressed. Thus, secondary aging effects due to the burn-up of accumulated hydrocarbons and the ensuing thermal damage to the catalyst are avoided. It is also advantageous that in a preferred embodiment the support material is acidic. Thus, the incorporation of the sulfur dioxide contained in the exhaust gas into the support material in the form of
10 sulfates is made more difficult. The incorporation of the sulfur components contained in the exhaust gas of combustion engines in catalysts is based on an acid-base reaction and is especially observed in the case of basic support materials.

Thus, the catalyst according to the present invention preferably exhibits the following combination of features:

- 15 It comprises a catalytically active coating on an inert ceramic or metal honeycomb body, said coating comprising at least one platinum group metal selected from the group consisting of platinum, palladium, rhodium and iridium on a fine, oxidic support material. The oxidic support material is a fine silicon dioxide preferably having one or more of (more preferably all of) the following properties:
- 20 a) it is comprised of aggregates of essentially spherical primary particles having an average particle diameter of between 15 and 60 nm,
 - b) the specific surface is between 30 and 150 m²/g,
 - c) the maximum of the pore radius distribution is above 20 nm,
 - d) the total volume of pores having a pore diameter of less than 30 nm is less than
25 0.2 ml/g, and
 - e) the pH value of a 4 weight-% aqueous dispersion of the support material is less than 6.

Preferably, platinum is used as catalytically active component in the catalyst according to the present invention, which is applied in a highly dispersed form onto the support
30 material by means of known methods.

The catalyst according to the present invention can additionally comprise zeolites in the catalytically active coating to reduce the emission of hydrocarbons at low exhaust gas temperatures. The zeolites can also be coated with platinum to allow a continuous

combustion of the adsorbed hydrocarbons. Thus, the zeolites also contribute to the reduction of the accumulation of hydrocarbons on the catalyst. Preferred zeolites include a dealuminated Y-zeolite, a beta-zeolite and a ZSM-5 zeolite, each with a modulus of more than 40. The modulus of a zeolite denotes its molar ratio of silicon dioxide to aluminum oxide. The higher the modulus, the lower the zeolite's aluminum oxide content. As a rule, the temperature stability and the stability of a zeolite against an acid attack increase as its modulus increases.

The mentioned zeolites can be used alone, in combination with each other or in combination with other zeolites. Preferably, the weight ratio of the silicon dioxide to the zeolites contained in the catalyst is between 6:1 and 1:2. In order to ensure a continuous burn-up of the hydrocarbons adsorbed by the zeolites, it is sufficient that only a small part of the total platinum contained in the catalyst be present on the zeolites. It has been found that 1 to 20 wt.-% of the total platinum present in the catalyst is sufficient for this purpose.

The catalyst according to the present invention comprises an inert honeycomb body onto which the catalytically active coating has been deposited. Honeycomb bodies suitable for the catalyst include ceramic bodies (for example made from cordierite) or metal bodies, as are used on a large scale for the purification of exhaust gases from vehicles. They usually have a cylindrical shape, and flow ducts for the exhaust gases to be purified run through the length of the cylinder from one end to another. The density of the flow ducts throughout the cross-section of the honeycomb bodies is referred to as cell density. It is typically between 40 and 250 cm⁻². The catalytically active coating is generally provided on the walls of the flow ducts and is therefore in contact with the exhaust gas flowing by.

The loading of the catalytically active coating is important for the catalytic activity of the catalyst. The loading is expressed as a concentration, i.e. as weight per external volume of the honeycomb body (g/l). This concentration is preferably between 40 and 300 g/l honeycomb body volume for the entire catalytically active coating and between 0.01 and 8 g/l honeycomb body volume for the platinum group metals.

For the preparation of the catalyst, preferably a slurry or coating suspension of the fine powder materials of the future catalytically active coating is prepared and the honeycomb body is coated therewith. The processes for coating honeycomb bodies with the catalytically active coating are well known to the person skilled in the art. The slurry of the powder materials is preferably prepared with water.

The application of the platinum group metals onto the support materials (silicon dioxide, zeolites and optionally further components) can be carried out at different times during the production process. Preferably, the platinum group metals are applied onto the support materials prior to the preparation of the coating suspension. This allows a selective application of the platinum group metals in different concentrations on the various support materials. For instance, a higher concentration of platinum group metal can be applied on the silicon dioxide than on the zeolite(s).

For the application of the platinum group metals on the powdery support material those processes are preferably used that lead to a high degree of dispersion of the platinum group metals on the surfaces of the support materials and to particle sizes of the metal crystallites of between 1 and 50 nm, preferably between 2 and 20 nm. Especially suitable processes are the pore volume impregnation and homogeneous precipitation.

During pore volume impregnation of a given amount of support material, precursors of the platinum group metals are dissolved in an amount of water the volume of which corresponds to 70 to 110% of the water absorption capacity of the support material determined beforehand. It is advantageous to agitate the support material e.g. in a coating pan while it is being sprayed with the platinum group metal solution. After completion of the pore volume impregnation, the impregnated support material forms a powder, which, despite its water content, is still flowable.

Homogeneous precipitation is described for example in U.S. Patent No. 6,103,660. In this process, the support material is suspended in water together with a precursor compound of the platinum group metals. An injection of a basic or acidic solution into the suspension by means of a capillary (capillary injection) causes the precursor compound to precipitate on the surface of the support material. In order to guarantee a uniform precipitation throughout the entire suspension, the basic or acidic solution is added slowly and distributed uniformly throughout the suspension by stirring.

Precursor compounds of the platinum group metals include all soluble compounds that can be converted into the catalytically active components during calcination in air. Examples of such compounds include hexachloroplatinic acid, tetrachloroplatinic acid, diaminedinitroplatinum-(II), tetraamineplatinum-(II)-chloride, ammoniumtetrachloroplatinate-(II), ammoniumhexachloroplatinate-(IV), platinummethylenediaminedichloride, tetraamineplatinum-(II)-nitrate, tetraamineplatinum-(II)-hydroxide, methylethanolamine-platinum-(II)-hydroxide, ethanolamineplatinum-(IV)-hexahydroxide, platinum nitrate, palladium chloride, palladium nitrate, diaminedinitropalladium-(II),

tetraaminepalladium-(II)-hydroxide, rhodium chloride, rhodium nitrate and hexachloroiridium acid.

After impregnation and prior to further processing, the catalytically active components can be fixated on the support material by means of calcination in air at temperatures
5 between 200 and 600 °C. This causes the precursor compounds of the platinum group metals to decompose into oxides of various oxidation states. Calcination can for example be carried out in a rotary kiln. Preferably, calcination is carried out by means of spray calcination. During spray calcination, the impregnated material is blown into a hot gas flow generated by burning methane and is calcined at a gas temperature of from
10 700 to 1000 °C and a dwell time in the gas flow of from fractions of a second to a few minutes, e.g. preferably 0.1 s to 1 min, more preferably 0.5 s to 5 s. Spray calcination of powdery substances is described in U.S. Patent No. 6,228,292 B1. However, calcination prior to further processing of the catalyzed support materials is not always necessary.

Both the non-porous silicon dioxide to be used according to the present invention and
15 the other oxidic support materials of the catalyst can be coated with the desired catalytically active platinum group metals in this manner; usually, the platinum group metals are applied in concentrations of between 0.01 to 10 wt.-%, based on the total weight of the support material and platinum group metals.

For coating the honeycomb body with the thus obtained catalyst materials, a, generally
20 aqueous, suspension of these materials is prepared. Then the honeycomb body can be coated with this suspension by means of known methods; i.e. essentially, a coating is applied to the wall surfaces of the partitions between the flow ducts. The coating is then dried at elevated temperatures and optionally calcined in air at temperatures between 200 and 600 °C. If necessary, the thus obtained coating can be further impregnated with
25 additional precursor compounds of the platinum group metals or of non-noble metals.

In the preparation of the coating suspension, it is advantageous to use the pyrogenic silicon dioxide to be used according to the present invention in an agglomerated form with a compacted bulk density of more than 200 g/l, preferably more than 500 g/l and even more preferably more than 600 g/l. In this agglomerated form it can be processed
30 more easily to form a coating suspension. In contrast, the non-agglomerated pyrogenic silicon dioxide only has a compacted bulk density of less than 100 g/l and is therefore difficult to process.

The compacted bulk density is the quotient of the weight and the volume of a powder after compacting in a compacting volumometer under certain set conditions (see DIN ISO 787/XI). The terms "primary particles", "aggregates" and "agglomerates" as used in the present invention are defined in DIN 53206, Sheet 1.

- 5 The process of spray drying has proven to be especially suitable for the agglomeration of the powdery pyrogenic silicon dioxide. For this purpose, the powdery material is suspended in water with the help of known dispersion devices. Suspensions having a solids content of between 100 and 600 g/l are suitable for the subsequent spray drying process. The suspension is for example introduced into a spray dryer using a two-fluid
10 nozzle and dried at operating temperatures between 200 and 450 °C. The thus formed agglomerates have an average particle size between 15 and 30 µm.

As an alternative to the process described above, wherein the powdery support materials are first loaded with the catalytically active platinum group metals and optional promoters, i.e. are catalyzed, and then applied onto the honeycomb body in the form of
15 a coating, it is also possible to coat the honeycomb body with the non-catalyzed support materials and then to introduce the platinum group metals and optionally the promoters into the coating by means of impregnation. It is also possible to combine the two processes. For example, a coating of pyrogenic silicon dioxide and zeolites with a weight ratio of silicon dioxide to zeolites of from 6:1 to 1:2 can be impregnated with
20 platinum to obtain an oxidation catalyst for the purification of exhaust gases from e.g. diesel engines.

Due to the acidity and the low porosity of the support materials used in the catalyst of the present invention, it only absorbs low amounts of sulfur from the exhaust gas and thus maintains a high degree of catalytic activity even after a long operating life with
25 exhaust gas containing sulfur dioxide. It is therefore excellently suited for the oxidative purification of exhaust gases from diesel engines. For example, after the oven aging described in Application Example 1, less than 0.25 wt.-% sulfur dioxide, based on the total weight of the catalyst consisting of honeycomb body and coating, was measured when synthetic exhaust gas with 85 vol.-ppm sulfur dioxide flowed through the catalyst.
30 After aging in the engine for 45 hours, as described in Application Example 2, also less than 0.25 wt.-% sulfur dioxide, based on the total weight of the catalyst consisting of honeycomb body and coating, was measured when diesel fuel with 2400 wt.-ppm sulfur was used. Furthermore, the specific surface area of the catalyst had decreased by less than 20% compared to the value prior to aging.

The following examples and examinations will explain the present invention in more detail. However, they are not construed as to be limiting.

5

EXAMPLES

Examination of support materials

Various metal oxides used in the following catalysts were characterized with respect to their specific surface area, their pore structure and their acidity. The acidity was
10 determined as the pH value of an aqueous dispersion of the respective support material with 4 weight-% support material, based on the total weight of the dispersion. The results are shown in Table 1.

Table 1 Characterization of metal oxides with respect to their specific surface area, pore structure and pH value of an aqueous dispersion

15

No.	Support material	Specific surface area [m ² /g]	Maximum of the pore radius distribution [nm]	Pore volume for pores < 30 nm [ml/g]	pH value of a 4 wt.-% aqueous dispersion
1	Al ₂ O ₃	134	10	0.47	8.0
2	Al ₂ O ₃ /SiO ₂ *)	311	6.5	0.65	7.7
3	Al ₂ O ₃ /SiO ₂ *)	153	10	0.50	7.5
4	SiO ₂	234	10	0.80	5.2
5	SiO ₂	159	10.5	0.75	5.4
6	SiO ₂	65	45	0.09	4.7

*) aluminum silicate with 5 wt.-% SiO₂

Support material no. 6 fulfills the requirements of the catalyst according to the present invention. It is a pyrogenically prepared support material with an average primary
20 particle size of 40 nm. Its surface area is relatively small compared to support materials no. 1 to no. 5. The low surface area is due to its low porosity, which is expressed by the pore radius distribution and the low mesopore volume. The pH value of the material in a 4 wt.-% aqueous dispersion is acidic (pH=4.7). This results in a markedly reduced

incorporation of sulfur dioxide or sulfur trioxide, which are also acidic. Thus, a catalyst on the basis of this support material is resistant to exhaust gas containing sulfur dioxide.

In each of the following Examples and Comparative Examples, two different open-cell honeycomb bodies (Honeycomb Body Type 1 and Honeycomb Body Type 2) were coated with a catalytic coatings. The characteristics of these honeycomb bodies are listed in Table 2.

Table 2 Characteristics of the employed honeycomb bodies

Type	Material	Diameter [cm]	Length [cm]	Cell density [cm ⁻²]	Wall thickness [mm]
1	Cordierite	11.83	7.6	62	0.2
2	Cordierite	11.83	15.24	62	0.16

10 Comparative Example 1

Two catalysts were prepared from a mixture of two powders catalyzed with platinum.

For the preparation of Powder 1, 1 kg of support material no. 3 (aluminum silicate) was provided in a coating pan. The aluminum silicate had a water absorption capacity of 800 ml/kg. The aluminum silicate was continuously agitated while it was sprayed with 766 ml of an aqueous solution of ethanolamineplatinum-(IV)-hexahydroxide ((EA)₂Pt(OH)₆ = (HO-C₂H₄-NH₃)₂+Pt^{IV}(OH)₆) at a volumetric flow rate of 56 ml/(kg · min). The moist powder, still flowable, was calcined by blowing it into a hot gas flow generated by burning methane. The calcination was conducted at a gas temperature of 780 °C and a dwell time in the gas flow of about one second (spray calcination).

20 The Pt-aluminum silicate powder (Powder 1) thus prepared had a platinum content of 2.79 wt.-%. A sample of this material was examined under a transmission electron microscope. Figure 1 shows a photograph of the structure of this catalyst material.

For the preparation of Powder 2, 1 kg of a Y-zeolite having a modulus of 60 was provided in a coating pan. The zeolite had a water absorption capacity of 1350 ml/kg. The Y-zeolite was continuously agitated while it was sprayed with 242 ml of an aqueous solution of ethanolamineplatinum-(IV)-hexahydroxide at a volumetric flow

rate of 56 ml/(kg · min). The moist powder, still flowable, was calcined as described in connection with Powder 1.

The Pt-zeolite powder (Powder 2) had a platinum content of 0.88 wt.-%.

5 Six parts by weight of Powder 1 and one part by weight of Powder 2 were suspended in water and homogenized by grinding in a ball mill. The solids concentration of the finished coating suspension was 35 wt.-%. The pH value of the coating suspension was 6.5.

10 One Honeycomb Body Type 1 and one Honeycomb Body Type 2 were coated with 126 g dry substance per liter of honeycomb body volume by immersion into the coatingsuspension. The coating was air-dried at 120 °C, calcined in air at 300 °C for 4 hours and finally reduced in a flow of forming gas (95 vol.-% N₂ and 5 vol.-% H₂) for 2 hours at 500 °C.

The finished catalysts had a platinum content of 3.17 g per liter of catalyst volume.

15 Important preparation conditions for the catalyst of this and the following examples are summarized in Table 3.

Comparative Example 2

20 Two more comparative catalysts were prepared analogously to Comparative Example 1. In contrast to Comparative Example 1, support material no. 2 with double the specific surface area (5 wt.-% silicon dioxide, specific surface area 311 m²/g) was used in Powder 1.

Comparative Example 3

Two more comparative catalysts were prepared analogously to Comparative Example 1. In contrast to Comparative Example 1, support material no. 1 (pure aluminum oxide) with a specific surface area of 134 m²/g was used in Powder 1.

Comparative Example 4

25 Two more comparative catalysts were prepared analogously to Comparative Example 1. In contrast to Comparative Example 1, silicon dioxide with a specific surface area of 234 m²/g (support material no. 4) was used in Powder 1.

Example 1

Two catalysts were prepared from a mixture of two powders catalyzed with platinum.

For the preparation of Powder 1, 1 kg of support material no. 6 (low-porosity silicon dioxide) with a specific surface area of $65 \text{ m}^2/\text{g}$ was provided in a coating pan. The low-porosity silicon dioxide had a water absorption capacity of 500 ml/kg. The silicon dioxide was continuously agitated while it was sprayed with 445 ml of an aqueous solution of ethanolamineplatinum-(IV)-hexahydroxide at a volumetric flow rate of 56 ml/(kg · min). The moist powder, still flowable, was calcined by blowing it into a hot gas flow generated by burning methane. The calcination was conducted at a gas temperature of 780 °C and a dwell time in the gas flow of about one second (spray calcination).

The Pt-silicon dioxide powder (Powder 1) thus prepared had a platinum content of 2.79 wt.-%. A sample of this material was examined under a transmission electron microscope. Figure 2 shows a photograph of the structure of this catalyst material. The essentially spherical structure of the pyrogenic support material can be seen clearly. The spheres are compact, free of pores and have a smooth surface on which the platinum particles are located (black spots). This structure is maintained even if the material is processed further and can still be detected in the finished catalyst coating.

It becomes immediately clear from Figure 2 that the specific surface area of the support material is solely due to the geometrical surface of the spheres. In contrast, the support material of Figure 1 has a highly irregular structure with a large specific surface area.

Powder 2 of Comparative Example 1 was used as the second catalyst powder.

Six parts by weight of Powder 1 and one part by weight of Powder 2 were suspended in water and homogenized by grinding in a ball mill. The solids concentration of the finished coating suspension was 35 wt.-%. The pH value of the coating suspension was 5.1.

Analogous to Comparative Example 1, two monolithic honeycomb bodies were prepared by coating with 126 g dry substance per liter of honeycomb body volume.

The coating was air-dried at 120 °C, calcined in air at 300 °C for 4 hours and finally reduced in a flow of forming gas for 2 hours at 500 °C.

The finished catalysts had a platinum content of 3.17 g per liter of catalyst volume.

Example 2

Two catalysts were prepared from a mixture of two powders catalyzed with platinum.

Powder 1 of Example 1 was used as the first catalyst powder.

5 For the preparation of Powder 2, 1 kg of a mixture consisting of 500 g of a Y-zeolite with a modulus of 60 and 500 g of a ZSM-5 zeolite with a modulus > 400 was provided in a coating pan. The zeolite mixture had a water absorption capacity of 1180 ml/kg. The zeolite mixture was continuously agitated while it was sprayed with 320 ml of an aqueous solution of ethanolamineplatinum-(IV)-hexahydroxide at a volumetric flow rate of 56 ml/(kg · min). The moist powder, still flowable, was not calcined, but used
10 directly in the preparation of the coating suspension.

The Pt-zeolite powder (Powder 2) had a platinum content of 0.50 wt.-%.

2.2 parts by weight of Powder 1 and one part by weight of Powder 2 were suspended in water and homogenized by grinding in a ball mill. The solids concentration of the finished coating suspension was 35 wt.-%. The pH value of the coating suspension was
15 4.9.

Analogous to Comparative Example 1, two monolithic honeycomb bodies (type 1 and type 2) were prepared by coating with 97 g dry substance per liter of honeycomb body volume.

The coating was air-dried at 120 °C, calcined in air at 300 °C for 4 hours and finally
20 reduced in a flow of forming gas for 2 hours at 500 °C.

The finished catalysts had a platinum content of 3.17 g per liter of catalyst volume.

Example 3

Two more catalysts were prepared analogously to Example 2. In contrast to Example 2, Powder 1 was not spray-calcined but, like Powder 2, was in a moist state when it was
25 further processed to form the coating suspension.

Example 4

Two more catalysts were prepared analogously to Example 2. In contrast to Example 2, Powder 1 had a platinum concentration of 2.52 wt.-%.

5 For the coating dispersion, 1.2 parts by weight of Powder 1 and one part by weight of Powder 2 were used. Analogous to Comparative Example 1, three monolithic honeycomb bodies were prepared by coating with 66 g dry substance per liter of honeycomb body volume.

The finished catalysts had a platinum content of 1.06 g per liter of catalyst volume.

Example 5

10 Two more catalysts were prepared analogously to Example 2. In contrast to Example 2, tetraamineplatinum-(II)-nitrate $[\text{Pt}(\text{NH}_3)_4](\text{NO}_3)_2$ was used as platinum precursor for Powder 1 and Powder 2.

Example 6

15 Two more catalysts were prepared analogously to Example 2. In contrast to Example 2, tetraamineplatinum(II)-hydroxide $[\text{Pt}(\text{NH}_3)_4](\text{OH})_2$ was used as platinum precursor for Powder 1 and Powder 2.

Table 3: Composition and preparation conditions of the examined catalysts

Example	Support oxide	Zeolite	Platinum salt	Concentration [g/l]	Weight ratio Pt-support oxide/Pt-zeolite	Platinum loading [g/l]	Calcination of the Pt-support oxide powder
CE1	No. 3	Y-Zeolite, modulus 60	(EA) ₂ Pt(OH) ₆	126	6 : 1	3.17	Spray calcination
CE2	No. 2	Y-Zeolite, modulus 60	(EA) ₂ Pt(OH) ₆	126	6 : 1	3.17	Spray calcination
CE3	No. 1	Y-Zeolite, modulus 60	(EA) ₂ Pt(OH) ₆	126	6 : 1	3.17	Spray calcination
CE4	No. 4	Y-Zeolite, modulus 60	(EA) ₂ Pt(OH) ₆	126	6 : 1	3.17	Spray calcination
E1	No. 6	Y-Zeolite, modulus 60	(EA) ₂ Pt(OH) ₆	126	6 : 1	3.17	Spray calcination
E2	No. 6	Y-Zeolite, modulus 60 ZSM-5, modulus > 400	(EA) ₂ Pt(OH) ₆	97	2.2 : 1	3.17	Spray calcination
E3	No. 6	Y-Zeolite, modulus 60 ZSM-5, modulus > 400	(EA) ₂ Pt(OH) ₆	97	2.2 : 1	3.17	none
E4	No. 6	Y-Zeolite, modulus 60 ZSM-5, modulus > 400	(EA) ₂ Pt(OH) ₆	66	1.2 : 1	1.06	Spray calcination
E5	No. 6	Y-Zeolite, modulus 60 ZSM-5, modulus > 400	[Pt(NH ₃) ₄](NO ₃) ₂	97	2.2 : 1		Spray calcination
E6	No. 6	Y-Zeolite, modulus 60 ZSM-5, modulus > 400	[Pt(NH ₃) ₄](OH) ₂	97	2.2 : 1	3.17	Spray calcination

Application Example 1

The catalytic activity of the exhaust gas purification catalysts of the above examples was measured with a model gas test unit. This unit can simulate all the gaseous exhaust gas components of the actual exhaust gas from a diesel engine. The test conditions and model gas composition can be inferred from Table 4. Propene was used as hydrocarbon component.

Table 4: Test conditions and model gas composition for the determination of the conversion rates of the pollutants CO, HC, NO_x and SO₂ in the model gas test unit.

Component	Concentration	
CO	350	[vppm]
H ₂	117	[vppm]
C ₃ H ₆	90	[ppmC ₃]
SO ₂	20	[vppm]
NO	270	[vppm]
O ₂	6	[vol.-%]
H ₂ O	10	[vol.-%]
CO ₂	10.7	[vol.-%]
N ₂	balance	
amount of gas	1950	[NI/h]*
size of catalyst	Ø 25 mm x 76 mm	
space velocity	50000	[h ⁻¹]
heating rate	15	[°C/min]

10 * l/h under normed conditions (pressure :101.3 kPa, temperatur: 0°C).

For measuring the gas components present in the exhaust gas, the measuring devices listed in Table 5 were used.

Table 5: List of the measuring devices used for measuring the exhaust gas concentration in the model gas test unit

Analyzed gas	Measuring device	Manufacturer
O ₂	Oxymat	Siemens AG
hydrocarbon	FID	Pierburg Meßtechnik
NO _x	CLD 700 Elht	Zellweger ECO-Systeme
CO	Binos	Rosemount
CO ₂	Binos	Rosemount
SO ₂	Binos	Rosemount

The measurements were carried out both with fresh and aged catalysts (oven aging: 48
 5 hours at 350 °C in the model exhaust gas flow: space velocity 15,000 h⁻¹, 10 vol.-% H₂O, 10 Vol.-% O₂, 10 vol.-% CO₂, 85 vol.-ppm SO₂, 270 vol.-ppm NO, balance N₂).

The exhaust gas was heated at a rate of 15 °C/min in order to determine the light-off temperatures.

The following formula was used for the calculation of the conversion rates:

$$10 \quad X = \frac{N_E - N_A}{N_E} \cdot 100\%$$

X = conversion rate [%]

NE = concentration of the pollutant before entering the catalyst [vol.-ppm]

NA = concentration of the pollutant after exiting the catalyst [vol.-ppm]

The measuring results for both the fresh and the aged catalysts are shown in Table 6.
 15 Table 6 also lists the sulfur concentration of the aged catalysts, determined by post-mortem analysis using a combined combustion/IR spectrometric method (LECO Instruments).

Table 6 clearly shows that the catalysts of the present invention prepared in Examples E1 to E6 exhibit an excellent sulfur-resistance, contrary to the comparative catalysts
 20 from Comparative Examples CE1 to CE4. This becomes obvious from the very low sulfur uptake by the catalysts of the present invention on the one hand and the still excellent catalytic activity after aging on the other hand.

Table 6: Catalytic activity of the catalysts from the examples in a fresh state and after oven aging, as well as sulfur uptake of the aged catalysts

Catalysts	Fresh		Aged ¹		
	T _{50,CO}	T _{50,HC}	T _{50,CO}	T _{50,HC}	S-Conc.
	[°C] ²	[°C]	[°C]	[°C]	[%] ³
CE1	144	158	161	174	0.90
CE2	155	169	185	201	1.50
CE3	149	166	169	189	1.20
CE4	152	165	170	182	0.61
E1	145	155	146	155	0.10
E2	141	152	141	153	0.10
E3	144	155	144	157	0.10
E4	185	193	186	193	0.08
E5	153	162	155	164	0.10
E6	151	158	153	159	0.11

¹ Oven aging for 48 hours at 350 °C in the model exhaust gas flow: space velocity 15,000 h⁻¹, 10 vol.-% H₂O, 10 vol.-% O₂, 10 vol.-% CO₂, 85 vol.-ppm SO₂, 270 vol.-ppm NO, balance N₂

² catalytic activity of the catalysts characterized by the so-called light-off temperature, at which 50% of the pollutants are converted

³ determination of the sulfur concentration of the aged catalysts by post-mortem analysis using a combined combustion/IR spectrometric method (LECO Instruments).

Application Example 2

In a second Application Example, the catalytic activity of the exhaust gas purification catalysts of the above exemplary catalysts was measured both in a fresh and in an aged state in an actual diesel engine exhaust gas. Aging was carried out by repeatedly passing through the aging cycle depicted in Figure 1. Aging was carried out in a modern automobile diesel engine with a displacement volume of 1.9 L. For this aging process, a diesel fuel containing 2400 wt.-ppm sulfur, which is 10 times more than in conventional diesel fuels, was used. This ensured that the catalysts would age much faster. The evaluation of the catalytic activity and the physicochemical data of the examined

catalysts correspond to the actual aging of a catalyst after about 30,000 kilometers. This aging is representative of a catalyst aged during driving in actual traffic.

5 The catalytic activity was determined with the engine by a so-called light-off test. For this purpose, the catalyst was first conditioned with diesel exhaust gas for 5 minutes at an exhaust gas temperature of 100 °C. Then a stepwise test was carried out wherein every 20 minutes the exhaust gas temperature was increased by 10 °C. The increase in the exhaust gas temperature was achieved by increasing the load on the engine.

The light-off temperatures of the examined catalysts in the fresh and the aged states are listed in Table 7 by giving the T₅₀-temperatures for CO and HC.

10 Table 7 also contains additional physicochemical post-mortem data of the aged catalysts. The sulfur concentration was determined using the LECO method, and the specific surface areas were determined using the BET method according to DIN 66131.

15 Table 7 shows that engine aging hardly decreases the catalytic activity of the catalysts of the present invention prepared in Examples E1 to E6, whereas the comparative catalysts of Comparative Examples CE1 to CE4 show a considerable decrease in catalytic activity. The physicochemical analyses show that the deterioration is due to the decrease in the specific surface area caused by a "clogging of the pores", adsorbed hydrocarbons and the incorporation of large amounts of the catalyst poison sulfur. Due to the chemistry and morphology of the employed support materials, the catalysts of the present invention prepared in Examples E1 to E6 do not exhibit these effects.

20

Table 7: Catalytic activity and physicochemical characterization of the catalysts of the examples in a fresh state and after engine aging (45 hours with diesel fuel containing 2400 wt.-ppm sulfur)

Catalyst	Fresh			Aged			
	T _{50,CO}	T _{50,HC}	BET	T _{50,CO}	T _{50,HC}	BET	S-Conc.
	[°C] ¹	[°C]	[m ² /g] ²	[°C]	[°C]	[m ² /g]	[%] ³
CE1	110	168	33	154	193	23	0.98
CE2	125	173	51	175	208	18	1.47
CE3	115	176	31	165	201	22	1.37
CE4	123	171	45	166	197	33	0.71
E1	114	173	36	115	176	36	0.10
E2	110	170	36	110	175	36	0.10
E3	112	170	35	113	172	35	0.09
E4	135	191	29	137	194	29	0.07
E5	121	182	35	123	185	35	0.09
E6	120	179	35	122	182	36	0.10

5 ¹ catalytic activity of the catalysts characterized by the so-called light-off temperature, at which 50% of the pollutants are converted

² determination of the specific surface area of the catalysts using the BET method

³ determination of the sulfur concentration of the aged catalysts by post-mortem analysis using a combined combustion/IR spectrometric method (LECO

10 Instruments).

CLAIMS

1. Catalyst for the purification of exhaust gases from an internal combustion engine comprising a catalytically active coating on an inert ceramic or metal honeycomb body, said coating comprising at least one platinum group metal selected from the group consisting of platinum, palladium, rhodium and iridium on a fine, oxidic support material, wherein the oxidic support material is a low-porosity material on the basis of silicon dioxide and comprises aggregates of essentially spherical primary particles having an average particle diameter of between 7 and 60 nm.
5
2. Catalyst according to claim 1, wherein the oxidic support material has an average particle diameter of the primary particles of between 20 and 50 nm.
10
3. Catalyst according to claim 2, wherein the oxidic support material has a pore radius distribution with a maximum above 20 nm.
4. Catalyst according to claim 3, wherein the oxidic support material has a pore volume wherein the portion of the pore volume with pore diameters of less than 30 nm is less than 0.2 ml/g.
15
5. Catalyst according to claim 4, wherein the pH value of a 4 weight-% aqueous dispersion of the support material is less than 6.
6. Catalyst according to claim 1, wherein the support material is doped with one or more oxides selected from the group consisting of aluminum oxide, zirconium oxide, alkaline-earth metal oxides and rare earth oxides and wherein the total weight of all doping elements is between 0.01 and 20 wt.-%, based on the total weight of the support material.
20
7. Catalyst according to claim 6, wherein the support material is doped with aluminum oxide in an amount of between 0.05 and 1 wt.-%.
8. Catalyst according to claim 1, wherein the oxidic support material is a silicic acid pyrogenically prepared by means of flame oxidation or flame hydrolysis.
25
9. Catalyst according to claim 1, wherein one of the platinum group metals is platinum.

10. Catalyst according to claim 9, wherein the catalytically active coating additionally comprises one or more zeolites on which platinum is present in a highly disperse form.
- 5 11. Catalyst according to claim 10, wherein one of the zeolites is a dealuminated Y-zeolite, a beta-zeolite, or a ZSM-5 zeolite, each with a modulus of more than 40.
12. Catalyst according to claim 10, wherein the weight ratio of the oxidic support material to the zeolite(s) is 6:1 to 1:2.
- 10 13. Catalyst according to claim 10, wherein at least 1 wt.-% but not more than a maximum of 20 wt.-% of the total amount of platinum present in the catalytically active coating is present on the zeolite(s).
14. Catalyst according to claim 1, wherein the catalytically active coating is present on the honeycomb body in a concentration of 40 to 300 g/l honeycomb body volume.
- 15 15. Catalyst according to claim 14, wherein the platinum group metals are present in a concentration of 0.01 to 8 g/l honeycomb body volume.
16. Catalyst according to claim 1, wherein the oxidic support material has the following properties:
 - 20 a) it comprises aggregates of essentially spherical primary particles having an average particle diameter of between 15 and 60 nm,
 - b) the specific surface area is between 30 and 150 m²/g,
 - c) the maximum of the pore radius distribution is above 20 nm,
 - d) the total volume of pores having a pore diameter of less than 30 nm is less than 0.2 ml/g, and
 - 25 e) the pH value of a 4 weight-% aqueous dispersion of the support material is less than 6.
17. Catalyst according to claim 16, wherein the specific surface area of the silicon dioxide is less than 100 m²/g.
- 30 18. Catalyst according to claim 16, wherein the catalyst additionally comprises one or more zeolites, wherein the weight ratio of silicon dioxide to the zeolites is between 6:1 to 1:2.

19. Catalyst according to claim 18, wherein the platinum group metal comprises platinum, said platinum being present both on the silicon dioxide and on the zeolite(s), wherein at least 1 wt.-% but not more than a maximum of 20 wt.-% of the total amount of platinum present in the catalyst is present on the zeolite(s).
- 5 20. Process for the preparation of a catalyst for the purification of exhaust gases from an internal combustion engine comprising a catalytically active coating on an inert ceramic or metal honeycomb body, said coating comprising at least one platinum group metal selected from the group consisting of platinum, palladium, rhodium and iridium on a fine, oxidic support material, wherein the oxidic support material
10 is a low-porosity material on the basis of silicon dioxide and comprises aggregates of essentially spherical primary particles having an average particle diameter of between 7 and 60 nm, the method comprising the step of coating the honeycomb body with a coating suspension containing the oxidic support material, wherein the oxidic support material is used in spray-dried form having a compacted bulk
15 density of more than 200 g/l for the preparation of the coating suspension.
21. Process according to claim 20, wherein the compacted bulk density is more than 500 g/l.
22. Process according to claim 20, wherein at least one platinum group metal is applied to the oxidic support material before preparation of the coating
20 suspension.
23. Process according to claim 22, wherein the coating suspension additionally comprises one or more zeolites in a weight ratio of the oxidic support material to the zeolite(s) of 6:1 to 1:2.
24. Process according to claim 23, wherein the at least one platinum group metal
25 comprises platinum.
25. Process according to claim 24, wherein platinum is present on the zeolite(s) in an amount of 1 to 20 wt.-%, based on the total amount of platinum on the oxidic support material and the zeolite(s).
26. Process according to claim 20 or 21, wherein after coating the honeycomb body with the coating suspension containing the oxidic support material, the coated
30 honeycomb body is dried and calcined and subsequently the thus prepared coated

honeycomb body is impregnated with a precursor of at least one platinum group metal.

27. Process according to claim 26, wherein the at least one platinum group metal comprises platinum.
- 5 28. Process according to claim 27, wherein the coating suspension additionally comprises one or more zeolites in a weight ratio of the oxidic support material to the zeolite(s) of 6:1 to 1:2.
29. Use of the catalyst according to any of claims 1 to 19 for the purification of exhaust gases from diesel engines.

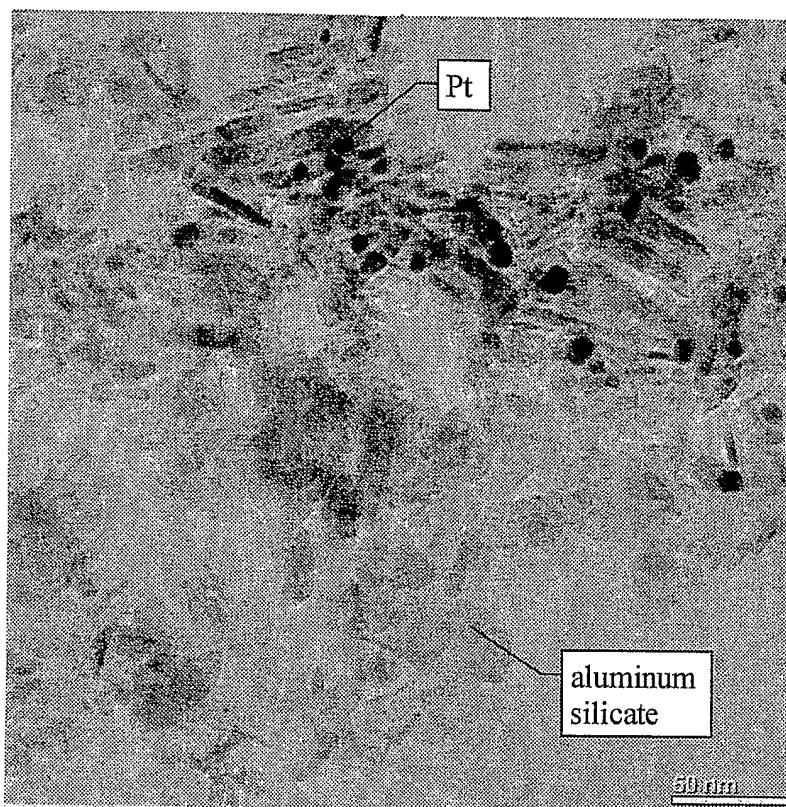


Figure 1

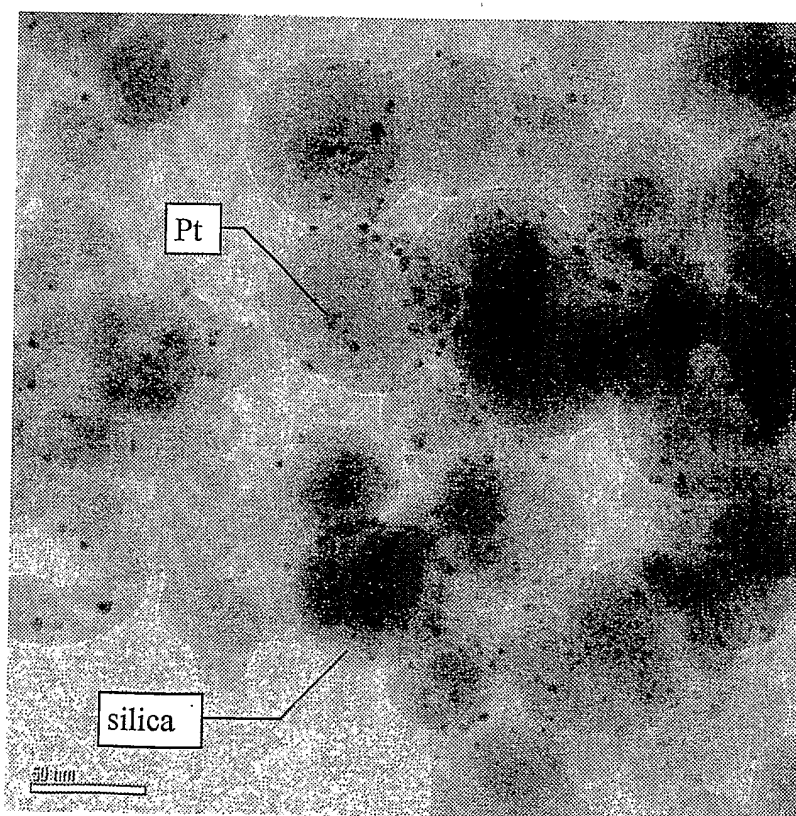


Figure 2

INTERNATIONAL SEARCH REPORT

Internati	Application No
PCT/EP	02/08890

A. CLASSIFICATION OF SUBJECT MATTER		
IPC 7	B01J21/08 B01J35/02	B01J23/40 B01J37/00
	B01J35/10 B01J37/02	B01J37/08 B01J35/04
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
IPC 7 B01J		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
EPO-Internal, PAJ, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 002 918 A (DELLER KLAUS ET AL) 26 March 1991 (1991-03-26) column 2, line 64 -column 3, line 2 column 3, line 15 - line 16 column 1, line 61 column 1, line 20 claims 1,5; examples 2,5,7	1-3,5-8, 10-12, 14,25, 26,29
Y	PATENT ABSTRACTS OF JAPAN vol. 1997, no. 01, 31 January 1997 (1997-01-31) & JP 08 243397 A (NISSAN MOTOR CO LTD), 24 September 1996 (1996-09-24) abstract ----- -/--	1-3,5-8, 10-12, 14,25, 26,29
<input checked="" type="checkbox"/> Further documents are listed in the continuation of box C. <input checked="" type="checkbox"/> Patent family members are listed in annex.		
° Special categories of cited documents :		
A document defining the general state of the art which is not considered to be of particular relevance *E* earlier document but published on or after the international filing date *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) *O* document referring to an oral disclosure, use, exhibition or other means *P* document published prior to the international filing date but later than the priority date claimed		*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. *&* document member of the same patent family
Date of the actual completion of the international search	Date of mailing of the international search report	
5 November 2002	13/11/2002	
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Jochheim, J	

INTERNATIONAL SEARCH REPORT

Internati	Application No
PCT/EP	02/08890

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>EP 0 807 615 A (DEGUSSA) 19 November 1997 (1997-11-19) page 2, line 31-38 page 3, line 28 - line 30 page 7; figure 1</p> <p style="text-align: center;">---</p>	1-3,25
A	<p>EP 0 916 402 A (DEGUSSA) 19 May 1999 (1999-05-19) page 2, line 35 - line 45 page 3, line 40 - line 41 page 7</p> <p style="text-align: center;">---</p>	1,2,25
A	<p>PATENT ABSTRACTS OF JAPAN vol. 018, no. 248 (C-1198), 12 May 1994 (1994-05-12) & JP 06 031174 A (NISSAN MOTOR CO LTD), 8 February 1994 (1994-02-08) abstract</p> <p style="text-align: center;">---</p>	1-3,5-8, 10-12, 14,25, 26,29
A	<p>US 5 976 480 A (KLEINSCHMIT PETER ET AL) 2 November 1999 (1999-11-02) column 1, line 57 -column 2, line 24; example 2; table 1</p> <p style="text-align: center;">-----</p>	8

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