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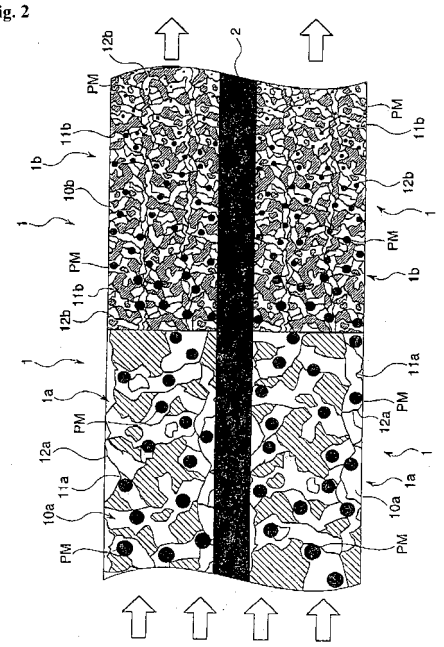
(54) PLASMA REACTOR ELECTRODE

(57) [Object] To provide a plasma reactor electrode capable of effectively removing PM (particulate matter) while suppressing increase of an exhaust pressure of an exhaust gas.

[SolutionMeans] A plasma reactor electrode installed in a plasma reactor P, disposed in an exhaust gas flow path H through which an exhaust gas passes, includes at least a low specific surface area region 1a in the exhaust gas flow path H and a high specific surface area region 1b, having a specific surface area higher than the specific surface area of the low specific surface area region.

Fig. 2



EP 2 022 953 A1

Description

Technical Field

[0001] The present invention relates to a plasma reactor electrode used in an apparatus, etc., for removing components contained in a smoke exhaust discharged from a factory, plant, internal combustion engine, etc., and having an adverse effect on an environment.

Background Art

[0002] As conventional methods for reducing emission amounts of CO (carbonmonoxide), HC (hydrocarbons), NOx (nitrogen oxides), and PM (particulate matter) contained in an exhaust gas discharged, for example, from an automobile engine and particularly from a diesel engine, generally, a catalyst (including an SCR) is used for CO, HC, and NOx, and a DPF (diesel particulate filter) is used for PM. However, with a DPF, as a collection rate of PM increases, a state of poor flow of exhaust gas, that is, a state of high exhaust pressure occurs and causes lowering of engine output. To avoid this, a method of forcibly combusting and removing the accumulated PM by increasing a temperature of the exhaust gas (forced combustion) is used with a DPF. Because generally to increase the temperature of the exhaust gas, fuel is intentionally fed to the catalyst by post injection or injector injection and a reaction heat generated in this process is used, excess fuel besides that used for engine combustion is necessary and consequently, degradation of fuel consumption occurs.

[0003] As a system capable of avoiding the above issue seen with DPFs, there is known a configuration using a plasma reactor in an exhaust gas purifying apparatus including a catalyst. For example, a plasma reactor described in Patent Document 1 has a plasma inducer that generates plasma. After putting the plasma in contact with an exhaust gas, the exhaust gas is passed through a filter to make soot particles, in other words, the PM in the exhaust gas be retained in the filter and the PM is combusted by the plasma.

[0004] Meanwhile, there also has been developed an art employing a porous electrode having a porous structure and exhibiting both an action of generating plasma inside the pores to combust the PM by the plasma and an action of improving combustion by increasing a retention time of the PM by detour of the exhaust gas inside the porous structure and capture of the PM inside the pores (for example, Japanese Patent Application No. 2005-292998 Specification).

Patent Document 1: Japanese Unexamined Patent Application Publication No. 2002-339731

Disclosure of the Invention

Problems to be Solved by the Invention

[0005] When a filter with a porous structure is disposed adj acent an electrode or a porous electrode having a porous structure is employed as in the abovementioned documents, although an area of contact with the PM can be increased to facilitate capture of the PM and combustion of the PM, in a case where the plasma generated by the electrode does not act adequately on the PM, the PM is not removed and becomes clogged inside the reactor or is discharged as it is.

[0006] Although to improve the PM capturing performance, use of a filter or porous electrode of smaller pore diameter, in other words, a higher specific surface area can be considered, when a porous structure with a shape of high specific surface area is selected, an issue of increased exhaust pressure of the exhaust gas arises. In addition, the PM remains captured inside the pores of the filter or the porous electrode, causing clogging of the filter and further increase of the exhaust pressure.

[0007] An object of the present invention is to provide a plasma reactor electrode capable of effectively removing PM (particulate matter) while suppressing increase of exhaust pressure of an exhaust gas.

Means for Solving the Problems

[0008] To achieve the above object, the present invention provides the following. That is, a plasma reactor electrode according to a first aspect of the present invention is installed in a plasma reactor, disposed in an exhaust gas flow path through which an exhaust gas passes, and includes: a first region, having a first specific surface area (low specific surface area region) ; and a second region, having a second specific surface area (high specific surface area region) higher than the first specific surface area.

[0009] Here, the present inventors have confirmed that the lower the specific surface area of the electrode, the higher the light emission luminance (FIG. 5). In addition, the present inventors found that the higher the light emission luminance in a process of plasma generation from the electrode, the greater a difference of PM removal rate between a plasma generating state and a plasma non-generating state (FIG. 5).

Thus with the plasma reactor electrode according to the first aspect of the present invention, the low specific surface area region is preferably positioned upstream the high specific surface area region in the exhaust gas flow path.

[0010] With the plasma reactor electrode with the above configuration, by disposing the low specific surface area region at the upstream side in the exhaust gas flow path, a large amount of plasma can be generated at the upstream side, the PM can be captured reliably by disposing the high specific surface area region of high

PM capturing performance at the downstream side, and the PM can be oxidized, in other words, combusted favorably by an action of the plasma generated in the high specific surface area region and the plasma or a plasma-activated exhaust gas component generated at the low specific surface area region at the upstream side and moving along with the exhaust gas to the downstream side.

[0011] Here, the present invention is not limited to a mode where the low specific surface area region and the high specific surface area region are disposed integrally, and these regions may respectively be separate bodies. Also, the low specific surface area region and the high specific surface area region may be disposed apart from each other.

[0012] It has been confirmed that the light emission luminance of the plasma is significantly high in a region with a specific surface area of no more than 1000m2/m3, and by disposing the region with the specific surface area of no more than 1000m2/m3 as the low specific surface area regionpositioned at the upstream side in the exhaust gas flow path, the plasma exhibiting the high light emission luminance can be made to act on the PM not only in the low specific surface area region but also in the high specific surface area region at the downstream side to which the plasma moves along the exhaust gas flowpath. Aconfiguration is thus realized where the plasma can be made to act favorably in the high specific surface area capable of adequately capturing the PM.

[0013] A plasma reactor electrode according to a second aspect of the present invention includes a region having a specific surface area of no more than 1000m2/m3 and region differing from the aforementioned region and having a specific surface area of no less than 1000m2/m3.

[0014] With this arrangement, by the region having the specific surface area of no more than 1000m2/m3, the PM removal performance can be improved effectively by the plasma exhibiting the high light emission luminance as described above, and by the region having the specific surface area of no less than 1000m2/m3, the PM capturing performance can be improved effectively, thereby realizing an electrode enabling capture of the PM at a high probability while enabling the plasma generated in a state of high light emission luminance to react with the captured plasma.

[0015] Preferably, a region constituting a porous structure is included to further facilitate the capture of the PM.

[0016] Furthermore preferably, as a configuration for increasing the light emission luminance of the plasma, a region, having a structure where a plurality of protrusions, at which charges concentrate, are formed on a surface, may be included.

Effects of the Invention

[0017] With the first aspect of the present invention including, in the exhaust gas flowpath, the low specific surface area region and the high specific surface area region, having the specific surface area higher than the specific surface area of the low specific surface area region, while capturing the PM at a high probability by significant improvement of the PM capturing performance by the provision of the high specific surface area region, increase of the exhaust pressure of the exhaust gas can be suppressed by the provision of the low specific surface area region.

Also, by disposing the high specific surface area region at the downstream side of the low specific surface area region in the exhaust gas flow path, a large amount of plasma can be generated at the upstream side, the PM can be captured reliably by the high specific surface area region of high PM capturing performance disposed at the downstream side, and the PM can be oxidized, in other words, combusted favorably by the action of the plasma, generated in the high specific surface area region, and the plasma, moving to the downstream side along with the exhaust gas that has passed through the plasma field generated by the low specific surface area region at the upstream side.

[0018] With the second aspect of the present invention including the region having the specific surface area of no more than 1000m2/m3 and the region having the specific surface area of no less than 1000m2/m3, while capturing the PM at a high probability by significant improvement of the PM capturing performance by the provision of the region having the specific surface area of no less than 1000m2/m3, increase of the exhaust pressure of the exhaust gas can be suppressed by the provision of the region having the specific surface area of no more than 1000m2/m3.

[0019] A plasma reactor electrode capable of effectively removing PM (particulate matter) while suppressing increase of an exhaust pressure of an exhaust gas can thus be provided.

Brief Description of the Drawings

[0020]

FIG. 1 is a schematic view of a plasma reactor according to an embodiment of the present invention.

FIG. 2 is an explanatory diagram of principal portions of the same embodiment.

FIG. 3 is an explanatory diagram of a configuration of an electrode of a modification example of the same embodiment.

FIG. 4 is an explanatory diagram of a configuration of an electrode of another modification example of the same embodiment.

FIG. 5 is a diagram of a relationship of a specific surface area of an electrode and a radiation luminance by plasma.

FIG. 6 is a diagram of a relationship of the specific surface area of the electrode and a PM removal rate.

FIG. 7 shows photographs taken during plasma light

emission from a porous electrode and a wave foil electrode.

FIG. 8 is a diagram of a relationship of the specific surface area of the electrode, the PM removal rate, and a maximum exhaust pressure.

Best Modes for Carrying Out the Invention

[0021] An embodiment according to the present invention shall now be described with reference to the drawings.

[0022] As shown in FIGS. 1 and 2, a plasma reactor P according to the present embodiment is installed in an exhaust gas flow path H through which an exhaust gas discharged, for example, from a diesel engine or other internal combustion engine E passes, and has a structure where electrodes 1 and dielectrics 2 are laminated alternately in an interior of a casing P1 of the plasma reactor P. The exhaust gas passes through along a direction indicated by arrows in which the electrodes 1 and the dielectrics 2 extend. In FIG. 2, particulate matter PM, indicated by PM, is illustrated schematically.

[0023] Each dielectric 2 is disposedbetween two of the electrodes 1 as shown in FIG. 2, and although in the present embodiment, a plate material composed of alumina is employed, the present invention is not limited by this configuration of the dielectrics 2 and dielectrics of various shapes may be employed.

[0024] Here, each plasma reactor electrode 1 according to the present embodiment is installed in the plasma reactor P disposed in the exhaust gas flow path H through which the exhaust gas passes and is characterized in including at least a low specific surface area region (first region) 1a positioned at an upstream side in the exhaust gas flow path H and a high specific surface area region (second region) 1b having a higher specific surface area than the low specific surface area region 1a.

[0025] The electrode 1 according to the present embodiment is characterized in including a region in which the specific surface area is no more than 1000m2/m3, that is, the low specific surface area region 1a having openings of pore diameter no less than a fixed dimension, and a region in which the specific surface area is no less than 1000m2/m3, that is, the high specific surface area region 1b having openings of pore diameter no more than the fixed dimension.

The specific surface area can be measured in compliance with ISO 9277.

[0026] A specific configuration of the electrode 1 shall now be described specifically.

[0027] In the present embodiment, the electrode 1 is composed, for example, of nickel or copper. As shown in FIG. 2, the low specific surface area region 1a and the high specific surface area region 1b are configured as porous structures. Although unillustrated, in the present embodiment, the low specific surface area region 1a and the high specific surface area region 1b are connected, for example, by brazing, and for the connection, any of various conductive materials having heat resistance may be employed and a method for connection is not restricted to brazing and any of various existing connection methods may be employed.

[0028] The electrode 1 has the porous structure shown specifically in FIG. 2 in likewise manner in both the low specific surface area region 1a and the high specific surface area region 1b. That is, the respective surfaces have shapes with practically no flat portions and have a plurality of penetrating pores 10a and 10b penetrating through at least from one surface to another surface, a plurality of recesses 11a and 11b that are depressed at the respective surfaces but do not penetrate through, and a plurality of protrusions 12a and 12b. The respective surfaces have uneven shapes and have height differences formed across substantially the entireties, and the protrusions 12a and 12b become portions at which charges concentrate when a voltage is applied to the electrodes 1 and contribute to improving efficiency of plasma discharge. The recesses 11a and 11b are not necessarily required and may be formed as portions lower than the protrusions 12a and 12b by the forming of the protrusions 12a and 12b. The penetrating pores 10a and 10b do not necessarily have to penetrate directly through from one surface to another surface. It suffices that upon installation in the plasma reactor P, the exhaust gas can pass through from an upstream side to a downstream side. In this case, the penetrating pores 10a and 10b do not necessarily have to be straight and may be bent or branched in a forked or triple forked manner, etc. The penetrating pores 10a and 10b have, at inner walls thereof, uneven shapes similar to the shapes of the surfaces, and in recessed portions thereof or between the inner walls, effectively obstruct movement of the particulate matter PM and other matter contained in the exhaust gas and in some cases temporarily capture the particulate matter PM so that a time taken for the particulate matter PM to pass through the electrode 1 exceeds a time required for the plasma to combust the particulate matter.

[0029] As shown in FIG. 2, the low specific surface area region 1a has the specific surface area no more than 1000m2/m3 and includes the penetrating pores 10a that open at no less than fixed dimension and is thereby set to make a light emission luminance of the plasma high and enabled to make the exhaust gas in the low specific surface area region 1a be activated, that is, have a high energy. In the present embodiment, a low specific surface area region exhibiting, for example, a specific surface area of 500m2/m3 and having openings of approximately 1.9mm diameter is employed.

[0030] The specific surface area of the high specific surface area region 1b is set higher than that of the low specific surface area region 1a to improve the particulate matter PM capturing performance. In the present embodiment, the high specific surface area region has, for example, a specific surface area of 1250m2/m3 and has penetrating pores 10b with openings of approximately 0.9mm diameter. By the specific surface area being no

less than 1000m2/m3 and the openings being no more than a fixed dimension, an inner diameter or inner dimension of the penetrating pores 10b can be set to a dimension that makes the penetrating pores 3 in the high specific surface area region 1b particularly difficult to pass through. The particulate matter PM can thereby be lowered in speed of passage through the penetrating pores 10b and be retained inside the electrode 1 for no less than a predetermined time in which the particulate matter PM can be combusted by the plasma. However, because of not being closed alternately as in a DPF, a pressure loss can be made low. Although the recesses 11b are not limited in size and shape, a size enabling the particulate matter PM to be adsorbed readily by a diffusion mechanism is preferable.

[0031] With this configuration, the exhaust gas flows into the penetrating pores 10a of the low specific surface area region 1a from the upstream side, passes through the penetrating pores 10a, and moves into the penetratingpores 10b of the high specific surface area region 1b at the downstream side as shown in FIG. 2.

[0032] When the exhaust gas passes through the electrode 1, substantially all of the particulate matter PM contained in the exhaust gas flows downstream along the interiors of the penetrating pores 10a and 10b of the respective electrodes 1 while being impeded in movement and being detoured by being temporarily captured, etc., in some cases. Each electrode 1 thus also functions as a filter with respect to the particulate matter PM. Because carbon particles constitute a main element of the particulate matter PM, the captured particulate matter PM also functions as a portion of the electrodes 1. Thus, when a voltage is applied to the electrodes 1, electrons 1 are discharged from the electrode 1 itself as well as from the captured particulate matter PM and plasma discharge is thereby started. Thus, even if the particulate matter PM are collected, the plasma can be generated without lowering of discharge efficiency.

[0033] In particular, because while the plasma is generated in a state of high light emission luminance from the low specific surface area region 1a having the penetrating pores 10a with openings of 1.9mm diameter so that the specific surface area is no more than 1000m2/m3 to make the exhaust gas inside the plasma reactor P have a high energy so that a state enabling removal of the particulate matter PM at a high proportion is attained, the particulate matter PM retention time can be secured reliably by the high specific surface area region 1b having the penetrating pores 10b with openings of 0.9mm diameter so that the specific surface area is no less than 1000m2/m3, the particulate matter PM captured in the penetrating pores 10a and 10b are successively combusted from surfaces thereof and made small in diameter and finally removed by being oxidized completely as schematically shown in FIG. 2. The penetrating pores. 10a and 10b thus do not become clogged and even if the exhaust gas is supplied to the plasma reactor P continuously, the exhaust pressure at the electrode 1 does not rise. Increase of the exhaust pressure, such as that occurring in a DPF, due to clogging of the penetrating pores 10a and 10b can thus be prevented, and upon employment in a diesel engine, degradation of fuel consumption and lowering of output can be prevented effectively.

As a method for preparing a porous body, a known method, such as a method disclosed in Japanese Unexamined Patent Application Publication No. S53-65206, Japanese Unexamined Patent Application Publication No. S62-263974, or Japanese Unexamined Patent Application Publication No. H11-217602 may be used.

<Modification Example>

[0034] A modification example related to the present embodiment shall now be described with reference to FIG. 3. Portions of the present modification example having the same configuration as those of the embodiment described above shall be provided with the same symbols and detailed description thereof shall be omitted.

[0035] A plasma reactor electrode A1 according to the modification example of the present embodiment employs a metal plate A1 having, as the low specific surface area region 1a, a structure with a plurality of cut surfaces A14 formed on a surface as charge-concentrating protrusions.

[0036] As the metal plate A1, that composed of a metal such as nickel, copper, iron, stainless steel, tungsten, etc., can be cited as an example. A thickness of the electrode A1 is for example 200×10-6m (meters) and is not limited to this value as long as a strength adequate for maintaining the substantially wave-like shape mentioned above can be obtained.

[0037] As shown in FIG. 3, the metal plate A1 includes raised portions A11 and depressed portions A12 in a continuous, alternating manner in a lateral direction. The metal plate A1 also has the raised portions A11 and the depressed portions A12 in a continuous, alternating manner in a longitudinal direction.

Here, the longitudinal direction is a direction in which the exhaust gas flows (direction indicated by arrows in FIG. 3). Meanwhile, the lateral direction is a direction substantially orthogonal to the longitudinal direction. The specific surface area of the metal plate A1 is no more than 1000m2/m3 as in the embodiment described above.

[0038] By the depressed portion A12 continuing alternately between the raised portion A11 and the depressed portion A12 in the longitudinal direction of the metal plate A1, a plurality of, that is, several cut surfaces A14 exposed toward the longitudinal direction are formed at the boundaries of the raised portions A11 and the depressed portions A12 in the same manner as at an end surface A13 of the metal plate A1 in the longitudinal direction. An opening of 5mm diameter is formed by each cut surface A14. The cut surfaces A14, which are portions where charges generated upon application of voltage to the electrode 1 concentrate, may be formed, for example, by cutting a raised portion A11 that is continuous in the lon-

gitudinal direction to depress the raised portion A11 at predetermined intervals. The present modification example has a shape where, in the lateral direction, the raised portions A11 and the depressed portions A12 continue alternately at portions and the raised portions A11 and the depressed portions A12 are continuous at other portions, and the present invention includes such a shape, and although not illustrated, the present invention obviously also includes a structure where raised portions A11 and depressed portions A12 of the same length continue alternately in the lateral direction.

[0039] Such a metal plate A1 can be manufactured for example by passing a metal plate material between two rotating bodies, having recesses and protrusions, while pressing the metal plate material. Thus, by continuously processing metal plate materials of a predetermined width, the metal plates A1 of the same shape can be manufactured readily, thereby enabling reduction of manufacturing cost. Moreover, by using a metal plate material of thinplate thickness as in the first embodiment, lightweightness and reduction of pressure loss can be achieved.

<Another Modification Example>

[0040] In another modification example, a metal plate B1, having a plurality of charge-concentrating portions formed by cutting and raising so as to protrude from one surface of a flat metal plate material, is employed as shown in FIG. 4 as the low specific surface area region 1a in a manner similar to the above-described modification example. That is, with the metal plate B1, protrusions B10, each having a triangular pyramidal shape formed by cutting and raising, are separated at predetermined distances, in other words, disposed at predetermined pitches in a longitudinal direction and a lateral direction. The longitudinal direction and the lateral direction are the same as those of the above-described modification example. As with the above-described embodiment and modification example, the specific surface area of the metal plate B1 is set to no more than 1000m2/m3.

[0041] With each protrusion B10, a bottom surface of the triangular pyramidal shape is made a penetrating pore and side surfaces B11 are formed so as to cover the penetrating pore. The two side surfaces B11 are separated at a front side in the longitudinal direction and are joined at a rear side in the longitudinal direction. An opening B12 of triangular shape is thereby formed at the front side in the longitudinal direction of the protrusion B10 and a cut surface B13 substantially equal to a plate thickness of the metal plate material is formed at a periphery of the opening B12. In the present embodiment, each protrusion B10 is disposed at an intermediate position between protrusions B10 in a front column so as not to overlap with a protrusion B10 in the front column. That is, the respective protrusions B10 are positioned so as to be centered at respective apexes of a triangular network.

[0042] With each protrusion B10, a ridge B14, formed by the respective side surfaces B11, and an apex B15, positioned above the opening B12, take on sharp shapes, and these, together with an edge forming the cut surface B13, cause the concentration of charges to be significant.

[0043] Even with the metal plate B1 of the above configuration, because a plurality of cut surfaces B13 are disposedprotrudingly, the same effects as those of the above-described embodiment are exhibited.

[0044] The protrusions B10 do not necessarily have to be disposed at predetermined pitches and may respectively be positioned randomly or arbitrarily. With the protrusions B10, although it is easy to manufacture those of the same height when a cutting and raising process is performed, the protrusions do not necessarily have to be made the same in height and it suffices that the protrusions have a clear cut surface B13 and a sharp apex B15.

[0045] As described above, with the electrodes 1 for the plasma reactor P according to the present embodiment, by including both the low specific surface area region 1a, having the specific surface area of no more than 1000m2/m3 and openings with the pore diameter of no less than the fixed dimension and being high in radiation luminance by plasma, that is, being high in particulate matter PM removal performance by the plasma, and the high specific surface area region 1b, having the specific surface area of no less than 1000m2/m3 and openings with the pore diameter of no more than the fixed dimension and being high in the particulate matter PM capture rate, the particulate matter PM removal performance by the plasma is made high by activation of the exhaust gas by the electrodes 1 as a whole and the time in which the particulate matter PM is retained inside the electrodes 1 and made to react with the plasma can be secured effectively. Moreover, the exhaust gas containing the particulate matter PM can be retained or temporarily captured for an adequate time by the high specific surface area region 1b upon the exhaust gas being put in a state of high energy by plasma being generated at high luminance in the low specific surface area region 1a. The plasma can thus be made to react favorably at an adequate activity and for an adequate reaction time with the particulate matter PM.

[0046] Because each electrode 1 includes the low specific surface area region 1a positioned at the upstream side in the exhaust gas flow path H and the high specific surface area region 1b positioned at the downstream side and having the specific surface area higher than that of the low specific surface area region 1a, the plasma is generated at the state of high light emission luminance at the upstream side, and by disposing the high specific surface area region 1b of high particulate matter PM passage inhibiting performance at the downstream side, the particulate matter PM can be oxidized, in other words, combusted favorably by action of the plasma, generated in the high specific surface area region 1b, and the plasma, generated at the low specific surface area region 1a at the upstream side and moving along with the activated

exhaust gas to the downstream side, while securing the particulate matter PM inside the electrode 1 reliably for an adequate time.

[0047] By positioning the region having the specific surface area of no more than 1000m2/m3 at which the radiation luminance by plasma is high in the low specific surface area region 1a positioned at the upstream side to activate the exhaust gas by the plasma exhibiting the high light emission luminance and by activating the exhaust gas by the plasma further while retaining it for a fixed time in the high specific surface area region 1b at the downstream side when the exhaust gas moves along the exhaust gas flow path H, the particulate matter PM can be positioned and oxidized/combusted in the exhaust gas that has been activated for an adequate time. The plasma can thus be made to act for an adequate time in the state where the exhaust gas is activated by the plasma in the high specific surface area capable of adequately retaining the particulate matter PM.

[0048] With the above-described embodiment, because the low specific surface area region 1a and the high specific surface area region 1b are configured as porous structures, the role of the electrode 1 can be served while retaining or temporarily capturing the particulate matter PM favorably.

[0049] Furthermore, with the respective modification examples described above, the low specific surface area region 1a is made to have a structure having the plurality of cut surfaces A14 or cut surfaces B13, which are charge-concentratingprotrusions, formed on the surface to make high the light emission luminance of the plasma favorably, readily activate the exhaust gas, and further improve the particulate matter PM removal performance by the plasma.

[0050] Although an embodiment of the present invention has been described above, specific configurations of the respective portions are not limited to those of the above-described embodiment and various modifications are possible within a range not deviating from the gist of the present invention.

[0051] For example, although in the embodiment described above, the low specific surface area region and the high specific surface area region are disposed along the direction of extension of the exhaust gas flow path, that is, the direction in which the exhaust gas flows, the low specific surface area region and the high specific surface area region may instead be disposed in a direction orthogonal to the direction in which the exhaust gas flows. Specifically, the specific surface areamaybe varied in the direction orthogonal to the direction of flow of the exhaust gas by respectively laminating electrodes having mutually different uniform specific surface areas, or the specific surface area may be varied in the orthogonal direction in a single electrode.

[0052] Furthermore, in consideration that when the exhaust gas flows through the plasma generator, the exhaust gas tends to concentrate at a central portion in the exhaust gas flow path, electrodes respectively differing in specific surface area may be positioned so that the plasma can be generated with priority at the center of the exhaust gas flow path. Or, electrodes respectively differing in specific surface areamaybepositioned so that the exhaust gas flows uniformly inside the exhaust gas flow path.

[0053] Although the low specific surface area region and the high specific surface area region are configured by an electrode having two types of specific surface areas, the present invention is not limited to this configuration. That is, the electrode configuration may be constituted of three or more regions having different specific surface areas and, for example, a structure, with which the specific surface area increases in multiple steps from the upstream side to the downstream side, may be employed.

[0054] Besides the above, the specific configurations of the respective portions are not restricted to those of the embodiment described above and various modifications are possible within a range not deviating from the gist of the present invention.

Examples

[0055] Although an example according to the present invention shall now be described, the present invention is not restricted to this example.

1. Plasma radiation luminance measurement test of porous electrodes

[0056] Measurement of the radiation luminance by plasma was performed on porous electrodes having four types of specific surface areas.

1.1 <Test Materials>

[0057] The following porous electrodes were tested:

#5: Porous electrode having a specific surface area of 500m2/m3 (pore diameter: approximately 1.9mm)
#8: Porous electrode having a specific surface area of 850m2/m3 (pore diameter: approximately 1.3mm)
#12: Porous electrode having a specific surface area of 1250m2/m3 (pore diameter: approximately 0.9mm)
#58 : Porous electrode having a specific surface area of 5800m2/m3 (pore diameter: approximately 0.45mm)

1.2 <Test Method>

[0058] Using a high-voltage pulse power supply with a 600Hz primary voltage being set to 100V to 300V, a 600Hz boosted secondary voltage of 2 to 6kV was applied to each electrode and the light emission luminance upon light emission due to plasma generation was measured. The power supply for plasma generation is config-

ured of the two stages of a primary power supply boosting up to 500V DC and a pulse power supply boosting up to 10kV.

1.3 <Test Results>

[0059] Test results are shown in a graph in FIG. 5. As shown in this figure, it was found that the lower the specific surface area, in other words, the larger the pore diameter, the higher the light emission luminance of the plasma. It was found that the radiation luminance by plasma is especially high with #5 and #8, with which the specific surface area is no more than 1000m2/m3.

2. PM removal rate measurement test of porous electrodes

[0060] The porous electrodes tested in the plasma radiation luminance measurement test were subject to a mode evaluation using a dynamometer. The respective PM removal rates in cases of employing the respective electrodes were measured.

2.1 <Test Materials>

[0061] The same porous electrodes as those tested in the plasma radiation luminance measurement test of porous electrodes were tested.

2.2 <Test Method>

[0062] In evaluating the PM removal rate in 10- and 15-mode evaluations using the dynamometer, the high-voltage pulse power supply set to a 600Hz primary voltage of 400V was used to apply a 600Hz boosted secondary voltage of 8kV to each electrode, and the PM removal rate during plasma generation (plasma on) and the PM removal rate when the voltage was not applied (plasma off) were measured respectively.

2.3 <Test Results>

[0063] The test results are shown in a graph in FIG. 6. In the figure, each arrow schematically indicates a difference between voltage application and non-application states for the same electrode. As shown in the figure, regardless of application and non-application of voltage, the PM becomes more readily trapped and the PM removal rate thus tends to increase as the specific surface area increases. However, the difference of PM removal rate due to current application in each electrode is higher the lower the specific surface area, in other words, the higher the light emission luminance in the plasma radiation luminance measurement test.

[0064] Thus, from these results, it canbe said that the radiation luminance by plasma and the PM removal rate due to the plasma are highly correlated. That is, it was found that with #5 and #8, with which the specific surface area is nomore than 1000m2/m3, the PM removal rate difference between the plasma generating state and the plasma non-generating state is large and PM removal by plasma can be performed effectively. It was found that with #12 and #58, with which the specific surface area is no less than 1000m2/m3, the PM removal rate is especially high.

3. Comparative plasma radiation luminance measurement test between the metal plate according to the modification example and the porous electrode

3.1 <Test Materials>

[0065] The porous electrode according to FIG. 2 employed as the low specific surface area region in the embodiment described above and a metal plate having the same configuration as the metal plate A1 shown in FIG. 3 employed in the modification example of the embodiment (referred to hereinafter and in the drawing as the "wave foil electrode") were tested. The wave foil electrode is made to have openings with a diameter of approximately 5mm.

3.2 <Test Method>

[0066] Using the high-voltage pulse power supply with a 600Hz primary voltage set to 100V to 300V, a 600Hz boosted secondary voltage of 2 to 6kV was applied to each electrode and the light emission luminance upon light emission due to plasma generation was measured.

3.3 <Test Results>

[0067] Plasma light emissions by the respective electrodes are shown in photographs in FIG. 7. As indicated at the lower right of each photograph in the figure, whereas the porous electrode (#5) indicated a relative value of 58.1, the wave foil electrode, having an even lower specific surface area and larger openings, exhibited a relative value of 73.3, thus showing that the wave foil electrode is higher in radiation luminance by plasma.

4. PM removal rate and exhaust pressure measurement test of porous electrodes

[0068] Plasma radiation luminance of three types of electrodes were measured.

4.1 <Test Materials>

[0069] The following porous electrodes were tested:

#5: Porous electrode having a specific surface area of 500m2/m3 (pore diameter: approximately 1.9mm)
#12: Porous electrode having a specific surface area of 1250m2/m3 (pore diameter: approximately 0.9mm)

#5+#12: Electrode having the porous electrode #5 at the upstream side of the exhaust gas flow path and the porous electrode #12 at the downstream side (referred to hereinafter and in the drawing as the "multi-stage electrode.")

4.2 <Test Method>

[0070] In evaluating the PM removal rate and the exhaust pressure in the 10- and 15-mode evaluations using the dynamometer, the high-voltage pulse power supply set to a 200Hz primary voltage of 400V was used to apply a 200Hz boosted secondary voltage of 8kV to each electrode, and the PM removal rate in the state of plasma generation and the maximum exhaust pressure at the respective electrodes during the mode tests were measured respectively.

4.3 <Test Results>

[0071] The test results are shown in graphs in FIG. 8. As can be seen from FIG. 8A, the multi-stage electrode according to the present invention indicated a high removal rate similar to that of #12. Meanwhile, as can be seen from FIG. 8B, it was found that the multi-stage electrode according to the present invention, although exhibiting a maximum exhaust pressure higher than #5, exhibits a significantly lower maximum exhaust pressure in comparison to #12 that exhibits practically the same PM removal rate.
These results thus show that with the multi-stage electrode according to the present invention, increase of the exhaust pressure of the exhaust gas can be suppressed while maintaining a high PM removal rate.

Industrial Applicability

[0072] The plasma reactor electrode according to the present invention is used in an apparatus, etc., for removing components contained in a smoke exhaust discharged from a factory, plant, internal combustion engine, etc., and having an adverse effect on an environment.

Claims

1. A plasma reactor electrode installed in a plasma reactor that is disposed in an exhaust gas flow path through which an exhaust gas passes, the plasma reactor electrode comprising:

   a first region having a first specific surface area; and
   a second region having a second specific surface area that is higher than the first specific surface area.

2. The plasma reactor electrode according to Claim 1, wherein
   the first region is positionedmore upstreamin the exhaust gas flow path than the second region.

3. The plasma reactor electrode according to Claim 1, wherein
   the specific surface area of the first region is no more than 1000m2/m3.

4. The plasma reactor electrode according to Claim 1, wherein the second region has a porous structure.

5. The plasma reactor electrode according to Claim 1, wherein the first regionhas a structure having a plurality of protrusions, at which charges concentrate, formed on a surface.

6. A plasma reactor electrode installed in a plasma reactor that is disposed in an exhaust gas flow path through which an exhaust gas passes, the plasma reactor electrode comprising:

   a region having a specific surface area of no more than 1000m2/m3; and
   a region that is different from the aforementioned region and having a specific surface area of no less than 1000m2/m3.

7. The plasma reactor electrode according to Claim 6, further comprising:

   a region having a porous structure.

8. The plasma reactor electrode according to Claim 6, further comprising:

   a region with a structure having a plurality of protrusions, at which charges concentrate, formed on a surface.

Fig. 1

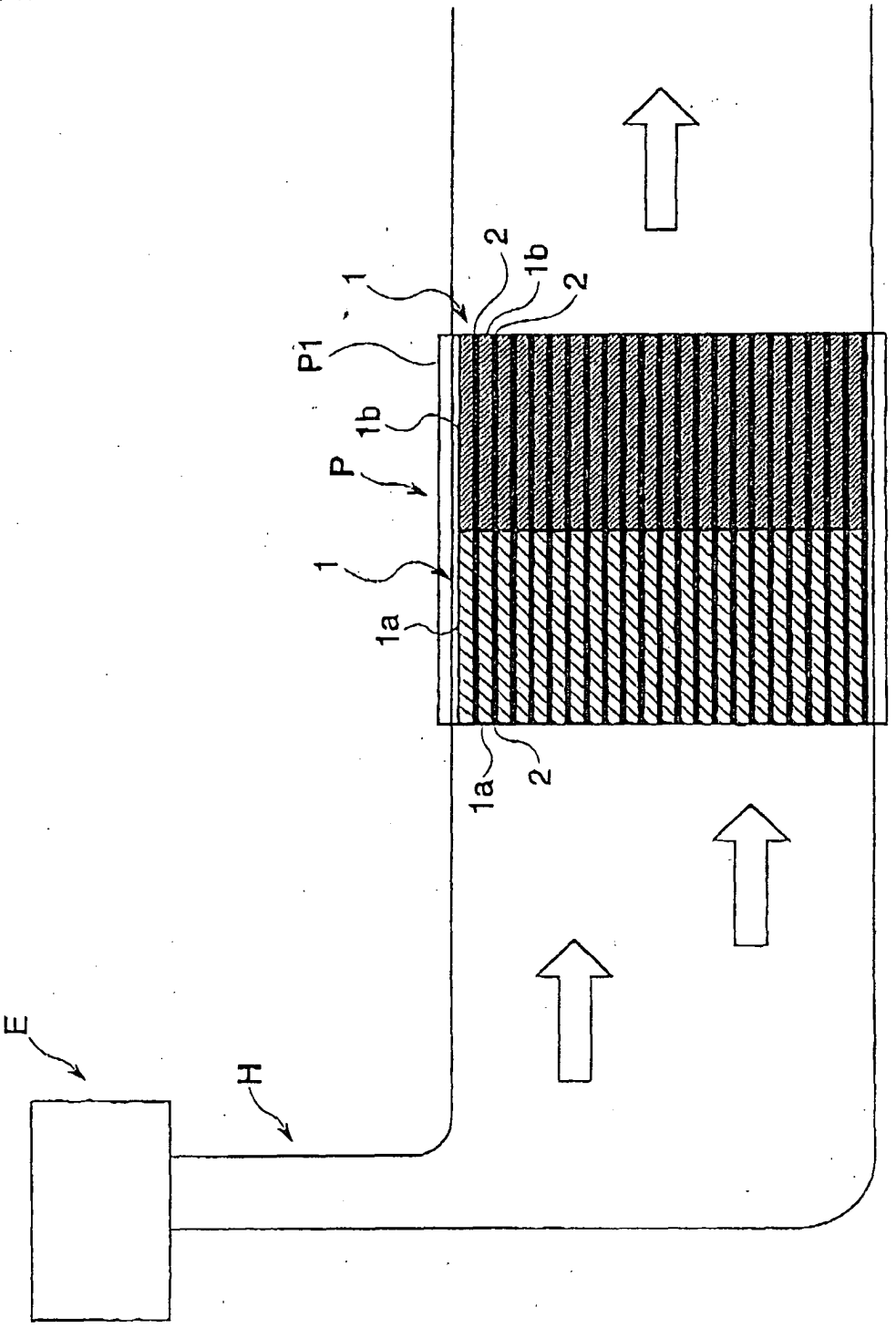


Fig. 2

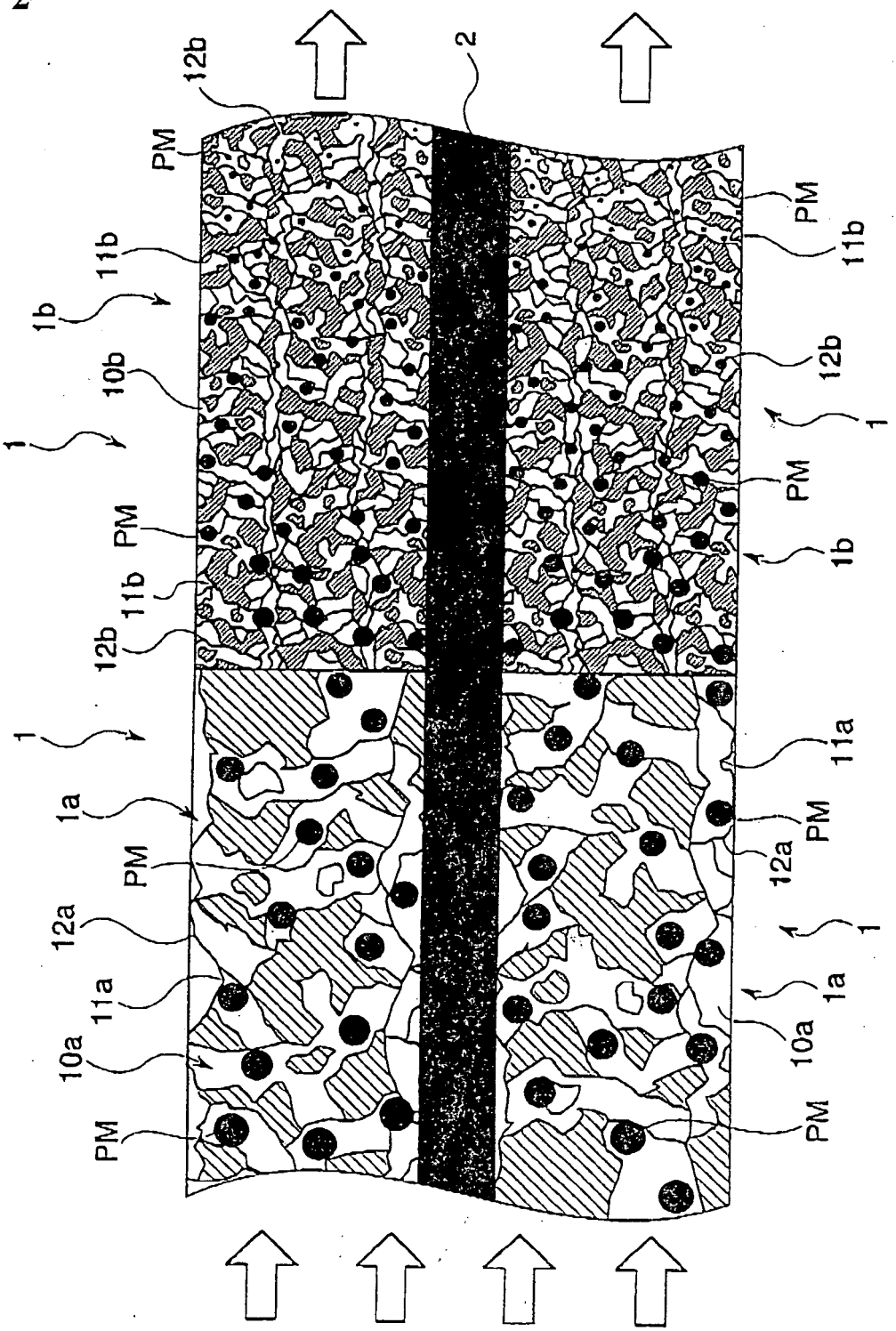
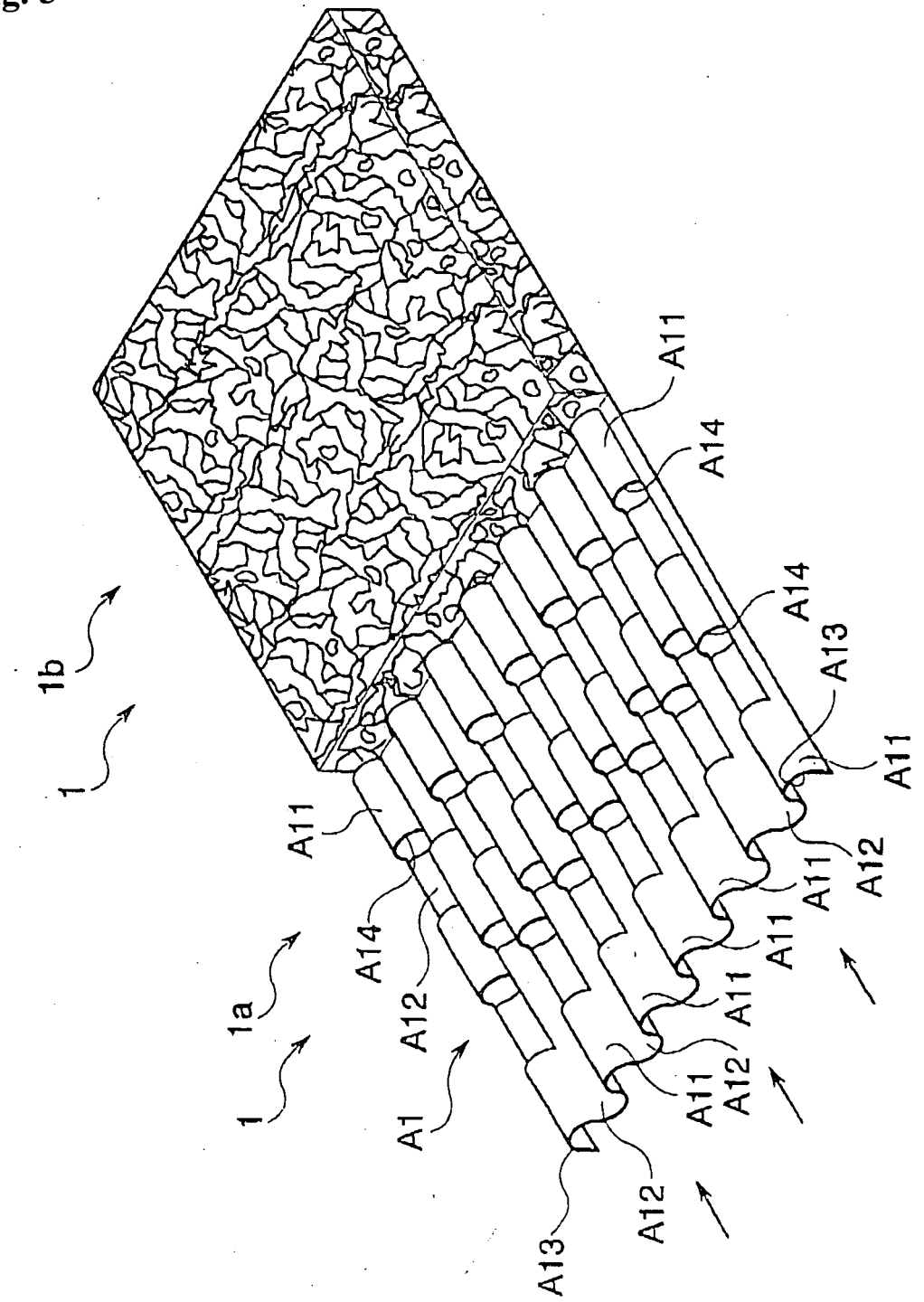

12b
2
PM
11b
1b
10b
1
PM
11b
12b
1
1a
PM
12a
11a
10a
PM
PM
11b
12b
1
PM
1b
11a
PM
12a
1
1
1a
10a
PM

Fig. 3


1b
1
A11
A14
A14
A13
A11
A11
A12
A11
A11
A11
A12
A11
A12
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A13
1a
1
A14
A12
A1

Fig. 4

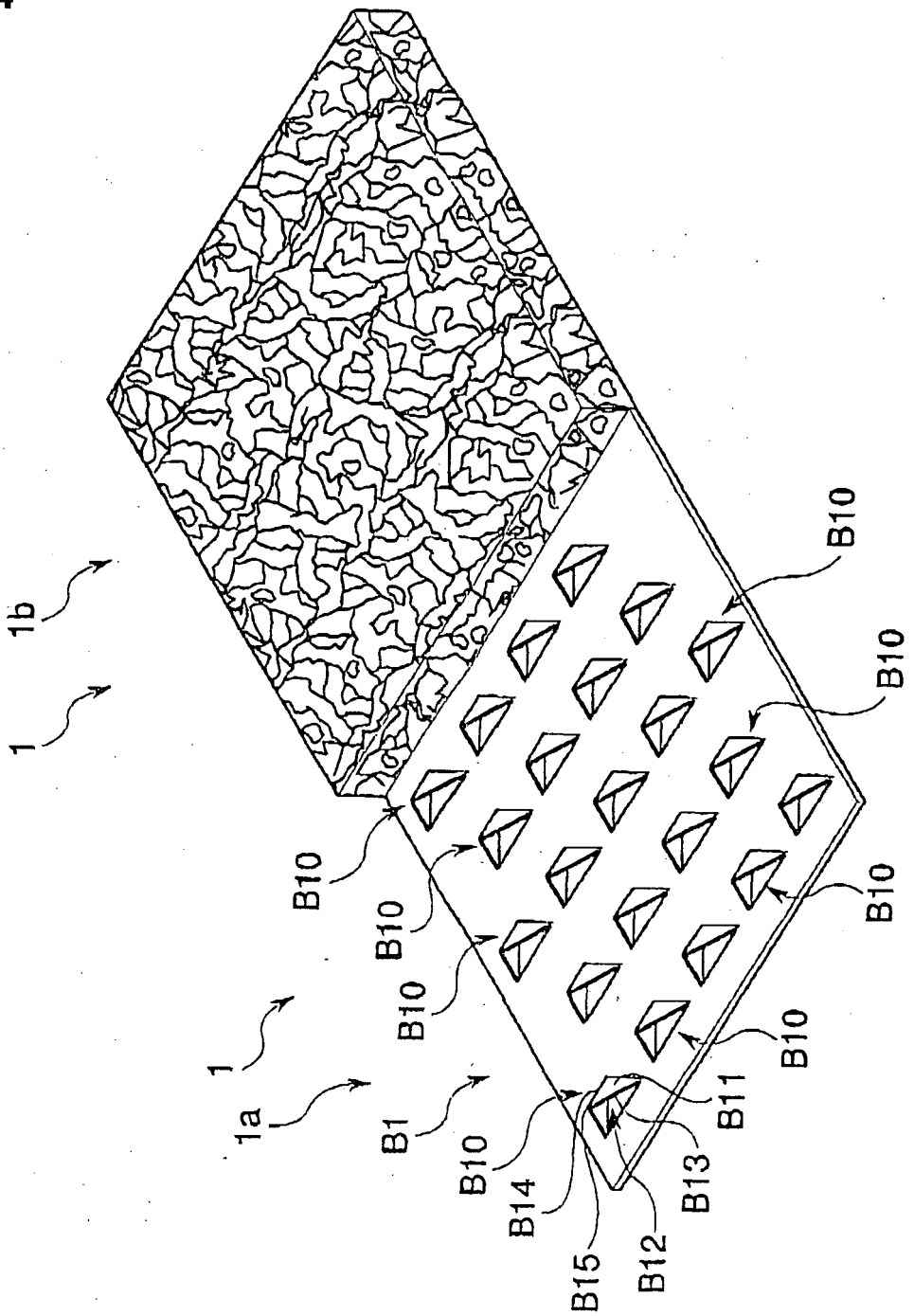

1b
1
B10
B10
B10
B10
B10
B10
B10
B10
1
1a
B1
B10
B14
B15
B12
B13
B11

Fig. 5

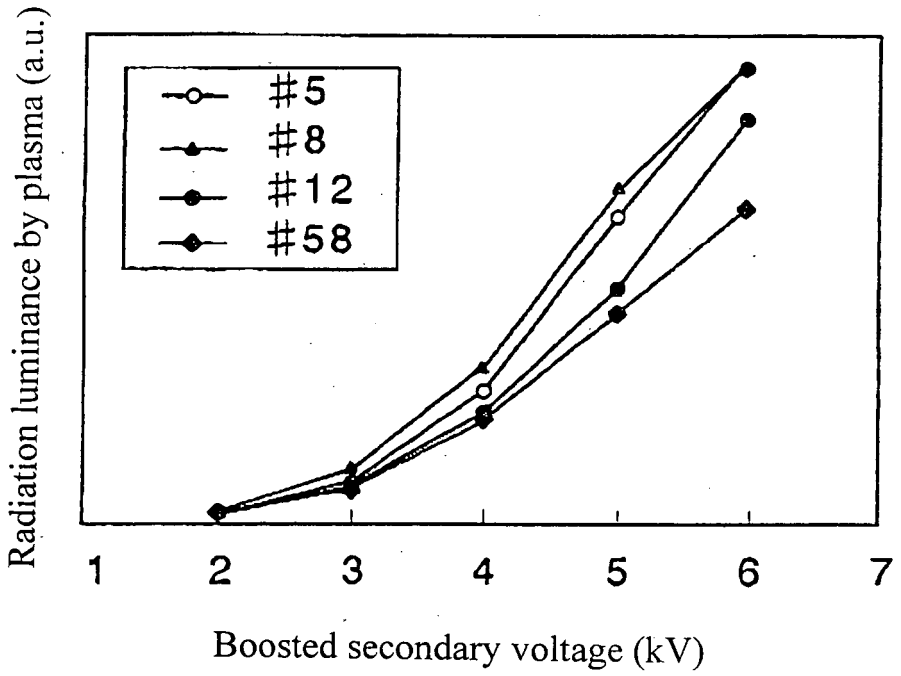

Radiation luminance by plasma (a.u.)
#5
#8
#12
#58
1
2
3
4
5
6
7
Boosted secondary voltage (kV)

Fig. 6

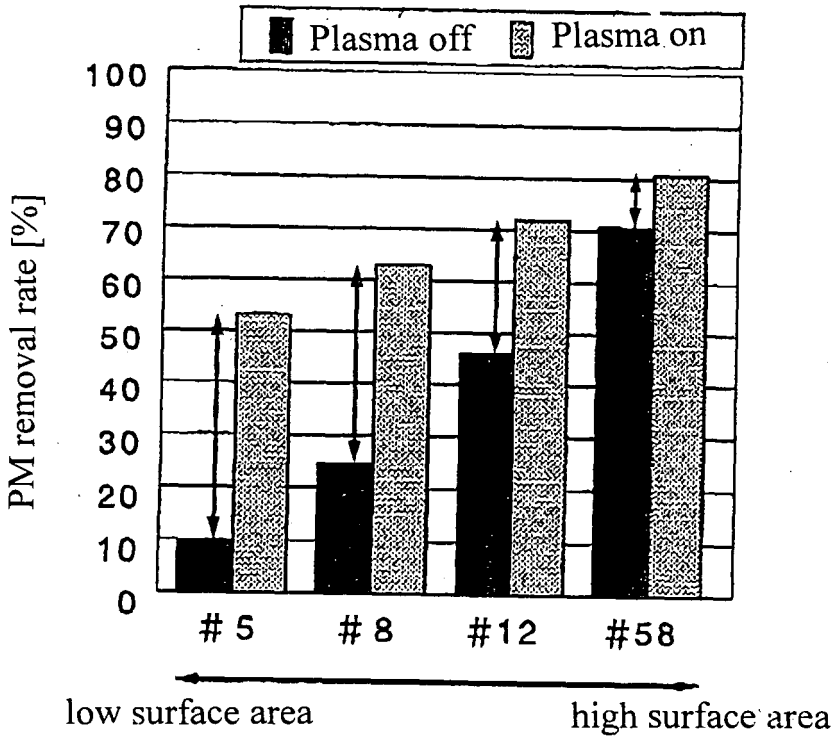
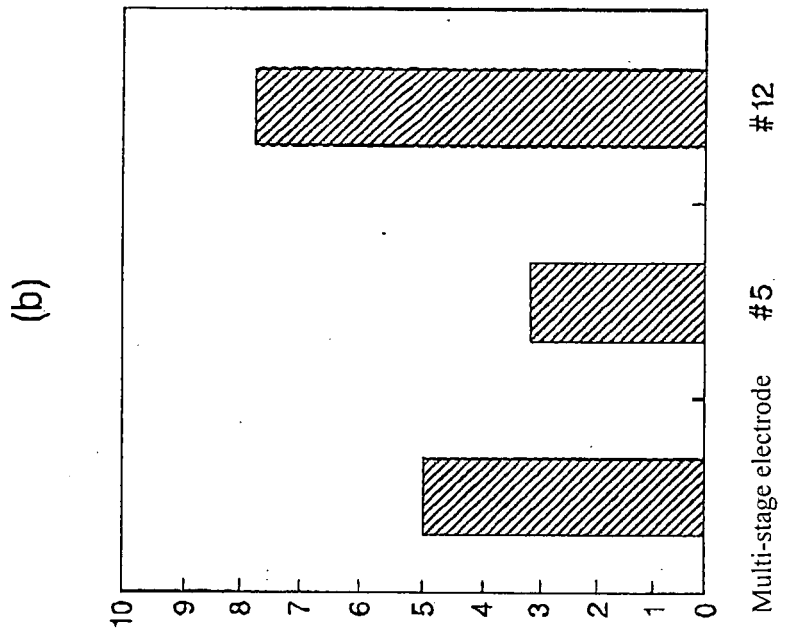

Plasma off
Plasma on
PM removal rate [%]
100
90
80
70
60
50
40
30
20
10
0
#5
#8
#12
#58
low surface area
high surface area

Fig. 7

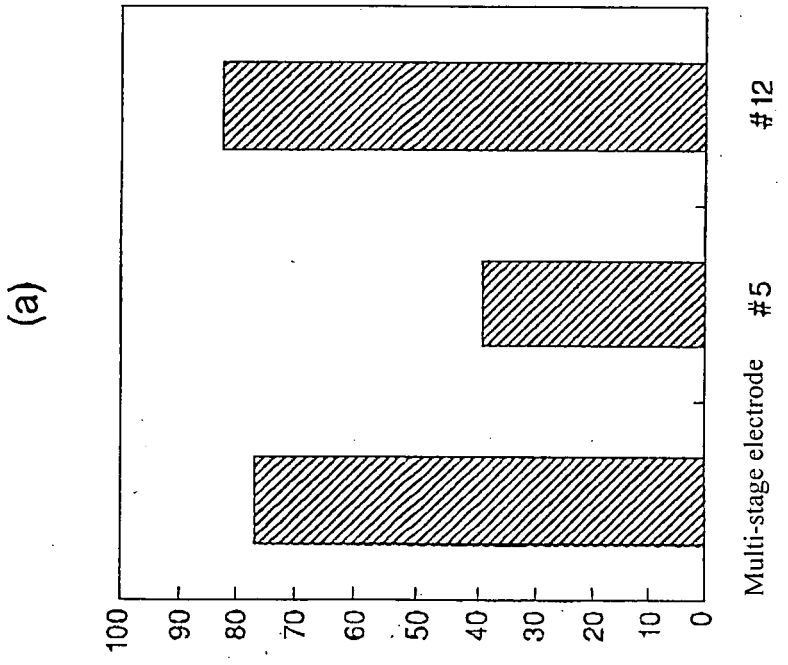
Wave foil electrode

Porous electrode

Fig. 8



Maximum pressure in the plasma reactor during 10-15 Japanese test mode (kPa)



PM removal rate [%]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/060708

A. CLASSIFICATION OF SUBJECT MATTER
F01N3/02(2006.01)i, *F01N3/08*(2006.01)i

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)
F01N3/02, F01N3/08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2007
Kokai Jitsuyo Shinan Koho 1971-2007 Toroku Jitsuyo Shinan Koho 1994-2007

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2004-346768 A (Toyota Motor Corp.), 09 December, 2004 (09.12.04), Par. Nos. [0044] to [0045]; Fig. 4 (Family: none)	1-8
Y	JP 2003-172123 A (Toyota Central Research and Development Laboratories, Inc.), 20 June, 2003 (20.06.03), Par. No. [0058]; Fig. 2 (Family: none)	1-8
Y	JP 1-307429 A (Kin-Chung R. Chiu), 12 December, 1989 (12.12.89), Page 3, lower left column, lines 4 to 15 & US 4735633 A & EP 276720 A2 & CN 1030192 A & HK 51595 A & KR 9407057 B	1-8

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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"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
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 August, 2007 (08.08.07)	21 August, 2007 (21.08.07)
Name and mailing address of the ISA/ Japanese Patent Office Facsimile No.	Authorized officer Telephone No.

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP2007/060708

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JP 2003-286829 A (HYUNDAI MOTOR Co.), 10 October, 2003 (10.10.03), Claim 9 & US 2003/0180199 A1 & DE 10245312 A & FR 2837660 A	4,7
Y	JP 8-59208 A (Hideyori TAKAHASHI), 05 March, 1996 (05.03.96), Fig. 1 (Family: none)	5,8
A	JP 2005-320895 A (Toshiba Corp.), 17 November, 2005 (17.11.05), Par. Nos. [0106] to [0107]; Fig. 12 (Family: none)	2

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

REFERENCES CITED IN THE DESCRIPTION

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- JP 2005292998 A **[0004]**
- JP 2002339731 A **[0004]**
- JP S5365206 B **[0033]**
- JP S62263974 B **[0033]**
- JP H11217602 B **[0033]**