Particulate Matter Purification System for Exhaust Gas in Semiconductor Process Flows

Technical Field

The present invention belongs to the technical field of particulate removal in semiconductor manufacturing processes and relates to a particulate matter purification system for exhaust gas in semiconductor process flows.

Background of the Invention

Particulate matter control has been a persistent challenge throughout the evolution of semiconductor manufacturing. In semiconductor manufacturing, thin-film processes—such as deposition (e.g., CVD, ALD, PECVD) and removal (e.g., plasma etching, plasma asher)—involve continuous phase transitions between the gaseous and solid states, resulting in the constant generation of particulate matters.

Driven by Moore's Law, integrated circuit manufacturing is seeing increasingly smaller chip sizes, making the control of particulate matter ever more stringent. During the manufacturing process of integrated circuit chips—particularly during the deposition and removal of thin films (both metallic and non-metallic)—significant quantities of micro- and nano-scale particulate matters are inevitably generated. The presence of these particulate matters within the vacuum chamber not only reduces wafer yield but also allows them to enter the exhaust system via vacuum pipelines, thereby increasing the load on the vacuum system and complicating maintenance. Therefore, the removal of particulate contaminants is a critical step in semiconductor manufacturing processes.

Particulate matter originates from two sources: the factory processing and production environment, and solid particles of various sizes generated by complex gas-phase reactions during the wafer fabrication process—with the latter being the primary source. Statistics show that in the production of 4M DRAM with a 1 mm design linewidth, 50% of the contaminating particles originate from the manufacturing environment, while the remaining 50% are generated by the process equipment. In the production of 16M DRAM with 0.5μm linewidths, particles generated by process equipment account for 60% of the total; for 64M DRAM with 0.35μm linewidths, this figure rises to 75%; and for 256M DRAM with 0.25μm linewidths, particles from process equipment reach as high as 90%, making them the primary source of

contamination.

As previously mentioned, particulates are primarily formed within the vacuum chamber; since the chamber is connected to the exhaust system, these particulates inevitably enter the exhaust system along with the residual gases from the gas-phase reactions, thereby contaminating the exhaust system. On one hand, particulate matter adheres to the walls of the exhaust duct as it passes through, becoming difficult to dislodge and causing permanent contamination. On the other hand, the particles are released into the environment via the exhaust system, resulting in environmental pollution. Since the vacuum system operates continuously around the clock to maintain the vacuum level within the chamber, particulate matters inevitably accumulate in the exhaust pipeline; shutting down the system for maintenance would disrupt the continuous operation of the semiconductor manufacturing process and increase system costs. Therefore, the removal and collection of particulate matters from the exhaust system is currently a critical technical issue in the field of semiconductor manufacturing.

Currently, in the field of semiconductor manufacturing, a typical vacuum system is shown in Figure 1: semiconductor products are processed within a vacuum chamber, where various physicochemical reactions occur—such as the transformation between gaseous and solid states—exemplified by the reaction: SiH_4 (gaseous) + NH_3 (gaseous) → Si_3N_4 (solid) + H_2 (gaseous). However, these chemical reactions are often incomplete, resulting in the formation of various by-products, which serve as a primary source of particle generation. The vacuum pump connects to the vacuum chamber via a fore-vacuum duct and maintains the vacuum environment within the chamber. The pump's exhaust is routed through an exhaust piping to an exhaust treatment system; after the system treats the hazardous gases, the processed exhaust is discharged into the facility's main exhaust header (central scrubber).

Patent Publication No. CN117357991A discloses a treatment process for semiconductor production exhaust gas, comprising: a pre-treatment in which the exhaust gas is introduced into a pre-treatment unit to undergo preliminary dust removal; a gas-mixing treatment in which the output from the pre-treatment unit is introduced into the gas-mixing unit for slow-flow deceleration treatment; a purification treatment in which the output from the gas-mixing unit is introduced into a purification unit for plasma combustion purification treatment; a cooling treatment in which the output from the purification treatment is introduced into a cooling unit for cooling; a discharge

treatment in which the output from the cooling unit is discharged via an external discharge unit. This scheme is not only structurally complex but also requires treatment via combustion, posing certain safety risks.

In actual operating conditions, particles are primarily generated within the vacuum chamber. Furthermore, as the reactivity of the process gases gradually diminishes, they tend to agglomerate into particles; these particles can form within the fore vacuum piping and subsequently enter the vacuum pump, downstream exhaust lines, abatement equipment, and the main facility exhaust header (central scrubber).

The following schemes—or combinations thereof—are available for particle removal from vacuum exhaust lines:

I. A filtration device, such as a screen mesh, can be installed upstream of the dry pump in a vacuum system to filter out particles by controlling the mesh's pore size, as shown in Figure 2. However, this method is rarely used because the mesh can impede the vacuum pump's pumping speed and carries a risk of clogging.

II. Adding thermal insulation to the fore-vacuum piping and exhaust lines maintains high temperatures within the pipes, thereby suppressing particle generation; this is a commonly adopted method, as illustrated in Figure 3. However, the drawback of this approach is that particles generated within the chamber still accumulate in the downstream vacuum system, increasing the load on the system and failing to provide a fundamental solution to the problem.

III. Building upon the second method but adopting the opposite approach, a cold trap is installed in the upstream vacuum piping to rapidly condense reactive gases or cause them to aggregate into particles, thereby removing them (as shown in Figure 4). The drawback of this method is that the high gas flow velocity within the piping hinders the cold trap from functioning effectively.

Summary of the Invention

To address the problems existing in the prior art, the present invention aims to provide a particulate matter purification system for exhaust gas in semiconductor process flows. This system features convenient operation, all-weather operation, high efficiency, and low cost.

The technical solution of the present invention is:

A particulate matter purification system for exhaust gas in semiconductor process

flows, characterized in that the system comprises a refrigeration unit, a plasma diversion unit, and a particulate matter collection unit; wherein the refrigeration unit, the plasma diversion unit, and the particulate matter collection unit are arranged in sequence on an exhaust piping between a vacuum chamber and a vacuum pump; wherein the particulate matter collection unit is provided with a collection trough and an exhaust port; and wherein:

the refrigeration unit is configured to cool the exhaust gas discharged from the vacuum chamber to promote condensation and growth of particulate matter in the exhaust gas into particles and then to force the exhaust gas to flow into the plasma diversion unit;

the plasma diversion unit is configured to produce a free charge distribution region and a sheath electric field and to charge the particulate matter in the exhaust gas when the input exhaust gas flows through the free charge distribution region, and the charged particulate matter is then repelled and guided by the sheath electric field to move into the collection trough of the particle collection unit; and

the exhaust port of the particulate matter collecting unit is connected to the vacuum pump via an exhaust duct for discharging through the vacuum pump the residual exhaust gas which has been filtered out the particulate matter.

Furthermore, the refrigeration unit is a condensing module, the plasma diversion unit is an electrostatic repulsion module, and the particulate matter collecting unit is a dust collection module, the collection trough and the exhaust port being provided on a bottom of the dust collection module; wherein the electrostatic repulsion module includes a cylinder B provided with a first spherical cap-shaped perforated metal plate and a second spherical cap-shaped perforated metal plate in the cylinder B; wherein the first spherical cap-shaped perforated metal plate serves as a negative electrode, the second spherical cap-shaped perforated metal plate serves as a positive electrode, and the first spherical cap-shaped perforated metal plate is located below the second spherical cap-shaped perforated metal plate; wherein the collection module includes a cylinder C, the collection trough being provided at a bottom edge of an inner wall of the cylinder C and the exhaust port being provided at a central region of the bottom of the cylinder C; wherein tops of the first and second spherical cap-shaped perforated metal plates face upward; wherein the first spherical cap-shaped perforated metal plate is used to generate plasma by means of gas discharge breakdown to form the free charge

distribution region, and the sheath electric field is formed by means of the plasma on an inner wall surface of the cylinder B, on a surface of the first spherical cap-shaped perforated metal plate, and on a surface of the second spherical cap-shaped perforated metal plate, respectively, the sheath electric field on the surfaces of the first and second spherical cap-shaped perforated metal plates is used to repel the charged particulate matter to move toward and slide down a side wall of the cylinder B, and the sheath electric field on the surface of the cylinder B is used to repel the particulate matter to move away from the surface of the inner wall of the cylinder B and slide downward into the collection trough of the dust collection module.

Furthermore, metal holes on the first spherical cap-shaped perforated metal plate have a diameter of no greater than 7 mm, and the first spherical cap-shaped perforated metal plate has a thickness of 0.5mm and a grid radius of 3 mm; wherein metal holes on the second spherical cap-shaped perforated metal plate have a diameter of no greater than 7 mm, and the second spherical cap-shaped perforated metal plate has a thickness of 0.5 mm and a grid radius of 3 mm; wherein a curvature of the second spherical cap-shaped perforated metal plate is smaller than a curvature of the first spherical cap-shaped perforated metal plate; wherein the cylinder B has an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 300 mm, and a height of the second spherical cap-shaped perforated metal plate is 40 mm, and the first spherical cap-shaped perforated metal plate has a height of 60 mm and a maximum diameter of 120 mm; and wherein the second spherical cap-shaped perforated metal plate is at a distance of 100 mm away from the top of the cylinder B, and a perpendicular distance between the first spherical cap-shaped perforated metal plate and the second spherical cap-shaped perforated metal plate is 50 mm.

Furthermore, the collection module comprises a cylinder C, the collection trough and the exhaust port being provided at a bottom of the cylinder C; wherein the collection trough has a width of 20 mm and a depth of 30 mm; wherein an inner diameter of the cylinder C is smaller than an inner diameter of the cylinder B; wherein the first spherical cap-shaped perforated metal plate is electrically connected to a power supply system outside the cylinder B through an interface on the side wall of the cylinder B, and the second spherical cap-shaped perforated metal plate is grounded through an interface on the side wall of the cylinder B; and wherein the condensing module comprises a cylinder A and a water-cooling pipe, an upper end of the cylinder A being connected to

an exhaust gas discharge port of the vacuum chamber, and a lower end of the cylinder A being connected to the electrostatic repulsion module; and wherein the water-cooling pipe is wound around an outer wall of the cylinder A for cooling the exhaust gas.

Furthermore, the refrigeration unit is a cooling module, and the plasma diversion unit comprises a plasma generation module and a diversion module; wherein the exhaust piping includes a section of Y-shaped duct; wherein the Y-shaped duct has an input port, a straight-through outlet, and a side outlet duct; wherein the plasma generation module and the diversion module are arranged within the Y-shaped duct, wherein:

one end of the cooling module is connected to the exhaust port of the vacuum chamber in the semiconductor manufacturing process, and the other end of the cooling module is connected to the input port of the Y-shaped duct for cooling the exhaust gas discharged from the vacuum chamber, so that upon cooling, chemical components within the exhaust gas undergo accelerated condensation and growth into particles and then enter the Y-shaped duct;

the plasma generation module is used to form a plasma region above the entrance of the side outlet duct of the Y-shaped duct, for charging the particles flowing through the plasma region to form charged particles;

the diversion module is used to repel and guide the charged particles into the side outlet duct by means of the sheath electric field generated by itself;

the collection trough of the particulate matter collection unit is connected to the outlet of the side outlet duct of the Y-shaped duct for collecting the inflowing particulate matter; and

the straight-through outlet of the Y-shaped duct serves as the exhaust port of the particulate matter collection unit and is connected to the vacuum pump through the exhaust duct, for discharging through the vacuum pump the residual gas which has been filtered out the particulate matter.

Furthermore, the plasma generation module and the diversion module are the same metal grid; wherein the metal grid is electrically connected to a power supply located outside the Y-shaped duct to provide a negative voltage for the metal grid, and the sheath electric field is formed on a surface of the metal grid by the plasma; the metal grid is obliquely placed at an angle of 45° within the Y-shaped duct; and the mesh radius of the metal grid is 3 mm, and the thickness of wires of the metal grid is 1 mm.

Furthermore, the refrigeration unit is a condensing module, the plasma diversion unit comprises a plasma generation module and a diversion module, and the particulate matter collection unit is a dust collection module, the collection trough and the exhaust port being provided at a bottom of the dust collection module; wherein the diversion module is a tower-shaped structure composed of metal wires or metal meshes, positioned with its apex facing upward; wherein the plasma generation module is used to generate plasma through discharge, forming a plasma region on a flow passage through which the exhaust gas flows, the plasma region being used to charge the particles within the exhaust gas to form charged particles, the charged particles then entering the region where the diversion module is located; and wherein the diversion module generates a sheath electric field for repelling the charged particles, forcing the charged particles to move away from a side wall of the tower-shaped structure and then move downward and fall into the collection trough, and the residual gas, which has been filtered out the particulate matter, is output through the exhaust port.

Furthermore, the plasma generation module and the diversion module are located within a cylinder B; wherein the diversion module is a tower-shaped structure composed of a metal mesh or a spiral multi-layer metal mesh; wherein the plasma generation module applies inductively coupled discharge to generate the plasma; wherein the sheath electric field of the diversion module causes the charged particles to move away from a sidewall of the tower-shaped structure and towards a sidewall of the cylinder B; and wherein the plasma forms the sheath electric field on an inner wall surface of the cylinder B, and the charged particles move away from the inner wall surface of the cylinder B under the action of the sheath electric field and fall into the collection trough under the action of gravity.

Furthermore, the plasma generation module comprises a first metal electrode plate and a second metal electrode plate placed vertically in parallel with each other, the first metal electrode plate and the second metal electrode plate being symmetrically placed on two sides of an axis of the cylinder B; wherein the first metal electrode plate is electrically connected to a power supply system outside the cylinder B through an interface on a sidewall of the cylinder B, and the second metal electrode plate is connected to a ground wire for generating the plasma through discharge to charge the particles in the exhaust gas to form negatively charged particles; and wherein the diversion module repels the charged particles through the sheath electric field formed

on its surface by the plasma, or the diversion module is electrically connected to a negative-voltage power supply outside the cylinder B through an interface on the sidewall of the cylinder B to generate a sheath electric field for repelling the charged particles.

Furthermore, the refrigeration unit is a condensing module, and the plasma diversion unit comprises a plasma generation module and a diversion module; wherein the exhaust piping includes a section of T-shaped duct; wherein the condensing module and the T-shaped duct are sequentially arranged between the vacuum chamber and the vacuum pump of the semiconductor manufacturing process as a horizontal exhaust passage, the plasma generation module and the diversion module being arranged within a horizontal section of the T-shaped duct, and a lower end outlet of a vertical section of the T-shaped duct being connected to the collection trough of the particulate matter collection unit; wherein an inlet of the horizontal section of the T-shaped duct is connected to the condensing module, and an outlet of the horizontal section of the T-shaped duct serves as the exhaust port of the particulate matter collection unit and is connected to the vacuum pump through an exhaust duct; wherein the plasma generation module is used to generate plasma through discharge, forming a plasma region within the horizontal section of the T-shaped duct to charge the particles in the passing exhaust gas to form charged particles; wherein the diversion module is used to generate a sheath electric field for repelling the charged particles, guiding the charged particles toward the vertical section of the T-shaped duct to fall into the dust collection module, and outputting the residual gas which has been filtered out particulate matter, through the outlet of the horizontal section of the T-shaped duct.

Furthermore, the plasma generation module and the diversion module are the same metal grid; wherein the metal grid is electrically connected to a power supply located outside the T-shaped duct, for providing a negative voltage for the metal grid, and the sheath electric field is formed on a surface of the metal grid through the plasma; wherein the metal grid is obliquely placed at an angle of 45° within the T-shaped duct, and wherein the metal grid has a mesh radius of 3 mm and a wire diameter of 1 mm.

The advantages of the present invention are as follows:

The method disclosed in the present invention theoretically achieves 100% efficiency in removing particulates from residual gases generated during semiconductor manufacturing processes; it not only enables environmentally friendly operation with

zero particulate emissions but also provides significant protection for the backing vacuum pumps of the vacuum system. Designed equipment using this method is capable of long-term operation and entails very low costs.

Brief Description of the Drawings

Figure 1 shows a schematic diagram of a vacuum system in the field of semiconductor manufacturing.

Figure 2 is a schematic diagram of a vacuum system with a filtration unit installed upstream of the dry pump.

Figure 3 shows the schematic diagram of a vacuum system with added thermal insulation functionality.

Figure 4 shows the schematic diagram of a vacuum system with added cooling functionality.

Figure 5 is a schematic structural diagram of Embodiment 1.

Figure 6 is a schematic structural diagram of Embodiment 2.

Figure 7 is a schematic diagram of a first optional structure of Embodiment 3.

Figure 8 is a schematic diagram of a second optional structure of Embodiment 3.

Figure 9 is a schematic structural diagram of Embodiment 4.

Detailed Description of the Invention

The present invention is further described in detail below with reference to the accompanying drawings; the examples provided are merely for the purpose of explaining the invention and are not intended to limit its scope.

Embodiment 1

As shown in Figure 5, Embodiment 1 comprises a condensation module, an electrostatic repulsion module, and a collection module; these three modules are arranged in sequence along the piping of a semiconductor manufacturing exhaust system—typically positioned vertically and in sequence, on the exhaust line connecting the vacuum chamber and the vacuum pump.

The primary function of the condensation module is to provide a transitional buffer zone between the semiconductor manufacturing vacuum chamber and the electrostatic repulsion module; this allows residual gases exhausted from the vacuum chamber to cool and promotes the growth of particulates, thereby reducing the generation of new

particulates after the gases pass through the electrostatic repulsion module.

The electrostatic repulsion module is primarily used to generate uniform plasma and charge particles, subsequently guiding their movement through electrostatic repulsion. The electrodes used to generate the plasma consist of two spherical-cap shaped perforated metal plates positioned vertically within a cylinder and separated by a specific distance; a DC glow discharge is employed to produce the plasma, with the aim of achieving a spatially uniform distribution of free charges. As the residual gas particulates flow through this uniform plasma, the free charges (electrons and ions) within the plasma collide with and adsorb onto the surfaces of the particulates, thereby charging them. The electric charge acquired by a particulate matter stabilizes when the electron and ion charging rates reach equilibrium. Since the mass of an electron is far smaller than that of an ion—and consequently, the thermal velocity of electrons is much higher than that of ions—particulates typically collect more electrons and ultimately acquire a negative charge. By adjusting discharge parameters to modify variables such as electron density, the electric charge of the particulates can ultimately be controlled. When an energized spherical-cap metal orifice plate is placed in the plasma, a sheath electric field forms on its surface; as negatively charged particulates approach this surface, the sheath electric field repels them, causing them to move along the sides of the spherical cap toward the cylinder wall and eventually enter the dust collection module.

The primary function of the collection module is to collect particulate matter arriving from the diversion module by means of grooves located at the upper end of the metal cylinder. Groove structures of various shapes and dimensions can be configured according to specific requirements. After being repelled by the sheath electric field, the particulates move along the surface of the spherical-cap shaped metal perforated plate—driven by airflow and gravity—from the center of the duct toward the sidewall; upon passing the electrostatic repulsion module, they naturally fall into the collection trough, thereby achieving particle collection. The spherical-cap shaped metal perforated plate could be detached to wash periodically according to the actual situation.

Particulates within the semiconductor process chamber are carried out by the residual gas flow and enter a pre-positioned cylinder A. The cylinder A is made of metal, with an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 350 mm; its upper end is connected to the exhaust duct. A water-cooling system—

specifically, a water-cooling pipe made of aluminum or copper—is installed on the exterior of cylinder A; the pipe features an upper water outlet and a lower water inlet, allowing 5°C cooling water to flow continuously over the cylinder A to lower its temperature.

A cylinder B is positioned beneath the cylinder A and connected to it via a flange; it is made of quartz, with an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 300 mm. Two spherical-cap shaped metal perforated plates—serving as the grounding electrode and the negative-voltage electrode—are placed parallel to each other inside the cylinder B. Both electrodes are made of metal; the grounding electrode has a height of 40 mm, and the negative-voltage electrode has a height of 60 mm, with both having a maximum diameter of 120 mm. The curvature of the grounding electrode is smaller than that of the negative-voltage electrode, and both are secured near the inner wall of the cylinder A using a mounting fixture. The grounding electrode is positioned 100 mm above the top of the cylinder B, while the negative-voltage electrode is located 50 mm vertically below the grounding electrode. Insulated wires connect the grounding electrode and the negative-voltage electrode—via power input ports on the sidewall of the cylinder B—to an external DC negative-voltage power supply and a ground connection, respectively; the voltage of the DC negative-voltage power supply is -400 V. After residual gas is introduced into the semiconductor process chamber and the negative DC power supply is energized, a uniform plasma can be generated in the vicinity of and between the negative-voltage electrode and the grounding electrode.

Another cylinder C is positioned beneath the cylinder B and connected to it via a flange. A collection trough—measuring 20 mm in width and 30 mm in depth—is located on the side wall just below the connection point. The inner diameter of the cylinder C is 120 mm, which is smaller than that of the cylinder B. The other end of the cylinder C is connected to a vacuum pump via an exhaust duct, through which the purified residual gas is extracted.

During operation, the DC negative-voltage power supply is activated, generating a uniform plasma between the grounding electrode and the negative-voltage electrode. Residual gases and particulates flowing from the semiconductor process chamber enter the cylinder A; following condensation, the particulates undergo further growth and proliferation. As they pass through the plasma situated between the grounding and negative-voltage electrodes, the particulates adsorb a significant amount of electric

charge. Since the velocity of electrons exceeds that of ions, the particulates acquire a net negative charge once their charge state stabilizes. As they pass the grounded electrode, the negatively charged particulates are repelled by the negatively charged, spherical-cap shaped metal perforated plate and move toward the sidewall of the cylinder B, subsequently falling into the collection trough of the cylinder C, whereas the residual gas remains unaffected as it passes the grounding electrode and the negative-voltage electrode.

The contact electrode and the negative-voltage electrode of the spherical-cap shaped metal perforated plate play a crucial role in the collection of residual particulate matter; therefore, the selection of the plate's dimensional parameters requires strict control. First, the metal perforated plate should not be too thick; this reduces mass and facilitates forging. Second, the plate should have sufficient height and width to ensure that dust particles have enough time to migrate toward the sidewall of the cylinder B. Finally, the aperture size should not exceed 7 mm to prevent particulate matter from being swept through the plate by the residual gas flow. Extensive testing has shown that the optimal removal of residual gas particulates is achieved with a plate thickness of 0.5 mm and an aperture radius of 3 mm.

Particulate matter accumulating in the collection trough requires periodic cleaning by opening the cylinder C; the cleaning frequency depends on the duration of use, as an excessive buildup of particulates reduces the effective depth of the trough—thereby hindering further collection and lowering purification efficiency. Adding a certain amount of adsorbent material to the collection trough can prevent collected particulates from being blown back out by the airflow, thereby enhancing purification efficiency.

The purification process of Embodiment 1 includes the following steps:

A1. Three cylindrical sections—Cylinder A, Cylinder B, and Cylinder C—are provided. Cylinder A is connected via a flange to the exhaust system piping of a semiconductor manufacturing process; these cylinders are installed in sequence from top to bottom along the vertical duct connecting the vacuum chamber and the vacuum pump. The cylinders A, B, and C may be made of metal or glass.

B1. The condensation module features a water-cooling pipe wound around the cylinder A; cold water flows continuously through the pipe, cooling the gas inside the cylinder A, promoting the condensation of residual chemical components in the gas into particles, and thereby enhancing the efficiency of subsequent dust removal.

C1. The electrostatic repulsion module, located within the cylinder B, comprises first and second spherical-cap shaped metal perforated plates arranged vertically without touching each other; these serve as the negative electrode and the positive electrode, respectively, and are positioned with their apexes facing upward and their bottoms not in contact with cylinder B. The first spherical-cap shaped metal perforated plate connects to an external power supply system via an interface on the sidewall of the cylinder B to serve as the negative electrode, while the second spherical-cap shaped metal perforated plate connects to the ground via an interface on the sidewall of the cylinder B to serve as the grounding electrode.

D1. The cylinder C contains a dust collection module; a groove is provided near the flange at the upper end of the cylinder C, and it connects to the flange at the lower end of the cylinder B to collect particulate matter discharged from the cylinder B.

E1. When the power system is activated and residual gas exiting the semiconductor manufacturing vacuum chamber flows downward through the spherical-cap shaped metal perforated plates within the cylinder B, a discharge occurs that breaks down the gas; this generates a uniform plasma between the first and second spherical-cap shaped metal perforated plates, and the required plasma environment is achieved by controlling the DC voltage applied to the first spherical-cap shaped metal perforated plate. As the particulate matter within the residual gas flows downward through the plasma region formed inside the cylinder B, the plasma rapidly charges the particles, rendering them negatively charged. The plasma diffuses outward, generating sheaths on the surface of the cylinder B and on the surfaces of the first and second spherical-cap shaped metal perforated plates.

F1. As the negatively charged particles continue to move downward with the airflow under the influence of gravity and approach the negatively charged spherical-cap shaped metal orifice plates, they are repelled by the sheath electric fields on the surfaces of the first and second spherical-cap shaped metal orifice plates; consequently, the particles slide down along these sheath layers toward the sidewall of the cylinder B. Upon reaching the groove in the upper flange of the cylinder C, the particles enter the groove, thereby completing the process of collecting particles from the residual gas.

G1. After a period of operation, remove the cylinder B, the cylinder C, and the first and second spherical-cap shaped metal perforated plates from the exhaust duct; clean the grooves and any particulate matter from the surfaces; and reinstall the components

to resume the process of removing particulates from the residual gas. To ensure operational efficiency, a spare set of equipment may be prepared for rotational use.

The primary purpose of the spherical-cap shaped metal perforated plates configured in Step C1 is to generate a uniform plasma that charges the particulate matter by means of the two spherical-cap shaped metal perforated plates; this facilitates the guidance of the charged particles' trajectories, causing them to move downward and outward along the sheath layer of the plates' surfaces until they are finally collected within the groove of the cylinder C. The first and second spherical-cap shaped metal perforated plates are connected to a power supply and ground, respectively, with the aim of generating a uniform plasma via gas discharge between them. A negative DC power supply is used to generate a glow discharge plasma between the two spherical-cap shaped metal perforated plates.

The plasma generated in Step E1 contains electrons, positive ions, negative ions, and various reactive species. When particulate matter enters the plasma, the electrons—owing to their much lower mass compared to other particles and consequently much higher velocities—reach and adsorb onto the surface of the particles first. When the charging current from electrons balances the charging current from other particles, the electric charge on the particles reaches a steady state, and the particles exhibit a negative charge.

Step F1 involves using the sheath electric field on the surface of the spherical-cap shaped metal perforated plate to guide the negatively charged particulate matter from Step E1 into the groove of the upper flange of the cylinder B, thereby completing the collection process. As the particulate matter flows downward through the cylinder B along with the residual gas, it first passes through the plasma region to become charged; subsequently, during its downward movement, it travels along the surface of the spherical-cap shaped metal perforated plate toward the groove in the upper flange of the cylinder C.

In step G1, since the generated plasma forms a sheath layer on the inner wall surface of the cylinder B, the sheath electric field exerts an electric force on the electro-negative particles that drives them away from the inner wall surface of thecylinder B; consequently, the particles cannot reach the inner wall surface of the cylinder B, thereby preventing contamination of the cylinder B by the particles. The cylinder B may be made of glass or metal.

The advantages of Embodiment 1 are as follows:

The present invention involves installing three cylindrical sections in series along the vertical exhaust duct connecting the semiconductor process vacuum chamber and the downstream vacuum pump. First, a water-cooling pipe is mounted on the exterior of the first cylindrical section (Section A) to ensure the thorough condensation of residual gas particles generated during semiconductor manufacturing, thereby enhancing dust removal efficiency. Subsequently, within the second cylindrical section (Section B), a uniform plasma is generated via direct current (DC) discharge; as particulate matter flows through the plasma region along with the residual gas, charged particles within the plasma collide with and adhere to the particulates, imparting a negative charge to them. As the negatively charged particulates continue to flow downward through the charged, spherical-cap shaped metal perforated plate located within the second cylinder section B, they are repelled by the sheath electric field on the surface and guiled along the surface of the spherical-cap shaped metal perforated plate toward the cylinder sidewall, ultimately entering a groove in the end flange of the third cylinder section C, thereby achieving particulate collection. Theoretically, the efficiency of this invention in removing particulates from semiconductor manufacturing exhaust gas can reach 100% (with a measured efficiency of 99.2%); it is not only environmentally friendly—producing zero particulate emissions—but also effectively protects equipment such as exhaust lines and downstream vacuum pumps. The designed particulate removal device using this method is low-cost and suitable for continuous industrial-scale operation, thereby resolving the issue of particulate contamination in semiconductor manufacturing exhaust gas.

Embodiment 2

The structure of Embodiment 2 is shown in Figure 6 and comprises a cooling module, a plasma generation module, a diversion module, and a collection trough; the cooling module, the plasma generation module, and the diversion module are assembled and integrated in sequence onto the piping of a semiconductor manufacturing exhaust system, while the collection trough is connected to a side outlet of the plasma generation module and the diversion module.

The cooling module comprises a gas conduit and a water-cooling pipe, installed downstream of the vacuum chamber exhaust port, the water-cooling pipe being coiled around the gas conduit, with cold water entering through the lower opening of the

water-cooling pipe and exiting through the upper opening of the water-cooling pipe. Upon cooling, chemical constituents within the residual gas accelerate their condensation and growth into particles. Incorporating this cooling module promotes particle growth, enhances the efficiency of particle removal from the residual gas, and reduces the concentration of pollutants in the final exhaust.

The plasma generation module and the diversion module are positioned within a section of Y-shaped duct located beneath the cooling module. The plasma generation module primarily serves to produce a uniform plasma, aiming to achieve a spatially uniform distribution of electrons and ions. As the particulate matter within the residual gas flows through the plasma, electrons and ions collide with the particles and adsorb onto their surfaces, thereby charging the particles. When the electron charging current and the ion charging current reach equilibrium, the charge acquired by the particles reaches saturation. Since the mass of an electron is far less than that of an ion—and consequently, the thermal velocity of electrons is much higher than that of ions—particles typically end up carrying a negative charge. By adjusting discharge parameters to modify variables such as electron density, the charge level of the particles can ultimately be controlled. In summary, the plasma module is designed to generate a uniform plasma and charge the particles flowing through it.

The diversion module consists of a grid structure with a negative bias voltage; it is elliptical in shape and positioned at an angle within a Y-shaped duct. Its function is to utilize the grid's negative bias voltage to repel negatively charged particulate matter, thereby directing the particles within the exhaust duct toward the side outlet of the Y-shaped duct. The diversion module shares the metal grid structure with the plasma generation module. After flowing through the plasma module and becoming charged, the particulate matter is simultaneously repelled by the sheath electric field at the surface of the negative bias voltage grid structure, causing the negatively charged particles to move along the grid's surface. Residual gas particles generated in the semiconductor process vacuum chamber exhibit a uniform density distribution upon entering the exhaust duct. Upon reaching the diversion module, the particulate matter moves along the inclined mesh structure toward the lower outlet of the Y-shaped duct, thereby clearing the duct of particles. After passing through the diversion module, the particles enter the collection trough.

A collection trough is positioned at the side outlet of the diversion module to collect

particulate matter discharged from the module. Depending on actual requirements, a recessed structure of specific dimensions may be incorporated. Subjected to gravity and the repulsive force of a negative bias voltage metal mesh, particles within the exhaust duct move along the mesh surface toward the side of the Y-shaped duct; after passing through the diversion module, they naturally fall into the side collection trough, thereby achieving particle collection. The particulate matter in the exhaust duct passes sequentially through these four modules and is ultimately collected in the collection trough. Since the plasma module and the diversion module carry a negative bias voltage, they repel negatively charged particulate matter; consequently, the particles do not contaminate these two modules, meaning they do not require cleaning.

Particulates within the semiconductor process chamber are extracted along with exhaust gas via the exhaust duct of the semiconductor manufacturing exhaust system; they pass through a gas-conveying duct—which has an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 400 mm—and enter an adjacent Y-shaped duct. A water-cooling pipe is coiled around the outer wall of the gas-conveying duct to cool the exhaust gas, causing the particulates to condense, grow, and increase in quantity before flowing into the adjacent Y-shaped duct. The Y-shaped duct is made of glass, with an inner diameter of 160 mm and an outer diameter of 165 mm. An elliptical metal screen mesh is obliquely positioned inside the duct at a 45º angle to the horizontal; the mesh has a major axis of 170 mm and a minor axis of 120 mm, with its edges spaced 20 mm from the inner wall of the Y-shaped duct. The lower end of the elliptical metal screen mesh extends into the inlet of the Y-shaped duct's lateral outlet branch. An insulated wire is used to connect the elliptical metal mesh to an external RF power supply (80 W, 13.56 MHz) through a pre-existing port in the wall of the Y-shaped duct, with the connection properly sealed; upon evacuating residual gas from the vacuum chamber and energizing the RF power supply, a uniform plasma is generated at the side of the elliptical metal mesh.

A collection trough is positioned at the side outlet of the Y-shaped duct; the outlet of the side branch of the Y-shaped duct connects to the collection trough via a flange. The inner and outer diameters of the collection trough match those of the Y-shaped duct—160 mm and 165 mm, respectively—and the depth of the collection trough is 200 mm.

The straight-through outlet of the Y-shaped duct is connected to a vacuum pump

via an exhaust duct and a flange; the residual gas—having been stripped of particulates—is discharged by the vacuum pump.

During operation, the external RF power supply is activated, generating a uniform plasma near the elliptical metal mesh; residual gases and particulates flowing from the semiconductor process chamber enter the gas-guiding duct, where cooling promotes particulate growth and accumulation, before subsequently entering the Y-shaped duct. As particles pass through the plasma near the elliptical metal mesh, they acquire a significant amount of electric charge; since the velocity of electrons exceeds that of ions, the particles carry a negative charge once their charge state stabilizes. Negatively charged particles are repelled by the sheath electric field at the surface of the elliptical metal mesh with the negative bias voltage; they are guided by the inclined mesh into the side outlet branch of the Y-shaped duct and subsequently fall into a collection trough, whereas residual gas passes through the metal mesh unaffected.

Metal screen meshes play a decisive role in the collection of residual particulate matter; therefore, special attention must be paid to their size and placement. On one hand, the inclination angle of the metal mesh must be appropriate to ensure that particulate matter in the residual gas has sufficient time—guided by the mesh—to enter the side outlet channel of the Y-shaped duct. On the other hand, the pore radius of the metal mesh should be no greater than 5 mm to ensure that particulates can be intercepted and guided by the mesh while minimizing the impact on airflow. Testing determined that optimal performance is achieved with a metal mesh having a pore radius of 3 mm and a wire thickness of 1 mm.

The method for collecting particle in Embodiment 2 mainly includes the following steps:

A2. Install a section of gas-guiding duct; one end of the duct is connected via a flange to the exhaust port of the semiconductor manufacturing process exhaust system piping, while the other end is connected to the inlet of a Y-shaped duct. The Y-shaped duct features an inlet, a straight-through outlet, and a side outlet duct; a spiral water-cooling pipe is tightly wound around the exterior of the gas-guiding duct, with cold water circulating through the cooling pipe—entering via the lower opening and exiting via the upper opening.

B2. A Y-shaped duct is connected to the vertical duct situated between the vacuum chamber and the vacuum pump; the inlet of the Y-shaped duct connects to the gas-

guiding duct via a flange, while its straight-through outlet connects to the vacuum pump via an exhaust duct.

C2. The Y-shaped duct comprises a plasma generation module and a diversion module. An elliptical metal mesh is obliquely positioned at the center of the Y-shaped duct to create a plasma region above the inlet of the side outlet duct of the Y-shaped duct; this region charges particles flowing through it to generate plasma, which is then repelled and directed into the side outlet duct. An appropriate gap is maintained between the metal mesh and the Y-shaped duct; if necessary, the metal mesh can be bent to facilitate the guidance of particle movement. The metal mesh is connected to a power source outside of the Y-shaped duct. By initially applying a specific voltage to the metal mesh to induce a discharge in the surrounding gas and generate plasma, a negative bias voltage is automatically established on the mesh; this negative bias voltage generates a sheath electric field that repels negatively charged particles, thereby creating a diversion effect. Consequently, in the present invention, the metal mesh serves as both the plasma generation module and the diversion module.

D2. The outlet of the side outlet duct of the Y-shaped duct connects to a collection trough; a collection trough is positioned at the side outlet of the Y-shaped duct and connected to the outlet of the side outlet duct of the Y-shaped duct via a flange. It connects to a Y-shaped duct via a flange and is used to collect particulate matter diverted by the metal mesh.

E2. Activate the power system so that the residual gas flowing out of the semiconductor manufacturing vacuum chamber undergoes a gas discharge—occurring near the metal mesh within the Y-shaped duct—thereby generating a uniform plasma. The required plasma is generated by controlling parameters such as the power supply output. The metal mesh is connected to an external power source and maintained at a negative bias voltage.

F2. As the particulate matter within the residual gas flows through the plasma region formed within the Y-shaped duct along with the residual gas, the plasma rapidly charges the particles, rendering them negatively charged. As these negatively charged particles continue to move downstream with the gas flow and approach the negatively charged elliptical metal mesh grid, they are repelled by the sheath electric field at the grid's surface; consequently, they move along the surface of the elliptical metal mesh grid—downward and toward the inlet of the side outlet duct of the Y-shaped duct. When

the particulate matter flows to a point below the outlet of the side outlet duct of the Y-shaped duct and enters the collection trough, the process of collecting particulate matter from the residual gas is completed.

G2. After a certain period of operation, remove the collection trough from the exhaust duct, clean out the particulate matter within the collection trough, and reinstall it to resume the process of recovering particulates from the residual gas.

Step C2 involves providing an external power source to the elliptical metal mesh to generate a uniform plasma via gas discharge in the vicinity of the mesh. The power source may be an RF power supply (operating at 13.56 MHz with a power output of 1–200 W) or a standard AC power supply (operating at a frequency in the range of tens of kilohertz); regardless of the type of power source used, a specific negative bias voltage must be applied. The elliptical metal mesh is placed obliquely inside the Y-shaped duct to block the straight-through outlet of the Y-shaped duct and simultaneously guide particulate matter to the side outlet duct of the Y-shaped duct.

Following the plasma generation in Step E2, a quasi-neutral environment containing free electrons, ions, and various other reactive species is established within the region. As particulate matter approaches the elliptical metal mesh along with the gas flow, surrounding free electrons and ions collide with and adhere to the particles, causing them to become charged; given that the velocity of free electrons far exceeds that of ions, the particles typically exhibit a negative charge once the charge state reaches equilibrium.

The plasma generated in step F2 creates a non-electroneutral region on the surface of the elliptical metal mesh; this region contains a strong electric field capable of exerting a repulsive force on electronegative particulate matter. Upon experiencing this repulsion, the particulate matter moves along the direction of the elliptical metal mesh's inclination; unable to pass through the mesh, it is instead diverted to move along the side outlet of the Y-shaped duct.

In Embodiment 2, the collection efficiency was tested by continuously feeding pine pollen particles into the system. During the experiment, the system's air pressure was maintained at 80 Pa, and 5.437 g of pine pollen particles—with an average particle size of approximately 40 micrometers—were slowly and evenly introduced into the gas-guiding duct. The vast majority of these particles were effectively collected via the described method and deposited into the collection trough. Post-experiment

measurement showed that the mass of particles in the collection trough was 5.421 g, representing a collection efficiency of 99.7%.

Embodiment 3

Embodiment 3 comprises a condensation module, a plasma generation module, a diversion module, and a dust collection module arranged in sequence along the piping of a semiconductor manufacturing exhaust system; typically, these are arranged vertically in that order from top to bottom between the vacuum chamber and the vacuum pump.

The condensation module consists of a thin condensation pipe spirally wound around the exterior of the uppermost duct; cold water enters through a lower opening of the pipe and exits through an upper opening of the pipe, cooling the residual gas within the duct to promote particle growth and ensure the complete condensation reaction of substances contained in the residual gas, thereby minimizing the likelihood of forming new particles after the residual gas passes through the structure of the invention.

Plasma generation modules are primarily used to produce uniform plasma; common methods include capacitively coupled plasma (CCP), inductively coupled plasma (ICP), and direct current (DC) discharge. The objective of generating uniform plasma is to achieve a spatially uniform distribution of electrons and ions. As residual gas particulates flow through a uniform plasma, electrons and ions within the plasma collide with the particulates and adsorb onto the surfaces of the particulates, thereby charging them. When the electron charging current and the ion charging current reach equilibrium, the electric charge acquired by the particulates attains a steady state. Since the mass of electrons is much smaller than that of ions, and their thermal velocity is correspondingly much higher, particles typically acquire a negative charge. By adjusting discharge parameters to modify variables such as electron density, the charge level of the particles can be controlled. In summary, the plasma module is designed to generate a uniform plasma and charge the particles flowing through it.

The diversion module refers to a grid structure with a negative bias voltage—such as a tower-shaped spiral grid, a conical grid, or a wedge-shaped grid—characterized by a design that is narrow at the top and wide at the bottom; its purpose is to utilize the grid's negative bias voltage to repel negatively charged particulate matter, thereby creating a barrier effect that pushes the particles within the exhaust duct toward the

duct's sidewalls. The diversion module is positioned adjacent to the plasma module. After the particulate matter flows through the plasma module and becomes charged, it enters the diversion module. Repelled by the sheath electric field at the surface of the negative bias voltage grid structure, the negatively charged particles move along the surface of the grid structure. Residual gas particulates generated within the vacuum chamber of semiconductor manufacturing equipment exhibit a uniform density distribution within the exhaust duct after entering the exhaust duct. Upon reaching the diversion module, the particulates travel along the grid structure—tapered at the top and wider at the bottom—toward the exhaust duct sidewalls, concentrating near the sidewalls and leaving the center of the duct free of particulates. After passing through the diversion module, the particulates enter the dust collection module.

The primary function of the dust collection module is to collect particulate matter—received from the diversion module—using a collection trough positioned at the upper end of the metal cylinder. Collection troughs of various shapes and dimensions can be configured according to specific requirements. Particulate matter within the exhaust duct moves along the surface of the grid—along with gas flow and driven by gravity—from the center of the duct toward the sidewall of the duct; after passing through the diversion module, the particles naturally fall into the collection trough of the dust collection module, thereby achieving collection of the particles. After sequentially passing through these four modules, the particulate matter from the exhaust duct is ultimately collected in the dust collection module. Since the plasma module and the diversion module carry a negative bias voltage that repels negatively charged particulates, they do not become contaminated by the particles and thus do not require cleaning. The dust collection module can simply be removed and cleaned periodically as needed.

As shown in Figure 7, residual gas exiting the semiconductor process chamber enters a pre-installed metal cylinder A with an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 400 mm. A cooling pipe is arranged around the exterior of the cylinder A; cold water—maintained at a temperature below 10°C—enters through the lower pipe opening, flows through the helical pipe, and exits through the upper pipe opening. Particulates generated by condensation reactions within the residual gas flow into the cylinder B along with the residual gas flow.

The cylinder B is made of quartz glass and has an inner diameter of 160 mm, an

outer diameter of 165 mm, and a length of 200 mm; its upper end is connected to the cylinder A. Two metal electrode plates—serving as the driving electrode and the grounding electrode—are positioned vertically and parallel to each other inside the cylinder B. These plates measure 80 mm in length, 60 mm in width, and 0.5 mm in thickness; they are secured near the inner wall of the cylinder B by a mounting fixture, positioned 20 mm below the top of the cylinder and 30 mm away from its central axis. The driving electrode is connected to an external power source—specifically an RF power supply operating at 100 W and 13.56 MHz—via an insulated wire passing through a power input interface in the sidewall of the cylinder B, while the grounding electrode is connected to a ground line. Once the RF power supply is activated, a uniform plasma is generated between the driving electrode plate and the grounding electrode. A tower-shaped wire structure (or mesh) is positioned beneath the two electrodes; this structure can be connected via a wire to an external negative voltage power supply (operating at -100 V). It is located slightly below the level of the driving electrode plate and the grounding electrode, at a vertical distance of 150 mm from the top of the cylinder B.

Another cylinder C is positioned beneath the cylinder B, and the two are connected by a flange; a collection trough—20 mm wide and 30 mm deep—is located on the side wall just below the connection point. The other end of the cylinder C is connected to a vacuum pump via an exhaust duct. The purified residual gas is discharged through the vacuum pump.

During operation, the RF power supply and negative voltage power supply are activated to generate a uniform plasma between the driving electrode and the grounding electrode. Residual gases and particulates flowing from the semiconductor process chamber enter the cylinder B; as they pass through the plasma situated between the driving electrode and the grounding electrode, they acquire a significant electric charge. Since the velocity of electrons exceeds that of ions, the particulates accumulate a net negative charge once their charge state stabilizes. After passing the electrodes, the negatively charged particles are repelled by the negative voltage metal wire (or mesh) and move toward the sidewall of the cylinder B, subsequently falling into the collection trough of the cylinder C, whereas the residual gas remains unaffected as it passes through the negative voltage metal wire (or mesh).

Metal wires (or meshes) play a crucial role in the collection of residual gas

particulate matter; therefore, the selection of their dimensional parameters requires strict control. First, the height of the wire mesh should be sufficient—neither too low nor too narrow—to ensure that dust particles have enough time to migrate toward the sidewall of the cylinder B. Second, the longer the flow-guiding module is, the more space it occupies; therefore, the height of the wire mesh should not be excessive. Finally, the mesh radius of the metal wires (or meshes) should be no greater than 2 mm to prevent particulate matter from being swept through the metal wires (or meshes) by the residual gas flow. Multiple tests demonstrated that the removal efficiency for residual gas particulates was optimal when the metal wires (or meshes) had a height of 100 mm, a base diameter of 120 mm, and a mesh radius of 1 mm.

Particulate matter accumulating in the collection trough requires periodic cleaning by opening the cylinder C; the cleaning frequency depends on the duration of use. Excessive accumulation must be avoided, as it would reduce the effective depth of the trough—thereby hindering further collection—and lower purification efficiency. Purification performance is further enhanced by adding an adsorbent to the collection trough to prevent the accumulated particles from being blown back out by the gas flow.

In the structure shown in Figure 8, residual gas flowing out of the semiconductor process chamber enters a pre-positioned cylinder A; the cylinder A is made of metal and has an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 400 mm. A condensation pipe is installed around the cylinder A; cold water is introduced through the lower pipe opening—with the temperature maintained below 10°C—and flows out through the upper pipe opening after passing through the helical pipe, while particulate matter generated within the residual gas flows into the cylinder B along with the residual gas. The cylinder B is made of quartz, with an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 300 mm; its upper end is connected to the upper cylinder B. A multi-layer spiral metal mesh is installed vertically inside the cylinder B, positioned 100 mm below the top of the cylinder; the mesh is connected to an external RF power supply—operating at 100 W and 13.56 MHz—via an insulated wire passing through a power input interface on the cylinder's sidewall. Upon introducing residual gas from the process chamber and activating the RF power supply, a uniform plasma is generated around the multi-layer spiral metal mesh.

During operation, when the RF power supply is activated, the region near the spiral multi-layer metal mesh inside the cylinder B becomes filled with uniform plasma. As

residual gases and particulates flowing from the semiconductor process chamber enter this plasma, they acquire a significant electric charge; since electrons move faster than ions, the particulates carry a negative charge once their charge state stabilizes. When passing through the spiral multi-layer metal mesh, the negatively charged particulates will be repelled by the spiral multi-layer metal mesh and move towards the side wall of the cylinder B, and then fall into the collection trough of the cylinder C. The residual gas is not affected when passing through the metal wire (mesh) with negative voltage.

The spiral multi-layer metal mesh plays a crucial role in collecting residual gas particulate matter; therefore, the selection of its dimensional parameters requires strict control. First, the height of the spiral multi-layer metal mesh should not be too low, and it must be sufficiently wide to ensure that dust particles have enough time to migrate toward the sidewall of the cylinder B. Second, a longer diversion module would occupy more space and increase costs; therefore, the height of the spiral multi-layer metal mesh should not be excessive. Finally, the mesh radius of the spiral multi-layer metal mesh should be no greater than 5 mm to ensure that particulate matter is not swept through the mesh by the residual gas flow. Multiple tests demonstrated that the spiral multi-layer metal mesh achieved the best removal efficiency for residual gas particulates with a height of 150 mm, a bottom diameter of 130 mm, and a mesh radius of 3 mm.

Unlike the configuration in Figure 7, the structure shown in Figure 8 eliminates the need to place two metal electrodes inside the cylinder and increases the number of metal mesh layers. The plasma fills almost the entire interior of the cylinder, removing concerns that particulate matter passing between the metal electrode plates and the cylinder sidewall—and thereby acquiring insufficient negative charge or becoming positively charged—might compromise removal efficiency.

The particulate matter purification method of Embodiment 3 mainly comprises the following steps:

A3. Three cylindrical sections—cylinder A, cylinder B, and cylinder C—are installed in the exhaust system piping of a semiconductor manufacturing process. They are connected to the vertical duct situated between the vacuum chamber and the vacuum pump, with the cylinder A positioned at the top, the cylinder B in the middle, and the cylinder C at the bottom.

B3. The cylinder A is part of the condensation module; a set of thin pipes is helically wound against the outer wall of the cylinder A, with cold water fed into the thin glass

pipes through the lower pipe opening and discharged through the upper pipe opening.

C3. The cylinder B contains a plasma generation module and a diversion module. The plasma generation module is positioned at the upper end inside the cylinder B and consists of two metal electrode plates—a first metal electrode plate and a second metal electrode plate—placed vertically and in parallel; these two plates are arranged symmetrically on opposite sides of the axis of the cylinder B. The first metal electrode plate is connected to an external power supply system via an interface on the side wall of the cylinder B.

D3. A diversion module—specifically, a tower-shaped metal wire (or mesh)—is installed at the lower end of the cylinder B; it is positioned with its apex pointing upward, its base not in contact with the cylinder B, and its vertical position slightly below that of the first and second metal electrode plates.

E3. The cylinder C contains a dust collection module; a collection trough is provided at the upper end of the cylinder C. The cylinder C has an inner radius smaller than that of the cylinder B and connects to the lower end opening of the cylinder B via a flange, serving to collect particulate matter discharged from the cylinder B.

F3. As residual gases are exhausted from the semiconductor process chamber, they first pass through the cylinder A, where the action of the condensation pipe promotes particle growth and condensation.

G3. The power supply system is activated to initiate a gas discharge and generate a uniform plasma; the desired plasma characteristics are achieved by controlling parameters such as the power input. The tower-shaped wire structure (or mesh) exhibits electronegativity within the plasma. Alternatively, this structure can be independently connected to a negative-voltage power supply located outside the cylinder B, allowing for precise control of its electric potential.

H3. As negatively charged particles continue to move downward with the gas flow under gravity and approach the vicinity of the negatively charged tower-shaped wire structure (or mesh), they are repelled by the sheath electric field at the surface of said structure and move downward along its surface toward the side wall of the cylinder B. When the particulate matter flows to the collection trough at the upper end of the cylinder C, it falls naturally into the trough, thereby completing the process of collecting the particulate matter from the residual gas.

I3. After a certain period of operation, remove the cylinder C from the exhaust duct,

clean the particulate matter from the collection trough, and reinstall it to resume the process of recovering particulate matter from the residual gas.

In Step C3, the first and second metal electrode plates are connected to a power source and ground, respectively, with the aim of generating a uniform plasma between them via gas discharge. An RF power source operating at 13.56 MHz with a power range of 2–200 W is used; alternatively, an AC discharge source with a frequency in the range of tens to hundreds of kilohertz may be employed. Alternatively, inductively coupled discharge may be used to generate plasma (eliminating the need for the first and second metal electrode plates); in this case, the cylinder B must be made of glass, and a metal coil is positioned around its exterior. By applying a high-voltage radio-frequency signal to the metal coil, a uniform inductively coupled plasma is generated within the cylinder B.

Step D3 involves installing a tower-shaped metal wire structure (or mesh) for two primary purposes: first, to establish a negative potential on the structure that repels and blocks subsequently arriving negatively charged particulate matter; and second, to guide the trajectory of the falling particles, directing them to move downward along the surface of the structure—spreading toward both sides—until they ultimately reach the collection trough of the cylinder C for collection. The negative potential of the tower-shaped metal wire (or mesh) can be established in two ways: one involves placing the structure directly into a plasma environment, where it automatically acquires a negative potential through the adsorption of electrons and ions—this negative potential repels electrons, subsequently leading to the formation of a sheath; the other method involves connecting the structure to an external negative voltage power supply (located outside the cylinder B), allowing for precise control of its potential.

In Step C3, the metal electrode plate is positioned slightly above the tower-shaped metal wire structure (or mesh). The purpose of this arrangement is to ensure that as particulate matter flows downward with the residual gas through the cylinder B, it first passes through the plasma region to become charged; subsequently, during its downward movement, it is repelled by the negative potential of the tower-shaped metal wire structure (or mesh) and travels along the surface into the collection trough at the upper end of the cylinder C.

The plasma generated in step G3 creates a sheath layer on the inner wall surface of the cylinder B; the sheath electric field exerts an electric force on electronegative

particles, driving them away from the inner wall surface of the cylinder B, thereby preventing the particles from reaching the inner wall surface of the cylinder A and avoiding contamination of cylinder B by the particles.

Step H3 involves using the sheath electric field at the surface of the conical metal wire (mesh) structure to guide the negatively charged particulate matter from Step E into the collection trough at the upper flange of the cylinder C, thereby completing the collection process.

In Embodiment 3, the collection efficiency is tested using the continuous introduction of pine pollen particles. In the experiment, the system pressure was maintained at 80 Pa, and 5.631 g of pine pollen particles—with an average particle size of approximately 40 μm—were slowly and evenly sprinkled into cylinder A. The vast majority of these particles were effectively collected via the described method and deposited into the collection trough. After the experiment, the particulate matter in the collection trough weighed 5.326 grams, representing a collection efficiency of 94.6%.

Embodiment 3 offers a high degree of protection for the backing vacuum pump of the vacuum system and theoretically achieves 100% efficiency in removing particulates from residual gases in semiconductor manufacturing processes, thereby enabling environmentally friendly operation with zero particulate emissions. The device designed according to the present invention is capable of continuous, long-term operation and entails very low equipment costs.

Embodiment 4

Embodiment 4 primarily comprises a condensation module, a plasma generation module, a diversion module, and a collection trough; the condensation module, plasma generation module, and diversion module are integrated into a single unit installed on the piping of a semiconductor manufacturing exhaust system, while the collection trough is connected beneath the plasma generation module and the diversion module.

The condensation module comprises a gas-guiding duct and a water-cooling pipe, installed downstream of the vacuum chamber's exhaust port; the water-cooling pipe wraps around the gas-guiding duct, with cold water entering through the lower pipe opening and exiting through the upper pipe opening. Upon cooling, chemical constituents within the residual gas accelerate their condensation and growth into particles. Incorporating this condensation module enhances particle collection efficiency and reduces contaminant components in the residual gas.

The plasma generation module is primarily used to produce uniform plasma, aiming to achieve a relatively uniform spatial distribution of electrons and ions. When particles from the residual gas pass through the plasma, the electrons and ions within the plasma collide with the particles and adsorb onto the particle surfaces, thereby charging the particles. When the electron charging current and the ion charging current reach equilibrium, the electric charge acquired by the particles reaches saturation. Since the mass of an electron is far smaller than that of an ion—and consequently, the thermal velocity of electrons is far greater than that of ions—particles typically end up carrying a negative charge. By adjusting discharge parameters to modify variables such as electron density, the charge on the particles can ultimately be controlled. In summary, the plasma module is designed to generate a uniform plasma and charge the particles flowing through it.

The diversion module consists of a grid structure with a negative bias voltage; it is elliptical in shape and obliquely positioned within a T-shaped duct. Its function is to utilize the grid's negative bias voltage to repel negatively charged particulate matter, thereby directing the particles within the exhaust duct toward the lower outlet of the T-shaped duct. The diversion module and the plasma generation module share a metal grid structure. As the particulate matter flows through the plasma module and becomes charged, the negatively charged particles are repelled by the sheath electric field at the surface of the negatively biased grid structure, causing them to move along the surface of the grid. Residual gas particulates generated within the vacuum chamber of semiconductor manufacturing equipment exhibit a uniform density distribution within the exhaust duct after entering the exhaust duct. Upon reaching the diversion module, the particulates travel along an inclined mesh structure toward the lower outlet of the T-shaped duct, thereby preventing particulates from reaching the horizontal outlet of the duct. After passing through the diversion module, the particulates enter the collection trough.

A cylindrical metal collection trough is positioned beneath the diversion module to collect particulate matter emerging from the diversion module. Depending on specific requirements, trough structures of various shapes and sizes may be employed. Within the exhaust duct, particles move from the surface of the metal mesh toward the lower section of the T-shaped duct—driven by gravity and the repulsive force of the negatively biased metal mesh—and, after passing through the diversion module,

naturally fall into the collection trough below, thereby achieving particle collection. Particulate matter within the exhaust duct passes sequentially through these four modules and is ultimately collected in the collection trough. Since the plasma module and the diversion module carry a negative bias voltage, they exert a repulsive force on negatively charged particles; consequently, the particles do not contaminate these two modules, meaning neither module requires cleaning.

An elliptical metal screen mesh is positioned diagonally at a 45-degree angle to the horizontal within the T-shaped duct; its edge maintains a 20 mm clearance from the horizontal section of the T-shaped duct, while its lower end extends slightly into the inlet of the vertical section of the T-shaped duct. An insulated wire is used to connect the elliptical metal mesh to an external RF power supply (80 W, 13.56 MHz) through a pre-drilled hole in the T-shaped duct wall, with the connection properly sealed; once residual gas is evacuated from the vacuum chamber and the RF power supply is activated, a uniform plasma is generated alongside the elliptical metal mesh.

A collection trough is positioned beneath the T-shaped duct, with the connection between the T-shaped duct and the collection trough secured by a flange. The outlet of the horizontal section of the T-shaped duct is connected to a vacuum pump via an exhaust duct and a flange, allowing the residual gas—after the removal of particulates—to be discharged via the vacuum pump.

During operation, the external RF power supply is activated, generating a uniform plasma near the elliptical metal mesh; residual gases and particulates flowing out of the semiconductor process chamber pass through a gas-guiding duct—where cooling promotes particulate growth and accumulation—before entering the T-shaped duct. As particles pass through the plasma near the elliptical metal mesh, they acquire a significant amount of electric charge; since the velocity of electrons exceeds that of ions, the particles carry a negative charge once their charge state stabilizes. Negatively charged particles are repelled by the sheath electric field at the surface of the negatively biased, elliptical metal mesh and move toward the lower section of the T-shaped duct, subsequently falling into the collection trough, whereas residual gases pass through the metal mesh unaffected.

Metal screen meshes play a decisive role in the collection of residual particulate matter; therefore, special attention must be paid to their size and placement. On one hand, the inclination angle of the metal mesh must be sufficiently large to ensure that,

guided by the mesh, particulate matter within the residual gas has enough time to enter the lower channel of the T-shaped duct. On the other hand, the pore radius of the metal mesh should not exceed 5 mm to ensure that particulates are intercepted and guided with minimal impact on airflow; if necessary, the metal mesh can be fabricated with an arc shape to facilitate flow guidance. Testing indicates that optimal results are achieved with a metal mesh having a pore radius of 3 mm and a wire thickness of 1 mm.

The particulate matter purification method of Embodiment 4 mainly comprises the following steps:

A4. A gas-guiding duct is installed and connected via a flange to the exhaust system piping of the semiconductor manufacturing process; a helical water-cooling pipe is tightly wrapped around the exterior of the gas-guiding duct, and cold water is circulated through the water-cooling pipe to cool the residual gas exhausted from the vacuum chamber. Both the gas-guiding duct and the water-cooling pipe are made of metal to facilitate heat conduction.

B4. A T-shaped duct section is installed such that its horizontal segment connects to the horizontal piping between the gas-guiding duct and the vacuum pump; one end of this horizontal segment is connected to the gas-guiding duct via a flange, while the other end connects to the vacuum pump via an exhaust duct. A collection trough is positioned beneath the vertical segment of the T-shaped duct and is connected to the bottom outlet of that vertical segment using a flange. The T-shaped duct is made of glass, and the collection trough is made of metal.

C4. The plasma generation module and the diversion module are contained within the T-shaped duct. An elliptical metal mesh is positioned obliquely at the center of the T-shaped duct, with a certain gap maintained between the edge of the mesh and the T-shaped duct. The metal mesh is connected to an external power source outside of the T-shaped duct. By initially applying a specific voltage to the metal mesh to induce a discharge in the surrounding gas and generate plasma, a negative bias voltage is automatically established on the mesh; this negative bias voltage generates a sheath electric field that repels negatively charged particles, thereby creating a flow-directing effect. Consequently, the metal mesh functions as both a plasma generation module and a diversion module.

D4. A collection trough is located beneath the T-shaped duct and connected to the T-shaped duct via a flange; it serves to collect particulate matter diverted by the metal mesh.

E4. When the power system is activated, residual gas exiting the semiconductor manufacturing vacuum chamber flows through a gas-guiding duct into the T-shaped duct; the plasma generation module within this duct discharges the gas to produce a uniform plasma. The plasma is tailored to meet specific requirements by controlling parameters such as power input. A metal mesh connected to an external power source is maintained at a negative bias voltage.

F4. As the particulate matter in the residual gas flows through the plasma region formed within the T-shaped duct along with the residual gas, the plasma rapidly charges the particles, rendering them negatively charged. As the negatively charged particles continue to move to the right with the gas flow and approach the negatively charged elliptical metal mesh grid, they are repelled by the sheath electric field at the grid's surface; consequently, they travel downward along the surface of the grid toward the lower outlet of the T-shaped duct. Upon reaching this lower outlet in the vertical section of the T-shaped duct, the particles enter the collection trough, thereby completing the process of collecting particles from the residual gas.

G4. After a certain period of operation, remove the collection trough from the exhaust duct, clean out the particulate matter, and reinstall the trough to resume the process of recovering particulates from the residual gas.

In Step A4, the gas-guiding duct can be replaced with a double-walled sleeve; by circulating cold water through the annular space between the double walls so that it comes into direct contact with the gas-guiding tube, the cooling effect is enhanced.

Step C4 involves connecting an external power source to the elliptical metal mesh to generate a uniform plasma via gas discharge in the vicinity of the mesh. The power source may be an RF power supply (operating at 13.56 MHz with a power output of 1–200 W) or a standard AC power supply (operating at a frequency in the range of tens to hundreds of kilohertz); regardless of the type of power source used, a specific negative bias voltage must be applied. The elliptical metal mesh is obliquely positioned within the horizontal section of the T-shaped duct to filter the gas flowing through it, directing particulate matter from the gas toward the lower outlet of the T-shaped duct's vertical section.

Following the plasma generation in Step E4, a quasi-electrically neutral environment containing free electrons, ions, and various other active species is established within the region. As particulate matter approaches the elliptical metal mesh with the gas flow, the surrounding free electrons and ions collide with and adhere to the particles, causing them to become charged; given that the velocity of free electrons far exceeds that of ions, the particles typically exhibit a negative charge upon reaching an equilibrium state.

The plasma generated in step F4 creates a non-electroneutral region on the surface of the elliptical metal mesh; this region contains a strong electric field capable of exerting a repulsive force on electronegative particulate matter. Upon experiencing this repulsion, the particulate matter moves along the direction of the elliptical metal mesh's inclination; unable to pass through the mesh, it is diverted to move along the outlet located at the bottom of the T-shaped duct.

In Embodiment 4, one T-shaped duct is installed in series with the horizontal exhaust duct connecting the semiconductor process vacuum chamber and the backing vacuum pump; an elliptical metal wire mesh is obliquely positioned at the center of the T-shaped duct. Plasma is generated via electric discharge; as particulate matter flows with the residual gas through the plasma region, electrons within the plasma charge the particles, rendering them negatively charged. When these negatively charged particles flow past the charged elliptical metal wire mesh, they are repelled by the electric field at its surface and guided downward along the mesh toward the lower section of the duct, ultimately entering a collection trough positioned beneath it, thereby achieving particle collection. The method of the present invention is simple and convenient to operate, achieving a theoretical particle collection efficiency of 100% (with 98% measured in practice) from semiconductor manufacturing exhaust gases; it is not only environmentally friendly—eliminating particulate emissions—but also effectively protects equipment such as exhaust lines and downstream vacuum pumps. Designed particle collection devices using this method are low-cost and suitable for continuous industrial-scale operation, thereby resolving the issue of particulate contamination in semiconductor manufacturing exhaust.

Although specific embodiments of the present invention have been disclosed for illustrative purposes—intended to facilitate an understanding of the invention and its implementation—those skilled in the art will appreciate that various substitutions,

changes, and modifications are possible without departing from the spirit and scope of the invention and the appended claims. Therefore, the present invention should not be limited to the specific embodiments disclosed; rather, the scope of protection is defined by the claims.

Claims

1. A particulate matter purification system for exhaust gas in semiconductor process flows, characterized in that the system comprises a refrigeration unit, a plasma diversion unit, and a particulate matter collection unit; wherein the refrigeration unit, the plasma diversion unit, and the particulate matter collection unit are arranged in sequence on an exhaust piping between a vacuum chamber and a vacuum pump; wherein the particulate matter collection unit is provided with a collection trough and an exhaust port; and wherein:

the refrigeration unit is configured to cool the exhaust gas discharged from the vacuum chamber to promote condensation and growth of particulate matter in the exhaust gas into particles and then to force the exhaust gas to flow into the plasma diversion unit;

the plasma diversion unit is configured to produce a free charge distribution region and a sheath electric field and to charge the particulate matter in the exhaust gas when the input exhaust gas flows through the free charge distribution region, and the charged particulate matter is then repelled and guided by the sheath electric field to move into the collection trough of the particle collection unit; and

the exhaust port of the particulate matter collecting unit is connected to the vacuum pump via an exhaust duct for discharging through the vacuum pump the residual exhaust gas which has been filtered out the particulate matter.

2. The system according to claim 1, wherein the refrigeration unit is a condensing module, the plasma diversion unit is an electrostatic repulsion module, and the particulate matter collecting unit is a dust collection module, the collection trough and the exhaust port being provided on a bottom of the dust collection module; wherein the electrostatic repulsion module includes a cylinder B provided with a first spherical cap-shaped perforated metal plate and a second spherical cap-shaped perforated metal plate in the cylinder B; wherein the first spherical cap-shaped perforated metal plate serves as a negative electrode, the second spherical cap-shaped perforated metal plate serves as a positive electrode, and the first spherical cap-shaped perforated metal plate is located below the second spherical cap-shaped perforated metal plate; wherein the collection module includes a cylinder C, the collection trough being provided at a bottom edge of an inner wall of the cylinder C and the exhaust port being provided at a

central region of the bottom of the cylinder C; wherein tops of the first and second spherical cap-shaped perforated metal plates face upward; wherein the first spherical cap-shaped perforated metal plate is used to generate plasma by means of gas discharge breakdown to form the free charge distribution region, and the sheath electric field is formed by means of the plasma on an inner wall surface of the cylinder B, on a surface of the first spherical cap-shaped perforated metal plate, and on a surface of the second spherical cap-shaped perforated metal plate, respectively, the sheath electric field on the surfaces of the first and second spherical cap-shaped perforated metal plates is used to repel the charged particulate matter to move toward and slide down a side wall of the cylinder B, and the sheath electric field on the surface of the cylinder B is used to repel the particulate matter to move away from the surface of the inner wall of the cylinder B and slide downward into the collection trough of the dust collection module.

3. The system according to claim 2, wherein metal holes on the first spherical cap-shaped perforated metal plate have a diameter of no greater than 7 mm, and the first spherical cap-shaped perforated metal plate has a thickness of 0.5mm and a grid radius of 3 mm; wherein metal holes on the second spherical cap-shaped perforated metal plate have a diameter of no greater than 7 mm, and the second spherical cap-shaped perforated metal plate has a thickness of 0.5 mm and a grid radius of 3 mm; wherein a curvature of the second spherical cap-shaped perforated metal plate is smaller than a curvature of the first spherical cap-shaped perforated metal plate; wherein the cylinder B has an inner diameter of 160 mm, an outer diameter of 165 mm, and a length of 300 mm, and a height of the second spherical cap-shaped perforated metal plate is 40 mm, and the first spherical cap-shaped perforated metal plate has a height of 60 mm and a maximum diameter of 120 mm; and wherein the second spherical cap-shaped perforated metal plate is at a distance of 100 mm away from the top of the cylinder B, and a perpendicular distance between the first spherical cap-shaped perforated metal plate and the second spherical cap-shaped perforated metal plate is 50 mm.

4. The system according to claim 2 or 3, wherein the collection module comprises a cylinder C, the collection trough and the exhaust port being provided at a bottom of the cylinder C; wherein the collection trough has a width of 20 mm and a depth of 30 mm; wherein an inner diameter of the cylinder C is smaller than an inner diameter of the cylinder B; wherein the first spherical cap-shaped perforated metal plate is electrically

connected to a power supply system outside the cylinder B through an interface on the side wall of the cylinder B, and the second spherical cap-shaped perforated metal plate is grounded through an interface on the side wall of the cylinder B; and wherein the condensing module comprises a cylinder A and a water-cooling pipe, an upper end of the cylinder A being connected to an exhaust gas discharge port of the vacuum chamber, and a lower end of the cylinder A being connected to the electrostatic repulsion module; and wherein the water-cooling pipe is wound around an outer wall of the cylinder A for cooling the exhaust gas.

5. The system according to claim 1, wherein the refrigeration unit is a cooling module, and the plasma diversion unit comprises a plasma generation module and a diversion module; wherein the exhaust piping includes a section of Y-shaped duct; wherein the Y-shaped duct has an input port, a straight-through outlet, and a side outlet duct; wherein the plasma generation module and the diversion module are arranged within the Y-shaped duct, wherein:

one end of the cooling module is connected to the exhaust port of the vacuum chamber in the semiconductor manufacturing process, and the other end of the cooling module is connected to the input port of the Y-shaped duct for cooling the exhaust gas discharged from the vacuum chamber, so that upon cooling, chemical components within the exhaust gas undergo accelerated condensation and growth into particles and then enter the Y-shaped duct;

the plasma generation module is used to form a plasma region above the entrance of the side outlet pipe of the Y-shaped duct, for charging the particles flowing through the plasma region to form charged particles;

the diversion module is used to repel and guide the charged particles into the side outlet duct by means of the sheath electric field generated by itself;

the collection trough of the particulate matter collection unit is connected to the outlet of the side outlet duct of the Y-shaped duct for collecting the inflowing particulate matter; and

the straight-through outlet of the Y-shaped duct serves as the exhaust port of the particulate matter collection unit and is connected to the vacuum pump through the exhaust duct, for discharging through the vacuum pump the residual gas which has been filtered out the particulate matter.

6. The system according to claim 5, wherein the plasma generation module and the diversion module are the same metal grid; wherein the metal grid is electrically connected to a power supply located outside the Y-shaped duct to provide a negative voltage for the metal grid, and the sheath electric field is formed on a surface of the metal grid by the plasma; the metal grid is obliquely placed at an angle of 45° within the Y-shaped duct; and the mesh radius of the metal grid is 3 mm, and the thickness of wires of the metal grid is 1 mm.

7. The system according to claim 1, wherein the refrigeration unit is a condensing module, the plasma diversion unit comprises a plasma generation module and a diversion module, and the particulate matter collection unit is a dust collection module, the collection trough and the exhaust port being provided at a bottom of the dust collection module; wherein the diversion module is a tower-shaped structure composed of metal wires or metal meshes, positioned with its apex facing upward; wherein the plasma generation module is used to generate plasma through discharge, forming a plasma region on a flow passage through which the exhaust gas flows, the plasma region being used to charge the particles within the exhaust gas to form charged particles, the charged particles then entering the region where the diversion module is located; and wherein the diversion module generates a sheath electric field for repelling the charged particles, forcing the charged particles to move away from a side wall of the tower-shaped structure and then move downward and fall into the collection trough, and the residual gas, which has been filtered out the particulate matter, is output through the exhaust port.

8. The system according to claim 7, wherein the plasma generation module and the diversion module are located within a cylinder B; wherein the diversion module is a tower-shaped structure composed of a metal mesh or a spiral multi-layer metal mesh; wherein the plasma generation module applies inductively coupled discharge to generate the plasma; wherein the sheath electric field of the diversion module causes the charged particles to move away from a sidewall of the tower-shaped structure and towards a sidewall of the cylinder B; and wherein the plasma forms the sheath electric field on an inner wall surface of the cylinder B, and the charged particles move away from the inner wall surface of the cylinder B under the action of the sheath electric field and fall into the collection trough under the action of gravity.

9. The system according to claim 8, wherein the plasma generation module comprises a first metal electrode plate and a second metal electrode plate placed vertically in parallel with each other, the first metal electrode plate and the second metal electrode plate being symmetrically placed on two sides of an axis of the cylinder B; wherein the first metal electrode plate is electrically connected to a power supply system outside the cylinder B through an interface on a sidewall of the cylinder B, and the second metal electrode plate is connected to a ground wire for generating the plasma through discharge to charge the particles in the exhaust gas to form negatively charged particles; and wherein the diversion module repels the charged particles through the sheath electric field formed on its surface by the plasma, or the diversion module is electrically connected to a negative-voltage power supply outside the cylinder B through an interface on the sidewall of the cylinder B to generate a sheath electric field for repelling the charged particles.

10. The system according to claim 1, wherein the refrigeration unit is a condensing module, and the plasma diversion unit comprises a plasma generation module and a diversion module; wherein the exhaust piping includes a section of T-shaped duct; wherein the condensing module and the T-shaped duct are sequentially arranged between the vacuum chamber and the vacuum pump of the semiconductor manufacturing process as a horizontal exhaust passage, the plasma generation module and the diversion module being arranged within a horizontal section of the T-shaped duct, and a lower end outlet of a vertical section of the T-shaped duct being connected to the collection trough of the particulate matter collection unit; wherein an inlet of the horizontal section of the T-shaped duct is connected to the condensing module, and an outlet of the horizontal section of the T-shaped duct serves as the exhaust port of the particulate matter collection unit and is connected to the vacuum pump through an exhaust duct; wherein the plasma generation module is used to generate plasma through discharge, forming a plasma region within the horizontal section of the T-shaped duct to charge the particles in the passing exhaust gas to form charged particles; wherein the diversion module is used to generate a sheath electric field for repelling the charged particles, guiding the charged particles toward the vertical section of the T-shaped duct to fall into the dust collection module, and outputting the residual gas which has been filtered out particulate matter, through the outlet of the horizontal section of the T-

shaped duct.

11. The system according to claim 10, wherein the plasma generation module and the diversion module are the same metal grid; wherein the metal grid is electrically connected to a power supply located outside the T-shaped duct, for providing a negative voltage for the metal grid, and the sheath electric field is formed on a surface of the metal grid through the plasma; wherein the metal grid is obliquely placed at an angle of 45° within the T-shaped duct, and wherein the metal grid has a mesh radius of 3 mm and a wire diameter of 1 mm.