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High throughput and high position accurate method for particle inspection of mask pods

Abstract

A method of inspecting an outer surface of a mask pod includes moving a stage holding a mask pod such that the stage stops at each location of a plurality of locations under an outer surface of the mask pod for a predefined amount of time. At each location of the plurality of locations, the method further includes directing a stream of air to the outer surface of the mask pod, capturing an image of scattered air from each location of the plurality of locations of the outer surface of the mask pod, and determining a number of particles in the scattered air as a sampled number of particles based on the captured image. The method also includes generating a map of particles on the outer surface of the mask pod based on the sampled number of particles at each of the plurality of locations.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS (1) This application is a continuation application of U.S. patent application Ser. No. 18/126,880 filed on Mar. 27, 2023, now U.S. Pat. No. 12,013,646, which is a continuation application of U.S. non-provisional patent application Ser. No. 17/402,043, now U.S. Pat. No. 11,614,691, filed on Aug. 13, 2021, the entire content of each application is incorporated herein by reference.

BACKGROUND
(1) During an integrated circuit (IC) design, a number of patterns of the IC, for different steps of IC processing, are generated on a substrate, e.g., a wafer. The patterns may be produced by projecting, e.g., imaging, layout patterns of a photo mask on a photo resist layer of the substrate. A lithographic process transfers the layout patterns of the photo masks to the photo resist layer of the substrate such that etching, implantation, or other steps are applied only to predefined regions of the substrate. In general, the reticles, e.g., the extreme ultraviolet (EUV) photo mask, are transferred inside a mask pod between different EUV lithographic systems. Each mask pod has an outer pod and an inner pod inside the outer pod. The outer pod is opened outside the EUV lithographic system and the inner pod is retrieved from the outer pod. The inner pod is transferred to the EUV lithographic system. The inner pod is opened inside the EUV lithographic system and the EUV photo mask is retrieved from the inner pod to be used for EUV lithography. The particles attached on an outer surface of the inner pod may be transferred into the EUV lithographic system and may be deposited on the EUV photo mask or on the optics used for EUV lithography and, thus, may cause non-uniformity in the critical dimension (CD) of the resist patterns generated on the substrate. Therefore, it is desirable to carry the EUV photo mask inside a clean inner pod when transferring the EUV photo mask into the lithographic system for performing the lithographic process.

Description

BRIEF DESCRIPTION OF THE DRAWING
(1) The present disclosure is best understood from the following detailed description when read with the accompanying figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale and are used for illustration purposes only. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.
(2) FIG. **1** shows a process flow for generating a photo resist pattern on a semiconductor substrate.
(3) FIG. **2** shows a schematic diagram of dual mask pod for storing and transferring an EUV photo mask.
(4) FIG. **3** shows a process flow for generating a photo resist pattern on a semiconductor substrate in accordance with some embodiments of the present disclosure.
(5) FIG. **4** shows a schematic view of an EUV lithography (EUVL) exposure device for generating a photo resist pattern on a wafer.
(6) FIGS. **5**A and **5**B show a mask pod loaded on a stage and an inspection system for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure.
(7) FIG. **6** shows a control system for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure.
(8) FIG. **7** shows a flow diagram of an exemplary process for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure.
(9) FIGS. **8**A and **8**B illustrate an apparatus for inspecting the particles on a mask pod in

accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION

(10) The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

(11) Further, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly. In addition, the term “being made of” may mean either “comprising” or “consisting of.” In the present disclosure, a phrase “one of A, B and C” means “A, B and/or C” (A, B, C, A and B, A and C, B and C, or A, B and C), and does not mean one element from A, one element from B and one element from C, unless otherwise described.

(12) In some embodiments, the reticles are stored and transferred, inside mask pods, between IC processing stations, e.g., between the EUV lithographic systems of the IC processing stations. In some embodiments, dual mask pods with an inner pod enclosed inside an outer pod are used for transferring the reticles. The reticle is inside the inner pod. When a reticle is used in a EUV lithographic system, the outer pod of the dual mask pod is opened and the inner pod, including the reticle inside the inner pod, is transferred inside the EUV lithographic system. Therefore, the inner pod, including the outer surface of the inner pod should be cleaned before transferring the inner pod and the reticle to the EUV lithographic systems. Thus, the inner pod of a dual pod needs inspection before being transferred inside the EUV lithographic system and if the inner pod is not clean and has particles on the outer surface of the inner pod, the inner pod may be cleaned. In some embodiments, the inner pod of a dual pod is inspected and cleaned offline before being transferred into the EUV lithographic system and in a stand-alone tool.

(13) One way of inspecting the inner pod of a reticle is capturing images of the outer surface of the inner pod from different locations of the outer surface of the inner pod, inspecting the captured images, e.g., enlarged captured images, and finding and counting the particles in the captured images. Capturing and processing images may take a long time and may need to rotate the inner pod such that the images are captured from a single viewing angle of the inner pod.

(14) In some embodiments, a stream of gas, e.g., a stream of air, is directed to the outer surface of the inner pod. The stream of gas may be directed through a nozzle to exert pressure on the particles attached to the outer surface of the inner pod to eject one or more particles from the outer surface of the inner pod. The ejected particles are carried with the scattered air that is returned from the outer surface of the inner pod. In some embodiment, the scattered air from the outer surface of the inner pod, including the one or more ejected particles is collected by, e.g., sucked into, a particle counter, where the particle counter determines the number of the ejected particles. In some embodiments, based on the speed of the stream of gas that is directed at the outer surface of the inner pod, and the amount of time the stream of gas is directed at each predefined location on the outer surface of the inner pod, a known percentage of the particles at the predefined locations are

ejected from the outer surface of the inner pod. Thus, the number of particles counted by the particle counter at each predefined location has a proportionality ratio with the number of particles attached to the outer surface of the inner pod. Therefore, the number of particles attached to the outer surface of the inner pod may be determined from the number of the ejected particles that are counted by the particle counter and using the proportionality ratio. In some embodiments, the stream of gas ejects the particles in an area covered by the extent of the stream of gas and, therefore, the number of the ejected particles that are counted by the particle counter corresponds to an area covered by the stream of gas. Thus, in some embodiments, the number of the ejected particles that are counted by the particle counter is a density of the particles (e.g., number of particles per unit area) at the surface area of the inner pod.

(15) In some embodiments, the number of particles or the density of particles attached to the outer surface of the inner pod may be compared with a threshold number of particles or a threshold density of particles and if the number of particles or the density of particles attached to the outer surface of the inner pod exceeds the threshold number of particles or the threshold density of particles, at one or more points, the inner pod may be designated for cleaning.

(16) In some embodiments, the reticle is mounted above the nozzle on a horizontal stage that moves the reticle laterally in X-direction and Y-direction. The nozzle that is used for directing the gas stream is mounted on a vertical stage. The vertical stage moves the nozzle up and down in Z-direction. The distance between the nozzle and the outer surface of the inner pod is adjusted by moving the vertical stage. In some embodiments, the nozzle on the top surface of the vertical stage is mounted such that the steam of gas is directed at a specific angle with respect to a perpendicular plane to the outer surface of the inner pod. Thus, the scattered gas from the outer surface of the inner pod is collected by the particle counter around an opposite angle with respect to the perpendicular plane. In some embodiments, the specific angle is adjusted to increase the efficiency of the particle counter for collecting the scattered gas and the particles carried with the scattered gas from the outer surface of the inner pod.

(17) The horizontal stage is moved in the XY-plane and the stream of air is directed at a plurality of locations on the outer surface of the inner pod. The horizontal stage stops at each one of the plurality of locations for a specific amount of time. As noted above, during the specific amount of time that the horizontal stage stops at each location, the scattered gas from the outer surface of the inner pod is collected by a particle counter. The particle counter determines the number of the particles ejected from the outer surface of the inner pod that are carried with the scattered gas. As described, the determined number of particles at each location is proportional to the number of particles on the outer surface of the inner pod. Thus, based on the readings of the particle counter at the plurality of the locations, the density of particles is sampled at the plurality of locations on the outer surface of the inner pod and a mapping of the density of particles on the outer surface of the inner pod may be generated. In some embodiments, the inner pod is flipped over and installed on the horizontal stage such that the number of particles, e.g., the density of particles, on another side of the outer surface of the inner pod is determined, e.g., measured.

(18) FIG. **1** shows a process flow **100** for generating a photo resist pattern on a semiconductor substrate by a lithographic system. In some embodiments, the process flow **100** is performed by the control system **600** of FIG. **6** or the computer system **800** of FIGS. **8**A and **8**B. In a resist coat operation **102**, a resist layer of a resist material is disposed, e.g., coated, on a top surface of a substrate, e.g., a wafer or a work piece. As shown in FIG. **4**, a photo resist layer **15** is disposed over a semiconductor substrate **210**. The post application bake (PAB) is performed at a PAB operation **104** and the semiconductor substrate **210** including the photo resist layer **15** is baked to drive out solvent in the resist material and solidify the photo resist layer on top of the semiconductor substrate **210**.

(19) In the present disclosure, the terms mask, photomask, and reticle are used interchangeably. In addition, the terms resist and photo resist are used interchangeably. At a mask receive operation

105, a reticle is received from another lithographic system. The mask receive operation **105** is described in more detail with respect to FIGS. **2** and **3**. The received reticle is loaded by a mask load and exposure operation **108** to an exposure device, which is described with respect to FIG. **4**. The mask load and exposure operation **108** also projects the mask, using actinic radiation of a radiation source onto the photo resist layer **15** of the semiconductor substrate **210**. In some embodiments, a layout pattern on the mask is projected by an extreme ultraviolet (EUV) radiation from an EUV light source onto the photo resist layer **15** to generate a resist pattern in the photo resist layer **15** on the semiconductor substrate **210**. A post exposure bake (PEB) is performed at a PEB operation **110** on the wafer where the resist layer **15** is further baked after being exposed to the actinic radiation and before being developed in a development operation **112**. By applying a developer solution to the photo resist layer **15**, the resist material of the resist layer is developed. For a positive tone resist material, in the development operation **112**, the exposed regions are developed by applying a developer solution and then the developed regions are removed and the remaining regions generate the resist pattern of the photo resist layer **15**. For a negative tone resist material, in the development operation **112**, the non-exposed regions are developed by applying the developer solution and the developed regions are subsequently removed and the remaining regions generate the resist pattern of the photo resist layer **15**. In some embodiments, the mask receive operation **105** is performed offline and outside the EUV lithographic system. The received reticle may be stored in a reticle library (not shown) under a vacuum environment.

(20) FIG. **2** shows a schematic diagram of dual mask pod **200** for storing and transferring an EUV photo mask. The dual mask pod **200** includes an inner pod **220**, which is enclosed inside an outer pod **230**. The inner pod **220** is enclosed between the outer pod door **204** and the outer pod shell **202**. The inner pod **220** includes an inner pod base plate **208** and an inner pod cover **206**. A reticle **205** is enclosed between the inner pod base plate **208** and the inner pod cover **206**. In some embodiments, the outer pod **230** is opened, e.g., the outer pod door **204** is removed, and the inner pod **220** is retrieved from the outer pod **230**. In some embodiments, the inner pod **220** is opened, e.g., the inner pod cover **206** is removed, and the reticle **205** is retrieved from the inner pod **220**. The inner pod cover **206** has a top outer surface **222** and side outer surfaces **221**. The inner pod base plate **208** also has a bottom outer surface (not shown) and side outer surfaces (not shown). In some embodiments, the reticle **205** is stored inside the dual mask pod **200**. The reticle **205** is inside an inner pod **220**, which is inside an outer pod **230** to keep the reticle **205** away from particles. In some embodiments, the reticle **205** is transferred between different lithographic systems inside the dual mask pod **200** to keep the reticle **205** away from the particles during transferring.

(21) FIG. **3** shows a process flow **300** for generating a photo resist pattern on a semiconductor substrate in accordance with some embodiments of the present disclosure. In a transfer dual pod operation **302**, a dual pod, e.g., the dual mask pod **200** of FIG. **2**, is transferred by a mask transfer system (not shown) to be used in an exposure device, e.g., an exposure device **400** of FIG. **4**, of an EUV lithographic system. In a retrieve inner pod operation **304**, the inner pod **220** is retrieved from the dual mask pod **200**. The retrieval operation is performed outside the exposure device **400**. The inner pod **220** that contains a reticle **205** is retrieved from the outer pod **230** of the dual mask pod **200**. In an inspect inner pod operation **306**, the inner pod **220** is inspected for particles that are deposited on the outer surface of the inner pod **220**, e.g., the top outer surface **222** of the inner pod cover **206**. In some embodiments, the inner pod **220** is inspected by the inspection system **500** for inspecting the particles on the mask pod of FIG. **5**B. If the inspection system **500** determines that the particles on the outer surface of the inner pod are above a threshold number of particles or the threshold density of particles, at one or more points, a clean inner pod operation **308** is performed on the outer surface of the inner pod **220**. In a wafer print operation **310**, the inner pod **220** is transferred to the exposure device **400** and the reticle **205** is retrieved from the inner pod and is used in the exposure device **400** for projecting the layout patterns of the reticle **205** on a resist layer of a wafer and developing a resist pattern on the wafer as described with respect to FIG. **1**. In some

embodiments, the wafer print operation **310** is consistent with the operations of the process flow **100**. The mask receive operation **105** of FIG. **1** includes the transfer dual pod operation **302**, the retrieve inner pod operation **304**, the inspect inner pod operation **306**, and the clean inner pod operation **308**. In some embodiments, the transfer dual pod operation **302**, the retrieve inner pod operation **304**, the inspect inner pod operation **306**, and the clean inner pod operation **308** are performed offline and before the reticle is transferred inside the exposure device **400**. In some embodiments, after inspecting and cleaning the inner pod **220**, the inner pod **220** is transferred into a reticle library (not shown) that is under vacuum environment and the photo mask is stored in the reticle library. In some embodiments, in the mask load and exposure operation **108**, the photo mask is retrieved from the reticle library. In some embodiments, one or more of the transfer dual pod operation **302**, the retrieve inner pod operation **304**, the inspect inner pod operation **306**, and the clean inner pod operation **308** are performed inside a load lock chamber of the EUV lithographic system and before the inner pod **220** is loaded into the exposure device **400** of the EUV lithographic system. In some embodiments, after the clean inner pod operation **308**, the inner pod **220** is stored before the inner pod **220** is loaded into the exposure device **400** of the EUV lithographic system.

(22) FIG. **4** shows a schematic view of an EUV lithography (EUVL) exposure device **400** for generating a photo resist pattern on a wafer. The EUVL exposure device **400** shows the exposure of photoresist coated substrate, a target semiconductor substrate **210**, with a patterned beam of EUV light. The exposure device **400** is an integrated circuit lithography tool such as a stepper, scanner, step and scan system, direct write system, device using a contact and/or proximity mask, etc., provided with one or more optics **205***a*, **205***b*, for example, to illuminate a patterning optic, such as a reticle, e.g., a reflective mask **205***c* consistent with reticle **205** of FIG. **2**, with a beam of EUV radiation **29**, to produce a patterned beam, and one or more reduction projection optics **205***d*, **205***e*, of the optical system for projecting the patterned beam onto the target semiconductor substrate **210**. A mechanical assembly (not shown) may be provided for generating a controlled relative movement between the target semiconductor substrate **210** and patterning optic, e.g., a reflective mask **205***c*. By the controlled relative movement, different dice of the substrate are patterned. As further shown, the EUVL exposure device **400** of FIG. **4** further includes the EUV radiation source **101** to irradiate the target resist layer **15** on top of the semiconductor substrate **210**. In some embodiments, because gas molecules absorb EUV light, the lithography system for the EUV lithography patterning, e.g., the exposure device **400** is under a vacuum environment to avoid EUV intensity loss. In some embodiments, a pressure inside the exposure device **400** is sensed by a pressure sensor **408** inside the exposure device **400** and is controlled by a vacuum pressure controller **406** that is coupled to the exposure device **400**.

(23) FIGS. **5**A and **5**B show a mask pod loaded on a stage and an inspection system **500** for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure. FIG. **5**A shows a mask pod holder for carrying an inner pod **504** consistent with the inner pod **220** of FIG. **2**, which is mounted on a horizontal stage **502**. The inner pod **504** is mounted by clamps **506** and a distance **508** that is placed between the inner pod **504** and the horizontal stage **502** and provides tolerance for loading, in some embodiments.

(24) FIG. **5**B shows an inspection system **500** that includes the inner pod **504** mounted by clamps **506** on the horizontal stage **502**. The horizontal stage is coupled to a stage controller **535** and the stage controller **535** moves the inner pod **504** in X-direction and Y-direction. The inspection system **500** also includes a vertical stage **510**, a gas tank **572**, a first pipe **522**, a second pipe **523**, and a gas flow controller **575**. The vertical stage is also coupled to a stage controller **535** and the stage controller **535** moves the vertical stage up or down in Z-direction. The gas flow controller **575** is coupled, from one end and via the second pipe **523**, to the gas tank **572**. In some embodiments, instead of the gas tank **572**, the second pipe **523** is connected to a gas source of an EUV lithographic system. The gas flow controller **575** is coupled from another end to a first end of the

first pipe **522**. The second end of the first pipe is connected to a nozzle **516** and the nozzle **516** is mounted on a top surface **511** of the vertical stage **510**. In some embodiments, the nozzle **516** is a tapered nozzle that produces a narrow beam of air capable of removing the particles. In some embodiments, the nozzle **516** is a slit nozzle that produces a narrow sheet of air. The gas flow controller **575** draws a stream of gas **512** or air, e.g., clean dry air (CDA), or nitrogen gas, from the gas tank **572** and sends the stream of gas **512** to nozzle **516**. The stream of gas **512** is directed at an incident angle θ with respect to a plane **526** vertical to an outer surface **518** of the inner pod **504**. In some embodiments, the stage controller **535** adjusts a distance between the nozzle **516** and the outer surface **518** and the gas flow controller **575** adjusts the incident angle θ. In some embodiments, the horizontal stage **502** moves in the X-direction and the nozzle **516** moves in the Y-direction to scan the outer surface **518** of the inner pod **504** the horizontal stage **502** moves stays in each position in the X-direction while the nozzle **516** moves in the Y-direction.

(25) In some embodiments, instead of the particle counter **565**, an imaging device (not shown) is mounted on the top surface **511** of the vertical stage **510**. The imaging device captures images of the scattered gas while the horizontal stage **502** moves, analyzes the captured images, and determines the number of particles in the scattered gas.

(26) The inspection system **500** also includes a particle counter **565** that is coupled to a first end of a third pipe **524** and a second end of the third pipe is mounted on the top surface **511** of the vertical stage **510** via a nozzle **521**. The particle counter **565** draws in, through the nozzle **521**, the scattered gas that is reflected from the stream of gas **512** and the particles that are ejected by the stream of gas **512**, from the outer surface **518**, and are carried by the scattered gas. The scattered gas and the particles carried by the scattered gas are drawn from the second end of the third pipe and generate a stream of gas **514**. The stream of gas **514** has an angle θ symmetrical with the incident angle θ with respect to the plane **526**. In some embodiments, the particle counter **565** determines, e.g., counts, the number of particles that are ejected from the outer surface **518** and are carried by the scattered gas **514**.

(27) In some embodiments, the stage controller **535** moves the horizontal stage **502** such that the stream of gas **512** is directed to a plurality of locations at the outer surface **518** of the inner pod **504**. In some embodiments, the horizontal stage **502** stops at each one of the plurality of locations for a predefined amount of time and the stream of gas **514** is drawn to, e.g., collected by, the particle counter **565** for the same predefined amount of time. Therefore, the particle counter **565** samples the number of particles ejected from the outer surface **518** of the inner pod **504** at the plurality of locations. In some embodiments, the predefined amount of time that the stage stops at the plurality of locations determines a proportionality factor between the number of ejected particles and the number of deposited particles at the plurality of locations. In some embodiments, the stream of gas **512** covers an area of the outer surface **518** of the inner pod **504** at each one of the plurality of locations. Thus, the number of particles counted by particle counter **565** when divided by the area covered by the stream of gas **512** generates the samples of the density of the ejected particles and if multiplied by the proportionality factor generates the samples of the density of the deposited particles on the outer surface **518** of the inner pod **504**. In some embodiments, a specific portion of the scattered gas, e.g., a collection factor of the scattered gas, and the particles carried by the scattered gas, is collected by the particle counter **565** and the proportionality factor includes the collection factor.

(28) The inspection system **500** also includes a mapping system **520** that is coupled to stage controller **535** and the particle counter **565**. The mapping system **520** receives the plurality of the locations from the stage controller **535** and also receives the number or the density of the particles deposited on the outer surface **518** of the inner pod **504** and generates a map of the number of particles or a map of the density of the particles on the outer surface **518** of the inner pod **504**. In some embodiments, the mapping system **520** or a main controller (not shown) coupled to the mapping system monitors the map of the number of particles or the map of the density of the

particles on the outer surface **518** of the inner pod **504** and if the map exceeds a threshold of the number of particles or a threshold of the density of the particles, a signal **530** for cleaning the inner pod **504** is generated and is sent to the main controller. In some embodiments, the amount of time the horizontal stage **502** stops at each one of the plurality of locations is from about 1 second to about 10 seconds. In some embodiments, the area covered by the stream of gas **512** is between 50 mm.sup.2 and 100 mm.sup.2, e.g., a radius of between 7 mm and 10 mm. In some embodiments, the mapping system **520** includes a memory **532** and the maps of the number of particles or the maps of the density of the particles on the outer surface **518** of the inner pod **504** are stored in the memory **532** based on a specific ID for each inner pod **220**. When an inner pod **504** is inspected and the maps of the number of particles or the maps of the density of the particle are calculated, the produced map is compared, based on the ID of inner pod, with the previously generated maps. When an anomaly is determined between the recently generated map and the maps stored in the memory **532** a signal **531** is generated by the mapping system **520** to indicate that other EUV lithographic systems or the mask transfer system are faulty.

(29) FIG. **6** shows a control system **600** for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure. The control system **600** includes an analyzer module **630** and a main controller **640** coupled to each other. In some embodiments, the control system **600** includes the stage controller **535** of FIG. **5**B, the mapping system **520** of FIG. **5**B, the gas flow controller **575** of FIG. **5**B, the particle counter **565** of FIG. **5**B, and the vacuum pressure controller **406** of FIG. **4**. In some embodiments, the main controller **640** is coupled to and controls the stage controller **535** of FIG. **5**B, the mapping system **520** of FIG. **5**B, the gas flow controller **575** of FIG. **5**B, the particle counter **565** of FIG. **5**B, and the vacuum pressure controller **406** of FIG. **4**. In some embodiments, the main controller **640** is directly coupled to the mapping system **520** or is coupled to the mapping system **520** via the analyzer module **630**. In some embodiments, a circuitry performs the operations of the analyzer module **630** and the main controller **640**.

(30) In some embodiments and referring to FIG. **5**B, the main controller **640** commands the gas flow controller **575**, to direct the stream of gas **512**, via the second pipe **523**, from the gas tank **572** to gas flow controller **575**, and also direct the stream of gas **512**, via the first pipe **522** and the nozzle **516** to the outer surface **518** of the mask pod **504**. In some embodiments, the main controller **640** commands the stage controller **535** to move the horizontal stage **502** the X-direction and the Y-direction to direct the stream of gas **512** at different locations of the outer surface **518**. In some embodiments, the main controller **640** commands the particle counter **565** to draw the stream of gas **514**, which is the scattered gas from the outer surface **518** of the plurality of locations via the third pipe **524** to the particle counter **565**. The main controller **640** commands the particle counter **565** to count the number of particles in the stream of gas **514** and send the counted number of particles to the mapping system **520**.

(31) In some embodiments, the main controller **640** commands the stage controller **535** to move the horizontal stage **502** and to direct the stream of gas **512** at different locations of the outer surface **518** for a predefined amount of time, e.g., from about 1 second to about 10 seconds. In addition, the main controller **640** commands the particle counter **565** to count the number of particles in the stream of gas **514** for the predefined amount of time and send the counted number of particles to the mapping system **520**. In some embodiments, the counted number of particles in the scattered gas from the outer surface **518** at each location is proportional to the number of particles on the outer surface **518** of the mask pod **504**. In some embodiments, the analyzer module **630** receives the counted number of particles and compares the counted number of particles with a threshold. If the counted number of particles, at one or more locations, is above the threshold, the analyzer module **630** sends a signal to the main controller **640** that the mask pod requires cleaning.

(32) FIG. **7** illustrates a flow diagram of an exemplary process **700** for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure. The process **700** or a portion of the process **700** may be performed by the system of FIG. **5**B. In some embodiments, the

process **700** or a portion of the process **700** is performed and/or is controlled by the computer system **800** described below with respect to FIGS. **8**A and **8**B. In some embodiments, the process **700** or a portion of the process **700** is performed by the control system **600** of FIG. **6** described above. The method includes an operation S**710**, where a stream of air is directed at a first location of a plurality of locations on an outer surface of the mask pod. As shown in FIG. **5**B, the stream of gas **512**, e.g., air, is directed at a first location of a plurality of locations on the outer surface **518** of the mask pod **504**. In operation S**720**, one or more particles are removed by the directed stream of air from the first location on the outer surface of the mask pod. In some embodiments, particles are attached to the outer surface **518** of the mask pod **504**. The stream of gas **512** ejects, e.g., removes, some of the particles from the outer surface **518** and scatters back from the outer surface **518** and carries the ejected particles. In operation S**730**, the scattered air from the first location of the outer surface of the mask pod is extracted, e.g., is collected. As shown in FIG. **5**B, the particle counter **565** draws the scattered gas from the outer surface **518** in the stream of gas **514**. The stream of gas **514** also draws the ejected particles to the particle counter. In operation S**740**, a number of particles in the extracted scattered air from the first location is determined as a sampled number of particles at the first location. In operation S**750**, the mask pod is moved and the stream of air is directed at other locations of the plurality of locations on the outer surface of the mask pod to determine the sampled number of particles at the other locations. As shown in FIG. **5**B, the stage controller **535** moves the horizontal stage **502** and the inner pod **504** mounted on the horizontal stage **502** in the X-direction and the Y-direction and the stream of gas **514** hits other locations on the outer surface **518** of the mask pod **504** and determines the sampled number of particles at the other locations. In operation S**760**, a map of the particles on the outer surface of the mask pod is generated based on the sampled number of particles at the plurality of locations. In some embodiments, the map includes one or more 3-dimensional graphs where each 3-dimensional graph shows the number of particles on each sampled point of each side of the inner pod **220**.

(33) FIGS. **8**A and **8**B illustrate an apparatus for inspecting the particles on a mask pod in accordance with some embodiments of the present disclosure. In some embodiments, the computer system **800** is used for performing the functions of the modules of FIG. **6** that include the main controller **640**, the analyzer module **630**, the stage controller **535**, the mapping system **520**, the vacuum pressure controller **406**, the gas flow controller **575**, and the particle counter **565**. In some embodiments, the computer system **800** is used to execute the process **700** of FIG. **7**.

(34) FIG. **8**A is a schematic view of a computer system that performs the functions of an apparatus for inspecting the particles on a mask pod. All of or a part of the processes, method and/or operations of the foregoing embodiments can be realized using computer hardware and computer programs executed thereon. In FIG. **8**A, a computer system **800** is provided with a computer **801** including an optical disk read only memory (e.g., CD-ROM or DVD-ROM) drive **805** and a magnetic disk drive **806**, a keyboard **802**, a mouse **803**, and a monitor **804**.

(35) FIG. **8**B is a diagram showing an internal configuration of the computer system **800**. In FIG. **8**B, the computer **801** is provided with, in addition to the optical disk drive **805** and the magnetic disk drive **806**, one or more processors, such as a micro processing unit (MPU) **811**, a ROM **812** in which a program such as a boot up program is stored, a random access memory (RAM) **813** that is connected to the MPU **811** and in which a command of an application program is temporarily stored and a temporary storage area is provided, a hard disk **814** in which an application program, a system program, and data are stored, and a bus **815** that connects the MPU **811**, the ROM **812**, and the like. Note that the computer **801** may include a network card (not shown) for providing a connection to a LAN.

(36) The program for causing the computer system **800** to execute the functions for inspecting the particles on a mask pod in the foregoing embodiments may be stored in an optical disk **821** or a magnetic disk **822**, which are inserted into the optical disk drive **805** or the magnetic disk drive **806**, and transmitted to the hard disk **814**. Alternatively, the program may be transmitted via a

network (not shown) to the computer **801** and stored in the hard disk **814**. At the time of execution, the program is loaded into the RAM **813**. The program may be loaded from the optical disk **821** or the magnetic disk **822**, or directly from a network. The program does not necessarily have to include, for example, an operating system (OS) or a third party program to cause the computer **801** to execute the functions of the control system for inspecting the particles on a mask pod in the foregoing embodiments. The program may only include a command portion to call an appropriate function (module) in a controlled mode and obtain desired results.

(37) According to some embodiments of the present disclosure, a method of inspecting an outer surface of a mask pod includes directing a stream of air at a first location of a plurality of locations on an outer surface of a mask pod and removing one or more particles by the directed stream of air from the first location on the outer surface of the mask pod. The method also includes extracting scattered air from the first location of the outer surface of the mask pod and determining a number of particles in the extracted scattered air from the first location as a sampled number of particles at the first location. The method further includes moving the mask pod and directing the stream of air at other locations of the plurality of locations on the outer surface of the mask pod to determine the sampled number of particles in extracted scattered air at the other locations. The method also includes generating a map of the particles on the outer surface of the mask pod based on the determined sampled number of particles at the plurality of locations such that for each location of the plurality of locations, the sampled number of particles in the extracted scattered air is proportional to a number of particles on the outer surface of the mask pod at the location. In an embodiment, the mask pod is moved in an X-direction and a Y-direction and the plurality of locations are distributed in the X-direction and the Y-direction on the outer surface of the mask pod. In an embodiment, the method further includes delivering the stream of air by a tube from an air tank and directing the stream of air from a nozzle, disposed at an end of the tube, to the outer surface of the mask pod. In an embodiment, the method further includes adjusting a distance between the nozzle and the outer surface of the mask pod and keeping a same distance between the nozzle and the outer surface of the mask pod for each one of the plurality of locations. In an embodiment, for each one of the plurality of locations, the stream of air is directed at a first angle of incidence to the outer surface of the mask pod. In an embodiment, the method further includes adjusting a flow rate of the stream of air from the nozzle and adjusting the first angle of incidence, and the first angle of incidence is adjusted between 65 degrees to 25 degrees with respect to perpendicular plane to the surface of the mask pod. In an embodiment, either the outer surface of the mask pod is above the nozzle, the stream of air is directed upward, and the scattered air from the outer surface of the mask pod flows downward, or the outer surface of the mask pod is below the nozzle, the stream of air is directed downward, and the scattered air from the outer surface of the mask pod flows upward.

(38) According to some embodiments of the present disclosure, a method for inspecting the particles on a mask pod includes directing a stream of gas at a plurality of locations on an outer surface of a mask pod and removing one or more particles by the directed stream of gas from each one of the plurality of locations on the outer surface of the mask pod. The method also includes sampling scattered gas from the outer surface of the mask pod at the plurality of locations to determine a first number of particles in the scattered gas from the plurality of locations. For each location of the plurality of locations, the first number of particles in the scattered gas is proportional to a number of particles on the outer surface of the mask pod at that location. In an embodiment, the method further includes determining a map of the particles on the mask pod based on the determined first number of particles at the plurality of locations. In an embodiment, the stream of gas is a stream of clean dry air. In an embodiment, prior to directing the stream of gas, the method includes receiving a photomask inside a dual mask pod, opening an outer pod of the dual mask pod, and removing an inner pod of the dual mask pod as the mask pod and the photomask is inside the inner pod. In an embodiment, the method further includes cleaning the

mask pod when the number of particles on the outer surface of the mask pod is above a threshold number of particles for one or more locations of the plurality of locations. In an embodiment, the method further includes directing the stream of gas from a nozzle to the outer surface of the mask pod. In an embodiment, the method further includes adjusting a distance between the nozzle and the outer surface of the mask pod and keeping a same distance between the nozzle and the outer surface of the mask pod for each one of the plurality of locations.

(39) According to some embodiments of the present disclosure, a system for inspecting the particles on a mask pod includes a gas source, a mask pod, a circuitry, and a first pipe having a nozzle connected to a first end of the first pipe. The system also includes a gas flow controller connected between to the gas source and a second end of the first pipe and the gas flow controller directs a stream of gas, supplied by the gas source via the first pipe, out of the nozzle. The system further includes a horizontal-stage that holds the mask pod and moves the mask pod in two perpendicular horizontal directions above the nozzle. The gas flow controller directs the stream of gas at a plurality of locations of an outer surface of the mask pod to remove one or more particles, by the directed stream of gas, from the outer surface of the mask pod. The system includes a particle counter coupled to a first end of a second pipe. The particle counter draws scattered gas from the plurality of locations, via a second end of the second pipe, into the particle counter, to determine a sample of a number of the removed particles from the outer surface of the mask pod at the plurality of locations. In an embodiment, the system further includes a vertical-stage such that the first end of the first pipe having the nozzle and the second end of the second pipe are mounted on a top surface of the vertical-stage. The vertical-stage moves up and down to adjust a distance between the top surface of the vertical-stage with the outer surface of the mask pod. In an embodiment, the system further includes a stage controller coupled to the horizontal-stage and the vertical-stage such that the stage controller adjusts the distance between the top surface of the vertical-stage with the outer surface of the mask pod in a Z-direction. The stage controller moves the horizontal-stage in an X-direction and a Y-direction to direct the stream of gas at the plurality of locations in the X-direction and the Y-direction on the outer surface of the mask pod. In an embodiment, a distance between each two neighboring locations of the plurality of locations in the X-direction or in the Y-direction is between about 1 millimeter and about 1 centimeter. In an embodiment, the circuitry receives X-direction and Y-direction data corresponding to the plurality of locations, receives the sampled number of removed particles from the outer surface of the mask pod at the plurality of locations, and generates a map of the sampled number of removed particles from the outer surface of the mask pod, the system further includes a mapping system coupled to the circuitry to receive the map of the sampled number of removed particles from the circuitry and to display the sampled number of removed particles. In an embodiment, the sampled number of removed particles is proportional to a number of particles on the outer surface of the mask pod.

(40) As described in the foregoing embodiments, a map of the particle on an outer surface of a mask pod is generated without rotating the mask pod to take images of the irregular outer surface with image processing techniques.

(41) The foregoing outlines features of several embodiments or examples so that those skilled in the art may better understand the aspects of the present disclosure. Those skilled in the art should appreciate that they may readily use the present disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments or examples introduced herein. Those skilled in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the present disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the present disclosure.

Claims

1. A method, comprising: moving a stage holding a mask pod such that the stage stops at each location of a plurality of locations under an outer surface of the mask pod for a predefined amount of time; at each location of the plurality of locations, directing a stream of air to the outer surface of the mask pod; capturing an image of scattered air from each location of the plurality of locations of the outer surface of the mask pod; and determining a number of particles in the scattered air as a sampled number of particles based on the captured image; and generating a map of particles on the outer surface of the mask pod based on the sampled number of particles at each of the plurality of locations.

2. The method of claim 1, wherein: the stage is moved in an X-direction and a Y-direction, and the plurality of locations are distributed in the X-direction and the Y-direction on the outer surface of the mask pod.

3. The method of claim 1, further comprising: delivering the stream of air by a tube from an air tank; and directing the stream of air from a nozzle, disposed at an end of the tube, to the outer surface of the mask pod.

4. The method of claim 3, further comprising: adjusting a distance between the nozzle and the outer surface of the mask pod such that a same distance between the nozzle and the outer surface of the mask pod is maintained at each location of the plurality of locations.

5. The method of claim 3, wherein, at each location of the plurality of locations, the stream of air is directed at a first angle of incidence to the outer surface of the mask pod.

6. The method of claim 5, further comprising: adjusting a flow rate of the stream of air from the nozzle; and adjusting the first angle of incidence, wherein the first angle of incidence is adjusted between 65 degrees to 25 degrees with respect to a perpendicular plane to the outer surface of the mask pod.

7. The method of claim 3, wherein either: the outer surface of the mask pod is located above the nozzle and the stream of air is directed upward, or the outer surface of the mask pod is located below the nozzle and the stream of air is directed downward.

8. The method of claim 1, wherein the mask pod is an inner pod of a dual mask pod, and the method further comprises: receiving the dual mask pod holding a photomask therein; opening an outer pod of the dual mask pod; and removing the inner pod of the dual mask pod.

9. The method of claim 1, further comprising: cleaning the mask pod when the number of particles on the outer surface of the mask pod is above a threshold number of particles for one or more locations of the plurality of locations.

10. A system, comprising: a gas source; a moving stage configured to hold a mask pod; a stage controller configured to control movement of the moving stage; a gas nozzle coupled to the gas source; an imager; and a processor, wherein: the gas source and the gas nozzle are configured to eject a stream of gas to the mask pod when the mask pod is held by the moving stage, the moving stage is controlled such that the mask pod is moved in two perpendicular horizontal directions such that the stream of gas is applied to a plurality of locations of an outer surface of the mask pod, and the moving stage stops at each location of the plurality of locations for a predefined amount of time, and the processor is configured to capture an image by the imager of scattered air from each location of the plurality of locations and generate a particle map of the outer surface of the mask pod based on the captured images.

11. The system of claim 10, further comprising a vertical-stage configured to vertically move the gas nozzle and the gas nozzle to adjust a distance between the gas nozzle and the outer surface of the mask pod.

12. The system of claim 11, wherein the stage controller is configured to adjust a location of the mask pod in an X-direction and a Y-direction.

13. The system of claim 12, wherein a distance between each two neighboring locations of the plurality of locations in the X-direction or in the Y-direction is between about 1 millimeter and

about 1 centimeter.
14. The system of claim 12, wherein the gas nozzle is inclined by a first angle with respect to a perpendicular plane to the outer surface of the mask pod.
15. The system of claim 14, wherein the first angle is between 65 degrees to 25 degrees with respect to the perpendicular plane to the outer surface of the mask pod.
16. A system, comprising: a gas source; a moving stage configured to hold a mask pod; a gas nozzle coupled to the gas source; an imager; and one or more controllers, wherein: the one or more controllers are configured to perform: moving the moving stage holding the mask pod such that the moving stage stops at each location of a plurality of locations under an outer surface of the mask pod for a predefined amount of time; at each location of the plurality of locations, directing a stream of gas from the gas nozzle to the outer surface of a mask pod; capturing an image of scattered air from each location of the plurality of locations of the outer surface of the mask pod using the imager; and determining a number of particles in the scattered air as a sampled number of particles based on the captured image; and generating a map of particles on the outer surface of the mask pod based on the sampled number of particles at each of the plurality of locations.
17. The system of claim 16, wherein the moving stage is configured to vertically change a distance between the gas nozzle and the outer surface of the mask pod.
18. The system of claim 16, wherein: the moving stage is configured to move in an X-direction and a Y-direction, and the plurality of locations are distributed in the X-direction and the Y-direction on the outer surface of the mask pod.
19. The system of claim 16, further comprising a vertical-stage configured to vertically move the gas nozzle to adjust a distance between the gas nozzle and the outer surface of the mask pod.
20. The system of claim 19, wherein a distance between each two neighboring locations of the plurality of locations in an X-direction or in a Y-direction is between about 1 millimeter and about 1 centimeter.