FILTER STRUCTURE, OPTICAL DETECTION SYSTEM, AND OPTICAL DETECTION METHOD

[0001] This application claims priority to Chinese Patent Application No. 202510124380.8, filed with CNIPA on January 26, 2025, entitled "FILTER, OPTICAL INSPECTION SYSTEM, AND OPTICAL INSPECTION METHOD", the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure relates to the field of semiconductor inspection technology, and in particular, to a filter, an optical inspection system, and an optical inspection method.

BACKGROUND

[0003] Optical imaging inspection is a key technology relied upon for process defect inspection in the semiconductor industry. As technology continues to advance, semiconductor manufacturing processes have shrunk from the micrometer level to the nanometer level, and more complex patterns require more precise defect inspection technologies.

[0004] In an imaging inspection system, a laser beam irradiates a feature region of an object to be inspected and/or a rough surface of the object to be inspected at a certain angle. The scattered light carrying frequency-domain information of the feature region and/or the scattered light from the rough surface of the object to be inspected are collected by an objective lens system. Parallel coherent light with the same incident angle forms light spots on a pupil plane, then passes through a tube lens system and is re-imaged on a sensing surface of a detector.

[0005] However, as periodic structural units from the object to be inspected shrink, defect signals of the object to be inspected will be buried in the scattered light signals of the periodic structural units and/or the rough surface of the object to be inspected, resulting in low accuracy of defect signals extraction from the object to be inspected.

SUMMARY

[0006] Embodiments of the present disclosure provide a filter, an optical inspection system, and an optical inspection method, which are used for filtering out primary diffraction signals and high-order diffraction spots of periodic structures of an object to be inspected on a pupil plane, so as to improve the accuracy of acquiring defect signals of

the object to be inspected.

[0007] A first aspect of the embodiments of the present disclosure provides a filter, including:

[0008] a first filter structure, configured to filter primary diffraction signals of periodic structural units from an object to be inspected; and

[0009] a second filter structure, configured to filter high-order diffraction spots of the periodic structural units from the object to be inspected.

[0010] The first filter structure includes at least one filter structure with a closed periphery. In a case where the object to be inspected has the structural units, the closed filter structure is further provided therein with a light-blocking structure connecting any two ends of the closed filter structure.

[0011] The second filter structure includes a plurality of light-blocking elements arranged in parallel, and a projection of a light-blocking element onto a plane where the high-order diffraction spots are located is not less than a diameter of a high-order diffraction spot.

[0012] Optionally, a spatial orientation of the light-blocking structure connecting any two ends of the closed filter structure is adapted to positions and shapes of scattered light spots from a rough surface of the object to be inspected.

[0013] Optionally, the light-blocking structure arranged within the closed filter structure and adapted to the positions and shapes of the scattered light spots from the rough surface of the object to be inspected includes: a segment-shaped light-blocking structure arranged at an end of the light-blocking structure, or segment-shaped light-blocking structures arranged at two ends of the light-blocking structure, or a polygonal light-blocking structure arranged at any position in the light-blocking structure, or a circular light-blocking structure disposed at any position in the light-blocking structure.

[0014] Optionally, the filter is arranged in an optical inspection system; a plurality of first filter structures are provided; the plurality of first filter structures are arranged in a same plane; and a distance between centers of two adjacent first filter structures is not less than a diameter of a pupil plane of the optical inspection system.

[0015] Optionally, the plurality of first filter structures are driven by a driving mechanism; and in a case where the object to be inspected is switched, different first filter structures are driven by the driving mechanism to substantially overlap with the pupil plane.

[0016] Optionally, an inner peripheral wall of the closed filter structure, and edges of the light-blocking structure are set to be non-sharp edge structures.

[0017] Optionally, the filter is arranged in an optical inspection system; in a case where a diameter of a pupil plane of the optical inspection system is D and a width of the light-blocking element is d, a quantity N of the light-blocking elements is calculated based on a following formula:

[0018] $N \geq \frac{D}{d}$.

[0019] Optionally, the plurality of light-blocking elements are arranged in at least one plane, and each plane of the at least one plane is perpendicular to a propagation direction of scattered light.

[0020] Optionally, the plurality of light-blocking elements are arranged in multiple planes, and light-blocking elements in different planes are partially stacked.

[0021] Optionally, the filter is arranged in an optical inspection system; a distance between two adjacent light-blocking elements in each plane is fixed; multiple light-blocking elements in each plane are driven by a same driving mechanism such that the multiple light-blocking elements in each plane substantially overlap with a pupil plane of the optical inspection system to block diffraction spots at a corresponding position of the pupil plane.

[0022] Optionally, each light-blocking element is driven by an independent driving mechanism, such that a plurality of independent driving mechanisms each drive a corresponding light-blocking element to substantially overlap with a pupil plane of the optical inspection system.

[0023] Optionally, edges of the light-blocking elements are set to be non-sharp edge structures.

[0024] Optionally, surfaces of the first filter structure and/or the second filter structure are coated with an anti-reflective film to reduce reflectivity of the first filter structure and/or reflectivity of the second filter structure.

[0025] Optionally, the light-blocking elements include strip-shaped light-blocking elements, cylindrical light-blocking elements, sawtooth-shaped light-blocking elements, or wavy light-blocking elements.

[0026] A second aspect of the embodiments of the present disclosure provides an optical inspection system, including:

[0027] a light source, configured to transmit coherent light of a preset wavelength to an object to be inspected at a preset angle;

[0028] an objective lens, configured to collect scattered light from the object to be inspected and focus parallel light or nearly parallel light in the scattered light onto a pupil plane;

[0029] the filter provided in the first aspect of the embodiments of the present disclosure, substantially overlapping with the pupil plane;

[0030] a tube lens system, configured to image the object to be inspected onto a detector; and

[0031] the detector, configured to detect defects of the object to be inspected based on an image of the object to be inspected.

[0032] Optionally, the optical inspection system further includes: an insertable reflector, a pupil imaging tube lens, and a pupil imaging detector.

[0033] The insertable reflector is configured to be inserted between the tube lens system and the detector to change a propagation direction of the scattered light such that the scattered light is incident on the pupil imaging tube lens; or the insertable reflector is configured to be inserted between the filter and the tube lens system to change the propagation direction of the scattered light such that the scattered light is incident on the pupil imaging tube lens.

[0034] The pupil imaging tube lens is configured to image the pupil plane onto the pupil imaging detector.

[0035] The pupil imaging detector is configured to observe the pupil plane based on the image of the pupil plane.

[0036] Optionally, the filter includes a first filter structure and a second filter structure; the second filter structure includes a plurality of light-blocking elements arranged in multiple planes; one plane among the multiple planes overlaps with the pupil plane; remaining planes among the multiple planes are arranged 0.1 mm to 2 mm in front of the pupil plane along a propagation direction of the scattered light; and the first filter structure is arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light.

[0037] Alternatively, the remaining planes among the multiple planes are arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light, and the first filter structure is arranged 0.1 mm to 2 mm in front of the pupil plane along the propagation direction of the scattered light.

[0038] Optionally, the filter includes a first filter structure and a second filter structure;

the second filter structure includes a plurality of parallel strip-shaped light-blocking elements; widths of the strip-shaped light-blocking elements are related to diameters of high-order diffraction spots of periodic structural units; lengths of the strip-shaped light-blocking elements are not less than a diameter of the pupil plane; and a quantity of the strip-shaped light-blocking elements is related to the diameter of the pupil plane and a width of each strip-shaped light-blocking element.

[0039] Optionally, the optical inspection system further includes a beam expanding and shaping module arranged between the light source and the object to be inspected, the beam expanding and shaping module includes a beam expander and a shaping element; and the shaping element includes a phase element with a two-dimensional structure.

[0040] A third aspect of the embodiments of the present disclosure provides an optical inspection method applied to the optical inspection system provided in the second aspect of the embodiments of the present disclosure. The method includes:

[0041] observing the image of the pupil plane through a pupil imaging detector to obtain a distribution state of scattered signals in the pupil plane;

[0042] driving an appropriate first filter structure to filter scattered signals of a rough surface of the object to be inspected and primary diffraction signals of periodic structural units from the object to be inspected among the scattered signals, or to filter the primary diffraction signals of the periodic structural units from the object to be inspected; and

[0043] driving a second filter structure to filter high-order diffraction signals of the periodic structural units from the object to be inspected among the scattered signals.

[0044] As can be seen from the above technical solutions, the embodiments of the present disclosure have the following advantages.

[0045] In the embodiments of the present disclosure, the filter includes a first filter structure and a second filter structure. The first filter structure is configured to filter the primary diffraction signals of the periodic structural units from the object to be inspected, and the second filter structure is configured to filter the high-order diffraction spots of the periodic structural units from the object to be inspected. Thus, during the inspection of defects of the object to be inspected, the first filter structure can filter the primary diffraction signals of the periodic structural units from the object to be inspected, and the second filter structure can filter the high-order diffraction spots of the periodic structural units from the object to be inspected. Thereby, the accuracy of acquiring the defect signals of the object to be inspected is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] FIG. 1 is a schematic diagram of a first filter structure in embodiments of the present disclosure;

[0047] FIG. 2 is a schematic diagram of a second filter structure in embodiments of the present disclosure;

[0048] FIG. 3 is a schematic diagram of first filter structures with different light-blocking structures in embodiments of the present disclosure;

[0049] FIG. 4 is a schematic structural diagram of a servo motor, a ball screw, a guide rail, and a first filter structure in embodiments of the present disclosure;

[0050] FIG. 5 is a schematic diagram of a first position and a second position in a pupil plane in embodiments of the present disclosure;

[0051] FIG. 6 is a schematic diagram of strip-shaped light-blocking elements that are partially stacked in embodiments of the present disclosure;

[0052] FIG. 7 is a schematic structural diagram of a servo motor, a ball screw, a guide rail, and a second filter structure in embodiments of the present disclosure;

[0053] FIG. 8 is a schematic diagram of an embodiment of an optical inspection system in embodiments of the present disclosure;

[0054] FIG. 9 is a schematic diagram showing positions of a first filter structure and a second filter structure in embodiments of the present disclosure;

[0055] FIG. 10 is a schematic diagram showing a position relationship between a first filter structure and a second filter structure in embodiments of the present disclosure;

[0056] FIG. 11 is a schematic diagram of another embodiment of an optical inspection system in embodiments of the present disclosure; and

[0057] FIG. 12 is a schematic diagram of an embodiment of an optical inspection method in embodiments of the present disclosure.

DETAILED DESCRIPTION

[0058] Embodiments of the present disclosure provide a filter, an optical inspection system, and an optical inspection method, which are used for filtering out primary diffraction signals and high-order diffraction spots of periodic structures of an object to be inspected on a pupil plane, so as to improve the accuracy of acquiring defect signals of the object to be inspected.

[0059] To enable those skilled in the art to better understand the solutions of the present

disclosure, the technical solutions in the embodiments of the present disclosure will be clearly and completely described below with reference to the accompanying drawings of the embodiments of the present disclosure. However, the described embodiments are merely some but not all embodiments of the present disclosure. Based on the embodiments of the present disclosure, all other embodiments obtained by those skilled in the art without creative effort shall be included in the protection scope of the present disclosure.

[0060] The terms such as “first”, “second”, “third”, and “fourth” used in the specification, claims, and accompanying drawings of the present disclosure are used to distinguish similar objects and are not necessarily used to describe a specific order or sequence. It should be understood that data used in such way can be interchanged where appropriate so that the embodiments described herein can be implemented in a sequence other than that illustrated or described herein. Furthermore, the terms “comprising” and “having”, and any derivatives thereof, are intended to cover non-exclusive inclusion, such that a process, method, system, product, or device that includes a series of steps or units is not necessarily limited to those steps or units that are explicitly listed, but may include other steps or units that are not explicitly listed or that are inherent to such process, method, product, or device.

[0061] In practical semiconductor inspection scenarios, if a surface of the object to be inspected is etched with structural units that are periodically arranged or if the object to be inspected has a rough surface, then during the inspection of the object to be inspected, incident light irradiates the surface of the object to be inspected, and scattered light will be formed on the surface of the object to be inspected. The scattered light from the periodic structural units will form light spots at a pupil plane of an objective lens system (that is, the back focal plane of the objective lens), and scattered light spots of a rough surface will also form light spots at the pupil plane of the objective lens system, resulting in defect signals of the object to be inspected being buried in the above scattered light spot signals.

[0062] Specifically, the rough surface of the object to be inspected may be a rough surface of an un-etched portion of the object to be inspected, or it may be a rough surface of the periodic structural unit of an etched portion of the object to be inspected. A specific position of the rough surface in the object to be inspected is not limited here. The object to be inspected in the embodiments of the present disclosure may be a wafer, mask, glass,

etc. A type of the object to be inspected is not specifically limited here.

[0063] For ease of understanding, the filter in the embodiments of the present disclosure is described below.

[0064] Specifically, in the embodiments of the present disclosure, the filter is configured to perform filtering on a pupil plane of the optical inspection system. The filter in the present disclosure includes a first filter structure and/or a second filter structure. The first filter structure is configured to filter the primary diffraction signals of the periodic structural units from the object to be inspected. The second filter structure is configured to filter the high-order diffraction spots of the periodic structural units from the object to be inspected.

[0065] As an optional embodiment, the periodic structural units may be structural units arranged periodically along a vertical direction and along a horizontal direction. The structural units may be structures such as grooves and protrusions. A specific form of the structural units is not specifically limited here.

[0066] The first filter structure and the second filter structure are described below.

[0067] Specifically, the first filter structure in the embodiments of the present disclosure includes at least one filter structure with a closed periphery. In a case where the object to be inspected is provided therein with the structural units, the closed filter structure is further provided therein with a light-blocking structure connecting any two ends of the closed filter structure. A width of the light-blocking structure is related to the numerical aperture (NA) of the illumination source. The larger the numerical aperture (NA) of the illumination source is, the larger the width of the light-blocking structure is; conversely, the smaller the numerical aperture (NA) of the illumination source is, the smaller the width of the light-blocking structure is. For ease of understanding, FIG. 1 is a schematic diagram of a first filter structure.

[0068] In practical inspection scenarios, as long as the surface of the object to be inspected is provided with a structural unit, a bright ray of light will be formed at the center of the pupil plane, which is a primary diffraction signal generated by the structural unit. In order to filter out the primary diffraction signal, the embodiments of the present disclosure further provide a light-blocking structure connecting any two ends of the closed filter structure in the closed filter structure of the first filter structure, so as to filter out the ray of light formed by the structural unit on the surface of the object to be inspected at the center of the pupil plane. A width of the ray of light is directly related to the numerical aperture (NA) of the illumination source.

[0069] Optionally, in the embodiments of the present disclosure, the closed filter structure may be an annular filter structure, or a filter structure with a square, rectangular, or polygonal periphery. The shape of the periphery of the filter structure is not specifically limited here.

[0070] Furthermore, in the embodiments of the present disclosure, the second filter structure includes a plurality of light-blocking elements arranged in parallel. A projection of the light-blocking element onto a plane where the high-order diffraction spots are located is not less than a diameter of the high-order diffraction spot. The plurality of light-blocking elements are configured to filter the high-order diffraction spots formed from the incident light by the plurality of periodic structural units at the pupil plane of the optical inspection system. It can be easily understood that the periodic structural units from the object to be inspected generally form a plurality of periodic diffraction spots at the pupil plane. The plurality of light-blocking elements may only need to block the plurality of periodic diffraction spots. In practical inspection scenarios, in a case where the periodic structural units from the object to be inspected are structural units periodically arranged along the vertical direction and along the horizontal direction, the plurality of light-blocking elements may be strip-shaped light-blocking elements arranged in parallel along the horizontal direction or the vertical direction at the pupil plane. In a case where the periodic structural units from the object to be inspected are structural units periodically arranged along a first direction, the plurality of light-blocking elements are light-blocking elements arranged in parallel along the first direction. The first direction is a direction that is at any angle to the horizontal direction. For ease of understanding, FIG. 2 is a schematic diagram of a second filter structure composed of a plurality of light-blocking elements.

[0071] Specifically, in the embodiments of the present disclosure, the light-blocking elements may be strip-shaped light-blocking elements, cylindrical light-blocking elements, sawtooth-shaped light-blocking elements, or wavy light-blocking elements, as long as the projections of the light-blocking elements on the plane where the high-order diffraction spots are located can block the high-order diffraction spots. The shape of the light-blocking elements is not specifically limited here.

[0072] Furthermore, in the case where the light-blocking elements are strip-shaped light-blocking elements, the widths of the strip-shaped light-blocking elements are related to the diameters of the high-order diffraction spots of the periodic structural units. For example, the larger the diameter of the high-order diffraction spot is, the larger the width

of the strip-shaped light-blocking element is. In practical applications, the width of the strip-shaped light-blocking element is generally set to be slightly larger than the diameter of the high-order diffraction spot. To enable the strip-shaped light-blocking elements to completely block the plurality of periodic high-order diffraction spots, a length of the strip-shaped light-blocking element is generally set to be no less than a diameter of the pupil plane in the optical inspection system, and a quantity of strip-shaped light-blocking elements is related to the diameter of the pupil plane and the width of each strip-shaped light-blocking element.

[0073] Specifically, in practical application scenarios, the strip-shaped light-blocking elements may be set as strip-shaped light-blocking rods, as long as they can block the high-order diffraction spots. The specific form of light-blocking elements among the strip-shaped light-blocking elements is not specifically limited here.

[0074] As an optional embodiment, a quantity N of light-blocking elements may be calculated based on the following formula:

[0075] $N \geq \frac{D}{d}$

where D is the diameter of the pupil plane in the optical inspection system, and d is the width of each light-blocking element.

[0076] In the embodiments of the present disclosure, the quantity N of light-blocking elements may be calculated based on the above formula, thereby improving the convenience and accuracy of acquiring the quantity N of light-blocking elements.

[0077] Furthermore, in the embodiments of the present disclosure, the light-blocking elements may be made of plastic, wood, or composite material. The material of the light-blocking elements is not specifically limited here.

[0078] In the embodiments of the present disclosure, the filter includes a first filter structure and a second filter structure. The first filter structure is configured to filter the primary diffraction signals of the periodic structural units from the object to be inspected, and the second filter structure is configured to filter the high-order diffraction spots of the periodic structural units from the object to be inspected. Thus, during the inspection of defects of the object to be inspected, the first filter structure can filter the primary diffraction signals of the periodic structural units from the object to be inspected, and the second filter structure can filter the high-order diffraction spots of the periodic signals of the object to be inspected is improved.

[0079] As an optional embodiment, the first filter structure may further filter the scattered light spots of the rough surface of the object to be inspected. In practical inspection scenarios, the position of the rough surface of the object to be inspected varies, and accordingly, the size and position of the light spot formed at the pupil plane are also uncertain. In order to filter out the light spots formed from the rough surface at the pupil plane, in the embodiments of the present disclosure, a spatial orientation of the light-blocking structure connecting any two ends of the closed filter structure in the first filter structure is adapted to the positions and shapes of the scattered light spots from the rough surface of the object to be inspected. The light-blocking structure adapted to the shapes of the scattered light spots from the rough surface of the object to be inspected means that the shape of the light-blocking structure is adapted to the form of the scattered light spots from the rough surface of the object to be inspected. In practical inspection scenarios, the light-blocking structure adapted to the shapes of the scattered light spots from the rough surface of the object to be inspected may be segment-shaped, circular, polygonal, or arc-shaped. The shape of the light-blocking structure adapted to the shapes of the scattered light spots from the rough surface of the object to be inspected is not specifically limited here.

[0080] As an optional embodiment, in the case where the object to be inspected is etched with the structural units, based on the shapes and positions of most of rough surfaces in the object to be inspected, in the embodiments of the present disclosure, the light-blocking structure in the first filter structure adapted to the positions and shapes of the scattered light spots from the rough surface of the object to be inspected is specifically arranged as follows:

[0081] A segment-shaped light-blocking structure is arranged at an end of the light-blocking structure, segment-shaped light-blocking structures are arranged at two ends of the light-blocking structure, or a circular light-blocking structure located at any position in the light-blocking structure. For ease of understanding, the corresponding figures are respectively shown in parts A, B, and C in FIG. 3.

[0082] Since the light-blocking structure in the first filter structure adapted to the positions and shapes of the scattered light spots from the rough surface of the object to be inspected is set to be segment-shaped, polygonal and circular, the scattered light spots from most of the rough surfaces of the object to be inspected may be filtered out. Thereby, the versatility of the first filter structure and the accuracy of filtering out the scattered light

spots from the rough surfaces of the object to be inspected are improved.

[0083] As an optional embodiment, the position and shape of the rough surface of each type of object to be inspected are uncertain. In order to achieve filtering of the scattered light spots of the rough surfaces of different types of objects to be inspected, there may be a plurality of first filter structures in the embodiments of the present disclosure, the first filter structures are arranged in the same plane, and a distance between centers of two adjacent first filter structures is not less than the diameter of the pupil plane in the optical inspection system. Therefore, the plurality of first filter structures may be driven by a driving mechanism; and when the object to be inspected is switched, different first filter structures may be driven to substantially overlap with the pupil plane by the driving mechanism.

[0084] The form of the plurality of first filter structures may be determined based on the type of object to be inspected. In a case where there are three or four types of objects to be inspected, three or four first filter structures are set accordingly, and the three or four filter structures are arranged in the same plane and driven by the driving mechanism. Therefore, a first first filter structure is configured to perform filtering when a first-type object to be inspected is inspected, and a second first filter structure or third first filter structure is configured to perform filtering when a second-type object to be inspected or third-type object to be inspected is inspected. Thus, the convenience of switching the first filter structures in different inspection scenarios is improved.

[0085] It should be noted that the embodiments of the present disclosure assume that one type of object to be inspected corresponds to one type of first filter structure. However, in practical inspection scenarios, one type of object to be inspected may correspond to multiple types of first filter structures, or multiple types of objects to be inspected may correspond to the same type of first filter structure. The type of object to be inspected when switching different first filter structures is not limited here.

[0086] As a specific embodiment of the driving mechanism, the embodiments of the present disclosure may adopt a servo motor to drive a ball screw to push the first filter structures to slide along a guide rail, thereby switching different first filter structures when inspecting different types of objects to be inspected. For ease of understanding, FIG. 4 is a schematic diagram showing the servo motor 401, the ball screw 402, the guide rail 403 and the first filter structures 404.

[0087] Specifically, in the process of switching the first filter structures, in order to avoid

mutual interference between two adjacent first filter structures, in the embodiments of the present disclosure, the distance between the centers of two adjacent first filter structures may be no less than the diameter of the pupil plane, so that two first filter structures will not simultaneously filter the light spots at the pupil plane. Thus, the accuracy of filtering of the scattered light spots from the rough surface of the object to be inspected by each first filter structure is realized.

[0088] As an optional embodiment, in order to prevent sharp edges of the first filter structure from inducing diffraction of the scattered light at the edges of the first filter structure, in the embodiments of the present disclosure, an inner peripheral wall of the closed filter structure in the first filter structure, and edges of the light-blocking structure may be set to be non-sharp edge structures, e.g., set to be serrated or wavy. The form of the non-sharp edge structures is not specifically limited here.

[0089] In the embodiments of the present disclosure, the edges of the first filter structure may be set to be non-sharp edge structures, thus reducing the diffraction phenomenon caused by the scattered light at the inner peripheral wall of the closed filter structure in the first filter structure, and the edges of the light-blocking structure and in turn improving the accuracy of acquiring the defect signals of the object to be inspected.

[0090] Next, the second filter structure in the above embodiments will be described in detail.

[0091] As an optional embodiment, the plurality of light-blocking elements in the second filter structure are arranged in one or more planes, and the one or more planes are perpendicular to a propagation direction of the scattered light.

[0092] Specifically, in the case where the plurality of light-blocking elements are arranged in the same plane, a distance between two adjacent light-blocking elements may be fixed, and the plurality of light-blocking elements in the plane may be driven by the same driving mechanism. Therefore, the plurality of light-blocking elements arranged in the same plane are driven to substantially overlap with the pupil plane by the same driving mechanism. This driving method of the same driving mechanism driving the plurality of light-blocking elements enables the plurality of light-blocking elements to be driven to the position of the pupil plane in a single driving, thereby improving the convenience of filtering using the second filter structure.

[0093] It should be noted that when the plurality of light-blocking elements are arranged in the same plane and driven by the same driving mechanism, the distance between two

adjacent light-blocking elements needs to be fixed in advance. The distance between two adjacent light-blocking elements depends on the distance between the periodic structural units from the object to be inspected. Therefore, the method, in which the plurality of light-blocking elements are arranged in the same plane and driven by the same driving mechanism, only allows inspection of defects of fixed types of objects to be inspected.

[0094] To address the above issue, in the embodiments of the present disclosure, each light-blocking element among the plurality of light-blocking elements may be driven by an independent driving mechanism. In this way, the distance between two adjacent light-blocking elements may be changed through their independent driving mechanisms, thereby adapting to different types of objects to be inspected and improving the convenience of inspection for different types of objects to be inspected.

[0095] Specifically, in the case where the plurality of light-blocking elements are arranged in different planes, in order to ensure that the light-blocking elements in different planes can completely block the high-order diffraction spots generated by the periodic structural units at the pupil plane, a driving mechanism may be provided for multiple light-blocking elements in each plane, so that the driving mechanism drives the multiple light-blocking elements in the plane to a position overlapping with the pupil plane, so as to block high-order diffraction spots at a corresponding position of the pupil plane.

[0096] For ease of understanding, the following example is provided.

[0097] As shown in FIG. 5, it is assumed that there are N * N (N being a positive integer greater than or equal to 2) high-order diffraction spots at the pupil plane. For ease of description, assuming that N = 6, three light-blocking elements will be arranged in a first plane, and another three light-blocking elements will be arranged in a second plane. A first driving mechanism is provided for the three light-blocking elements in the first plane, and a second driving mechanism is provided for the three light-blocking elements in the second plane. Therefore, the first driving mechanism drives the three light-blocking elements in the first plane to the first position 501 in FIG. 5, and the second driving mechanism drives the three light-blocking elements in the second plane to the second position 502 in FIG. 5. As a result, the plurality of light-blocking elements can cover the 6 * 6 diffraction spots at the pupil plane.

[0098] It should be noted that, in order to illustrate the first position 501 and the second position 502, three light-blocking elements are shown on the same plane in FIG. 5. However, in practical application scenarios, the first plane and the second plane are two

different planes.

[0099] Furthermore, in the case where the plurality of light-blocking elements are arranged in different planes, the light-blocking elements in different planes may be partially stacked, which is equivalent to increasing the width of the light-blocking element, thereby improving the accuracy of the light-blocking elements in blocking multiple high-order diffraction spots. For ease of understanding, FIG. 6 is a schematic diagram showing light-blocking elements that are partially stacked.

[0100] Furthermore, in order to inspect multiple different types of objects to be inspected, in the embodiments of the present disclosure, a corresponding driving mechanism is provided for each light-blocking element in different planes, so that the distance between two adjacent light-blocking elements is changed through their independent driving structures, so as to adapt to different types of objects to be inspected and improve the convenience of inspection for different types of objects to be inspected.

[0101] As a specific embodiment, as shown in FIG. 7, in the embodiments of the present disclosure, the ball screw 702 may be driven by the servo motor 701 to push each light-blocking element 703 in the second filter structure to slide along the guide rail 704. Thereby, each light-blocking element 703 in the second filter structure is driven to a corresponding position of the pupil plane to block diffraction spots at the corresponding position of the pupil plane.

[0102] As an optional embodiment, in order to prevent sharp edges of the second filter structure from inducing diffraction of the scattered light at the edges of the second filter structure, in the embodiments of the present disclosure, edges of the light-blocking elements in the second filter structure may be set to be non-sharp edge structures, e.g., set to be serrated or wavy. The form of the non-sharp edge structures is not specifically limited here.

[0103] In the embodiments of the present disclosure, the edges of the second filter structure may be set to be non-sharp edge structures, thus reducing the diffraction phenomenon caused by the scattered light at the edges of the light-blocking elements in the second filter structure, and in turn improving the accuracy of acquiring the defect signals of the object to be inspected.

[0104] As an optional embodiment, in the case where the filter includes the first filter structure and the second filter structure, the embodiments of the present disclosure require both the first filter structure and the second filter structure to overlap with the pupil

plane. The diameters of the high-order diffraction spots generated by the periodic structural units are small. Therefore, in order to achieve accurate filtering of the high-order diffraction spots generated by the periodic structural units, in the embodiments of the present disclosure, the second filter structure is arranged at the pupil plane, and the first filter structure is arranged at a first position 0.1 mm to 2 mm in front of or behind the pupil plane (for example, the first filter structure is arranged at a position ±1 mm away from the pupil plane). Thus, the first filter structure is as close as possible to the position of the pupil plane, so as to achieve accurate filtering of the scattered light spots formed from the rough surface of the object to be inspected and the primary diffraction signals (i.e., the primary diffraction spots) generated by the periodic structural units.

[0105] Furthermore, in the case where the second filter structure is arranged in multiple planes, one plane among the multiple planes may be arranged at the pupil plane, and remaining planes among the multiple planes may be arranged at a second position 0.1 mm to 2 mm in front of or behind the pupil plane. Thus, the remaining planes are as close as possible to the position of the pupil plane, so as to achieve accurate filtering of the high-order diffraction spots of the periodic structural units of the object to be inspected.

[0106] As an optional embodiment, in order to reduce the reflectivity of the first filter structure and/or the second filter structure, in the embodiments of the present disclosure, surfaces of the first filter structure and/or the second filter structure may be coated with an anti-reflective film to reduce the reflectivity of the first filter structure and/or the reflectivity of the second filter structure.

[0107] Specifically, the surfaces of the first filter structure and/or the second filter structure may be subjected to black coating treatment to reduce the reflectivity of the first filter structure and/or the reflectivity of the second filter structure.

[0108] Specifically, in the case where the object to be inspected is a wafer, there are two main types of optical noise in the scenario of patterned wafer defect inspection. The first type refers to the diffraction of incident light by the pattern of the wafer, including primary and high-order diffraction orders. Since the pattern of the wafer is regularly distributed, the diffracted light from the pattern exhibits a discrete distribution in the spatial frequency domain. The rule of discrete distribution is determined based on the pattern. The primary diffraction orders are distributed within the pupil plane, with high intensity and one-dimensional characteristics. However, distributions of primary diffraction orders from different patterns differ from each other, and all concentrate in the central band. The

second type of optical noise refers to scattered light caused by a rough substrate of the wafer. As the roughness and undulation of the substrate are random, the scattered light exhibits a continuous distribution in the frequency domain.

[0109] Based on the distribution characteristics of the two types of optical noise, the embodiments of the present disclosure may adopt a two-stage filter structure. The first filter structure is configured to suppress and filter the scattered signals from the rough surface of the object to be inspected and the primary diffraction signals from the periodic structural units, or to suppress and filter the primary diffraction signals from the periodic structural units. The second filter structure is configured to suppress higher-order diffraction in the first type of optical noise. Thereby, the noise is suppressed better, the signal-to-noise ratio (SNR) is improved, and the inspection accuracy is improved.

[0110] Furthermore, in the embodiments of the present disclosure, the first filter structure and the second filter structure may realize dual filtering on the same pupil plane, thereby improving the filtering effect on optical noise. To meet the need for efficient optical noise filtering in dark-field pattern wafer defect inspection, the embodiments of the present disclosure may achieve filtering of two types of noise on the same pupil plane. Therefore, compared with the existing technical solution where a relay optical device is added to the optical inspection system to form two pupil planes, optical aberrations and other optical errors will not be introduced, and the inspection accuracy is guaranteed.

[0111] The optical inspection system in the embodiments of the present disclosure will be described below with reference to FIG. 8.

[0112] In the embodiments of the present disclosure, the optical inspection system includes a light source 801, an objective lens 802, a filter 803, a tube lens system 804, and a detector 805.

[0113] Specifically, the light source 801 is configured to transmit light of a preset wavelength to an object to be inspected 806 at a preset angle. Here, the light source 801 may be a red laser, a blue laser, or an LED light source. The type of the light source 801 is not specifically limited here.

[0114] The objective lens 802 is configured to collect scattered light from the object to be inspected and focus the scattered light onto a pupil plane.

[0115] The pupil plane here is the back focal plane of the objective lens 802.

[0116] The filter 803 substantially overlaps with the pupil plane, so as to filter the scattered signals of the rough surface of the object to be inspected and the primary

diffraction signals of the periodic structural units from the object to be inspected or to filter the primary diffraction signals of the periodic structural units from the object to be inspected, and to filter the high-order diffraction spots of the periodic structural units from the object to be inspected.

[0117] It should be noted that the filter 803 here is similar to that described in the above embodiments, reference can be made thereto, and details will not be repeated here.

[0118] The tube lens system 804 is configured to image the object to be inspected onto the detector 805.

[0119] The objective lens 802 and the tube lens system 804 described here are similar to those described in existing technologies, and details will not be repeated here.

[0120] The detector 805 is configured to detect defects of the object to be inspected based on an image of the object to be inspected.

[0121] Specifically, the detector 805 may be a photodiode, a photodetector, or an avalanche photodetector. The type of the detector 805 is not specifically limited here.

[0122] In the embodiments of the present disclosure, the optical inspection system is configured to inspect defects of the object to be inspected. In the inspection process, the filter 803 includes a first filter structure and a second filter structure. The first filter structure is configured to filter the scattered signals of the rough surface of the object to be inspected and the primary diffraction signals of the periodic structural units from the object to be inspected or to filter the primary diffraction signals of the periodic structural units from the object to be inspected. The second filter structure is configured to filter the high-order diffraction spots of the periodic structural units from the object to be inspected. Thus, during the inspection of defects of the object to be inspected, the first filter structure can filter the primary diffraction signals of the periodic structural units from the object to be inspected, and the second filter structure can filter the high-order diffraction spots of the periodic structural units from the object to be inspected. Thereby, the accuracy of acquiring the defect signals of the object to be inspected is improved.

[0123] As an optional embodiment, based on the embodiment illustrated in FIG. 8, the edges of the first filter structure and the second filter structure in the filter 803 are set to be non-sharp edge structures, so as to avoid the diffraction phenomenon caused by the scattered light of the first filter structure and the second filter structure, and in turn improve the Poisson scattering resolution of the optical inspection system. Therefore, defects of the object to be inspected are inspected even when the resolution of the detector 805 is

less than the Poisson scattering resolution of the optical inspection system.

[0124] The Poisson scattering resolution of the optical inspection system is also called the point spread function (PSF) resolution precision, which is used for evaluating the imaging quality of the optical inspection system. Since the edges with the non-sharp structures of the first filter structure and/or the second filter structure can suppress the diffraction phenomenon caused by the scattered light, the optical energy in the image of the object to be inspected is concentrated mainly at the center. As a result, defects of the object to be inspected can still be detected even if the resolution of the detector 805 is less than the Poisson scattering resolution of the optical inspection system.

[0125] As an optional embodiment, based on the embodiment illustrated in FIG. 8, in order to improve the observation of the pupil plane, in the embodiments of the present disclosure, as shown in FIG. 11, an insertable reflector 807, a pupil imaging tube lens 808, and a pupil imaging detector 809 may be further arranged. In the case where the insertable reflector 807 is inserted between the tube lens system 804 and the detector 805, the scattered light is reflected to the pupil imaging tube lens 808. The pupil imaging tube lens 808 is configured to image the pupil plane onto the pupil imaging detector 809. The pupil imaging detector 809 is configured to observe the pupil plane based on the image of the pupil plane.

[0126] Optionally, the insertable reflector 807 may also be inserted between the filter 803 and the tube lens system 804, so that the scattered light is reflected to the pupil imaging tube lens 808. The pupil imaging tube lens 808 is configured to image the pupil plane onto the pupil imaging detector 809. The pupil imaging detector 809 is configured to observe the pupil plane based on the image of the pupil plane.

[0127] In the embodiments of the present disclosure, in order to observe the filtering condition on the pupil plane, the pupil plane may also be imaged onto the pupil imaging detector 809 in the embodiments of the present disclosure, so that the imaging condition of the pupil plane may be observed through the pupil imaging detector 809, which improves the convenience of observing the pupil plane.

[0128] As an optional embodiment, the filter 803 includes the first filter structure 8031 and the second filter structure 8032. In the case where the plurality of light-blocking elements in the second filter structure 8032 are arranged in the same plane, the second filter structure 8032 is arranged at the pupil plane, and the first filter structure 8031 is arranged 0.1 mm to 2 mm in front of the pupil plane or 0.1 mm to 2 mm behind the pupil

plane along the propagation direction of the scattered light, so that the first filter structure 8031 is as close as possible to the pupil plane. Therefore, the first filter structure 8031 filters the primary diffraction signals of the periodic structural units from the object to be inspected and/or the scattered light spots of the rough surface of the object to be inspected, and the second filter structure 8032 filters the high-order diffraction light spots of the periodic structural units from the object to be inspected. For ease of understanding, FIG. 9 is a schematic diagram showing the positions of the first filter structure 8031 and the second filter structure 8032.

[0129] As another optional embodiment, the filter 803 includes the first filter structure 8031 and the second filter structure 8032. In the case where the plurality of light-blocking elements in the second filter structure 8032 are arranged in multiple planes, one plane among the multiple planes may overlap with the pupil plane, and remaining planes among the multiple planes may be arranged 0.1 mm to 2 mm in front of the pupil plane along the propagation direction of the scattered light; and the first filter structure may be arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light.

[0130] Alternatively, the remaining planes among the multiple planes are arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light, and the first filter structure is arranged 0.1 mm to 2 mm in front of the pupil plane along the propagation direction of the scattered light. For ease of understanding, FIG. 10 is a schematic diagram showing the positions of the first filter structure 8031 and the second filter structure 8032.

[0131] In the embodiments of the present disclosure, the diameters of the diffraction spots generated by the periodic structural units of the object to be inspected are small. In order to achieve accurate filtering of the diffraction spots generated by the periodic structural units, in the embodiments of the present disclosure, the second filter structure 8032 is arranged at the pupil plane, and the first filter structure 8031 is as close as possible to the pupil plane, thereby achieving accurate filtering of the high-order diffraction spots generated by the periodic structural units from the object to be inspected.

[0132] As an optional embodiment, in order to control the size of the light spot formed by the incident beam irradiating the surface of the object to be inspected, in the embodiments of the present disclosure, a beam expanding and shaping module 810 may also be arranged between the light source 801 and the object to be inspected 806. The

beam expanding and shaping module 810 includes a beam expander and a shaping element. The beam expander is configured to expand the light from the light source to obtain a light spot of a preset size. The shaping element is a phase element with a two-dimensional structure, which shapes the expanded light, so as to achieve the purpose of controlling the numerical aperture (NA) of the incident light. For ease of understanding, FIG. 11 is a schematic diagram showing an optical inspection system including the insertable reflector 807, the pupil imaging tube lens 808, the pupil imaging detector 809, and the beam expanding and shaping module 810.

[0133] Based on the optical inspection system shown in FIG. 11, an optical inspection method of the optical inspection system will be described below with reference to FIG. 12.

[0134] In 1201, the image of the pupil plane is observed through the pupil imaging detector, so as to obtain a distribution state of the scattered signals in the pupil plane.

[0135] In the embodiments of the present disclosure, the insertable reflector 807, the pupil imaging tube lens 808, and the pupil imaging detector 809 cooperate with each other to image the pupil plane onto the pupil imaging detector 809, thereby enabling the image of the pupil plane to be observed through the pupil imaging detector 809.

[0136] In this way, the image of the pupil plane can be observed through the pupil imaging detector to obtain the distribution state of the scattered signals in the pupil plane. Therefore, according to the positions and shapes of the scattered signals of the rough surface of the object to be inspected, an appropriate first filter structure is selected. That is, according to the positions and shapes of the scattered signals of the rough surface of the object to be inspected, the appropriate first filter structure is selected from the first filter structures in FIG. 3.

[0137] In 1202, the appropriate first filter structure is driven to filter the scattered signals of the rough surface of the object to be inspected and the primary diffraction signals of the periodic structural units from the object to be inspected among the scattered signals, or to filter the primary diffraction signals of the periodic structural units from the object to be inspected.

[0138] After the appropriate first filter structure 8031 is determined, the appropriate first filter structure 8031 may be driven to filter the scattered signals of the rough surface of the object to be inspected and the primary diffraction signals of the periodic structural units from the object to be inspected among the scattered signals. Specifically, in the case where both the first filter structure and the second filter structure are present, the first filter

structure is arranged 0.1 mm to 2 mm in front of or behind the pupil plane along the propagation direction of the scattered light, so as to filter the scattered signals of the rough surface of the object to be inspected and the primary diffraction signals of the periodic structural units from the object to be inspected.

[0139] In 1203, the second filter structure is driven to filter high-order diffraction signals of the structural units from the object to be inspected among the scattered signals.

[0140] In the case where there are high-order diffraction signals (high-order diffraction spots) generated by the structural units of the object to be inspected in the pupil plane, the second filter structure is driven to filter the high-order diffraction signals of the structural units from the object to be inspected among the scattered signals, thereby improving the accuracy of filtering the scattered signals in the pupil plane.

[0141] The foregoing embodiments are merely intended to illustrate the technical solutions of the present disclosure, rather than to limit the same. Although the present disclosure has been described in detail with reference to the foregoing embodiments, those of ordinary skill in the art should understand that modifications can still be made to the technical solutions described in the foregoing embodiments, or equivalent replacements can be made to some of the technical features. Such modifications or replacements do not cause the essence of the corresponding technical solutions to deviate from the spirit and scope of the technical solutions of the embodiments of the present disclosure.

CLAIMS

1. A filter, comprising:

a first filter structure, configured to filter primary diffraction signals of periodic structural units from an object to be inspected; and

a second filter structure, configured to filter high-order diffraction spots of the periodic structural units from the object to be inspected; wherein

the first filter structure comprises at least one filter structure with a closed periphery; in a case where the object to be inspected has the structural units, the closed filter structure is further provided therein with a light-blocking structure connecting any two ends of the closed filter structure;

the second filter structure comprises a plurality of light-blocking elements arranged in parallel, wherein a projection of a light-blocking element onto a plane where the high-order diffraction spots are located is not less than a diameter of a high-order diffraction spot.

2. The filter according to claim 1, wherein a spatial orientation of the light-blocking structure connecting any two ends of the closed filter structure is adapted to positions and shapes of scattered light spots from a rough surface of the object to be inspected.

3. The filter according to claim 2, wherein the light-blocking structure arranged within the closed filter structure and adapted to the positions and shapes of the scattered light spots from the rough surface of the object to be inspected comprises: a segment-shaped light-blocking structure arranged at an end of the light-blocking structure, or segment-shaped light-blocking structures arranged at two ends of the light-blocking structure, or a polygonal light-blocking structure arranged at any position in the light-blocking structure, or a circular light-blocking structure disposed at any position in the light-blocking structure.

4. The filter according to claim 1, wherein the filter is arranged in an optical inspection system; a plurality of first filter structures are provided; the plurality of first filter structures are arranged in a same plane; and a distance between centers of two adjacent first filter structures is not less than a diameter of a pupil plane of the optical inspection system.

5. The filter according to claim 4, wherein the plurality of first filter structures are driven by a driving mechanism; and in a case where the object to be inspected is switched, different first filter structures are driven by the driving mechanism to substantially overlap with the pupil plane.

6. The filter according to claim 1, wherein an inner peripheral wall of the closed filter structure, edges of the light-blocking structure, and edges of the light-blocking elements are set to be non-sharp edge structures; or

edges of the light-blocking elements are set to be non-sharp edge structures.

7. The filter according to claim 1, wherein the filter is arranged in an optical inspection system; in a case where a diameter of a pupil plane of the optical inspection system is D and a width of the light-blocking element is d, a quantity N of the light-blocking elements is calculated based on a following formula:

$$N \geq \frac{D}{d}.$$

8. The filter according to claim 1, wherein the plurality of light-blocking elements are arranged in at least one plane, and each plane of the at least one plane is perpendicular to a propagation direction of scattered light.

9. The filter according to claim 8, wherein the plurality of light-blocking elements are arranged in multiple planes, and light-blocking elements in different planes are partially stacked; or

wherein the filter is arranged in an optical inspection system; a distance between two adjacent light-blocking elements in each plane is fixed; multiple light-blocking elements in each plane are driven by a same driving mechanism such that the multiple light-blocking elements in each plane substantially overlap with a pupil plane of the optical inspection system to block diffraction spots at a corresponding position of the pupil plane.

10. The filter according to claim 1, wherein the filter is arranged in an optical inspection system; each light-blocking element is driven by an independent driving mechanism, such that a plurality of independent driving mechanisms each drive a corresponding light-blocking element to substantially overlap with a pupil plane of the optical inspection system.

11. The filter according to claim 1, wherein the light-blocking elements comprise strip-shaped light-blocking elements, cylindrical light-blocking elements, sawtooth-shaped light-blocking elements, or wavy light-blocking elements.

12. An optical inspection system, comprising:

a light source, configured to transmit coherent light of a preset wavelength to an object to be inspected at a preset angle;

an objective lens, configured to collect scattered light from the object to be inspected

and focus parallel light or nearly parallel light in the scattered light onto a pupil plane;

the filter according to any one of claims 1 to 11, substantially overlapping with the pupil plane;

a tube lens system, configured to image the object to be inspected onto a detector; and

the detector, configured to detect defects of the object to be inspected based on an image of the object to be inspected.

13. The system according to claim 12, wherein the filter comprises a first filter structure and a second filter structure, wherein the second filter structure comprises a plurality of light-blocking elements arranged in multiple planes, one plane among the multiple planes overlaps with the pupil plane, remaining planes among the multiple planes are arranged 0.1 mm to 2 mm in front of the pupil plane along a propagation direction of the scattered light, and the first filter structure is arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light; or

the remaining planes among the multiple planes are arranged 0.1 mm to 2 mm behind the pupil plane along the propagation direction of the scattered light, and the first filter structure is arranged 0.1 mm to 2 mm in front of the pupil plane along the propagation direction of the scattered light.

14. The system according to claim 12, wherein the filter comprises a first filter structure and a second filter structure, wherein the second filter structure comprises a plurality of parallel strip-shaped light-blocking elements, widths of the strip-shaped light-blocking elements are related to diameters of high-order diffraction spots of periodic structural units, lengths of the strip-shaped light-blocking elements are not less than a diameter of the pupil plane, and a quantity of the strip-shaped light-blocking elements is related to the diameter of the pupil plane and a width of each strip-shaped light-blocking element.

15. An optical inspection method, applied to the optical inspection system according to any one of claims 12 to 14, the method comprising:

observing the image of the pupil plane through a pupil imaging detector to obtain a distribution state of scattered signals in the pupil plane;

driving an appropriate first filter structure to filter scattered signals of a rough surface of the object to be inspected and primary diffraction signals of periodic structural units from the object to be inspected among the scattered signals, or to filter the primary

diffraction signals of the periodic structural units from the object to be inspected; and

driving a second filter structure to filter high-order diffraction signals of the periodic structural units from the object to be inspected among the scattered signals.