

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization  
International Bureau



(10) International Publication Number

WO 2017/038007 A1

(43) International Publication Date  
9 March 2017 (09.03.2017)

(51) International Patent Classification:  
*H01L 21/027* (2006.01)   *B29C 59/02* (2006.01)

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(21) International Application Number:

PCT/JP2016/003579

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date:  
3 August 2016 (03.08.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
2015-174407 4 September 2015 (04.09.2015) JP

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

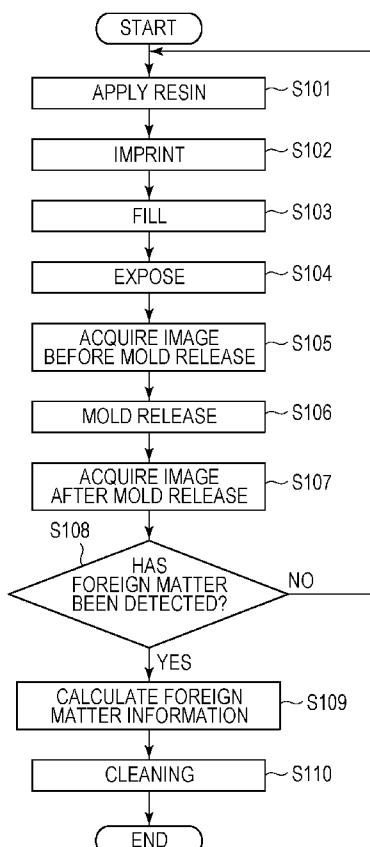
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(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,

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(54) Title: IMPRINT APPARATUS, IMPRINT METHOD, AND METHOD OF MANUFACTURING ARTICLE



(57) Abstract: A decrease in the throughput associated with foreign matter detection is suppressed. The present invention relates to an imprint apparatus (100) configured to form a pattern of an imprint material (114) on a substrate (103) by using a mold (102). The imprint apparatus (100) includes an image capturing unit (119) configured to capture an image of the imprint material (114), and a detection unit (120) configured to detect a foreign matter (503a) present between a placing unit (106) on which the substrate (103) is placed and the substrate (103). The detection unit (120) is configured to detect the foreign matter (503a) on the basis of a first resulting image captured by the image capturing unit (119) before the mold (102) is released from the imprint material (114) into which the mold (102) has been brought into contact and a second resulting image captured by the image capturing unit (119) after the mold (102) is released from the imprint material (114) into which the mold (102) has been brought into contact.



LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, **Published:**  
SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, — *with international search report (Art. 21(3))*  
GW, KM, ML, MR, NE, SN, TD, TG).

## Description

### Title of Invention: IMPRINT APPARATUS, IMPRINT METHOD, AND METHOD OF MANUFACTURING ARTICLE

#### Technical Field

[0001] The present invention relates to an imprint apparatus, an imprint method, and a method of manufacturing an article.

#### Background Art

[0002] An imprint technique is known as a method of forming a fine pattern on a substrate in order to manufacture a semiconductor device or the like. In the imprint technique, a mold having a portion in which a concave and convex pattern is formed (hereinafter, referred to as a pattern portion) is brought into contact with an imprint material, and a transfer pattern of the mold is formed on a substrate.

[0003] When a foreign matter is disposed between a placing unit on which a substrate is placed and the substrate, the substrate locally protrudes. If a pattern is formed in this state, a pattern defect may occur, or the pattern portion may be damaged.

[0004] PTL 1 describes a lithography apparatus that includes a detection device capable of detecting a foreign matter on a placing unit before a substrate is placed on the placing unit. The detection device includes an optical flat that is to be brought into contact with the placing unit, a laser light source that irradiates the optical flat and the placing unit with laser light, a monitor, and an image processing device. The detection device detects a foreign matter on the placing unit by analyzing a resulting image of an interference fringe captured on the optical flat with the use of the image processing device.

#### Citation List

#### Patent Literature

[0005] PTL 1: Japanese Patent Laid-Open No. 10-70069

#### Summary of Invention

[0006] The foreign matter detection device described in PTL 1 carries out foreign matter detection before a substrate is placed on the placing unit. Therefore, the step of bringing the optical flat and the substrate into contact with each other is carried out separately, and the throughput of the process involving the foreign matter detection that includes the inspection step and the processing step carried out on the inspected substrate may decrease. Accordingly, one aspect of the present invention provides an imprint apparatus and an imprint method that can suppress a decrease in the throughput associated with the foreign matter detection. An exemplary embodiment according to one aspect of the present invention provides an imprint apparatus configured to form a

pattern of an imprint material on a substrate by using a mold. The imprint apparatus includes an image capturing unit configured to capture an image of the imprint material, and a detection unit configured to detect a foreign matter present between the placing unit on which the substrate is placed and the substrate. The detection unit is configured to detect the foreign matter on the basis of a first resulting image captured by the image capturing unit before the mold is released from the imprint material into which the mold has been brought into contact and a second resulting image captured by the image capturing unit after the mold is released from the imprint material into which the mold has been brought into contact.

[0007] Further features of the present invention will become apparent from the following description of exemplary embodiments with reference to the attached drawings.

### **Brief Description of Drawings**

[0008] [fig.1A]Fig. 1A illustrates a configuration of an imprint apparatus according to an exemplary embodiment.

[fig.1B]Fig. 1B illustrates a configuration of a rectangular mold and a mold stage.

[fig.2A]Fig. 2A is a front view illustrating a structure of a mold.

[fig.2B]Fig. 2B illustrates the mold as viewed in the +Z-direction.

[fig.3]Fig. 3 is a flowchart illustrating an imprint method according to an exemplary embodiment.

[fig.4A]Fig. 4A is a schematic diagram illustrating a state in which a mold and an imprint material are in contact with each other.

[fig.4B]Fig. 4B illustrates an image representing a result obtained by capturing an image of an imprint material before a mold is released.

[fig.4C]Fig. 4C illustrates an image representing a result obtained by capturing an image of the imprint material after the mold is released.

[fig.5]Fig. 5 is a schematic diagram illustrating a state in which a mold has been released from an imprint material.

[fig.6]Fig. 6 is a flowchart illustrating a method of detecting a foreign matter according to an exemplary embodiment.

[fig.7]Fig. 7 illustrates a difference between images captured before and after a mold is released.

[fig.8]Fig. 8 is an illustration for describing batch imprinting.

### **Description of Embodiments**

[0009]

#### **First Exemplary Embodiment**

[0010]

#### **Configuration of Apparatus**

[0011] Fig. 1A illustrates a configuration of an imprint apparatus 100 according to the present exemplary embodiment. In Fig. 1A, the Z-axis (vertical direction in the present exemplary embodiment) corresponds to an axis that is parallel to an optical axis of ultraviolet radiation 104 that is emitted by a light source 101, transmitted through a mold 102, and incident on a substrate 103. The X-axis and the Y-axis are two axes that are orthogonal to each other within a plane perpendicular to the Z-axis.

[0012] A substrate stage (moving member) 105 includes a substrate holding unit (placing unit) 106 that holds the substrate 103. The substrate holding unit 106 is connected to a vacuum pump (not illustrated), and the force with which the substrate holding unit 106 holds the substrate 103 is controlled by controlling the vacuum pump. A mark mount 107 on which a reference mark is formed is provided on the substrate stage 105 at a position spaced apart from the substrate 103.

[0013] Fig. 1B illustrates a configuration of the rectangular mold 102 and a mold stage 108. The mold stage 108 includes a driving mechanism 125 that moves the mold 102 and a mold holding unit 110 that holds the mold 102 in the Z-axis direction.

[0014] With the use of the driving mechanism 125, an operation of pressing the mold 102 against an uncured imprint material (imprint material) 114 (illustrated in Fig. 1A) (contact operation) and an operation of releasing the mold 102 from the cured imprint material 114 are carried out. A cylindrical space 109 is formed in the mold stage 108 at a center portion thereof. The mold holding unit 110 sucks and holds the mold 102 through the vacuum suction force.

[0015] A curable composite (also referred to as uncured resin) that is cured as being provided with energy for curing is used for the imprint material 114. The energy for curing may be provided in the form of an electromagnetic wave, radiation, heat, or the like. The electromagnetic wave may be, for example, infrared radiation, a visible light ray, ultraviolet radiation, or the like that is selected from radiation having a wavelength of no less than 10 nm and no greater than 1 mm, or may be electromagnetic radiation, such as an X-ray or a gamma-ray. The radiation may be corpuscular radiation, such as an electron beam.

[0016] The curable composite is a composite that is cured as being irradiated with light or radiation or cured as being heated. Among such composites, a photocurable composite, which is cured by light, contains at least a polymeric compound and a photopolymerization initiator and may also contain a non-polymeric compound or a solvent as necessary. The non-polymeric compound is at least one selected from a group consisting of a sensitizer, a hydrogen donor, an internal mold lubricant, a surfactant, an antioxidant, a polymer component, or the like.

[0017] The polymeric compound is a compound that reacts with a polymerizing factor (e.g., radical) generated from a photopolymerization initiator and forms a solid made of a

macromolecular compound through a chain reaction (polymerization reaction). For example, the polymeric compound is a compound having one or more acryloyl groups or methacryloyl groups, or in other words, is a (meth)acrylic compound. The photopolymerization initiator is a compound that generates a polymerizing factor upon receiving light and, for example, is a radical generator, such as an acylphosphine oxide compound.

- [0018] The imprint material 114 is applied to the substrate 103 in the form of a film by a spin coater or a slit coater. Alternatively, the imprint material 114 may be applied to the substrate 103 by a liquid ejecting head in the form of a liquid droplet or in the form of an island or a film in which a plurality of liquid droplets are connected. The viscosity (viscosity at 25°C) of the imprint material 114 is, for example, no less than 1 mPa\*S and no greater than 100 mPa\*S.
- [0019] The contact operation and the releasing operation of the imprint material 114 and the mold 102 may be carried out by moving only the substrate stage 105 or by moving the mold stage 108 and the substrate stage 105 in combination.
- [0020] A pressure control unit 112 feeds or discharges a gas through a pipe 111 so as to control the pressure inside a space 113. The space 113 is a space enclosed by a glass plate 126 and a recess portion 102b in the mold 102. The air pressure inside the space 113 is made higher than the air pressure in the imprint apparatus 100 by the pressure control unit 112, and thus a pattern portion (pattern formed portion) 102a, which will be described later, is deformed so as to project toward the substrate 103. It is to be noted that the substrate holding unit 106 and the mold holding unit 110 may hold the respective objects to be held by utilizing the electrostatic force instead of utilizing the vacuum suction force.
- [0021] The mold 102 includes the rectangular pattern portion 102a provided at a center portion thereof, and a concave and convex pattern is formed in the pattern portion 102a. In addition, the recess portion 102b is formed in the mold 102 on the surface that is opposite to the surface where the pattern portion 102a is formed, and the recess portion 102b has a sectional area that is greater than that of the pattern portion 102a. The recess portion 102b has a depth of approximately 1 mm.
- [0022] Fig. 2A is a front view of the mold 102, and Fig. 2B illustrates the mold 102 as viewed in the +Z-direction. The pattern portion 102a is a portion which a pattern to be transferred is formed. The pattern portion 102a includes a base portion 201, concave portions 202, and convex portions 203. The base portion 201 has a thickness (length in the Z-axis direction) of approximately 30  $\mu\text{m}$ . With respect to the size of the concave and convex pattern, for example, the depth of the concave portion 202 from the top of the convex portion 203 is in a range from several ten nanometers to several hundred nanometers, and the width of the concave portion 202 and of the convex portion 203 is

in a range from approximately several nanometers to ten-odd nanometers.

- [0023] Marks 204 that are to be used to measure the position or the size of the pattern portion 102a are provided at four corners of the pattern portion 102a. The marks 204 are detected by a detection unit 115, which will be described later.
- [0024] When the imprint material 114 to be used for imprinting is photocurable, a material that can transmit the ultraviolet radiation 104 for curing is used as a material for the mold 102. Examples of such a material include glass, such as silica glass, silicic acid-based glass, calcium fluoride, magnesium fluoride, or acrylic glass; sapphire; gallium nitride; polycarbonate; polystyrene; acryl; and polypropylene. Alternatively, a multilayer member formed of any desired material among the above may also be used. Furthermore, the material for the mold 102 is selected so that the refractive index of the mold 102 is approximately the same as the refractive index of the imprint material 114.
- [0025] Referring back to Figs. 1A and 1B, a detection unit 116 detects an alignment mark (not illustrated) provided on the substrate 103 and a reference mark whose position relative to the substrate stage 105 is known. On the basis of the detection result, a control unit 120 obtains the position of the substrate 103 relative to the substrate stage 105. Furthermore, the control unit 120 obtains the shape, the positional deviation, and so on of a pattern region 117 of a base pattern provided on the substrate 103.
- [0026] The detection unit 115 detects the marks 204 (detailed description will be given later) provided on the mold 102 and alignment marks. The detection unit 115 obtains the positional deviation or the difference in shape between the pattern portion 102a and the pattern region 117 on the substrate 103 in which a pattern is to be formed, on the basis of a moire signal (interference fringe) generated by the marks 204 and the alignment marks.
- [0027] The detection unit 115 includes a plurality of scopes. A plurality alignment marks are provided per pattern region 117, and a plurality marks 204 are provided in the pattern portion 102a. Each of the scopes detects a pair of an alignment mark and a mark 204. For example, the detection unit 115 measures the marks at the four corners of the pattern region 117 simultaneously. A moire signal can be detected without a high-precision optical system. Therefore, the detection unit 115 is constituted by a plurality of scopes having low resolution (small NA).
- [0028] An application unit 118 supplies the uncured photocurable imprint material 114 to the pattern region 117.
- [0029] An image capturing unit 119 captures an image of the imprint material 114 during a period from the time when the mold stage 108 starts lowering the mold 102 to the time when the mold 102 is raised back to the original position after a transfer pattern of the pattern portion 102a is formed in the pattern portion 117.

[0030] The image capturing unit 119 includes a light source 119a formed of a light-emitting diode (LED) and an image capturing element 119b and captures an image of the imprint material 114 from the side of the mold 102 in which the recess portion 102b is formed. Specifically, the image capturing unit 119 captures an image of the imprint material 114 by using light that has been transmitted through the mold 102 and reflected by the substrate 103. The light source 119a emits light having a wavelength (e.g., approximately 400 nm to 500 nm) that is in a wavelength band different from that of the ultraviolet radiation 104 and to which the imprint material 114 is not sensitive. The image capturing element 119b is constituted by a charge-coupled device (CCD) sensor. The imaging field of view of the image capturing element 119b is a little larger than the area of the pattern portion 102a.

[0031] When the pattern portion 102a is brought into contact with the imprint material 114, an interference fringe is observed around the portion where the imprint material 114 and the pattern portion 102a are in contact with each other. By observing a change in the interference fringe, completion of a filling step (contact step) can be determined. The filling step is a step in which a region where the imprint material 114 and the pattern portion 102a are in contact with each other extends in a direction parallel to the substrate 103 and the concave portions 202 in the pattern portion 102a are filled with the imprint material 114.

[0032] The refractive index of the imprint material 114 and the refractive index of the mold 102 are substantially equal to each other, and thus after the concave portions 202 are filled with the imprint material 114, an image having substantially the same gradation number (pixel information) within the imaging field of view is observed. The gradation number is a value that indicates the shade of a color in a gray scale image. The term "substantially the same gradation number" means that, when the gradation number of each pixel in a gray scale image is subjected to binarization processing, the resulting gradation number is identical, for example. When a foreign matter is present on the surface of the substrate 103 that is to be treated (the surface facing toward the mold 102) or on the surface opposite to the surface to be treated (the surface facing toward the substrate holding unit 106), an image of an interference fringe or the like is observed due to the foreign matter.

[0033] A resulting image captured by the image capturing unit 119 is stored into a storage unit 121 by the control unit 120. Resulting images stored in the storage unit 121 include a still image at each individual moment.

[0034] The control unit (detection unit, calculation unit) 120 is connected to the light source 101, the mold stage 108, the detection unit 116, the application unit 118, the image capturing unit 119, the storage unit 121, and a cleaning unit 122. The control unit 120 controls these units so as to form a transfer pattern of the mold 102 onto the substrate

103 and detect a foreign matter present on the front or back surface of the substrate 103.

- [0035] The storage unit 121 stores programs indicated in the flowcharts illustrated in Figs. 3 and 6. The control unit 120 reads out a program stored in the storage unit 121 and controls the units connected to the control unit 120 so as to execute the program.
- [0036] The cleaning unit 122 is controlled by the control unit 120 and cleans the substrate holding unit 106 on the basis of the result of detecting a foreign matter 503a, which will be described later. The cleaning unit 122 includes a plate 124 having a polishing surface and a plate holding unit 123 that holds the plate 124 and can move in the Z-axis direction by being controlled by the control unit 120. The plate 124 is brought into contact with the surface of the substrate holding unit 106 in a state in which the substrate 103 is removed, and the plate 124 and the substrate holding unit 106 are moved relative to each other within the XY plane. Through this operation, the surface of the substrate holding unit 106 is cleaned, and the foreign matter 503a is rubbed off.

### **Method of Detecting Foreign matter**

- [0037] The imprint apparatus 100 detects a foreign matter by comparing an image (first resulting image) of the imprint material 114 acquired in a state in which the pattern portion 102a and the imprint material 114 are in contact with each other with an image (second resulting image) of the imprint material 114 acquired in a state in which the pattern portion 102a has been released from the cured imprint material 114.
- [0038] With reference to the flowchart illustrated in Fig. 3, a method of detecting a foreign matter carried out in a step of forming a pattern in a single pattern region 117 will be described.
- [0039] The pattern region 117 is positioned underneath the application unit 118 by moving the substrate stage 105. The application unit 118 applies an uncured imprint material 114 onto the pattern region 117 (S101).
- [0040] The pattern region 117 is positioned underneath the mold holding unit 110 by moving the substrate stage 105. The mold stage 108 lowers the mold 102 and the mold holding unit 110. While the mold 102 and the mold holding unit 110 are being lowered, the pressure control unit 112 feeds a gas into the space 113. The pressure inside the space 113 is made higher than the pressure of the space in which the imprint apparatus 100 is disposed, and thus the pattern portion 102a is deformed so as to project toward the lower side (the side toward the substrate 103). The amount of movement by which the mold 102 and the mold holding unit 110 are lowered is determined on the basis of the distance between the pattern portion 102a and the substrate 103 that has been measured in advance by a measuring unit (not illustrated).
- [0041] As the pattern portion 102a is deformed, the center portion of the pattern portion 102a comes into contact with the imprint material 114 (S102). After the pattern portion

102a makes contact with the imprint material 114, the pressure control unit 112 discharges the gas from the space 113 so as to gradually bring the pressure inside the space 113 closer to the pressure of the space in which the imprint apparatus 100 is disposed. Through this operation, the concave portions 202 become filled with the imprint material 114 starting from the center portion toward the end portions of the pattern portion 102a, and the region where the pattern portion 102a and the imprint material 114 are in contact with each other gradually increases (S103).

- [0042] After the concave portions 202 have been filled with the imprint material 114 (after the imprint material 114 and the mold 102 are brought into contact with each other), the light source 101 irradiates the imprint material 114 with the ultraviolet radiation 104, and the imprint material 114 is cured (S104). The timing at which the filling has been completed is determined by the control unit 120 on the basis of a resulting image captured by the image capturing unit 119. Alternatively, a predetermined period of time may be set in advance.
- [0043] As described above, the image capturing unit 119 captures an image of the imprint material 114 during a period from the time when the mold stage 108 starts lowering the mold 102 to the time when the mold 102 is raised back to the original position after a transfer pattern of the pattern portion 102a is formed in the pattern portion 117.
- [0044] After S102, an image associated with foreign matters 501a and 502a on the substrate 103 is captured. The image capturing unit 119 acquires an image during a period after the imprint material 114 has been cured and before the step of releasing the mold 102 from the imprint material 114 (releasing step) starts, and the control unit 120 stores the resulting image into the storage unit 121 (S105).
- [0045] The mold stage 108 raises the mold 102 and the mold holding unit 110 in the +Z direction in the mold releasing step (S106). While the mold 102 and the mold holding unit 110 are being raised, the pressure control unit 112 feeds a gas into the space 113, and the mold releasing step is finished when the region where the pattern portion 102a and the imprint material 114 are in contact with each other is eliminated. It is to be noted that, even when the imprint material 114 partially adheres to the pattern portion 102a, this adhering portion is ignored.
- [0046] The image capturing unit 119 captures an image of the imprint material 114 after the mold releasing step as well. The control unit 120 stores, into the storage unit 121, a resulting image captured by the image capturing element 119b acquired after the mold releasing step is completed (after the releasing operation is completed) (S107). The resulting image stored in the storage unit 121 in S105 is referred to as an image 504 (illustrated in Fig. 4B), and the resulting image stored in the storage unit 121 in S107 is referred to as an image 505 (illustrated in Fig. 4C). The image 504 and the image 505 are represented in gray scale.

[0047] The control unit 120 determines whether the image capturing element 119b has detected a foreign matter 503a between the substrate holding unit 106 and the substrate 103 on the basis of the image 504 and the image 505 (S108). If it is determined that no foreign matter 503a is present (foreign matter 503a is not detected), the steps S101 through S108 are repeated on a next pattern region 117. If it is determined that a foreign matter 503a is present (foreign matter 503a has been detected), the control unit 120 calculates foreign matter information (S109). The foreign matter information is information on the position and the size of the foreign matter 503a.

[0048] When the foreign matter 503a has been detected, the substrate holding unit 106 is transported to the cleaning unit 122, and the substrate side surface of the substrate holding unit 106 is cleaned (S110). At this point, the cleaning unit 122 carries out the cleaning on the basis of the foreign matter information, which has been acquired in S109, received from the control unit 120. The imprint apparatus 100 resumes the process of forming a pattern on the substrate 103 after the cleaning.

[0049] The control unit 120 notifies the user of an error upon a predetermined number of foreign matters 503a having been detected or a predetermined area occupied by foreign matters 503a having been detected. The cleaning unit 122 may clean the substrate holding unit 106 when the user is notified of an error or upon receiving a cleaning instruction issued by the user who has been notified of an error. Alternatively, the process of forming a pattern on the substrate 103 may be terminated upon the foreign matter 503a having been detected, instead of carrying out the cleaning.

[0050] A method of acquiring the image 504, the image 505, and the foreign matter information will be described.

[0051] Fig. 4A is a schematic diagram illustrating a state in which the mold 102 and the imprint material 114 are in contact with each other. Fig. 4A illustrates a state in which foreign matters 501a and 502a are present on the substrate 103 and a foreign matter 503a is present between the substrate holding unit 106 and the substrate 103. The mold 102 and the imprint material 114 are partially unable to make contact with each other due to the foreign matters 501a and 502a, and gaps 301 and 302 are thus present. Here, the thickness of the imprint material 114 is, for example, approximately 50  $\mu\text{m}$ , and the size of each of the foreign matters 501a, 502a, and 503a is from several micrometers to no greater than ten-odd micrometers.

[0052] Figs. 4B and 4C illustrate images acquired by the image capturing unit 119.

[0053] Fig. 4B illustrates the image 504 representing the result obtained by capturing an image of the imprint material 114 before the mold 102 is released (before releasing). A rectangle 401 corresponds to the outer periphery of the pattern portion 102a and indicates a boundary between the pattern portion 102a and a space surrounding the pattern portion 102a. Images of regions 501b and 502b are indicated inside the

rectangle 401.

- [0054] The pattern portion 102a deforms so as to project in the out-of-plane direction (Z-axis direction) with the points at which the pattern portion 102a are in contact with the foreign matters 501a and 502a serving as the respective centers. The gap 301 is a space formed between the pattern portion 102a and the imprint material 114 due to the foreign matter 501a. The gap 302 is a space formed between the pattern portion 102a and the imprint material 114 due to the foreign matter 502a. The refractive index of the gas present in the gaps 301 and 302 is different from the refractive index of the mold 102 and of the imprint material 114, and thus the images of the regions 501b and 502b appear.
- [0055] The substrate 103 gently projects with a point at which the substrate 103 is in contact with the foreign matter 503a serving as the center. Due to the rigidity of the substrate 103, the deformed area of the substrate 103 spreads widely in an out-of-plane direction and slopes gently. As the substrate 103 deforms in this manner, a gap is less likely to be generated between the pattern portion 102a and the imprint material 114, and an image associated with the foreign matter 503a is thus not captured.
- [0056] Fig. 4C illustrates the image 505 representing the result obtained by capturing an image of the imprint material 114 after the mold 102 is released (after releasing). In the image 505, an image of a region 501c appears at substantially the same position as the image of the region 501b, and an image of a region 502c appears at substantially the same position as the image of the region 502b. Furthermore, an image of a region 503c appears.
- [0057] The images of the regions 501c and 502c have substantially the same gradation number as the images of the regions 501b and 502b. The film thickness of the imprint material 114 in regions where the foreign matters 501a and 502a are present is less uniform than the film thickness of the imprint material 114 in a region in which the foreign matters 501a and 502a are not present (deviation in the film thickness is large). Due to this difference in the film thickness of the imprint material 114, a difference in the interference action of the light is produced, and thus the images of the region 501c and the region 502c appear.
- [0058] In addition, as illustrated in Fig. 5, the thickness of the imprint material 114 in a region 307 above the foreign matter 503a is less than the thickness of the imprint material 114 in other regions 308 due to the foreign matter 503a. This difference in the thickness produces a difference in the interference action of the light, and thus the image of the region 503c appears.
- [0059] The shape (distribution of the film thickness) of the imprint material 114 held after the mold 102 is released is the same as the shape of the imprint material 114 held before the mold 102 is released, but no image associated with the shape of the imprint

material 114 is observed before the mold 102 is released.

- [0060] The refractive index of the mold 102 and the refractive index of the imprint material 114 are substantially the same, and light is less likely to be reflected at the boundary between the mold 102 and the imprint material 114. In addition, the mold 102 is sufficiently thicker than the imprint material 114, and thus the total thickness of the mold 102 and the imprint material 114 is substantially the same as the thickness of the mold 102. Therefore, little interference action is produced in association with a subtle difference in thickness of the imprint material 114, and an interference fringe is less likely to be observed by the image capturing unit 119.
- [0061] On the other hand, after the mold 102 is released, a gas 309 having a refractive index that is different from the refractive index of the mold 102 and of the imprint material 114 is present between the mold 102 and the imprint material 114. Unlike the case before the mold 102 is released, light is reflected at the boundary between the gas 309 and the imprint material 114, and thus an interference fringe, which does not appear in an image obtained before the mold 102 is released, appears in association with the thickness distribution of the imprint material 114.
- [0062] Fig. 6 is a flowchart illustrating a method of acquiring the foreign matter information, such as the presence of a foreign matter 503a and the position and the size of the foreign matter 503a, with the use of the image 504 and the image 505.
- [0063] The control unit 120 reads out the image 504 and the image 505 stored in the storage unit 121 (S201). The control unit 120 subtracts the pixel information of the image 504 from the pixel information of the image 505 (S202). Specifically, the control unit 120 subtracts the gradation numbers of the pixels of the image 504 that correspond to the respective pixels of the image 505 from the gradation numbers of the pixels of the image 505. It is to be noted that the control unit 120 binarizes the image obtained through the subtraction.
- [0064] Fig. 7 illustrates an image 506 acquired in S202, and the image 506 represents a difference between the pixel information of the image of the imprint material 114 obtained before the mold 102 is released and the pixel information of the image of the imprint material 114 obtained after the mold 102 is released. Through the binarization, the image of the rectangle 401, which is common to the image 504 and the image 505, disappears, and only the image of the region 503c remains.
- [0065] Next, the control unit 120 successively compares the values of adjacent pixels and extracts a boundary at which a pixel having a value no greater than a predetermined threshold value is adjacent to a pixel having a value no less than the threshold value. The boundary extracted here coincides with the outline of the region 503c that represents the outline of the foreign matter 503a. In the present exemplary embodiment, since the binarization processing is carried out, a boundary at which the

value shifts from a lower value to a higher value corresponds to the outline of the foreign matter 503a.

- [0066] The control unit 120 obtains the positions of the vertices of the pattern portion 102a (the position of the pattern formed) relative to the imaging field of view of the image capturing element 119b (S203). Here, the control unit 120 extracts the positions of the four vertices of the rectangle 401 in the image 504 and the positions of the four vertices of the rectangle 401 in the image 505 and obtains a mean value of the position of each vertex.
- [0067] The control unit 120 groups together pixels contained in the enclosed boundary and identifies a group as a single foreign matter (S204). On the basis of the result obtained in S204, the control unit 120 determines whether a foreign matter 503a has been detected, or in other words, determines whether the foreign matter 503a is present.
- [0068] The control unit 120 obtains the position of the centroid of the region 503c and thus obtains the position of the centroid of the foreign matter 503a (S205). The position of the centroid obtained in S205 is the position of the foreign matter 503a relative to the imaging field of view of the image capturing element 119b. When a plurality of foreign matters 503a are detected in S204, the position of the centroid is obtained in a similar manner.
- [0069] The control unit 120 obtains the position of the centroid of the foreign matter 503a relative to the pattern portion 102a with the use of the results obtained in S204 and S205 (S206). Specifically, the control unit 120 obtains the position of the foreign matter 503a in the XY coordinate system with one of the four vertices of the pattern portion 102a obtained in S203 serving as the origin.
- [0070] Next, the control unit 120 obtains the position of the foreign matter 503a relative to the substrate stage 105 (S207).
- [0071] As the detection units 115 and 116 are used, the position of the substrate 103 relative to the substrate stage 105, the position of the pattern region 117 relative to the substrate 103, and the position of the pattern portion 102a relative to the pattern region 117 are known.
- [0072] The position of the foreign matter 503a relative to the substrate stage 105 can be obtained with the use of the aforementioned pieces of known information and the position of the centroid of the foreign matter 503a relative to the pattern portion 102a obtained in S206. Thus far, the method of detecting the foreign matter 503a and the method of obtaining the foreign matter information of the foreign matter 503a have been described.
- [0073] With the imprint apparatus 100 according to the present exemplary embodiment, a foreign matter 503a present between the substrate holding unit 106 and the substrate 103 can be detected with the use of the resulting images captured before and after the

mold 102 is released from the imprint material 114. The detection of a foreign matter 503a can be carried out in parallel to the processing of forming a pattern, and thus a decrease in the throughput can be suppressed as compared to a case in which the present exemplary embodiment is not applied.

[0074] In particular, the method of detecting a foreign matter 503a according to the present exemplary embodiment excels in that the throughput does not decrease even in a case in which the step of detecting a foreign matter 503a is carried out each time the substrate to be placed on the substrate stage 105 is replaced. Furthermore, the method excels in that foreign matters 501a and 502a on the front surface of the substrate 103 can be distinguished from a foreign matter 503a on the back surface of the substrate 103 even after the substrate 103 is placed on the substrate holding unit 106.

[0075] In a case in which a plurality of foreign matters 503a have been detected in S204, the processing in each of the steps S205 through S207 is repeated in a number equal to the number of the foreign matters 503a. Alternatively, after the processing in S205 through S207 is once finished, the processing in S205 through S207 may be carried out again on another foreign matter 503a.

[0076] The control unit 120 may determine that a fault has occurred at the point at which the region 501b or 502b has appeared in association with the foreign matter 501a or 502a before the mold 102 is released from the substrate 103 and may terminate the imprint processing. Alternatively, the control unit 120 may obtain the size of the foreign matter or the number of the foreign matters on the front surface of the substrate 103 and determine whether to continue with the imprint processing on the basis of the obtained result.

### **Other Exemplary Embodiment**

[0077] As described thus far, it is preferable that the step of capturing an image before the mold 102 is released be carried out after the imprint material 114 has been cured. Even in a case in which the intensity of light incident on the image capturing element 119b changes due to a change in the optical characteristics of the imprint material 114 before and after the imprint material 114 is cured, the pixel value in regions where the foreign matters 501, 502a, and 503a are not present in the images captured before and after the mold 102 is released can be retained constant. Therefore, it becomes easier to compare the image 504 and the image 505.

[0078] The imprint apparatus 100 may be an apparatus that carries out imprint processing by using a mold 802 (illustrated in Fig. 8) that includes a pattern portion 801 capable of forming a pattern in a plurality of pattern regions 117 through a single instance of imprint processing. As the image capturing unit 119 captures an image of the imprint material 114 with an imaging field of view that is substantially the same as the region that is subjected to the imprint processing at once, a foreign matter present between the

pattern regions 117 and the substrate holding unit 106 can be detected in an area larger than the area in which a foreign matter is detected in the exemplary embodiment described above.

[0079] It is sufficient that the cleaning unit 122 can clean at least one of the substrate holding unit 106 and the back surface of the substrate 103. In addition, the cleaning unit 122 does not have to carry out the cleaning on the basis of the foreign matter information. In this case, upon the foreign matter 503a having been detected, the cleaning unit 122 may clean the entire cleaning target region. The foreign matter information may be at least one of the position and the size of the foreign matter 503a.

[0080] Although an example in which the control unit 120 is equipped with both a function of a detection unit that detects a foreign matter 503a and a function of a calculation unit that acquires the foreign matter information has been illustrated, these functions may be provided separately on separate control boards. The imprint apparatus 100 may be an imprint apparatus 100 that employs a thermal curing technique instead of a photocuring technique. In addition, the imprint material according to exemplary embodiments of the present invention is an imprint material that is cured by various types of electromagnetic radiation including light or an imprint material that is cured by being heated. The imprint material is selected in accordance with the curing technique employed in the imprint apparatus 100.

[0081] In the present specification, the term "curing" means that the intermolecular coupling of at least part of molecules constituting the imprint material 114 changes.

[0082] In the present specification, the term "foreign matter" refers to a substance that is not intended to contribute to pattern formation. For example, a foreign matter can be a dried solid object resulting from the imprint material 114 that has been discharged from the application unit 118 and has drifted in the form of mist, a fine particle generated from a member constituting the imprint apparatus 100, dust that has entered from an outside space and is present in the imprint apparatus 100, or the like.

### Method of Manufacturing Article

[0083] A cured pattern formed by using the imprint apparatus is used permanently in at least part of a variety of articles or temporarily when a variety of articles are manufactured. The article is an electric circuit element, an optical element, a microelectromechanical sensor (MEMS), a recording element, a sensor, a mold, or the like. The electric circuit element can be a volatile or nonvolatile semiconductor memory, such as a dynamic random-access memory (DRAM), a static random-access memory (SRAM), a flash memory, or a magnetoresistive random-access memory (MRAM); a semiconductor device, such as a large scale integration (LSI), a CCD, an image sensor, or a field-programmable gate array (FPGA); or the like. The optical element can be a microlens, a photoconductive member, a waveguide, an anti-reflection film, a diffraction grating,

a polarizing element, a color filter, a light-emitting element, a display, a solar cell, or the like. The MEMS can be a digital micromirror device (DMD), a microchannel, an electromechanical conversion element, or the like. The recording element can be an optical disc, such as a compact disc (CD) or a digital versatile disc (DVD), a magnetic disk, a magneto-optical disk, a magnetic head, or the like. The sensor can be a magnetic sensor, an optical sensor, a gyro sensor, or the like. The mold can be a mold for imprinting or the like.

- [0084] A cured pattern is used as-is as a constituting element of at least part of the aforementioned article or used temporarily as a resist mask. The resist mask is removed after etching or ion implantation is carried out in the step of processing the substrate when the article is manufactured.
- [0085] Thus far, exemplary embodiments of the present invention have been described, but the present invention is not limited to these exemplary embodiments, and various modifications and changes can be made within the scope of spirit of the present invention.
- [0086] While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.
- [0087] This application claims the benefit of Japanese Patent Application No. 2015-174407 filed September 4, 2015, which is hereby incorporated by reference herein in its entirety.

## Claims

[Claim 1] An imprint apparatus configured to form a pattern of an imprint material on a substrate by using a mold, the imprint apparatus comprising:  
an image capturing unit configured to capture an image of the imprint material; and  
a detection unit configured to detect a foreign matter present between a placing unit on which the substrate is placed and the substrate,  
wherein the detection unit is configured to detect the foreign matter on the basis of a first resulting image captured by the image capturing unit before the mold is released from the imprint material into which the mold has been brought into contact and a second resulting image captured by the image capturing unit after the mold is released from the imprint material into which the mold has been brought into contact.

[Claim 2] The imprint apparatus according to Claim 1, wherein the image capturing unit is configured to capture an image of the imprint material by using light that has been transmitted through the mold.

[Claim 3] The imprint apparatus according to Claim 1 or 2, wherein the detection unit is configured to detect the foreign matter on the basis of a difference between pixel information of an image that is the first resulting image and pixel information of an image that is the second resulting image.

[Claim 4] The imprint apparatus according to any one of Claims 1 through 3 further comprising:  
a calculation unit configured to calculate at least one information of a position and a size of the foreign matter detected by the detection unit by using the second resulting image.

[Claim 5] The imprint apparatus according to Claim 4, wherein the calculation unit is configured to acquire the position of the foreign matter relative to a moving member that moves with the placing unit placed thereon on the basis of a position of a pattern formed portion of the mold relative to an imaging field of view.

[Claim 6] The imprint apparatus according to any one of Claims 1 through 5, further comprising:  
a cleaning unit configured to clean the placing unit,  
wherein the cleaning unit is configured to clean the placing unit in a case in which the detection unit has detected the foreign matter.

[Claim 7] The imprint apparatus according to any one of Claims 1 through 6, wherein the first resulting image is captured after the imprint material and the mold are brought into contact with each other and before an operation of releasing the mold from the imprint material is started, and the second resulting image is captured after the operation of releasing the mold from the imprint material is completed.

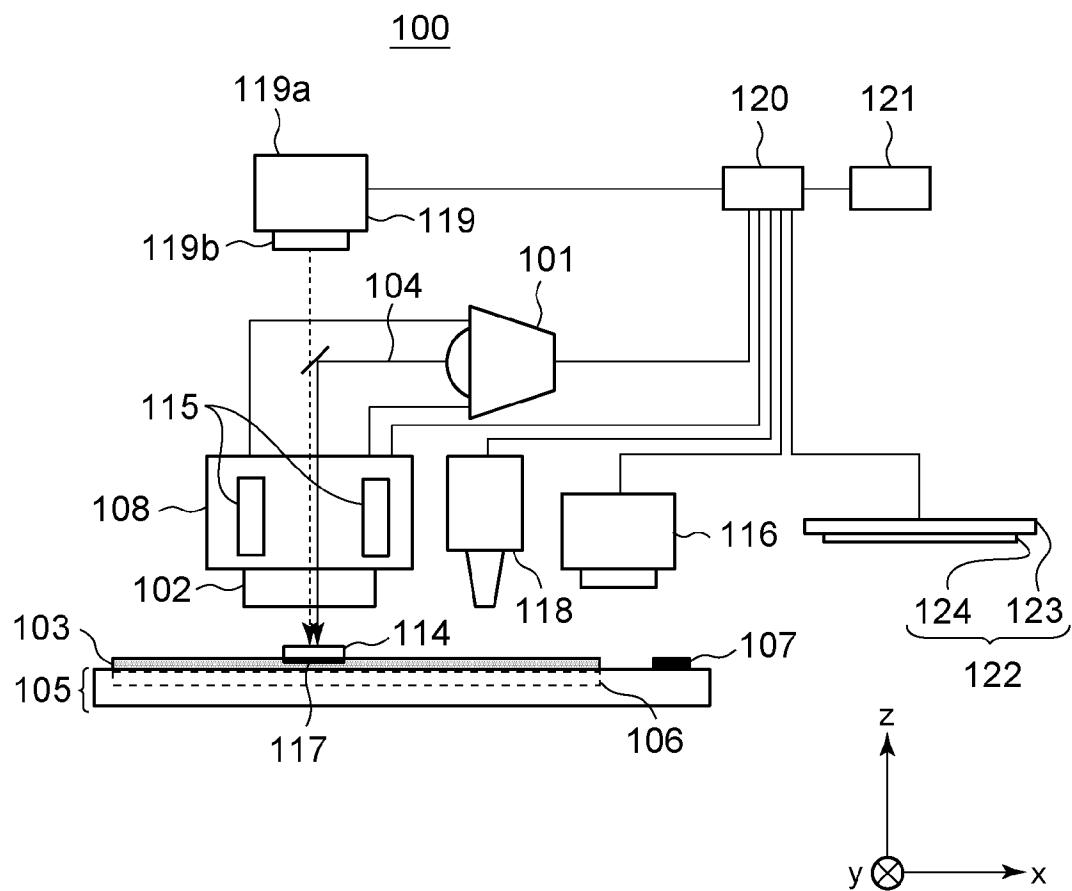
[Claim 8] The imprint apparatus according to any one of Claims 1 through 7, wherein the first resulting image is captured after the imprint material has been cured and before an operation of releasing the mold from the imprint material is started.

[Claim 9] An imprint method of forming a pattern of an imprint material on a substrate by using a mold, the imprint method comprising the steps of: bringing the imprint material and the mold into contact with each other; releasing the mold from the imprint material after the step of bringing; and detecting a foreign matter present between a placing unit on which the substrate is placed and the substrate on the basis of a first resulting image of the imprint material captured after the step of bringing and before the step of releasing and a second resulting image of the imprint material captured after the step of releasing.

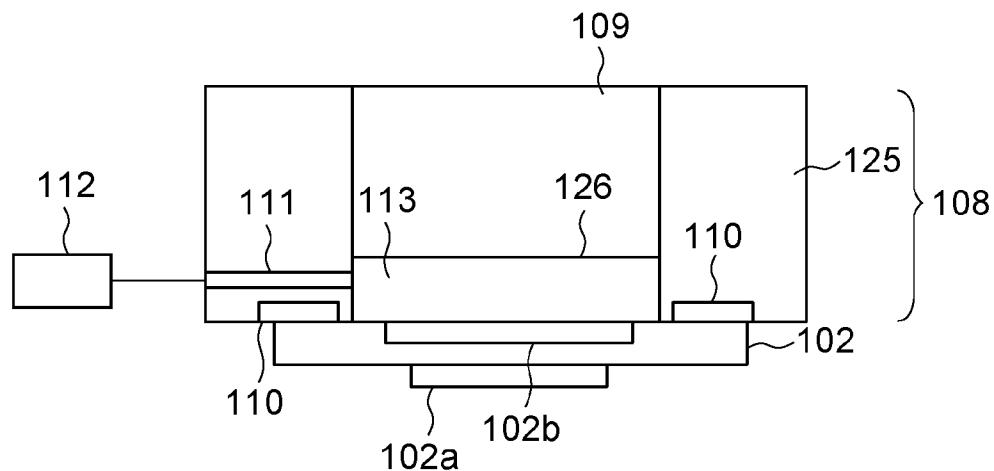
[Claim 10] The imprint method according to Claim 9, wherein a step of cleaning at least one of the placing unit and the substrate in a case in which the foreign matter has been detected in the step of detecting is included.

[Claim 11] A method of manufacturing an article, the method comprising the steps of: forming a pattern of an imprint material on a substrate by using the imprint apparatus according to any one of Claims 1 through 8; and processing the substrate on which the pattern has been formed in the step of forming.

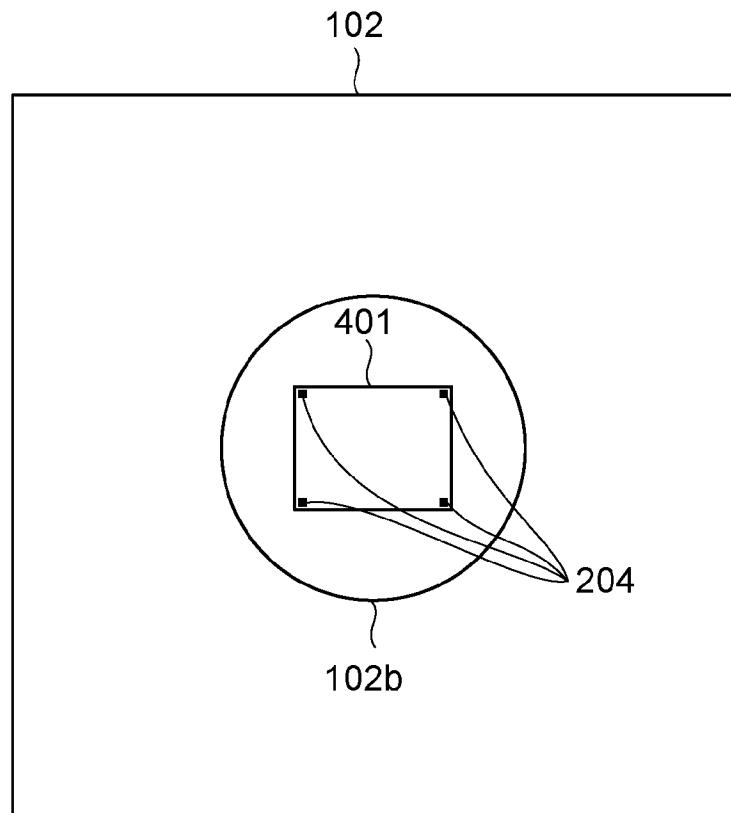
[Fig. 1A]



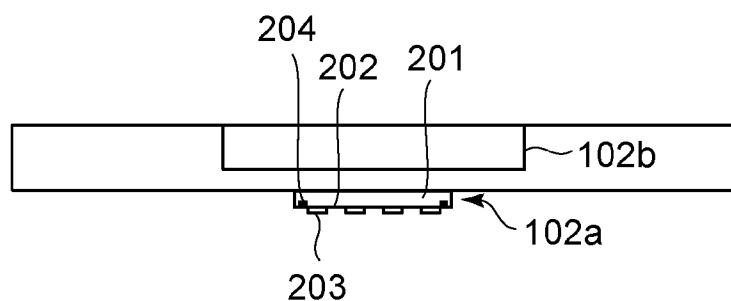
[Fig. 1B]



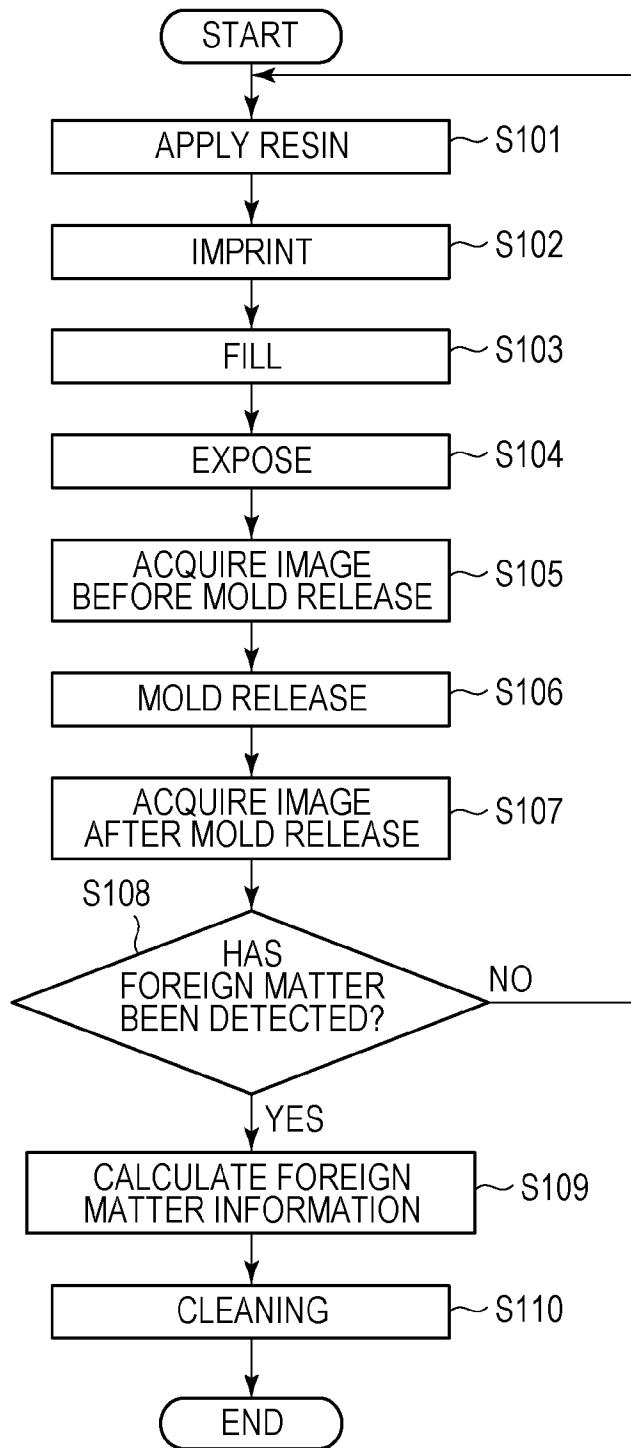
[Fig. 2A]



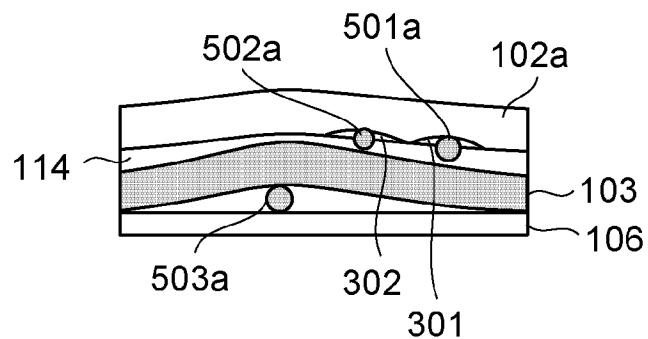
[Fig. 2B]



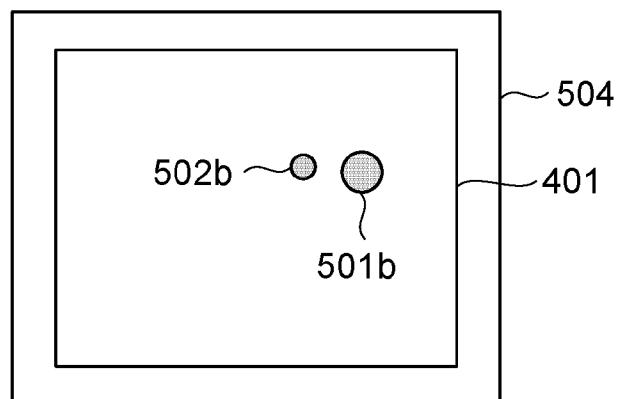
[Fig. 3]



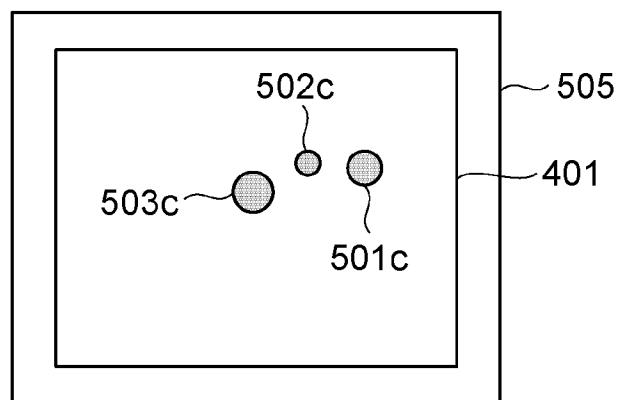
[Fig. 4A]



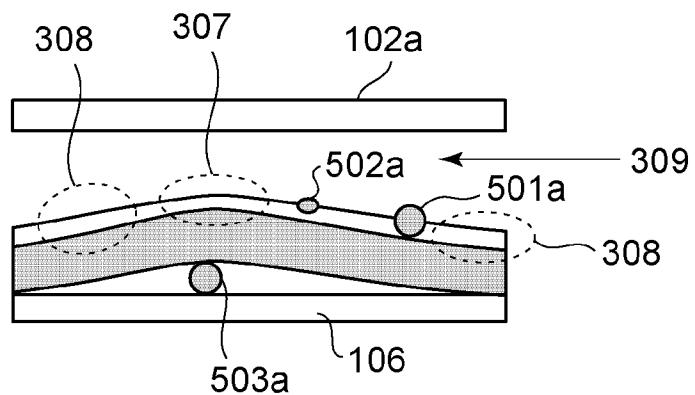
[Fig. 4B]



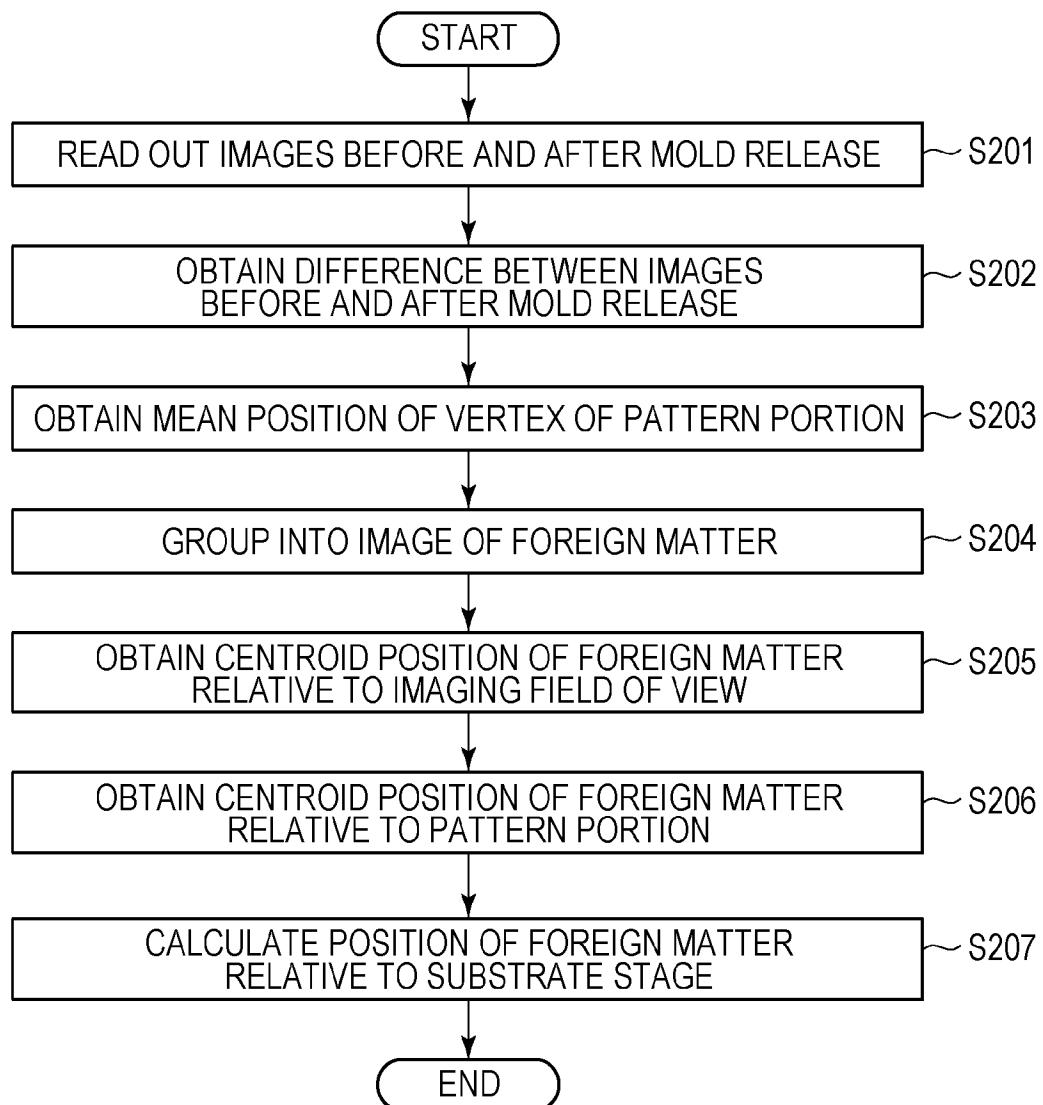
[Fig. 4C]



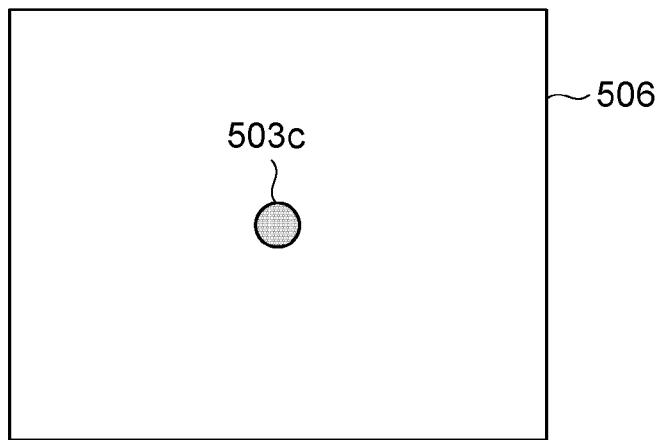
[Fig. 5]



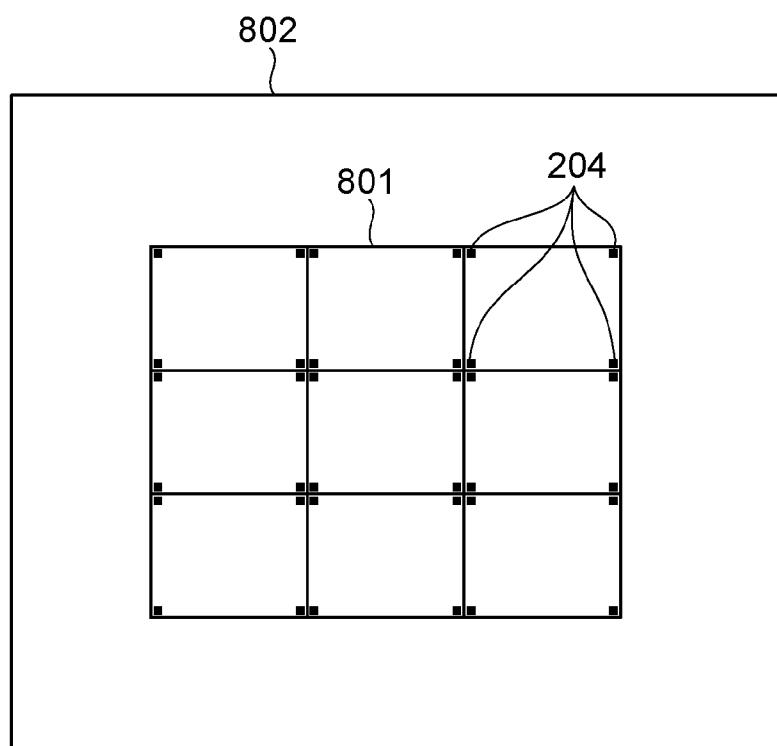
[Fig. 6]



[Fig. 7]



[Fig. 8]



**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/JP2016/003579

A. CLASSIFICATION OF SUBJECT MATTER		
Int.Cl. H01L21/027 (2006.01)i, B29C59/02 (2006.01)i		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
Int.Cl. H01L21/027, B29C59/02		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Published examined utility model applications of Japan 1922-1996 Published unexamined utility model applications of Japan 1971-2016 Registered utility model specifications of Japan 1996-2016 Published registered utility model applications of Japan 1994-2016		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-149469 A (SHOWA DENKO K.K.) 2010.07.08, [0006], Figs.3-4 (No Family)	1-11
A	JP 10-70069 A (CANON KABUSIKI KAISHA) 1998.03.10, [0010], Fig.1 (No Family)	1-11
A	JP 2009-212382 A (HITACHI HIGH-TECHNOLOGIES CORPORATION.) 2009.09.17, [0005]-[0010] (No Family)	1-11
A	US 2015/0076724 A1 (CANON KABUSHIKI KAISHA) 2015.03.19, [0044] & JP 2015-56589 A & KR 10-2015-0031202 A	1-11
P, A	US 2016/0158978 A1 (CANON KABUSHIKI KAISHA) 2016.06.09, [0053]-[0055] & JP 2016-111335 A & CN 105700291 A	1-11
Further documents are listed in the continuation of Box C.  See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed		
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search	Date of mailing of the international search report	
24.10.2016	08.11.2016	
Name and mailing address of the ISA/JP <b>Japan Patent Office</b> 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Authorized officer HATAE, Susumu	<div style="display: flex; align-items: center; justify-content: space-between;"> <div style="flex: 1; border: 1px solid black; padding: 2px; margin-right: 10px;">2G</div> <div style="flex: 1; border: 1px solid black; padding: 2px;">6002</div> </div>
Telephone No. +81-3-3581-1101 Ext. 3226		