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(S7) Abstract: Disclosed herein is a substrate support arrangement suitable for an EUV exposure process, the substrate support arrangement comprising: a substrate support arranged to support a substrate; and a power supply arrangement configured to generate an alternating electric field in the substrate when the substrate is illuminated by a EUV radiation.

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ANISOTROPIC RESIST PATTERNING

CROSS-REFERENCE TO RELATED APPLICATIONS

5 [0001] This application claims priority of EP application 22161267.4 which was filed on March 10, 2022 and which is incorporated herein in its entirety by reference.

FIELD

10 [0002] The present invention relates to the patterning of a resist in an EUV lithographic process. Embodiments apply an electric field that directionally influences the secondary electron movement in the resist when an EUV exposure process is performed on the resist. Embodiments may both improve the performance of the EUV exposure process and/or reduce the dose required for the EUV exposure process.

BACKGROUND

15 [0003] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern at a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

20 [0004] To project a pattern on a substrate a lithographic apparatus may use electromagnetic radiation. The wavelength of this radiation determines the minimum size of features which can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

25 [0005] There is a general desire to improve the patterning process by EUV radiation.

SUMMARY

30 [0006] According to a first aspect of the invention, there is provided a substrate support arrangement for an EUV exposure process, the substrate support arrangement comprising: a substrate support arranged to support a substrate; and a power supply arrangement configured to generate an alternating electric field in the substrate when the substrate is illuminated by EUV radiation.

35 [0007] According to a second aspect of the invention, there is provided an exposure process arrangement for an EUV exposure process, the exposure process arrangement comprising: the substrate support arrangement according to the first aspect; a wall with one or more openings arranged for EUV radiation to pass through; and an illumination region defined between the wall and the substrate support arrangement; wherein the illumination region comprises hydrogen such that plasma is generated in the illumination region when EUV radiation passes through the illumination region; and when plasma is

present in the illumination region, the plasma provides an electrically conductive path between the substrate support arrangement and the wall.

[0008] According to a third aspect of the invention, there is provided a lithographic apparatus comprising the substrate support arrangement according to the first aspect, or the exposure process arrangement according to the second aspect.

[0009] According to a fourth aspect of the invention, there is provided a method in an EUV exposure process, the method comprising: illuminating a substrate with a EUV beam; and applying an alternating electric field across the substrate when the substrate is illuminated.

[0010] According to a fifth aspect of the invention, there is provided a method comprising: performing an EUV exposure process on a substrate according to the method of the fourth aspect; and performing a development process on the exposed substrate.

[0011] According to a sixth aspect of the invention, there is provided a device manufactured according to the method of the fifth aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source;

- Figure 2A schematically shows a metal oxide nanocluster;

- Figure 2B schematically shows a metal oxide nanocluster 201 during, or soon after, an EUV exposure process;

- Figure 2C schematically shows a plurality of metal oxide nanoparticles 201 and ligands 202 after a plurality of exposed metal oxide nanoclusters have condensed;

- Figure 3 schematically shows the configuration of an exposure process arrangement for exposing a substrate with EUV radiation according to an embodiment;

- Figure 4A schematically shows the illumination of a resist 304 by EUV radiation according to an embodiment;

- Figure 4B schematically shows parts of the exposure process arrangement according to an embodiment;

- Figure 5A shows the voltage variation at the first major surface of a substrate W according to an embodiment;

- Figure 5B schematically shows voltages at different parts of the exposure process arrangement when an applied waveform is substantially at a positive peak 502 according to an embodiment;

- Figure 5C schematically shows voltages at different parts of the exposure process arrangement when an applied waveform is substantially at a negative peak 503 according to an embodiment;

- Figures 6A to 6C show different waveforms that may be applied in embodiments; and

- Figure 6D shows ion flux-energy distribution functions (IFEDF) when influenced by the different waveforms that may be applied in embodiments.

DETAILED DESCRIPTION

5 [00013] Figure 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS and a substrate table WT configured to support a substrate W.
10 W.

[00014] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a faceted field mirror device 10 and a faceted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B
15 with a desired cross-sectional shape and a desired intensity distribution. The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

[00015] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The
20 projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13,14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning
25 device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13,14 in Figure 1, the projection system PS may include a different number of mirrors (e.g., six or eight mirrors).

[00016] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a
30 pattern previously formed on the substrate W.

[00017] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or in the projection system PS.

[00018] The radiation source SO shown in Figure 1 is, for example, of a type which may be referred
35 to as a laser produced plasma (LPP) source. A laser system 1, which may, for example, include a CO₂ laser, is arranged to deposit energy via a laser beam 2 into a fuel, such as tin (Sn) which is provided from, e.g., a fuel emitter 3. Although tin is referred to in the following description, any suitable fuel

may be used. The fuel may, for example, be in liquid form, and may, for example, be a metal or alloy. The fuel emitter 3 may comprise a nozzle configured to direct tin, e.g. in the form of droplets, along a trajectory towards a plasma formation region 4. The laser beam 2 is incident upon the tin at the plasma formation region 4. The deposition of laser energy into the tin creates a tin plasma 7 at the plasma formation region 4. Radiation, including EUV radiation, is emitted from the plasma 7 during de-excitation and recombination of electrons with ions of the plasma.

[00019] The EUV radiation from the plasma is collected and focused by a collector 5. Collector 5 comprises, for example, a near-normal incidence radiation collector 5 (sometimes referred to more generally as a normal-incidence radiation collector). The collector 5 may have a multilayer mirror structure which is arranged to reflect EUV radiation (e.g., EUV radiation having a desired wavelength such as 13.5 nm). The collector 5 may have an ellipsoidal configuration, having two focal points. A first one of the focal points may be at the plasma formation region 4, and a second one of the focal points may be at an intermediate focus 6, as discussed below.

[00020] The laser system 1 may be spatially separated from the radiation source SO. Where this is the case, the laser beam 2 may be passed from the laser system 1 to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser system 1, the radiation source SO and the beam delivery system may together be considered to be a radiation system.

[00021] Radiation that is reflected by the collector 5 forms the EUV radiation beam B. The EUV radiation beam B is focused at intermediate focus 6 to form an image at the intermediate focus 6 of the plasma present at the plasma formation region 4. The image at the intermediate focus 6 acts as a virtual radiation source for the illumination system IL. The radiation source SO is arranged such that the intermediate focus 6 is located at or near to an opening 8 in an enclosing structure 9 of the radiation source SO.

[00022] Although Figure 1 depicts the radiation source SO as a laser produced plasma (LPP) source, any suitable source such as a discharge produced plasma (DPP) source or a free electron laser (FEL) may be used to generate EUV radiation.

[00023] The process of manufacturing semiconductors comprises coating a surface of the substrate with a resist. An exposure process may then be performed in which the surface coated by the resist is irradiated by the patterned EUV radiation beam. Photons in the patterned EUV radiation beam react with the resist to induce a change in the irradiated parts of the resist. A development process may then be performed in which either only the changed parts of the resist, or only the unchanged parts of the resist, are removed so that the surface of the substrate is coated with resist with a pattern that is dependent on the pattern of the EUV radiation beam. Further processes may then be performed to manufacture semiconductors in dependence on the pattern of the resist on the surface of the substrate.

[00024] A known resist suitable for use with lithography is a chemically amplified resist (CAR) and may be based on polymers. Upon exposure to electromagnetic radiation, the polymers in the CAR

absorb photons and secondary electrons may be generated. The generation of secondary electrons in the resist is how a high-energy photon loses most of its energy. The secondary electrons in the resist diffuse and may generate further secondary electrons with lower energies until the energy of the secondary electrons is lower than that required to break bonds in the CAR. The electrons generated
5 excite photo-acid generators (PAGs) which subsequently decompose and can catalyse a de-blocking reaction that occurs on the polymer. This leads to a change in solubility of the CAR.

[00025] Alternative resists for use in lithography, in particular EUV lithography, comprise metal oxide nanoclusters. These resists comprise metal oxide nanoparticles which are prevented from clustering together by each metal oxide nanoparticle having a ligand shell. Upon EUV exposure,
10 photons are absorbed by the nanoparticles and secondary electrons are generated that cause the metal oxide nanoparticles to cluster together. This changes the solubility of the exposed parts of the resist. A development process may then remove only the unexposed parts of the resist, or only the exposed parts of the resist. A metal oxide nanoparticle has a higher EUV absorption cross-section than the carbon atoms in a CAR and there is therefore a greater likelihood of EUV photons being absorbed.
15 Accordingly, metal oxide based resists require a less intense EUV beam and/or a shorter exposure time. Furthermore, the different conversion mechanism has potentially lower chemical noise than CAR resist system.

[00026] The exposure process of a metal oxide resist is explained in more detail with reference to Figures 2A to 2C.

20 [00027] Figure 2A schematically shows a metal oxide nanocluster. The metal oxide cluster comprises a metal oxide nanoparticle 201 that is surrounded by ligands 202. The ligands 202 form a shell around the metal oxide nanoparticle 201. The metal oxide nanoparticle 201 may be, for example, tin oxide. Each ligand may be a polymer structure.

[00028] Figure 2B schematically shows the metal oxide nanocluster 201 during, or soon after, an
25 EUV exposure process. A metal oxide nanoparticle 201 has absorbed an EUV photon and this has caused a photoelectron to be generated. The photoelectron further collides with atoms and has caused secondary electrons to be generated. The secondary electrons have caused the dissociation of at least one of the ligands 202 of a metal oxide nanoparticle 201 and an active site 203 has formed due to the dissociation.

30 [00029] Figure 2C schematically shows a plurality of metal oxide nanoparticles 201 and ligands 202 after a plurality of exposed metal oxide nanoclusters have condensed. Oxygen bonds 204 may have formed between the active sites 203 so as to bond a plurality of metal oxide nanoclusters together. The plurality of bonded together metal oxide nanoclusters shown in Figure 2C may have a different solubility to the unexposed metal nanoclusters as shown in in Figure 2A. In particular, the plurality of
35 bonded together metal oxide nanoclusters shown in Figure 2C may be insoluble in development fluid and therefore remain during a subsequently performed development process. However, unexposed

metal nanoclusters may be soluble in development fluid and therefore removed during the development process.

[00030] Important to the effectiveness of resist patterning by EUV radiation is the generation of secondary electrons in response to illumination by EUV radiation, and also the generation of active sites
5 by the secondary electrons.

[00031] Embodiments improve on known processes for resist patterning by EUV radiation. In embodiments, the movement directions of the secondary electrons is controlled in a way that improves patterning performance. Embodiments may also improve on known techniques by controlling the secondary electron energies so as to increase the generation of secondary electrons with an appropriate
10 energy for generating an active site 203.

[00032] Figure 3 schematically shows the configuration of an exposure process arrangement for exposing a substrate with EUV radiation according to an embodiment.

[00033] The exposure process arrangement comprises a substrate W. The substrate W comprises a substrate body 305. A first major surface of the substrate body may be coated with a layer of resist 304.
15 The resist 304 may comprise the above described metal oxide nanoclusters. The exposed major surface of the resist may correspond to a first major surface of the substrate W. A second major surface of the substrate body 305, that is on an opposing side of the substrate body 305 to the first major surface of the substrate body 305, may be secured to a substrate table 307 by an electrostatic clamp 306. The second major surface of the substrate body 305 may correspond to the second major surface of the
20 substrate W. The substrate table 307 and electrostatic clamp 306 may be referred to as a substrate support.

[00034] The first major surface of the substrate W may be arranged so that at least part of it may be illuminated by EUV radiation. The path of the EUV radiation may be orthogonal to the first major surface of the substrate W. An illumination region 302 may be defined between a grounded wall 301
25 and the first major surface of the substrate W. When the first major surface of the substrate W is illuminated, EUV radiation may pass through one or more openings in a grounded wall 301 and through the illumination region 302.

[00035] The above-described arrangement for illuminating the first major surface of the substrate W may be in accordance with known EUV techniques. In a difference to known EUV techniques, the
30 exposure process arrangement may further comprise a matching box 308 and a power supply arrangement 314. The power supply arrangement 314 may comprise a switch 309, a ground terminal 310, a sinusoidal waveform generator 311 and a flexible waveform generator 312. The switch 309 may control the type of waveform that is output by the power supply arrangement 314. When the switch 309 is applied to the sinusoidal waveform generator 311 or the flexible waveform generator 312, the
35 output of the power supply arrangement 314 may be an AC voltage. An AC voltage output from the power supply arrangement 314 may generate an alternating electric field 313 in the resist 304. The direction of the alternating electric field 313 in the resist 304 may be substantially orthogonal to the

first major surface of the substrate W. The direction of the alternating electric field 313 in the resist 304 may therefore be substantially in line with, or parallel to, the path of the EUV radiation that illuminates the first major surface of the substrate W.

[00036] As explained above, secondary electrons are generated in the resist 304 in response to photoelectrons generated by the illumination of the resist 304 by the EUV radiation. The alternating electric field 313 in the resist may move the secondary electrons in the direction of the alternating electric field 313. The secondary electrons are therefore moved in the direction that is in line with, or parallel to, the direction of the EUV radiation. This increases the movement of electrons through the depth of the resist 304 and thereby improves the effectiveness of the exposure process. The exposure process is therefore anisotropic to the extent that the patterning is increased in the direction of the alternating electric field 313.

[00037] The alternating electric field 313 may also be present in the substrate body 305, electrostatic clamp 306, and some non-metallic parts of the substrate table 307. However, these may not comprise any free electrons and so the alternating electric field 313 may have little effect.

[00038] The exposure process arrangement of embodiments is described in more detail below with reference to Figures 4A and 4B.

[00039] Figure 4A schematically shows the illumination of the resist 304 by EUV radiation. The illumination region 302 may comprise hydrogen. The illumination of the hydrogen by EUV radiation may generate a EUV plasma 303a within the illumination region 302. The illumination region 302 may therefore comprise EUV plasma 303a, a first sheath 303c at the substrate W end of the path of the EUV radiation, a second sheath 303d at the grounded wall 301 end of the path of the EUV radiation. There is an electric current path through the EUV plasma 303a between the first sheath 303c and the second sheath 303d. The EUV plasma 303a may effectively electrically connect the grounded wall 301 and the first major surface of the substrate W. Depending on the voltage at the first major surface of the substrate W, that is dependent on instantaneous state of the electric field 313, electrons may flow out of the resist 304 into the first sheath 303c or electrons may flow from the first sheath 303c into the resist 304. The height of the first sheath 303c may be dependent on the instantaneous state of the electric field 313. An aerial image 404 of EUV radiation is established at the resist 304. The peaks of the aerial image correspond to the illuminated parts the resist 304a. The troughs of the aerial image correspond to non-illuminated parts of the resist 304b.

[00040] Figure 4B schematically shows parts of the exposure process arrangement according to an embodiment. The substrate table 307 may comprise a main structure 307a and an electrode 307b. The main structure 307a of the substrate table 307 may be made from, for example, quartz. The electrode 307b may be metallic and arranged to generate and support the alternating electric field 313.

[00041] The power supply arrangement 314 may apply an alternating voltage to the electrode 307b via the matching box 308. The matching box 308 may comprise a capacitor and thereby isolate the DC component of the voltage generated by the power supply arrangement 314 from the DC component at

the electrode 307b. There may be a DC power path 403 to the electrode from a structure such as a focus ring 402.

[00042] The matching box 308 allows the DC voltage at the electrode 307b to be different from ground. In particular, the electrode 307b may be at a negative DC potential relative to ground and the electrode may thereby have a negative DC component. A negative DC potential at the electrode 307b may be a natural state of the electrode 307b that it drifts to and settles at during use.

[00043] The focus ring 402 may surround the substrate W. The DC power path may apply the negative DC potential to the focus ring 402. Alternatively, a separate power source may apply a DC potential to the focus ring 402. The purpose of the focus ring 402 is to reduce, or prevent, the bending of the first sheath 303c near the ends of the substrate W. Such bending is shown by the dotted lines in Figure 4B. The applied DC voltage to the focus ring may reduce, or prevent, such bending from occurring. Alternatively, or additionally, the focus ring 402 may be moved so that the extent of the focus ring 402 above, or below, the surface of the substrate W may be changed to reduce, or prevent, any bending of the first sheath 303c.

[00044] Figure 5A shows the voltage variation that may occur at the first major surface of the substrate W. V_s is the voltage at the first major surface of the substrate W. The frequency of the voltage waveform $V(t)$ may be dependent on the signal generated by the power supply arrangement 314. The power supply arrangement 314 may be arranged to output a signal from the sinusoidal waveform generator 311 only. The mean-to-peak amplitude, V_{RF} , of the voltage waveform $V(t)$ may also be dependent on the signal generated by the power supply arrangement 314. In presence of an appropriately tuned matching box or blocking capacitor network, a self-DC offset, V_b , 501 is formed. The effect of the self-DC offset, V_b , 501 is that no net charging of the substrate occurs over a whole cycle (period) of the waveform $V(t)$. The voltage waveform $V(t)$ may have a positive peak 502 and a negative peak 503. Due to the alternating voltage, there is an alternating electric field 313 through the resist 304 and the above-described anisotropic patterning achieved.

[00045] In a preferred implementation of embodiments, the alternating electric field 313 does not substantially result in net charge build-up on the first major surface of the substrate W. A net charge build-up may be prevented by the negative DC offset 501. When the voltage at the first major surface of the substrate W is negative, secondary electrons may be ejected from the resist 304 into the first sheath 303c. Positive charge build-up may therefore occur in the resist 304. When the voltage at the first major surface of the substrate W is positive, electrons may be attracted from the first sheath 303c into the resist 304. Negative charge build-up may therefore occur in the resist 304. The process of positive charge build-up may occur slower than the process of negative ion build-up. The negative bias causes the process of positive ion build-up to occur for longer than the process of negative ion build-up and thereby compensates for the different speeds of these processes so that there is substantially no net charge build-up on the first major surface of the substrate W.

[00046] In Figure 5A, V_p is the voltage at bulk plasma 303a, i.e. the plasma voltage. V_p may vary in dependence on the voltage at the first major surface of the substrate W. The frequency of V_p may be substantially the same as $V(t)$. The magnitude of V_p may be higher than the voltage, V_s , at the surface of the substrate W.

5 [00047] Figure 5B schematically shows voltages at different parts of the exposure process arrangement when $V(t)$ is substantially at a positive peak 502. V_s is the voltage at the exposed surface of the resist 304 and is positive.

[00048] Figure 5C schematically shows voltages at different parts of the exposure process arrangement when $V(t)$ is substantially at a negative peak 503. V_s is the voltage at the exposed surface
10 of the resist 304 and has changed to being negative. The sinusoidal waveform generator 311 thereby causes the alternating electric field 313 to occur through the resist.

[00049] The power supply arrangement 314 may be arranged to generate and output a number of different waveforms.

[00050] As shown in Figure 5A, the power supply arrangement 314 may be arranged to output a
15 signal generated by a sinusoidal waveform generator 311. Figures 6A and 6B show different voltage waveforms at the first major surface of the substrate W in response to different operating conditions of the sinusoidal waveform generator 311.

[00051] The waveform 601 shown in Figure 6A may be generated from a radio frequency signal output from the sinusoidal waveform generator 311. The sinusoidal waveform generator 311 may
20 output a signal with a frequency of about 14MHz and with no DC offset. The DC offset $-V_b$ may be applied by the matching box 308 and DC power path 403 as described earlier.

[00052] The waveform 602 shown in Figure 6B may be generated from a low frequency signal output from the sinusoidal waveform generator 311. The sinusoidal waveform generator 311 may
25 output a signal with a frequency of about 5.4MHz and with no DC offset. The DC offset $-V_b$ may be applied by the matching box 308 and DC power path 403 as described earlier.

[00053] The height of the first sheath 303c may be dependent on the instantaneous voltage at the first major surface of the substrate W. When the lower frequency signal is used, the oscillation of the height of the first sheath 303c is reduced and this may improve the stability of the system.

[00054] The waveforms 601, 602 shown in Figures 6A and 6B will both achieve the desired effect
30 of controlling the movement directions of the secondary electrons in a way that improves patterning performance without substantial charge build-up occurring on the first major surface of the substrate W.

[00055] According to a preferred embodiment, the shape of applied waveform also controls the secondary electron energies so as to increase the generation of secondary electrons with an appropriate
35 energy for generating an active site 203. A suitable waveform for achieving this may be generated by the flexible waveform generator 312 and output as the only output from the power supply arrangement 314.

[00056] The flexible waveform generator 312 may generate the tailored waveform 603 substantially as shown in Figure 6C. The waveform 603 is similar to a standard rectangular waveform in that each cycle comprises a linear high part, a linear low part and sharp rise and fall times. A difference to a standard rectangular waveform is that the low part may have a negative, i.e. falling, slope. The duty cycle of the waveform 603 may be such that the low part of the waveform 603 has a longer duration than the high part. The waveform 603 generated by the flexible waveform generator 313 may comprise the DC offset, i.e. $-V_b$. Alternatively, the DC offset may naturally occur due to the matching box 308, as described earlier.

[00057] The high part of the tailored waveform 603 has a positive voltage. During this period electrons in the first sheath 303c may be attracted into the resist 304. The low part of the waveform 603 has a negative voltage. During this period electrons in the resist 304 may be attracted into the first sheath 303c. The negative slope during the low part helps to prevent charge accumulation on the resist 304. An advantage of the tailored waveform 603 is that the height of the first sheath 303c may remain substantially stationary throughout the cycle of the tailored waveform 603. This may improve the stability of the system.

[00058] In embodiments, each DC bias voltage, V_b , may be in the range of 0 to 500V (applied as a negative bias voltage). The frequency of the tailored waveform may be less than about 100kHz. The duty cycle of the tailored waveform may be less than about 20%, and preferably less than about 10%.

[00059] The different waveforms 601, 602 and 603 may all control the movement of secondary electrons in a way that improves patterning performance. The different waveforms 601, 602 and 603 may also affect the energies of the secondary electrons in different ways. Figure 6D shows ion flux-energy distribution functions (IFEDF) when influenced by the different waveforms 601, 602 and 603. For the low frequency sinusoidal waveform 602, the ion energy distribution is the largest may be about 80eV wide. For the RF frequency sinusoidal waveform 601, the ion energy distribution is narrower but still may be about 25eV wide. For the tailored waveform 603 generated by the flexible waveform generator 313, the ion energy distribution is even narrower and may be about 6eV or 7eV wide.

[00060] In a preferred embodiment, the narrow energy distribution of the tailored waveform 603 may be tuned to the energy required by secondary electrons for generating an active site 203. This is the energy for breaking the bond between a metal oxide nanoparticle and a ligand, as described earlier with reference to Figures 2A to 2C. The required energy will depend on the specific type of metal oxide nanocluster that is used in the resist 304. The properties of the tailored waveform 603 may be set so that the secondary electron energy distribution is both narrow and substantially centred on the required energy.

[00061] A further advantage of embodiments is that the yield of secondary electrons may be increased. The alternating electric field may cause the secondary electrons to cascade and thereby an increase in the number of secondary electrons generated per EUV photon. The required EUV dose may therefore be reduced.

[00062] Embodiments include projecting a patterned beam of radiation onto a substrate W that is comprised by an exposure process arrangement according to the above-described embodiments. A development process may be subsequently performed on the substrate arrangement. These process may be performed in the manufacture of semiconductors by a lithographic apparatus.

5 [00063] Embodiments include devices manufactured according to the method of embodiments.

[00064] Embodiments include a number of modifications and variations to the above-described techniques.

[00065] The earlier described power supply arrangement 314 comprised a switch 309, a ground terminal 310, a sinusoidal waveform generator 311 and a flexible waveform generator 312. The switch
10 controls which one of the ground terminal 310, a sinusoidal waveform generator 311 and a flexible waveform generator 312 provides the output voltage of the power supply arrangement 314. When the ground terminal 310 provides the output voltage of the power supply arrangement 314, there will be no alternating electric field through the resist 304 and the operation of the exposure process arrangement will be according to known techniques. This is the simplest way of operating the system and may be
15 appropriate if the achieved line width roughness (LWR), local critical dimension uniformity (LCDU), defectivity and other performance characteristics, are appropriate. The exposure process arrangement may be operated according to embodiments only when the sinusoidal waveform generator 311 or flexible waveform generator 312 provides the output voltage of the power supply arrangement 314.

[00066] Embodiments also include the power supply arrangement 314 comprising only one
20 waveform generator, such as only the flexible waveform generator 312 or only the sinusoidal waveform generator 311.

[00067] In the above described embodiments, the EUV-induced plasma may electrically connect the grounded wall 301 and the first major surface of the substrate W. Embodiments also include the wall 301 not being grounded. For example, the wall may at a fixed DC potential that is different from
25 the ground potential.

[00068] The matching box 308 may be any type of matching circuit for applying an alternating voltage at the electrode 307b and allowing the electrode 307b to have a DC bias component.

[00069] Embodiments are set out in the following numbered clauses:

1. A substrate support arrangement for an EUV exposure process, the substrate support
30 arrangement comprising:

a substrate support arranged to support a substrate; and

a power supply arrangement configured to generate an alternating electric field in the substrate when the substrate is illuminated by EUV radiation.

2. The substrate support arrangement according to clause 1, wherein the direction of the
35 alternating electric field is substantially orthogonal to the major surfaces of the substrate.

3. The substrate support arrangement according to clause 1 or 2, wherein the direction of the alternating electric field is substantially normal to the substrate surface that is illuminated.

4. The substrate support arrangement according to any preceding clause, further comprising an electrode;

wherein the power supply arrangement is configured to generate the alternating electric field by applying an alternating voltage to the electrode.

5. The substrate support arrangement according to clause 4, wherein the electrode is comprised by the substrate support.

6. The substrate support arrangement according to clause 4 or 5, wherein the power supply arrangement comprises:

one or more waveform generators configured to generate the alternating voltage; and

10 a matching circuit configured to apply the generated alternating voltage to the electrode and configured so that, in use, a DC bias component occurs at the electrode.

7. The substrate support arrangement according to any of clauses 4 to 6, further comprising a DC power path configured to apply the DC bias component to a focus ring; and/or the focus ring is arranged so that its extent above or below the surface of the substrate is variable.

15 8. The substrate support arrangement according to clause 7, wherein the DC bias component is negative.

9. The substrate support arrangement according to clause 6, or any clause dependent thereon, wherein at least one waveform generator is configured to generate a waveform that is substantially a rectangular wave.

20 10. The substrate support arrangement according to clause 9, wherein the substantially rectangular wave comprises:

a high part with a substantially constant voltage; and

a low part with a decreasing voltage.

25 11. The substrate support arrangement according to clause 9 or 10, wherein the duty cycle of the substantially rectangular wave is 0.2 or less.

12. The substrate support arrangement according to clause 6, or any clause dependent thereon, wherein at least one waveform generator is configured to generate a waveform that is sinusoidal.

30 13. The substrate support arrangement according to clause 6, or any clause dependent thereon, wherein at least one waveform generator is controllable such that, when a substrate with a resist is supported by the substrate support, the properties of the waveform are controllable in dependence on the properties of the resist.

14. An exposure process arrangement for an EUV exposure process, the exposure process arrangement comprising:

the substrate support arrangement according to any preceding clause;

35 a wall with one or more openings arranged for EUV radiation to pass through; and

an illumination region defined between the wall and the substrate support arrangement;

wherein the illumination region comprises hydrogen such that plasma is generated in the illumination region when EUV radiation passes through the illumination region; and
when plasma is present in the illumination region, the plasma provides an electrically conductive path between the substrate support arrangement and the wall.

5 15. The exposure process arrangement according to clause 14, wherein the wall is grounded or the wall is also biased with a DC voltage.

16. The exposure process arrangement according to clause 14 or 15, wherein the wall is parallel to the surface of substrate.

10 17. A lithographic apparatus comprising the substrate support arrangement according to any of clauses 1 to 13, or the exposure process arrangement according to any of clauses 14 to 16.

18. A method in an EUV exposure process, the method comprising:
illuminating a substrate with a EUV beam; and
applying an alternating electric field across the substrate when the substrate is illuminated.

15 19. The method according to clause 18, wherein the direction of the alternating electric field is substantially orthogonal to the major surfaces of the substrate.

20. The method according to clause 19, wherein the direction of the alternating electric field is substantially normal to the surface that is illuminated.

21. The method according to any of clauses 18 to 20, further comprising generating the alternating electric field by applying a voltage waveform to an electrode.

20 22. The method according to clause 21, wherein the voltage waveform is substantially a rectangular wave.

23. The method according to clause 22, wherein the substantially rectangular wave comprises:
a high part with a substantially constant voltage; and
a low part with a decreasing voltage.

25 24. The method according to clause 23, wherein the duty cycle of the substantially rectangular wave is 0.2 or less.

25. The method according to clause 24, wherein the voltage waveform is sinusoidal.

26. The method according to any of clauses 21 to 25, further comprising controlling the voltage waveform in dependence on the properties of a layer of resist on the substrate.

30 27. A method comprising:
performing an EUV exposure process on a substrate according to the method of any of clauses 18 to 26; and
performing a development process on the exposed substrate.

28. A device manufactured according to the method of clause 27.

35 [00070] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. Possible other applications include the manufacture of integrated optical

systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc.

[00071] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus it will be apparent to one skilled in the art that
5 modifications may be made to the invention as described without departing from the scope of the claims set out below.

CLAIMS

1. A substrate support arrangement for an EUV exposure process, the substrate support arrangement comprising:

5 a substrate support arranged to support a substrate; and
a power supply arrangement configured to generate an alternating electric field in the substrate when the substrate is illuminated by EUV radiation.

10 2. The substrate support arrangement according to claim 1, wherein the direction of the alternating electric field is substantially orthogonal to the major surfaces of the substrate.

3. The substrate support arrangement according to claim 1 or 2, wherein the direction of the alternating electric field is substantially normal to the substrate surface that is illuminated.

15 4. The substrate support arrangement according to any preceding claim, further comprising an electrode;
wherein the power supply arrangement is configured to generate the alternating electric field by applying an alternating voltage to the electrode.

20 5. The substrate support arrangement according to claim 4, wherein the electrode is comprised by the substrate support.

6. The substrate support arrangement according to claim 4 or 5, wherein the power supply arrangement comprises:
25 one or more waveform generators configured to generate the alternating voltage; and
a matching circuit configured to apply the generated alternating voltage to the electrode and configured so that, in use, a DC bias component occurs at the electrode.

7. The substrate support arrangement according to any of claims 4 to 6, further comprising a DC
30 power path configured to apply the DC bias component to a focus ring; and/or
the focus ring is arranged so that its extent above or below the surface of the substrate is variable.

8. The substrate support arrangement according to claim 7, wherein the DC bias component is negative.

35

9. The substrate support arrangement according to claim 6, or any claim dependent thereon, wherein at least one waveform generator is configured to generate a waveform that is substantially a rectangular wave.

5 10. The substrate support arrangement according to claim 9, wherein the substantially rectangular wave comprises:
a high part with a substantially constant voltage; and
a low part with a decreasing voltage.

10 11. The substrate support arrangement according to claim 9 or 10, wherein the duty cycle of the substantially rectangular wave is 0.2 or less.

12. The substrate support arrangement according to claim 6, or any claim dependent thereon, wherein at least one waveform generator is configured to generate a waveform that is sinusoidal.

15

13. The substrate support arrangement according to claim 6, or any claim dependent thereon, wherein at least one waveform generator is controllable such that, when a substrate with a resist is supported by the substrate support, the properties of the waveform are controllable in dependence on the properties of the resist.

20

14. An exposure process arrangement for an EUV exposure process, the exposure process arrangement comprising:

the substrate support arrangement according to any preceding claim;

a wall with one or more openings arranged for EUV radiation to pass through; and

25 an illumination region defined between the wall and the substrate support arrangement;

wherein the illumination region comprises hydrogen such that plasma is generated in the illumination region when EUV radiation passes through the illumination region; and

when plasma is present in the illumination region, the plasma provides an electrically conductive path between the substrate support arrangement and the wall.

30

15. The exposure process arrangement according to claim 14, wherein the wall is grounded or the wall is also biased with a DC voltage.

16. The exposure process arrangement according to claim 14 or 15, wherein the wall is parallel to
35 the surface of substrate.

17. A lithographic apparatus comprising the substrate support arrangement according to any of claims 1 to 13, or the exposure process arrangement according to any of claims 14 to 16.

18. A method in an EUV exposure process, the method comprising:

5 illuminating a substrate with a EUV beam; and

applying an alternating electric field across the substrate when the substrate is illuminated.

19. The method according to claim 18, wherein the direction of the alternating electric field is substantially orthogonal to the major surfaces of the substrate.

10

20. The method according to claim 19, wherein the direction of the alternating electric field is substantially normal to the surface that is illuminated.

21. The method according to any of claims 18 to 20, further comprising generating the alternating electric field by applying a voltage waveform to an electrode.

15

22. The method according to claim 21, wherein the voltage waveform is substantially a rectangular wave.

23. The method according to claim 22, wherein the substantially rectangular wave comprises:
a high part with a substantially constant voltage; and
a low part with a decreasing voltage.

20

24. The method according to claim 23, wherein the duty cycle of the substantially rectangular wave is 0.2 or less.

25

25. The method according to claim 24, wherein the voltage waveform is sinusoidal.

26. The method according to any of claims 21 to 25, further comprising controlling the voltage waveform in dependence on the properties of a layer of resist on the substrate.

30

27. A method comprising:

performing an EUV exposure process on a substrate according to the method of any of claims 18 to 26;
and

performing a development process on the exposed substrate.

35

28. A device manufactured according to the method of claim 27.

Fig. 2A

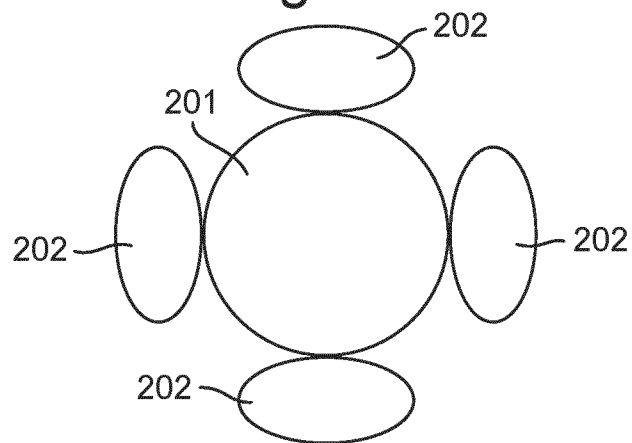


Fig. 2B

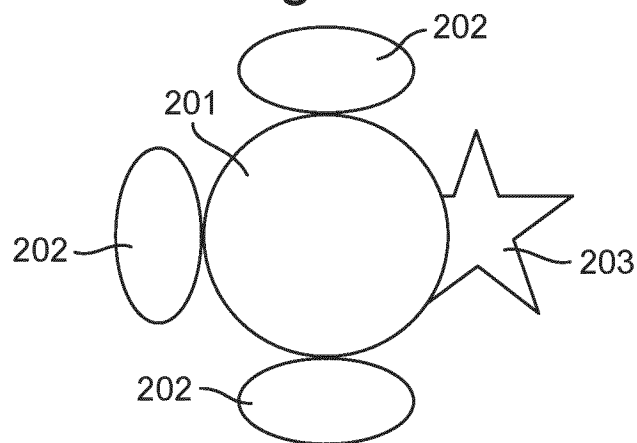


Fig. 2C

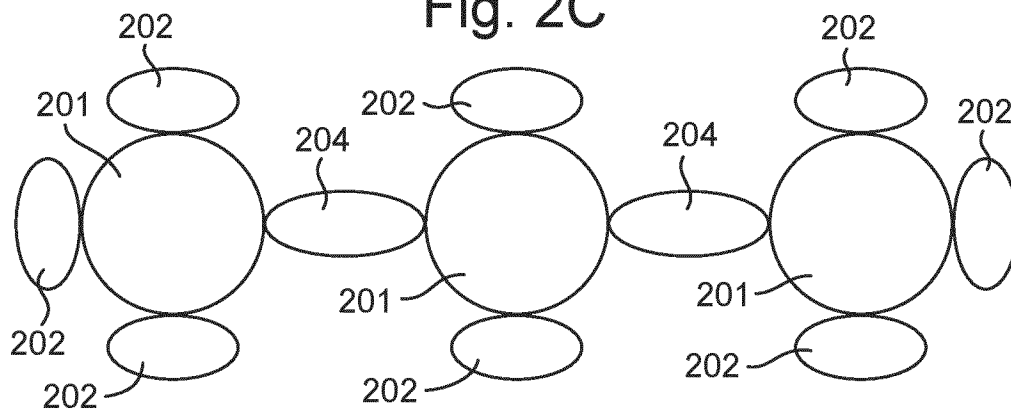


Fig. 3

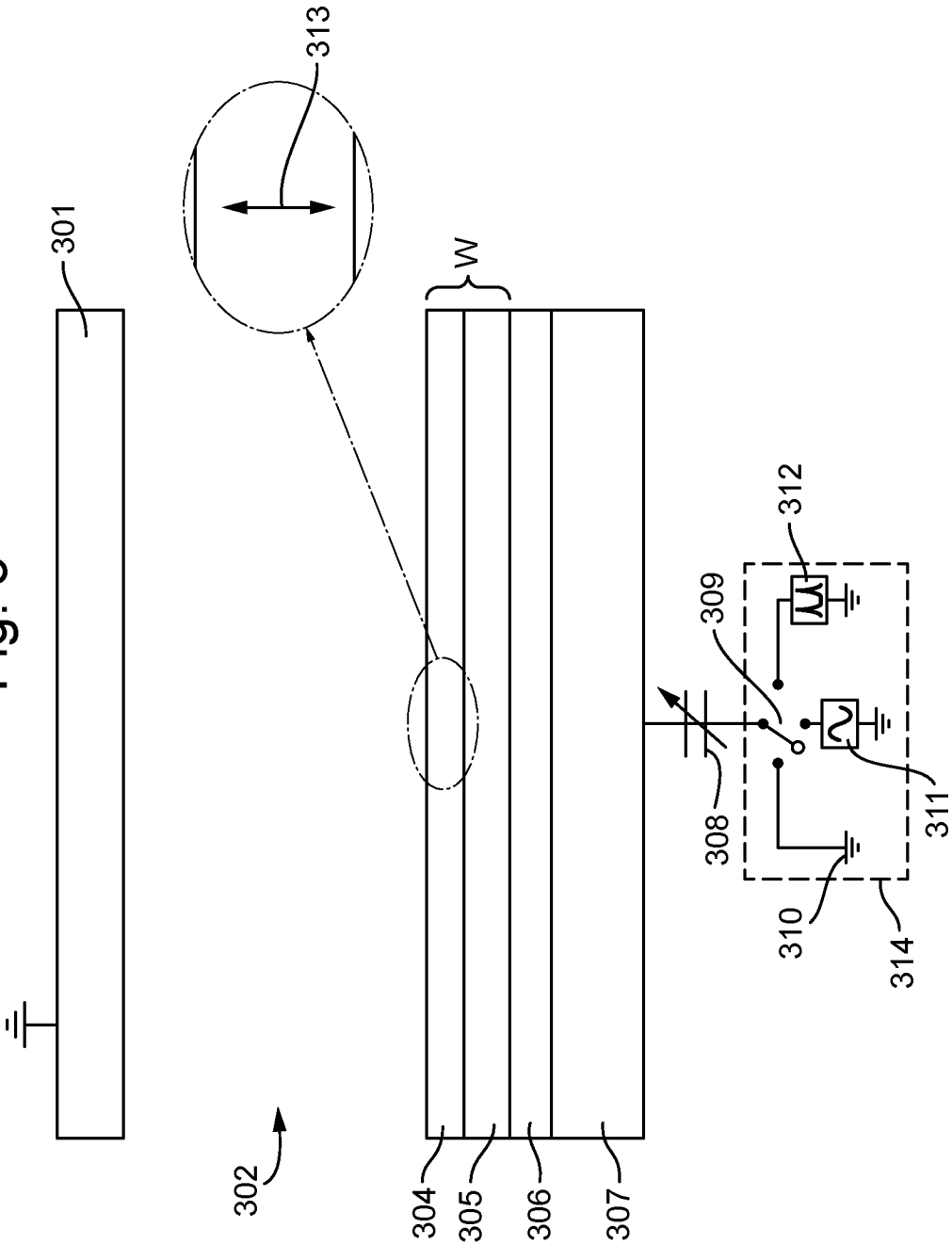


Fig. 4A

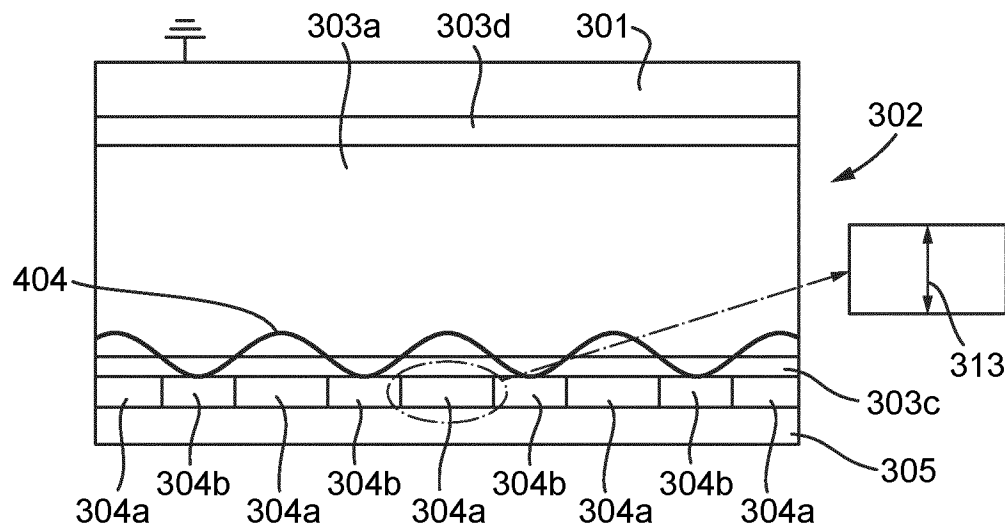


Fig. 4B

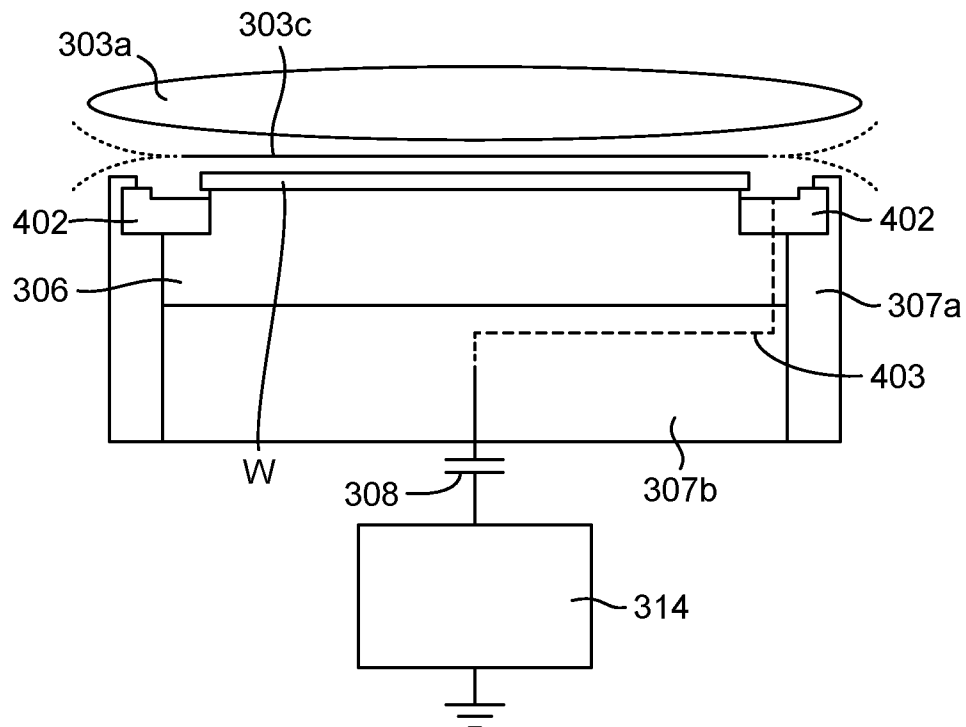


Fig. 5A

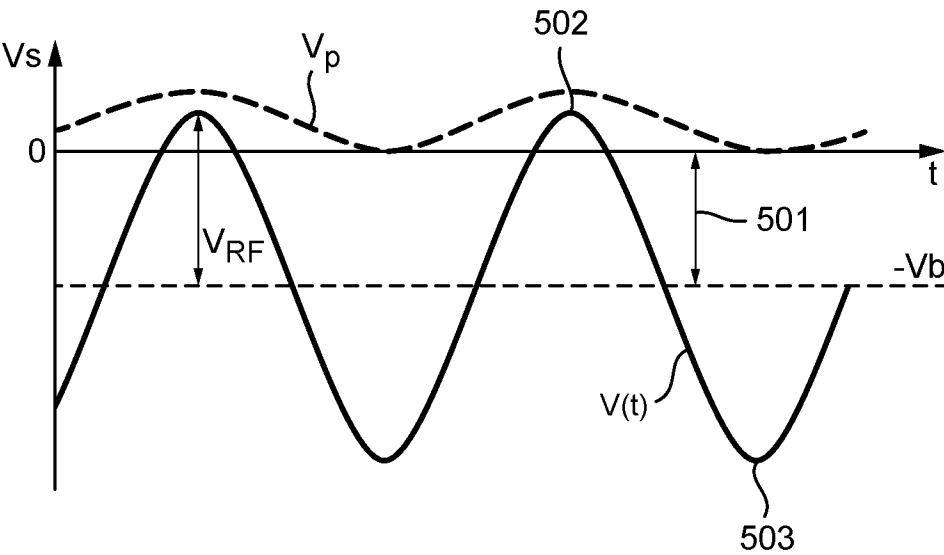


Fig. 5B

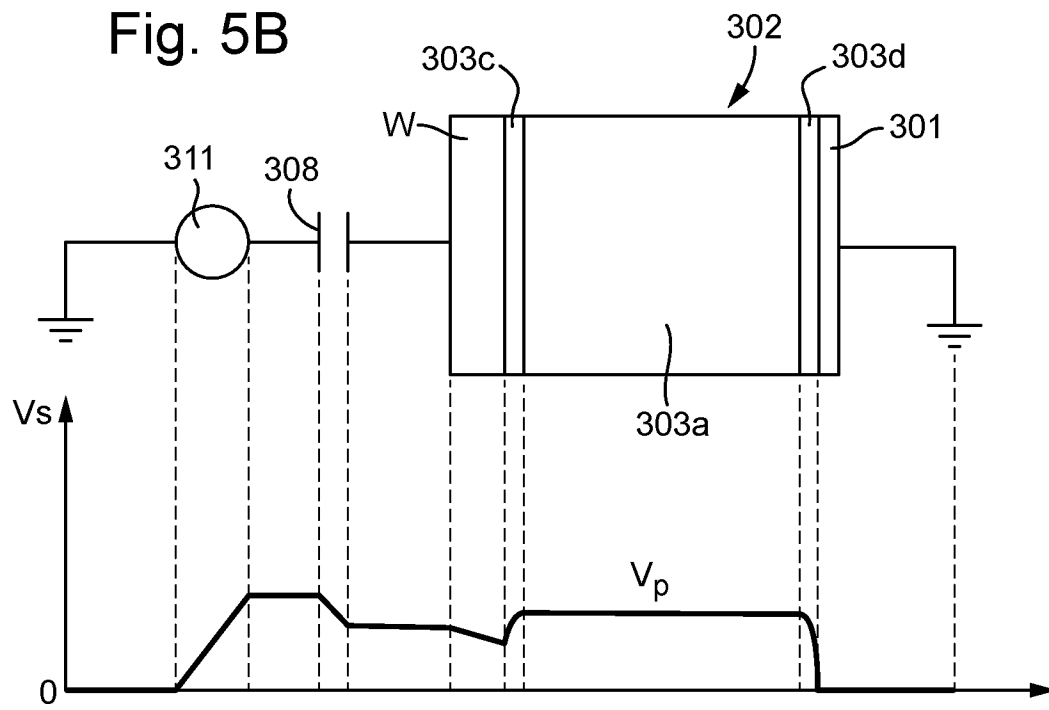


Fig. 5C

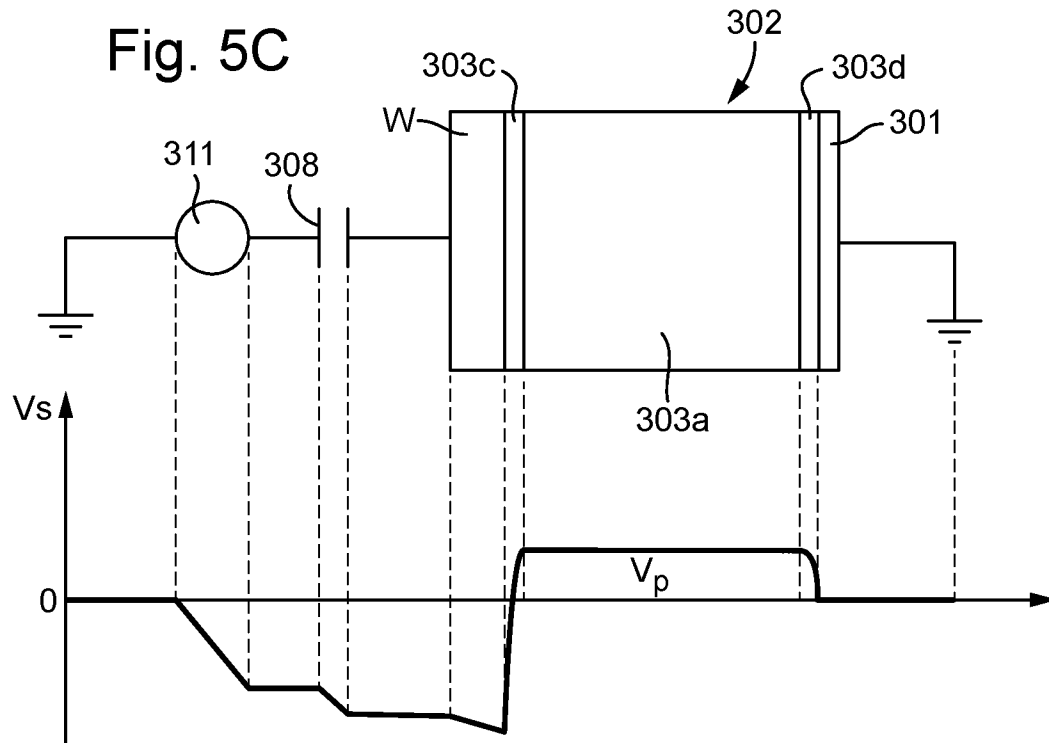


Fig. 6A

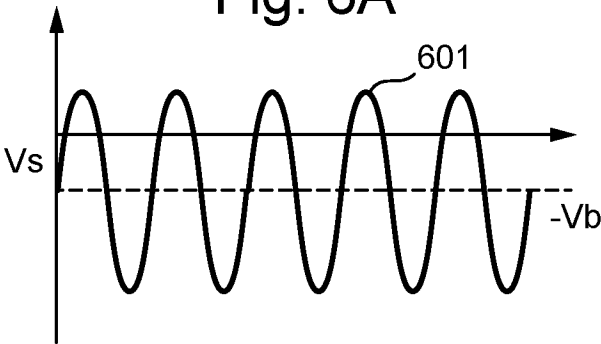


Fig. 6B

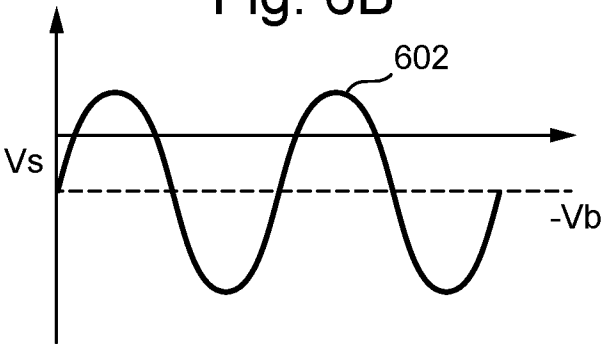


Fig. 6C

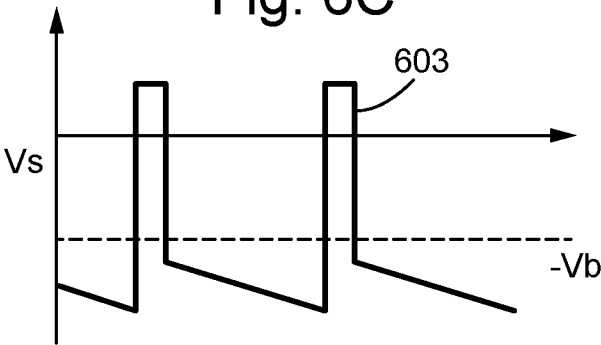
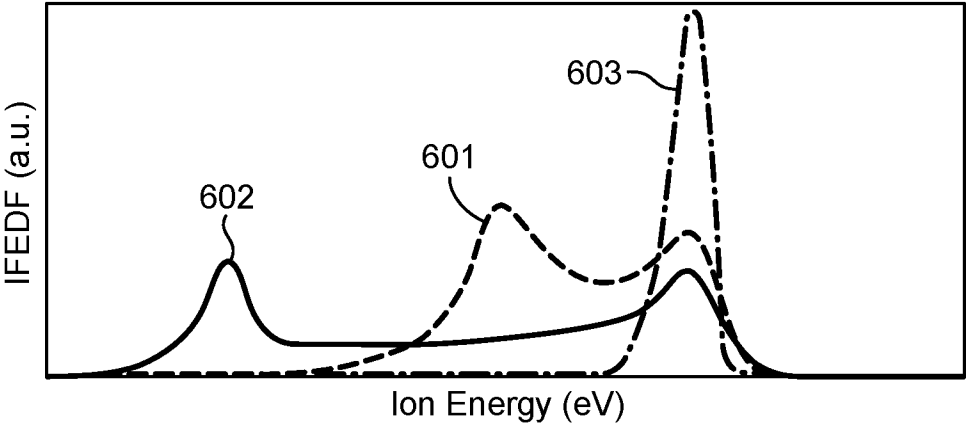


Fig. 6D



INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2023/054045

A. CLASSIFICATION OF SUBJECT MATTER INV. G03F7/20 G03F7/26 H01L21/027 ADD.		
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) G03F H01L		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/193755 A1 (WISE RICHARD S [US] ET AL) 10 July 2014 (2014-07-10)	1-9,
A	abstract	12-22,
	figure 1	25-28
	paragraphs [0001], [0005], [0014] - [0026], [0038]	10, 11,
	-----	23, 24
X	US 2020/019070 A1 (WENG MING-HUI [TW] ET AL) 16 January 2020 (2020-01-16)	1-9, 12,
A	abstract	13, 17, 28
	figures 1A, 1B, 1C, 7	10, 11,
	paragraphs [0027], [0031] - [0037], [0046]	14-16,
	-----	18-27
	-/--	
☒ 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
25 April 2023		08/05/2023
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Andersen, Ole

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/054045

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2003/008246 A1 (CHENG MOSONG [US] ET AL) 9 January 2003 (2003-01-09) abstract figure 1 paragraph [0055] -----	1-28

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2023/054045

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2014193755 A1	10-07-2014	US 2014193755 A1	10-07-2014
		US 2015042972 A1	12-02-2015
US 2020019070 A1	16-01-2020	CN 110716394 A	21-01-2020
		TW 202006474 A	01-02-2020
		US 10520833 B1	31-12-2019
US 2003008246 A1	09-01-2003	NONE	