US 20220115589A1

(19) **United States**

(12) **Patent Application Publication**

KUBO et al.

(10) **Pub. No.: US 2022/0115589 A1**

(43) **Pub. Date: Apr. 14, 2022**

(54) **METHOD FOR PROCESSING SUBSTRATE, PROCESSING APPARATUS, AND PROCESSING SYSTEM**

(71) Applicant: **Tokyo Electron Limited**, Minato-ku,Tokyo (JP)

(72) Inventors: **Takuya KUBO**, Minato-ku, Tokyo (JP); **Song yun KANG**, Minato-ku, Tokyo (JP)

(21) Appl. No.: **17/264,213**

(22) PCT Filed: **Jul. 30, 2019**

(86) PCT No.: **PCT/JP2019/029885**

§ 371 (c)(1),
(2) Date: **Jan. 28, 2021**

(30) **Foreign Application Priority Data**

Jul. 30, 2018 (JP) 2018-142317

Publication Classification

(51) **Int. Cl.**
H01L 43/12 (2006.01)
H01J 37/34 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 43/12*** (2013.01); *H01J 2237/332* (2013.01); *H01J 2237/334* (2013.01); ***H01J 37/3476*** (2013.01)

(57) **ABSTRACT**

A method of processing a substrate includes a first step, a second step and a third step. The substrate includes an etching layer and a mask. The mask is formed on a first surface of the etching layer. The first step forms a first film on a second surface of the mask. The second step forms a second film having a material of the etching layer on the first film by etching the first surface of the etching layer. The third step removes the first film and the second film by exposing the substrate after the second step to plasma of a processing gas. The first film has an electrode material. The processing gas includes oxygen.

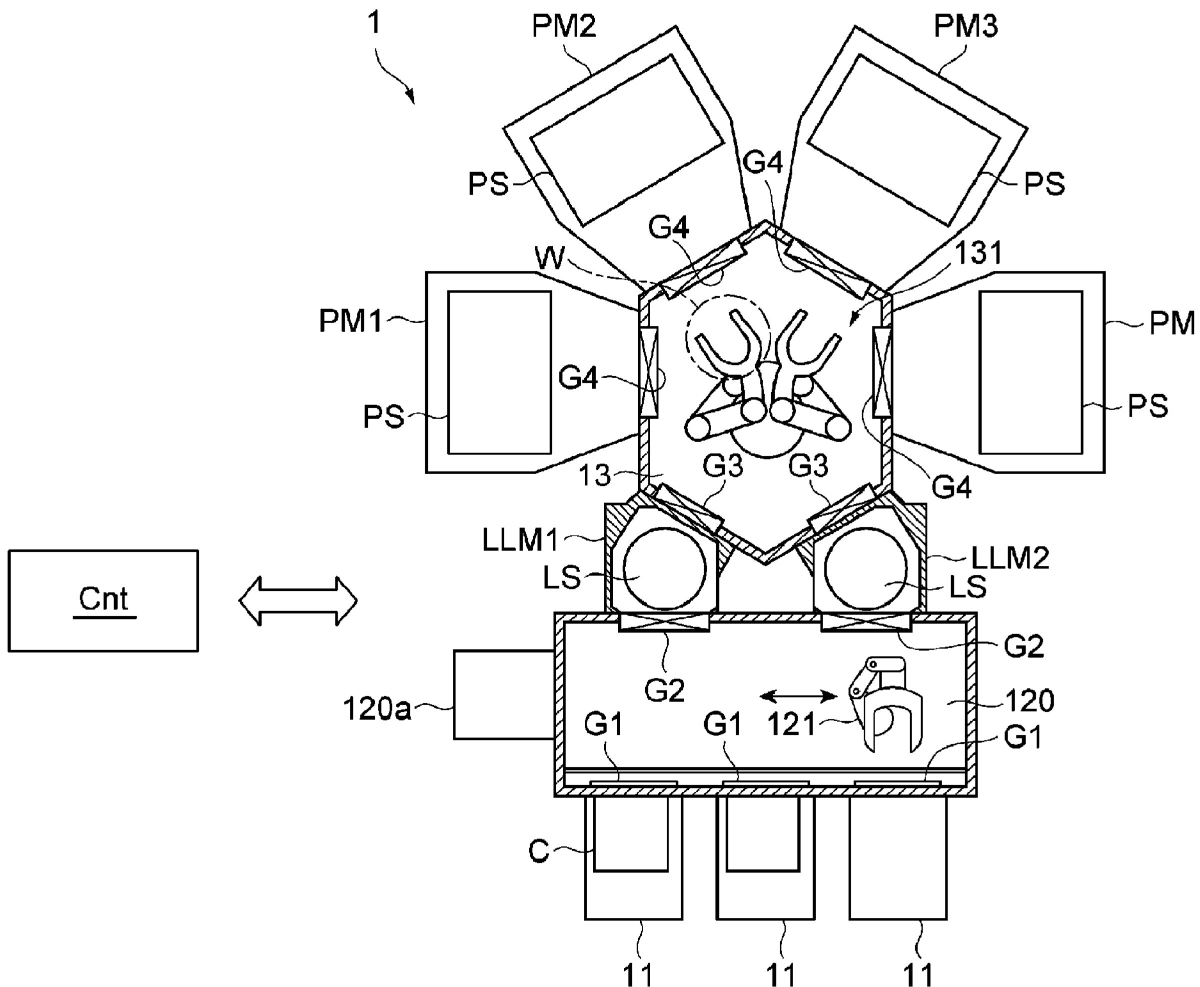


FIG. 1

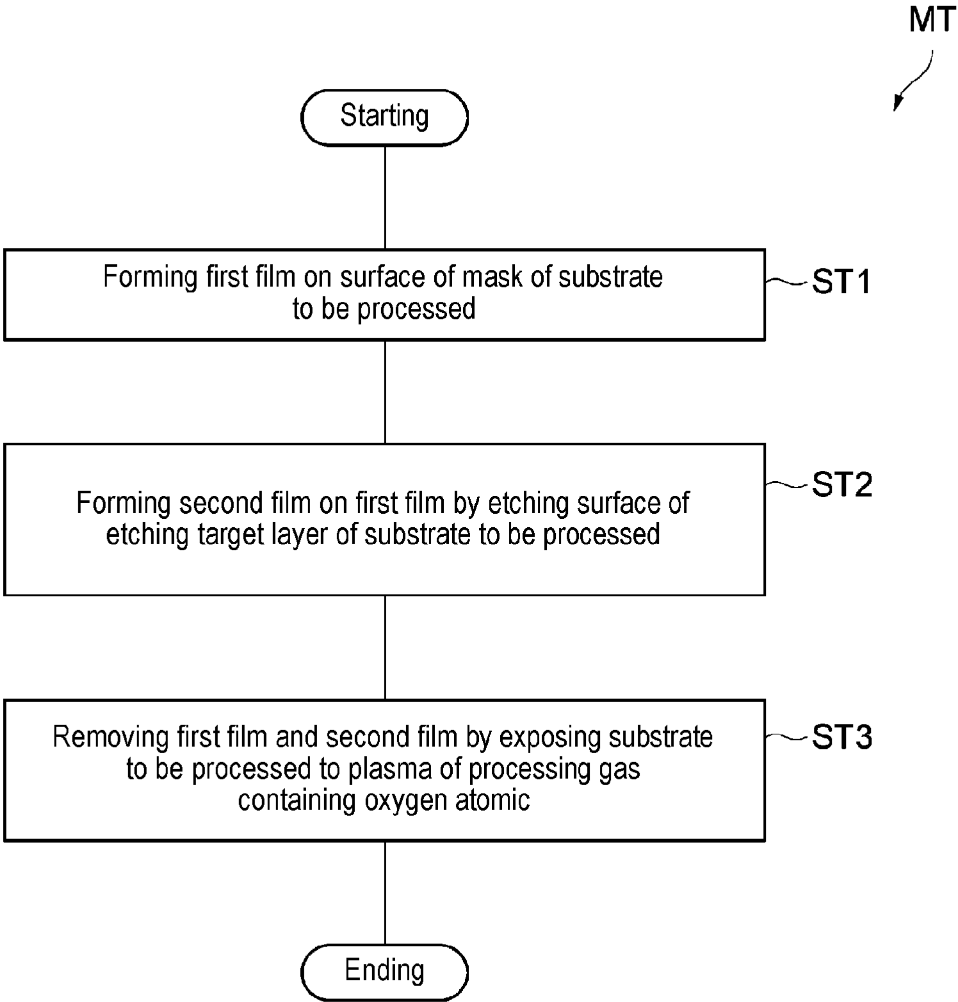


FIG. 2

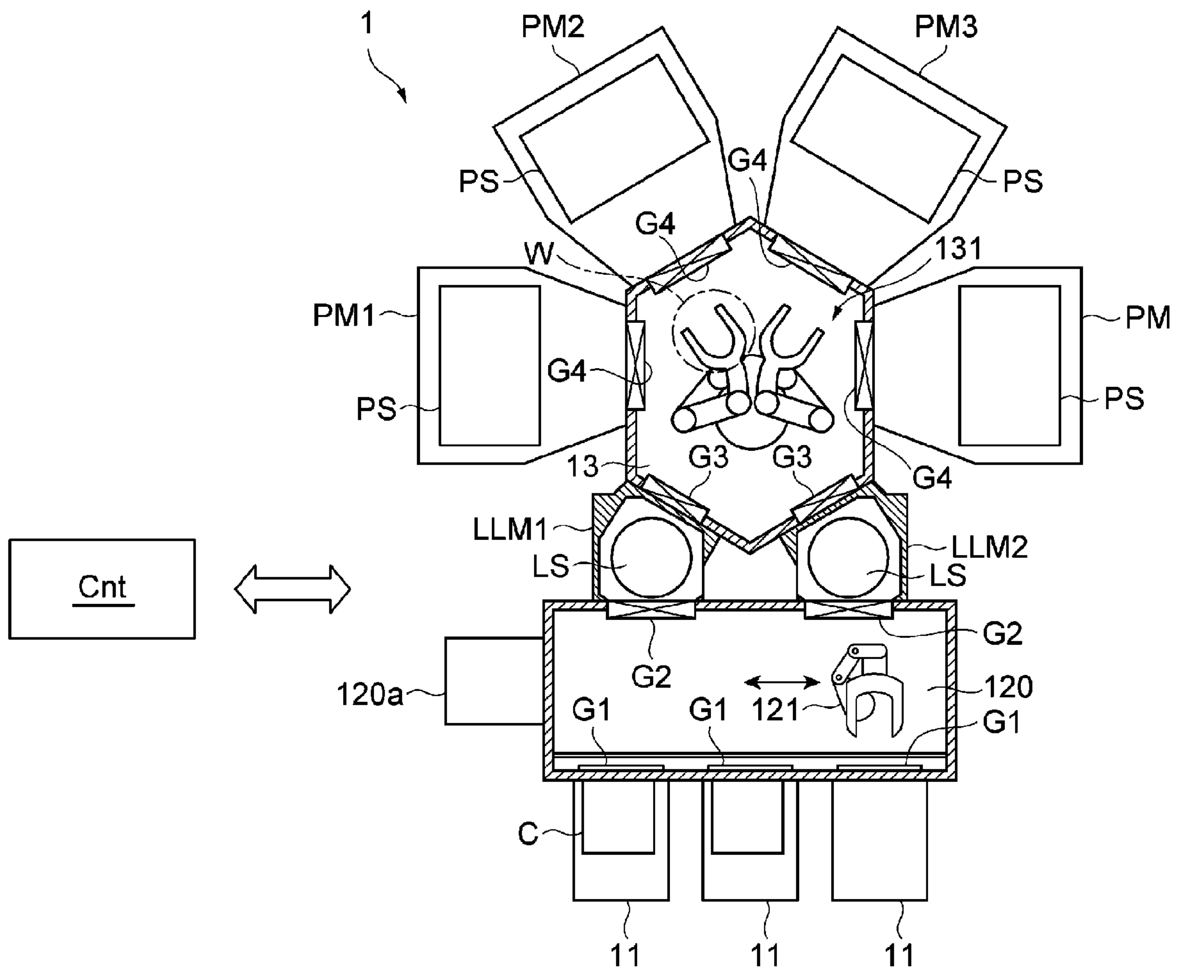
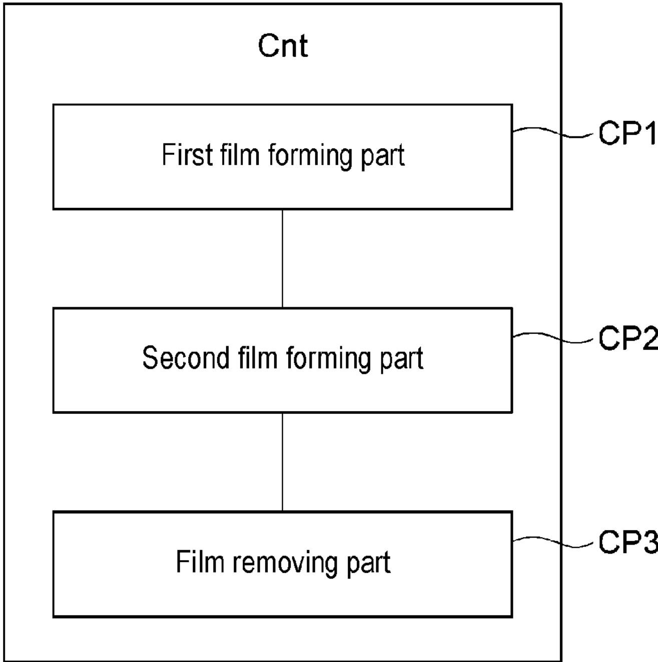


FIG. 3

FIG. 4



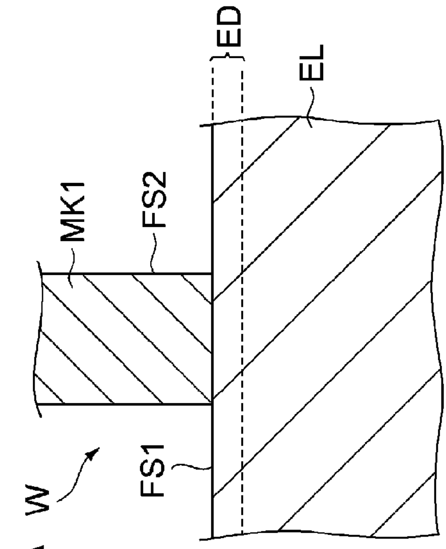


FIG. 5A

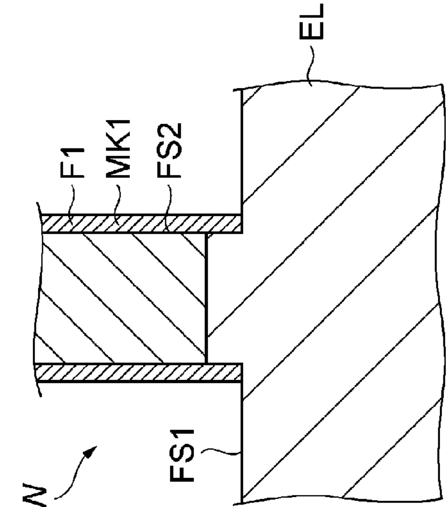


FIG. 5B

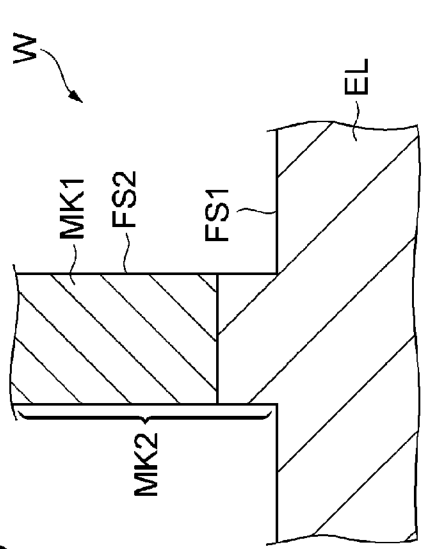


FIG. 5C

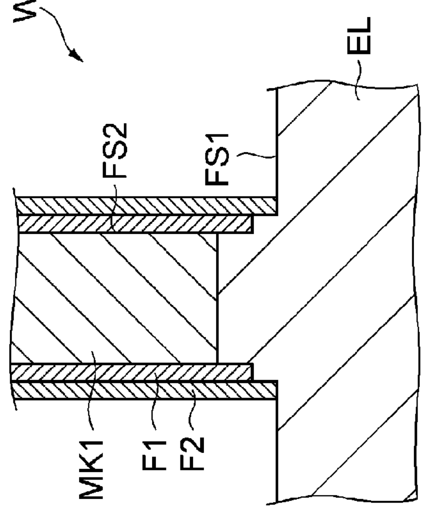
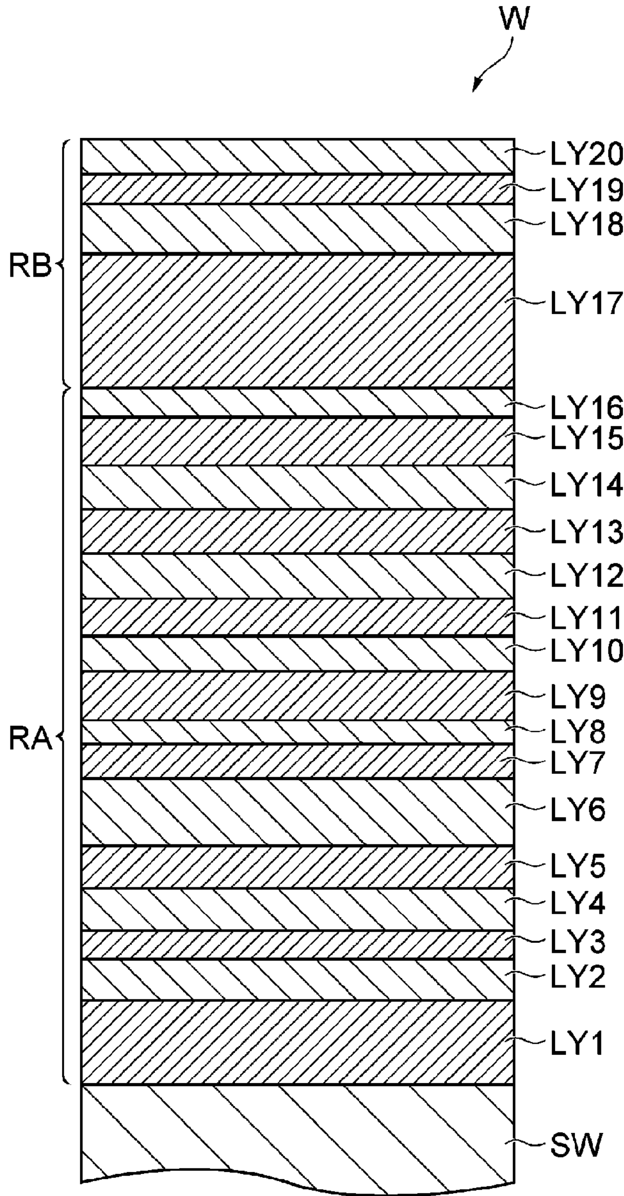


FIG. 5D

FIG. 6



METHOD FOR PROCESSING SUBSTRATE, PROCESSING APPARATUS, AND PROCESSING SYSTEM

TECHNICAL FIELD

[0001] Exemplary embodiments of the present disclosure relate to a substrate processing method, a processing apparatus, and a processing system.

BACKGROUND

[0002] Patent Document 1 discloses a technique related to a plasma processing method and a plasma processing apparatus. The technique disclosed in Patent Document 1 is a method of performing, by using a mask, a plasma etching process on each layer of a laminated body formed by sequentially laminating a first layer formed of a conductor made of a hard-to-etch material, a second layer formed of an insulator, and a third layer formed of a conductor.

PRIOR ART DOCUMENTS

Patent Documents

[0003] Patent Document 1: Japanese laid-open publication No. 2004-247584

SUMMARY

[0004] The present disclosure provides some embodiments of a technique capable of improving etching processing accuracy.

[0005] In one exemplary embodiment, there is provided a method of processing a substrate. The substrate includes an etching layer and a mask. The mask is formed on a first surface of the etching layer. The method includes a first step, a second step and a third step. The first step forms a first film on a second surface of the mask. The second step forms a second film having a material of the etching layer on the first film by etching the first surface of the etching layer. The third step removes the first film and the second film by exposing the substrate after the second step to plasma of a processing gas. The first film has an electrode material. The processing gas includes oxygen.

[0006] According to the present disclosure, it is possible to improve etching processing accuracy.

BRIEF DESCRIPTION OF DRAWINGS

[0007] FIG. **1** is a diagram illustrating a method according to an exemplary embodiment of the present disclosure.

[0008] FIG. **2** is a view illustrating a processing system according to an exemplary embodiment of the present disclosure.

[0009] FIG. **3** is a view illustrating a plasma processing apparatus according to an exemplary embodiment of the present disclosure.

[0010] FIG. **4** is a diagram illustrating a function of a controller illustrated in each of FIGS. **2** and **3**.

[0011] FIGS. **5**A to **5**D are views illustrating a flow of a process according to the method illustrated in FIG. **1** in a cross-sectional view of a substrate.

[0012] FIG. **6** is a view illustrating an example of a configuration of a substrate to which the method illustrated in FIG. **1** is applied.

DETAILED DESCRIPTION

[0013] Various exemplary embodiments will now be described. In one exemplary embodiment, a method of processing a substrate is provided. The substrate includes an etching layer and a mask. The mask is formed on a first surface of the etching layer. This method includes a first step, a second step, and a third step. In the first step, a first film is formed on a second surface of the mask. In the second step, a second film having a material of the etching layer is formed on the first film by etching the first surface of the etching layer. In the third step, the first film and the second film are removed by exposing the substrate after the second step to plasma of a processing gas. The first film has an electrode material. The processing gas includes oxygen.

[0014] According to the exemplary embodiment described above, the first film of the electrode material can be appropriately delaminated from the second surface of the mask together with the second film deposited on the first film and having the material of the etching layer by exposing the substrate to the plasma of the processing gas containing oxygen. Therefore, in the etching of the etching layer, a change in critical dimension (CD) of mask shape can be sufficiently suppressed while sufficiently maintaining a mask residual film. Thus, it is possible to avoid a situation in which the film containing the material of the etching layer is formed on the second surface of the mask by the etching of the etching layer, which makes fine etching process difficult.

[0015] In one exemplary embodiment, the etching layer includes an electrode material layer. The electrode material layer extends to the first surface. In the first step, the first film is formed by etching the electrode material layer and sputtering the material of the electrode material layer. As described above, it may be considered that the electrode material layer extends to the first surface of the etching layer. In this case, the formation of the first film of the electrode material is performed by the etching of the etching layer, and thus the etching of the etching layer and the formation of the first film are performed together in the first step. Thus, it is possible to simplify the processing.

[0016] In one exemplary embodiment, in the first step, the first film is formed by chemical vapor deposition or physical vapor deposition. As described above, since the first film can be formed through a film forming process by the chemical vapor deposition or the physical vapor deposition, the timing of the formation of the first film can be relatively flexibly adjusted.

[0017] In one exemplary embodiment, a series of steps including the first step, the second step, and the third step are repeatedly executed. Thus, the maintenance of the mask residual film and the suppression of the change in the CD of mask shape can be more remarkably realized.

[0018] In one exemplary embodiment, the etching layer includes a magnetic tunnel junction region. Although the magnetic tunnel junction region has a hard-to-volatile material, the exemplary embodiment described above may be applied to an etching layer having the magnetic tunnel junction region of the hard-to-volatile material.

[0019] In one exemplary embodiment, the first film has an electrode material of ruthenium or carbon. As described above, since the ruthenium or carbon electrode material can be used as the electrode material of the first film, the formation of the first film is relatively easily performed.

[0020] In one exemplary embodiment, a processing apparatus for processing a substrate is provided. The control

device includes a processing container configured to accommodate a substrate and a controller configured to control the processing apparatus. The controller includes a first film forming part, a second film forming part, and a film removing part. The first film forming part is configured to control the processing apparatus so as to form a first film having an electrode material on a second surface of a mask when the substrate accommodated in the processing container includes an etching layer and the mask and the mask is formed on a first surface of the etching layer. The second film forming part is configured to control the processing apparatus so as to form a second film having the material of the etching layer on the first film by etching the first surface of the etching layer after the formation of the first film by the first film forming part. The film removing part is configured to control the processing apparatus so as to remove the first film and the second film by exposing the substrate on which the second film is formed by the second film forming part to plasma of a processing gas having oxygen.

[0021] According to the exemplary embodiment described above, the first film of the electrode material can be appropriately delaminated from the second surface of the mask together with the second film deposited on the first film and having the material of the etching layer by exposing the substrate to the plasma of the processing gas containing oxygen. Therefore, in the etching of the etching layer, the change in the CD of mask shape can be sufficiently suppressed while sufficiently maintaining the mask residual film. Thus, it is possible to avoid a situation in which the film containing the material of the etching layer is formed on the second surface of the mask by the etching of the etching layer, which makes fine etching processing difficult.

[0022] In one exemplary embodiment, when the etching layer includes an electrode material layer and the electrode material layer extends to the first surface, the first film forming part is configured to control the processing apparatus so as to form the first film by etching the electrode material layer and sputtering the material of the electrode material layer. As described above, it may be considered that the electrode material layer extends to the first surface of the etching layer. In this case, the first film of the electrode material is formed by the etching of the etching layer, and the etching of the etching layer and the formation of the first film are performed together by the first film forming part. Thus, it is possible to simplify the processing.

[0023] In one exemplary embodiment, a processing system for processing a substrate is provided. The processing system includes a film forming apparatus configured to perform a film forming process on the substrate, an etching apparatus configured to perform an etching process on the substrate, and a controller configured to control the processing system. The controller includes a first film forming part, a second film forming part, and a film removing part. The first film forming part is configured to control the processing system so as to form a first film having an electrode material on a second surface of a mask when the substrate accommodated in the film forming apparatus includes an etching layer and the mask and the mask is formed on a first surface of the etching layer. The second film forming part is configured to control the processing system so as to form a second film having the material of the etching layer on the first film by transferring the substrate to the etching apparatus and etching the first surface of the etching layer after the formation of the first film by the first film forming part. The film removing part is configured to control the processing system so as to remove the first film and the second film by exposing the substrate on which the second film is formed by the second film forming part to plasma of a processing gas having oxygen.

[0024] According to the exemplary embodiment described above, the first film of the electrode material can be appropriately delaminated from the second surface of the mask together with the second film formed on the first film and having the material of the etching layer by exposing the substrate to the plasma of the processing gas containing oxygen. Therefore, in the etching of the etching layer, the change in the CD of mask shape can be sufficiently suppressed while sufficiently maintaining the mask residual film. Thus, it is possible to avoid a situation in which the film containing the material of the etching layer is formed on the second surface of the mask by the etching of the etching layer, which makes fine etching processing difficult.

[0025] In one exemplary embodiment, the first film forming part is configured to control the processing system to form the first film by chemical vapor deposition or physical vapor deposition. As described above, since the first film can be formed by the film forming process by the chemical vapor deposition or the physical vapor deposition, the timing of formation of the first film may be relatively flexibly adjusted.

[0026] Hereinafter, various exemplary embodiments will be described in detail with reference to the drawings. Further, like or equivalent parts in each drawing will be denoted by like reference numerals. A method MT illustrated in FIG. **1** is an exemplary embodiment of a method of processing a substrate. The method MT may be performed by a processing system **1** illustrated in FIG. **2**.

[0027] First, a configuration of the processing system **1** according to an exemplary embodiment of the present disclosure will be described with reference to FIG. **3**. The processing system **1** may be used to perform the method MT illustrated in FIG. **1**.

[0028] The processing system **1** includes carrier mounting ports **11**, an atmospheric transfer chamber **120**, a load lock module LLM**1**, and a load lock module LLM**2**. The processing system **1** further includes a vacuum transfer chamber **13**, a processing module PM**1**, a processing module PM**2**, a processing module PM**3**, and a processing module PM**4**.

[0029] The atmospheric transfer chamber **120** and the load lock module LLM**1** and the load lock module LLM**2** are connected to each other via door valves G**2** while maintaining airtightness. The load lock module LLM**1** and the load lock module LLM**2** and a transfer arm **131** are connected to each other via gate valves G**3** while maintaining airtightness. The transfer arm **131** and the processing modules PM**1** to PM**4** are connected to each other via gate valves G**4** while maintaining airtightness.

[0030] Transfer vessels C are mounted on the carrier mounting ports **11**. The carrier mounting ports **11** correspond to loading ports of the transfer vessels C. The transfer vessels C accommodate a plurality of substrates W. The transfer vessels C are connected to the atmospheric transfer chamber **120** via doors G**1**.

[0031] The atmospheric transfer chamber **120** transfers the substrates W discharged from the transfer vessels C under an atmospheric atmosphere. A transfer arm **121** is provided in

the atmospheric transfer chamber **120**. The transfer arm **121** can freely rotate, expand and contract, ascend and descend, and move left and right.

[0032] The transfer arm **121** discharges the substrates W one by one from the transfer vessel C and transfers the discharged substrates W. An alignment chamber **120***a* is provided on a side surface of the atmospheric transfer chamber **120**. The alignment chamber **120***a* incorporates an orienter for aligning the substrates W therein.

[0033] Each of the load lock module LLM**1** and the load lock module LLM**2** is connected to the atmospheric transfer chamber **120** via each of the door valves G**2**. Both the load lock module LLM**1** and the load lock module LLM**2** switch their respective internal states between an air atmosphere and a preliminary vacuum atmosphere and standby the substrates W. Both the load lock module LLM**1** and the load lock module LLM**2** are arranged so as to connect between the atmospheric transfer chamber **120** and the vacuum transfer chamber **13**.

[0034] A vacuum pump and a leak valve are connected to each of the load lock module LLM**1** and the load lock module LLM**2**. The vacuum pump and the leak valve switch the interior of each of the load lock module LLM**1** and the load lock module LLM**2** between the air atmosphere and the vacuum atmosphere.

[0035] A stage LS is provided in each of the load lock module LLM**1** and the load lock module LLM**2**. The stage LS places the loaded substrate W thereon.

[0036] The vacuum transfer chamber **13** is connected to each of the load lock module LLM**1** and the load lock module LLM**2** via each of the gate valves G**3**. The vacuum transfer chamber **13** transfers the substrate W in a vacuum atmosphere.

[0037] The processing modules PM**1** to PM**4** are connected to the vacuum transfer chamber **13** via the respective gate valves G**4**. A vacuum pump (not shown) for keeping the interior of the vacuum transfer chamber **13** in a vacuum atmosphere is connected to the vacuum transfer chamber **13**.

[0038] The transfer arm **131** is provided in the vacuum transfer chamber **13**. The transfer arm **131** may be configured to be rotatable and extendible. The transfer arm **131** transfers the substrate W between the load lock module LLM**1** and the load lock module LLM**2** and the processing modules PM**1** to PM**4**.

[0039] All the processing modules PM**1** to PM**4** perform a processing on the substrate W. Each of the processing modules PM**1** to PM**4** includes a processing container PS configured to accommodate the substrate W. The processing is performed on the substrate W accommodated in the processing container PS. The processing may be, for example, an etching process, a film forming process, or the like.

[0040] Each of the processing modules PM**1** to PM**4** can perform, for example, different kinds of processing on the substrate W.

[0041] In one embodiment, for example, the processing module PM**1** may be a film forming apparatus configured to perform the film forming process on the substrate W loaded into the processing container PS. In this case, the processing module PM**1** (film forming apparatus) may be a plasma processing apparatus **10** illustrated in FIG. **3**.

[0042] In one embodiment, for example, the processing module PM**2** may be an etching apparatus configured to perform an etching process on the substrate W loaded into the processing container PS. In this case, the processing module PM**2** (etching apparatus) may be the plasma processing apparatus **10** illustrated in FIG. **3**.

[0043] The processing system **1** includes a controller Cnt. The controller Cnt is configured to comprehensively control the operations of the respective parts of the processing system **1** (the transfer arm **121**, the processing modules PM**1** to PM**4**, and the like illustrated in FIG. **2**).

[0044] The controller Cnt may be physically configured as a computer device including a processor, a memory, a storage, a communication device, a bus, and the like (not shown). The processor of the controller Cnt includes a CPU, a memory, and the like.

[0045] The operations of the respective parts of the processing system **1** are implemented by causing the processor to read a computer program stored in the storage or the like (for example, a program that executes the method MT illustrated in FIG. **1**) in the processor and the memory and execute the computer program.

[0046] A processing operation of the substrate W by the processing system **1** described above will be schematically described. The substrate W accommodated in the transfer vessel C on the carrier mounting ports **11** is picked up by the transfer arm **121** and is arranged in the alignment chamber **120***a* while being transferred in the atmospheric transfer chamber **120**. After this alignment, the substrate W are transferred into either the load lock module LLM**1** or the load lock module LLM**2**.

[0047] After the substrate W is transferred into either the load lock module LLM**1** or the load lock module LLM**2**, the interior of each of the load lock module LLM**1** and the load lock module LLM**2** is kept in a preliminary vacuum atmosphere. Then, the substrate W is picked up by the transfer arm **131** and is transferred into the vacuum transfer chamber **13**. Thereafter, the substrate W is transferred between the vacuum transfer chamber **13** and the processing modules PM**1** to PM**4** where the substrate W is subjected to the processing. The processed substrate W is accommodated in the transfer vessel C through a reverse path (excluding the alignment chamber **120***a*) of the path during the loading.

[0048] Hereinafter, a configuration of the plasma processing apparatus **10** according to an exemplary embodiment of the present disclosure will be described with reference to FIG. **3**. The plasma processing apparatus **10** may be used to perform the method MT illustrated in FIG. **1**. The plasma processing apparatus **10** may be used in any of the processing modules PM**1** to PM**4** of the processing system **1** illustrated in FIG. **2**.

[0049] A structure of a vertical cross section of the plasma processing apparatus **10** is schematically illustrated in FIG. **3**. The plasma processing apparatus **10** illustrated in FIG. **3** is a capacitively coupled plasma processing apparatus.

[0050] The plasma processing apparatus **10** may be used to perform an etching process and a film forming process. In this case, when the method MT includes the etching process and the film forming process, the etching process and the film forming process may be performed by a common single apparatus (the plasma processing apparatus **10**). Furthermore, when the method MT includes the etching process and the film forming process, the etching process and the film forming process may be performed by separate processing apparatuses.

[0051] The plasma processing apparatus **10** includes a processing container **12**. The processing container **12**

accommodates a substrate W. The processing container **12** has a substantially cylindrical shape. The processing container **12** provides an internal space thereof as a chamber **12***c*. The processing container **12** is made of, for example, aluminum. The processing container **12** is connected to a ground potential.

[0052] A film having plasma resistance is formed on an inner wall surface of the processing container **12**, i.e., on a wall surface defining the chamber **12***c*. This film may be a film formed by anodizing or a film made of ceramics. This film made of ceramics is, for example, a film containing yttrium oxide.

[0053] An opening **12***g* for transferring the substrate W therethrough is formed on a sidewall **12***s* of the processing container **12**. The opening **12***g* can be opened and closed by a gate valve **14**.

[0054] Inside the chamber **12***c*, a support part **15** extends upward from the bottom of the processing container **12**. The support part **15** has a substantially cylindrical shape and has an insulating material such as quartz or the like.

[0055] A stage **16** is provided inside the chamber **12***c*. The stage **16** is configured to support the substrate W mounted on the stage **16**.

[0056] The substrate W may have a disk shape like a wafer. The stage **16** includes a lower electrode **18** and an electrostatic chuck **20**. The stage **16** is supported by the support part **15**.

[0057] The lower electrode **18** includes a first plate **18***a* and a second plate **18***b*. The first plate **18***a* and the second plate **18***b* contain metal such as aluminum or the like, and have a substantially disk shape. The second plate **18***b* is provided on the first plate **18***a* and is electrically connected to the first plate **18***a*.

[0058] The electrostatic chuck **20** is provided on the second plate **18***b*. The electrostatic chuck **20** has an insulating layer and an electrode built in the insulating layer.

[0059] A direct current power supply **22** is electrically connected to an electrode of the electrostatic chuck **20** via a switch **23**. When a direct current voltage from the direct current power supply **22** is applied to the electrode of the electrostatic chuck **20**, the electrostatic chuck **20** generates an electrostatic force. The electrostatic chuck **20** attracts the substrate W to the electrostatic chuck **20** by virtue of the electrostatic force to hold the substrate W.

[0060] A focus ring **24** is arranged on a peripheral portion of the second plate **18***b* so as to surround an edge of the substrate W and the electrostatic chuck **20**. The focus ring **24** is provided to improve the uniformity of plasma processing. The focus ring **24** has a material suitably selected according to the plasma processing, and has, for example, quartz.

[0061] The substrate W mounted on the electrostatic chuck **20** may be controlled by using a chiller unit for supplying a refrigerant to a flow path **18***f* and a heater power supply HP for supplying electric power to a temperature adjusting part HT.

[0062] The flow path **18***f* is provided inside the second plate **18***b*. The refrigerant is supplied from the chiller unit provided outside the processing container **12** to the flow path **18***f* via a pipe **26***a*. The refrigerant supplied to the flow path **18***f* is returned to the chiller unit via a pipe **26***b*. In this manner, the refrigerant is supplied to the flow path **18***f* so as to circulate in the flow path **18***f*. By controlling the temperature of the refrigerant by the chiller unit, the temperature of the substrate W supported by the electrostatic chuck **20** can be controlled.

[0063] The temperature adjusting part HT is provided on the electrostatic chuck **20**. The heater power supply HP is connected to the temperature adjusting part HT. By supplying electric power from the heater power supply HP to the temperature adjusting part HT, the temperature of the electrostatic chuck **20** is adjusted so that the temperature of the substrate W mounted on the electrostatic chuck **20** is adjusted. The temperature adjusting part HT may also be embedded in the second plate **18***b*.

[0064] The temperature adjusting part HT includes a temperature sensor (not shown), which detects an ambient temperature of the temperature adjusting part HT and outputs the detection result as a detection signal to the controller Cnt. The temperature detected by the temperature sensor is equal to the temperature of the substrate W mounted on the electrostatic chuck **20**.

[0065] A gas supply line **28** is provided in the plasma processing apparatus **10**. The gas supply line **28** supplies a heat transfer gas from a heat transfer gas supply mechanism, for example, a He gas, between the upper surface of the electrostatic chuck **20** and the rear surface of the substrate W.

[0066] The plasma processing apparatus **10** further includes an upper electrode **30**. The upper electrode **30** is provided above the stage **16** and is provided substantially parallel to the lower electrode **18**. The upper electrode **30** closes an upper opening portion of the processing container **12** together with a member **32**. The member **32** has an insulation property. The upper electrode **30** is supported on the upper portion of the processing container **12** via the member **32**.

[0067] The upper electrode **30** includes a ceiling plate **34** and a support **36**. The ceiling plate **34** faces the chamber **12***c*. A plurality of gas discharge holes **34***a* are formed in the ceiling plate **34**. The ceiling plate **34** has, for example, silicon, but not limited thereto, and may have a structure in which a plasma-resistant film is formed on a surface of a base material made of aluminum. The film may also be a film made of ceramics. The film made of ceramics is a film formed by anodizing, a film containing yttrium oxide, or the like.

[0068] The support **36** detachably supports the ceiling plate **34**. The support **36** has a conductive material such as aluminum or the like. A gas diffusion chamber **36***a* is provided inside the support **36**.

[0069] A plurality of gas holes **36***b* extend downward from the gas diffusion chamber **36***a*. The plurality of gas holes **36***b* respectively communicate with the plurality of gas discharge holes **34***a*. A gas introduction port **36***c* for guiding a gas to the gas diffusion chamber **36***a* is formed in the support **36**. A gas supply pipe **38** is connected to the gas introduction port **36***c*.

[0070] A gas source group **40** is connected to the gas supply pipe **38** via a valve group **42** and a flow rate controller group **44**. The gas source group **40** has a plurality of gas sources. The plurality of gas sources include at least one or more noble gas sources, a hydrocarbon gas source, and an oxygen-containing gas source.

[0071] The noble gas sources may include an Ar gas source. The hydrocarbon gas source may include, for

example, a CH_4 gas source. The oxygen-containing gas source may include, for example, an O_2 gas source.

[0072] The valve group **42** includes a plurality of valves. The flow rate controller group **44** includes a plurality of flow rate controllers such as a mass flow controller or the like. Each of the plurality of gas sources of the gas source group **40** is connected to the gas supply pipe **38** via a respective valve of the valve group **42** and a respective flow rate controller of the flow rate controller group **44**.

[0073] The plasma processing apparatus **10** can supply a gas from one or more gas sources selected from the plurality of gas sources of the gas source group **40** to the chamber **12***c* at an individually-adjusted flow rate.

[0074] Inside the chamber **12***c*, a baffle plate **48** is provided between the support part **15** and the sidewall **12***s* of the processing container **12**. The baffle plate **48** has, for example, a configuration in which a base material made of aluminum is coated with ceramics such as yttrium oxide or the like. A plurality of through-holes are formed in the baffle plate **48**.

[0075] An exhaust pipe **52** is connected to the bottom of the processing container **12** below the baffle plate **48**. An exhaust device **50** is connected to the exhaust pipe **52**. The exhaust device **50** has a pressure controller and a vacuum pump such as a turbo molecular pump, and thus can depressurize the chamber **12***c*.

[0076] The plasma processing apparatus **10** includes a first high frequency power supply **62**. The first high frequency power supply **62** is a power supply that generates a first high frequency for plasma generation, and generates a high frequency having a frequency in the range of 27 to 100 MHz, for example, a frequency of 60 MHz. The first high frequency power supply **62** is connected to the upper electrode **30** via a matching device **63**.

[0077] The matching device **63** has a circuit for matching an output impedance of the first high frequency power supply **62** with an input impedance on the side of a load (the side of the upper electrode **30**). The first high frequency power supply **62** may also be connected to the lower electrode **18** via the matching device **63**. When the first high frequency power supply **62** is connected to the lower electrode **18**, the upper electrode **30** is connected to the ground potential.

[0078] The plasma processing apparatus **10** includes a second high frequency power supply **64**. The second high frequency power supply **64** is a power supply that generates a second high frequency for bias for drawing ions into the substrate W. The frequency of the second high frequency is lower than the frequency of the first high frequency.

[0079] The frequency of the second high frequency is a frequency in the range of 400 kHz to 13.56 MHz, for example, 400 kHz. The second high frequency power supply **64** is connected to the lower electrode **18** via a matching device **65**.

[0080] The matching device **65** has a circuit for matching an output impedance of the second high frequency power supply **64** with an input impedance on the side of a load (the side of the lower electrode **18**).

[0081] The controller Cnt of the plasma processing apparatus **10** is similar to the controller Cnt of the processing system **1**. When the plasma processing apparatus **10** is any of the processing modules PM**1** to PM**4** of the processing system **1**, the controller Cnt of the processing system **1** functions as the controller Cnt of the plasma processing apparatus **10**.

[0082] Next, returning to FIG. **1**, the method MT will be described. FIGS. **4**, **5**A to **5**D, and **6** will be referred below. The method MT illustrated in FIG. **1** may be performed when the substrate W has a configuration illustrated in FIG. **5**A.

[0083] The substrate W illustrated in FIG. **5**A includes an etching layer EL, a mask MK**1**, and the like (further, a mask MK**2** or the like illustrated in FIG. **5**D). The mask MK**1** or the like is formed on a surface FS**1** (a first surface) of the etching layer EL. A surface FS**2** (a second surface) of the mask MK**1** (further, the mask MK**2** or the like) extends to the surface FS**1**.

[0084] In one exemplary embodiment, the substrate W having the configuration illustrated FIG. **5**A is used for, for example, manufacturing a magnetoresistive random access memory (MRAM). In this case, as illustrated in FIG. **6**, the substrate W may include a support substrate SW, a region RA, and a region RB. The region RA corresponds to the etching layer EL, and the region RB corresponds to the mask MK**1**. The etching layer EL has a magnetoresistive tunnel junction (MTJ) region.

[0085] The region RA is formed on the support substrate SW, and the region RB is formed on the region RA. The region RA includes layers LY**1** to LY**16**, and the region RB includes layers LY**17** to LY**20**. In the region RA, the layers LY**1** to LY**16** are sequentially laminated on the support substrate SW. In the region RB, the layers LY**17** to LY**20** are sequentially laminated on the region RA (on the layer LY**16**).

[0086] The support substrate SW has silicon (Si). The layer LY**1** has silicon dioxide (SiO_2). The layer LY**2** has tantalum (Ta). The layer LY**3** has ruthenium (Ru). The layer LY**4** has Ta. The layer LY**5** is an underling layer having platinum (Pt). The layer LY**6** is a magnetic layer having Pt/Co (where Co: cobalt). The layer LY**7** has Co. The layer LY**8** has Ru. The layer LY**9** is a magnetic layer having Pt/Co.

[0087] The layer LY**10** has Co. The layer LY**11** has Ta. The layer LY**12** has CoFeB (where Fe: iron, B: boron). The layer LY**13** has magnesium oxide (MgO). The layer LY**14** has CoFeB. The layer LY**15** has Ta. The layer LY**16** has Ru. The layer LY**17** has titanium nitride (TiN). The layer LY **18** has SiO_2. The layer LY**19** has silicon carbide (SiC). The layer LY**20** is a spin on glass (SOG) layer.

[0088] The controller Cnt which executes the method MT functionally includes a first film forming part CP**1**, a second film forming part CP**2**, and a film removing part CP**3**, as illustrated in FIG. **4**. The first film forming part CP**1**, the second film forming part CP**2**, and the film removing part CP**3** implement the execution of the method MT illustrated in FIG. **1**.

[0089] Either when the method MT includes only the etching process or when the method MT includes the film forming process and the etching process, the first film forming part CP**1**, the second film forming part CP**2**, and the film removing part CP**3** may be used. Either when the method MT includes only the etching process or when the method MT includes the film forming process and the etching process, only a single plasma processing apparatus **10** may be used.

[0090] Furthermore, when the method MT includes the film forming process and the etching process, each of the film forming process and the etching process may be performed by any of the processing modules PM**1** to PM**4** of the processing system **1**. Each of the processing modules PM**1** to PM**4** includes a film forming apparatus and an etching apparatus. Either or both of the film forming apparatus and the etching apparatus may be the plasma processing apparatus **10**.

[0091] Either when the method MT is performed by only the single plasma processing apparatus **10** or when the method MT is performed by the processing module PM**1** or the like of the processing system **1**, the method MT may be performed in a vacuum.

[0092] The method MT includes step ST**1** (first step), step ST**2** (second step), and step ST**3** (third step). The first film forming part CP**1** is configured to perform step ST**1**. The second film forming part CP**2** is configured to perform step ST**2**. The film removing part CP**3** is configured to perform step ST**3**.

[0093] In step ST**1**, as illustrated in FIG. **5**B, a first film F**1** is formed on the surface FS**2** of the mask MK**1**. The first film F**1** has an electrode material. The electrode material of the first film F**1** has, for example, Ru or carbon (C).

[0094] When the etching layer EL includes an electrode material layer ED as illustrated FIG. **5**A, the first film F**1** may be formed by the etching process in step ST**1**. The material of the electrode material layer ED includes the electrode material of the first film F**1**. The electrode material layer ED extends to the surface FS**1** of the etching layer EL. Step ST**1** is executed on the substrate W accommodated in the processing container **12** of the plasma processing apparatus **10**. In step ST**1**, the first film F**1** is formed on the surface FS**2** of the mask MK**1** by etching the electrode material layer ED and sputtering the material of the electrode material layer ED.

[0095] When the etching layer EL includes an MTJ region, the electrode material layer ED is included in the MTJ region, and may be, for example, a Ru layer. When the electrode material layer ED is a Ru layer, the etching process executed in step ST**1** may be reactive ion etching (RIE). A gas used for the etching process of RIE mainly includes a noble gas (for example, an Ar gas), but may include, for example, a CH_4 gas (further, an O_2 gas) together with the noble gas.

[0096] Furthermore, the first film F**1** may be formed by the film forming process in step ST**1**. In this case, step ST**1** is executed on the substrate W accommodated in the processing container **12** of the plasma processing apparatus **10** or in the processing container PS of the film forming apparatus (processing module PM**1** or the like) of the processing system **1**. In step ST**1**, the first film F**1** is formed by chemical vapor deposition (CVD) or physical vapor deposition (PVD).

[0097] In step ST**2**, as illustrated in FIG. **5**C, the surface FS**1** of the etching layer EL is etched to form a second film F**2** having the material of the etching layer EL on the first film F**1**. The second film F**2** is formed by an etching process in step ST**2**.

[0098] When step ST**1** is performed by the plasma processing apparatus **10**, step ST**2** is subsequently performed by the plasma processing apparatus **10** in which step ST**1** has been performed. When step ST**1** is performed by a film forming apparatus (processing module PM**1** or the like) of the processing system **1**, step ST**2** is performed by an etching apparatus after the substrate W is transferred to the respective etching apparatus (processing module PM**2** or the like) of the processing system **1**.

[0099] In step ST**2**, when the etching process is performed in step ST**1**, the etching process performed in step ST**1** may be continued. That is, the etching process performed in step ST**2** may be RIE. The gas used for the etching process of RIE mainly includes a noble gas (for example, an Ar gas), but may include, for example, a CH_4 gas (further, an O_2 gas) together with the noble gas.

[0100] In step ST**3**, as illustrated in FIG. **5**D, the first film F**1** and the second film F**2** are removed from the surface of the substrate W including the surface FS**1** and the surface FS**2** by exposing the substrate W after step ST**2** to plasma of a processing gas. By step ST**3**, the mask MK**2** including the mask MK**1** is formed. The mask MK**2** extends to the surface FS**1** of the etching layer EL after step ST**3**. The mask MK**2** can function as a new mask for the etching layer EL.

[0101] The processing gas used in step ST**3** may include oxygen (O). The processing gas may include oxygen and include a noble gas (an Ar gas or the like).

[0102] According to the method MT, when the substrate W is exposed to the plasma of the processing gas containing oxygen, the first film F**1** of the electrode material such as Ru or the like may be appropriately delaminated from the surface FS**2** of the mask MK**1** together with the second film F**2** deposited on the first film F**1** and having the material of the etching layer EL. Therefore, in the etching of the etching layer EL, the change in CD having the shape of the mask MK**1** or the like can be sufficiently suppressed while sufficiently maintaining the residual film of the mask MK**1** or the like. Thus, it is possible to avoid a situation in which the film containing the material of the etching layer EL is formed on the surface FS**2** of the mask MK**1** by the etching of the etching layer EL, which makes fine etching processing difficult.

[0103] Furthermore, it may be considered that the electrode material layer ED extends to the surface FS**1** of the etching layer EL. In this case, the formation of the first film F**1** of the electrode material is performed by the etching of the etching layer EL, and the etching of the etching layer EL and the formation of the first film F**1** are performed together in step ST**1** by the first film forming part CP**1**. Thus, it is possible to simplify the processing.

[0104] In addition, when the first film F**1** is formed by the film forming process based on the chemical vapor deposition or the physical vapor deposition, the timing of formation of the first film F**1** may be relatively flexibly adjusted.

[0105] Moreover, in one exemplary embodiment, step ST**1**, step ST**2**, and step ST**3** may be repeatedly executed. In this case, the maintenance of the mask residual film and the suppression of the change in the CD of mask shape can be more remarkably realized.

[0106] Furthermore, in one exemplary embodiment, the method MT may be used to, for example, etch an etching layer EL having an MTJ region including a film of a hard-to-volatile material. In this case, a mask residual film of 40 nm or more and a CD having a mask shape of 40 nm or less can be sufficiently realized. As described above, the MTJ region has a hard-to-volatile material, but the method MT may be applied to the etching layer having the MTJ region of the hard-to-volatile material in this way.

[0107] Furthermore, since the electrode material of Ru or C can be used for the first film F**1**, the formation of the first film F**1** can be relatively easily performed. For example, when the etching layer EL includes an MTJ junction region, the MTJ region includes a Ru layer. Therefore, the formation of the first film F**1** can be more easily performed by using Ru of the Ru layer.

[0108] It may be considered that the etching layer EL includes a plurality of electrode material layers ED (the layer LY**3** having Ru, the layer LY**8**, the layer LY**16**) arranged apart from each other as in the configuration of the substrate W illustrated in FIG. **6**. In this case, step ST**1**, step ST**2**, and step ST**3** may be repeatedly executed using the plurality of electrode material layers ED. In this case, in step ST**1**, the first film F**1** is formed by an etching process on the

electrode material layer ED. It may also be considered that the method MT includes both step ST**1** of forming the first film F**1** by the etching process and step ST**1** of forming the first film F**1** by the film forming process.

[0109] Although various exemplary embodiments have been described above, various omissions, substitutions, and modifications may be made without being limited to the aforementioned exemplary embodiments. Also, elements in different embodiments may be combined to form different embodiments.

[0110] From the foregoing, it should be understood that various embodiments of the present disclosure have been described herein for purposes of illustration, and that various modifications can be made without departing from the scope and spirit of the present disclosure. Accordingly, the various exemplary embodiments disclosed herein are not intended to be limiting, and the true scope and spirit thereof are represented by the appended claims.

EXPLANATION OF REFERENCE NUMERALS

[0111] **1**: processing system, **10**: plasma processing apparatus, **11**: carrier mounting port, **12**: processing container, **120**: atmospheric transfer chamber, **120***a*: alignment chamber, **121**: transfer arm, **12***c*: chamber, **12***g*: opening, **12***s*: sidewall, **13**: vacuum transfer chamber, **131**: transfer arm, **14**: gate valve, **15**: support part, **16**: stage, **18**: lower electrode, **18***a*: first plate, **18***b*: second plate, **18***f*: flow path, **20**: electrostatic chuck, **22**: direct current power supply, **23**: switch, **24**: focus ring, **26***a*: pipe, **26***b*: pipe, **28**: gas supply line, **30**: upper electrode, **32**: member, **34**: ceiling plate, **34***a*: gas discharge hole, **36**: support, **36***a*: gas diffusion chamber, **36***b*: gas hole, **36***c*: gas introduction port, **38**: gas supply pipe, **40**: gas source group, **42**: valve group, **44**: flow rate controller group, **48**: baffle plate, **50**: exhaust device, **52**: exhaust pipe, **62**: first high frequency power supply, **63**: matching device, **64**: second high frequency power supply, **65**: matching device, C: transfer vessel, Cnt: controller, CP**1**: first film forming part, CP**2**: second film forming part, CP**3**: film removing part, ED: electrode material layer, EL: etching layer, FS**1**: surface, FS**2**: surface, F**1**: first film, F**2**: second film, G**1**: door, G**2**: door valve, G**3**: gate valve, G**4**: gate valve, HP: heater power supply, HT: temperature adjusting part, LLM**1**: load lock module, LLM**2**: load lock module, LS: stage, LY**1** to LY**20**: layer, MK**1**: mask, MK**2**: mask, MT: method, PM**1**: processing module, PM**2**: processing module, PM**3**: processing module, PM**4**: processing module, PS: processing container, RA: region, RB: region, SW: support substrate, W: substrate

1. A method of processing a substrate, wherein the substrate includes an etching layer and a mask, and the mask is formed on a first surface of the etching layer, the method comprising:

a first step of forming a first film on a second surface of the mask;

a second step of forming a second film having a material of the etching layer on the first film by etching the first surface of the etching layer; and

a third step of removing the first film and the second film by exposing the substrate after the second step to plasma of a processing gas,

wherein the first film has an electrode material, and the processing gas includes oxygen.

2. The method of claim **1**, wherein the etching layer includes an electrode material layer, and the electrode material layer extends to the first surface, and

wherein in the first step, the first film is formed by etching the electrode material layer and sputtering the material of the electrode material layer.

3. The method of claim **1**, wherein in the first step, the first film is formed by a chemical vapor deposition or a physical vapor deposition.

4. The method of claim **1**, wherein a series of steps of the first step, the second step, and the third step are repeatedly executed.

5. The method of claim **1**, wherein the etching layer includes a magnetic tunnel junction region.

6. The method of claim **1**, wherein the first film has an electrode material of ruthenium or carbon.

7. A substrate processing apparatus, comprising:

a processing container configured to accommodate a substrate; and

a controller configured to control the substrate processing apparatus,

wherein the controller includes:

a first film forming part configured to control the substrate processing apparatus so as to form a first film having an electrode material on a second surface of a mask when the substrate accommodated in the processing container includes an etching layer and the mask and the mask is formed on a first surface of the etching layer;

a second film forming part configured to control the substrate processing apparatus so as to form a second film having the material of the etching layer on the first film by etching the first surface of the etching layer after the formation of the first film by the first film forming part; and

a film removing part configured to control the substrate processing apparatus so as to remove the first film and the second film by exposing the substrate on which the second film is formed by the second film forming part to plasma of a processing gas including oxygen.

8. The substrate processing apparatus of claim **7**, wherein when the etching layer includes an electrode material layer and the electrode material layer extends to the first surface, the first film forming part is configured to control the substrate processing apparatus so as to form the first film by etching the electrode material layer and sputtering the material of the electrode material layer.

9. A processing system for processing a substrate, comprising:

a film forming apparatus configured to perform a film forming process on the substrate;

an etching apparatus configured to perform an etching process on the substrate; and

a controller configured to control the processing system,

wherein the controller includes:

a first film forming part configured to control the processing system so as to form a first film having an electrode material on a second surface of a mask when the substrate accommodated in the processing container includes an etching layer and the mask and the mask is formed on a first surface of the etching layer;

a second film forming part configured to control the processing system so as to form a second film having the material of the etching layer on the first film by transferring the substrate to the etching apparatus and etching the first surface of the etching layer after the formation of the first film by the first film forming part; and

a film removing part configured to control the processing system so as to remove the first film and the second film by exposing the substrate on which the second film is formed by the second film forming part to plasma of a processing gas including oxygen.

10. The processing system of claim **9**, wherein the first film forming part is configured to control the processing system so as to form the first film by a chemical vapor deposition or a physical vapor deposition.

* * * * *