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(54) Title: FORMING COBALT INTERCONNECTIONS ON A SUBSTRATE

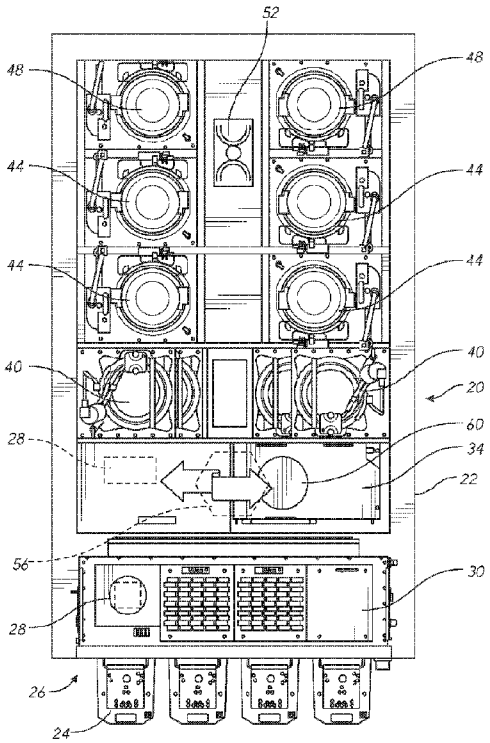


FIG. 1

(57) Abstract: A wafer electroplating system has at least one first electroplating chamber having a first electrolyte containing cobalt ions, and is adapted to electroplate a cobalt film onto a wafer at a first deposition rate. A second electroplating chamber has a second electrolyte containing cobalt ions, and is adapted to electroplate a cobalt film onto the wafer at a second deposition rate faster than the first deposition rate. The first and second electroplating chambers are within an enclosure of a processing system. A robot moves a wafer among the first and second electroplating chambers.

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FORMING COBALT INTERCONNECTIONS ON A SUBSTRATE

FIELD OF THE INVENTION

[0001] The field of the invention is systems and methods for electrochemically processing micro-scale work pieces, wafers or substrates.

BACKGROUND OF THE INVENTION

[0002] Microelectronic devices, such as micro-scale electronic, electro-mechanical or optical devices are generally fabricated on and/or in work pieces or substrates, such as silicon wafers. In a typical fabrication process, a wafer is placed in an electrolyte containing metal ions. A blanket layer or patterned layer of metal is plated onto the substrate by conducting electric current through the electrolyte and through a seed layer on the substrate. The substrate is then cleaned, etched and/or annealed in subsequent procedures, to form devices, contacts or conductive lines.

[0003] Currently, most micro-electronic devices are made on substrates plated with copper. Although copper has high conductivity, it typically requires a barrier layer such as tantalum nitride (TaN) to prevent diffusion of copper into the substrate. As the features get smaller, the barrier layer required for copper occupies a relatively larger volume, because a minimum barrier layer thickness must be maintained to prevent copper diffusion, regardless of feature size. In addition, consistently obtaining void-free copper filling of ever smaller features is increasingly difficult.

[0004] One approach proposed for overcoming these technical challenges is to replace copper with a metal that does not require a barrier layer, such as cobalt. Although cobalt has a higher resistance than copper (6uOhm-cm for cobalt versus 2uOhm-cm for copper), cobalt may not require a barrier layer because it does not

diffuse into the silicon or dielectric. Using cobalt instead of copper may also help to overcome the increased copper resistivity due to scattering of the charge carrying electrons and the decrease in the cross sections of the conductor lines. However, existing systems and methods for plating cobalt for this purpose are disadvantageous relative to currently available copper processes. Accordingly, improved systems and methods for creating microelectronic devices with cobalt are needed.

SUMMARY OF THE INVENTION

[0005] A wafer electroplating system has at least one first electroplating chamber having a first electrolyte containing cobalt ions, and is adapted to electroplate a cobalt film onto a wafer at a first deposition rate. A second electroplating chamber has a second electrolyte containing cobalt ions, and is adapted to electroplate a cobalt film onto the wafer at a second deposition rate faster than the first deposition rate. The first and second electroplating chambers are within an enclosure of a processing system. A robot moves a wafer among the first and second electroplating chambers. A system having a single plating chamber may also be used.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] Fig. 1 is a schematic plan view of a processing apparatus.

[0007] Fig. 2 is a flow chart, split over two drawing sheets, showing a process which may be performed using the apparatus of Fig. 1.

[0008] Fig. 3 is a schematic plan view of an alternative processing apparatus.

[0009] Fig. 4 is a schematic plan view of another alternative processing apparatus.

DETAILED DESCRIPTION

[0010] As shown in Fig. 1 a processing system 20 has multiple processing apparatus, chambers or stations within an enclosure 22. In a typical configuration, a docking station 26 is provided at a front end of the enclosure. Containers 24 holding wafers 60 are docked and unsealed at the docking station. A load robot 36 moves wafers 60 from docked containers 24 into one or more stations in the enclosure 22. One or more plasma or thermal treatment chambers 30, anneal chambers 34, wafer clean chambers 40, slow cobalt plating chambers 44 and fast cobalt plating chambers may be used. In the example shown, two wafer clean chambers 40, four slow cobalt plating chambers 44 and two fast cobalt plating chambers 48 are shown. The chambers may be modular units that can be individually swapped out of the system 20 for maintenance or repair. A process robot 52 moves wafers 60 among the chambers. A buffer 56 in the form of stacked shelves may be provided to facilitate handoff of wafers from the load robot 36 to the process robot 52, and vice versa.

[0011] In the example of Fig. 1, the four slow cobalt plating chambers 44 and the two fast cobalt plating chambers 48 enable high volume manufacture of cobalt interconnects. As shown in Fig. 2, the system 20 of Fig. 1 may perform processing of wafers beginning at step 102 where a wafer container 24 is loaded or docked on or at the system 20. Wafers 60 in the container 24 have a conductive seed layer. At step 104 the load robot 36 removes a wafer 60 from the wafer container 24. If the wafer container 24 is sealed with the enclosure 22 of the system 20, the wafer 60 may be maintained in a controlled environment at all times. The controlled environment may be

a low oxygen environment to prevent oxidation of the seed layer, or other surfaces of the wafer 60.

[0012] If the wafer 60 has a notch, typically used to indicate a crystal orientation, at step 106 the wafer may be rotated slightly to align the notch, at an alignment station 28. The load robot 36 optionally then moves the wafer 60 from the alignment station 28 (if used) to the plasma chamber 30 to provide a thermal or plasma pretreatment step to reduce or remove oxidation from the seed layer. This step may optionally be performed in upstream equipment before the wafer 60 is delivered to the system 20. This step and the notch alignment steps may be omitted.

[0013] The load robot 36 then hands off the wafer to the process robot 52, typically with the wafer temporarily placed on a shelf or buffer 56. At step 110 the process robot 52 moves the wafer 60 into one of the slow cobalt plating chambers 44. These chambers 44 may have a wet contact ring, i.e., a contact ring that does not make a liquid-tight seal against the wafer surface. The wet contact ring allows deposition of cobalt onto the seed layer, out to the edge of the wafer 60. At step 112 cobalt is electroplated onto the seed layer of the wafer 60 within a slow cobalt plating chamber 44. This plating step 112 is intentionally designed as a slow process that may be optimized for filling extremely small features in a wafer having a high resistance seed layer. Step 112 continues until the features are filled with plated cobalt.

[0014] After the features are filled, the wafer is then moved at step 114 to a cleaning chamber 40 to remove any electrolyte left on the wafer from the slow cobalt plating process at step 112. At step 116 the wafer 60 may be moved to the anneal

chamber 34 for annealing to improve the plated cobalt film properties and gap fill performance of the plated cobalt in the filled features.

[0015] As shown by the dotted line in Fig. 2 running from step 116 back up to step 112, multiple cycles of slow cobalt plating may be used, with each cycle partially filling the features of the wafer, and with each slow cobalt plating step 112 followed by an annealing step 116. After the features are filled using step 112 one or more times, the wafer 60 may be optionally cleaned again at step 114 and then moved by the process robot 52 to one of the fast cobalt plating chambers 48, where at step 118 an overburden layer of cobalt is applied onto the wafer 60. The overburden layer acts as a sacrificial layer for a subsequent Chemical Mechanical Planarization or CMP step.

[0016] The fast cobalt plating chambers 48 may use a wet contact ring or a dry contact ring. Typically the fast cobalt plating chambers 48 also use an electrolyte different from the electrolyte in the slow cobalt plating chambers 44. A dry contact ring refers to a contact ring having a seal which seals the electrolyte away from the electrical contacts or fingers of the contact ring. The fast cobalt plating chambers 48 may deposit a cobalt film at a rate 2 or 5- to 20 times faster than the slow cobalt plating chambers.

[0017] The wafer 60 is then optionally rinsed and dried at step 120, and/or bevel etched or backside cleaned at step 122, with or without a follow on anneal at step 124. At step 126 the wafer 60 is returned to a wafer container 24. The wafer container 24 is then moved via factory automation to a subsequent system for downstream processing.

[0018] The plating steps in the slow and fast cobalt plating chambers 44 and 48 may be controlled using an algorithm so that wafers can be run in parallel using multiple slow and fast chambers simultaneously, to enable wafer throughput to meet high

volume manufacturing needs. The use of the slow and fast plating steps 112 and 118 produces wafers having essentially a single cobalt plated film filling the pattern on the wafer, and an overburden layer with no detectable interface between the plated film and the seed layer.

[0019] Fig. 3 shows an alternative system 70 including a rinse/dry and/or bevel etch chamber 72, two wafer cleaning chambers 40, and a total of five slow and fast cobalt plating chambers. Depending on the specific application, in this configuration, there may be four or three slow cobalt plating chambers and one or two fast cobalt plating chambers.

[0020] Fig. 4 shows an alternative compact system 80 having a single slow cobalt plating chamber 44 and a single additional chamber 40 for cleaning the wafer by spin rinsing and drying the wafer, and optionally also providing a bevel etch process. This compact system may be paired with another similar compact system having a single fast cobalt plating chamber 48, and a single additional chamber 40 for cleaning and/or bevel etching the wafer. After processing in the first system 80, the wafer is moved into the second system to complete the plating process. Several of the compact systems 80 having the slow cobalt plating chamber 44 may be matched up and operate with a single system 80 having a fast cobalt plating chamber.

[0021] Various known electro-chemical deposition or plating chambers may be used as the slow cobalt plating chambers 44 and as the fast cobalt plating chambers 48, such as the plating chambers described in U.S. Patent No. 8,496,790. As used here, the term wafer includes any substrate on which microelectronic or other micro-scale devices are formed.

[0022] Cobalt is several times more resistive than copper. The resistance between a cobalt containing seed layer and the contact pins of the contact ring may therefore be much higher than with copper. If the contact pins are exposed to air, joule heating may burn the seed layer, resulting in defects. This effect may be avoided using a wet contact ring (having no seal) where the contact pins and the entire seed layer are immersed in the electrolyte, which largely negates joule heating. As a result, for plating a more highly resistive seed layer, such as a cobalt or nickel seed layer, having a resistance of e.g., greater than 50, 100 or 200 ohms/square (and up to e.g., 1000 or 5000 ohms/square), a wet contact ring may advantageously be used, for example in the slow plating chamber. After the initial plating, when the metal layer is much less resistive, as when plating in the fast plating chamber, a dry plating ring may be used.

CLAIMS

1. A processing system comprising:

an enclosure having a wafer loading station;

at least one first electroplating chamber within the enclosure and having a first electrolyte containing cobalt ions, with the first electroplating chamber adapted to electroplate a cobalt film onto a wafer at a first deposition rate; and

at least one second electroplating chamber within the enclosure and having a second electrolyte containing cobalt ions, with the second electroplating chamber adapted to electroplate a cobalt film onto a wafer at a second deposition rate, and with the second deposition rate faster than the first deposition rate; and

at least one robot for moving a wafer from the loading station to one or more of the first and/or second electroplating chambers.

2. The processing system of claim 1 with at least one of the first and second electroplating chambers having a wet contact ring.

3. The processing system of claim 2 with the second electroplating chamber having a dry contact ring.

4. The processing system of claim 1 with the second deposition rate five to twenty times greater than the first deposition rate.

5. The processing system of claim 1 further including an anneal chamber within the enclosure.

6. The processing system of claim 5 further including a plasma or thermal pretreatment chamber within the enclosure.

7. The processing system of claim 1 having twice as many first electroplating chambers relative to second electroplating chambers.

8. The processing system of claim 1 further including:

a plurality first electroplating chambers within the enclosure, with each first electroplating chamber having the first electrolyte containing cobalt ions, and with each first electroplating chamber adapted to electroplate a cobalt film onto a wafer at the first deposition rate;

a plurality second electroplating chambers within the enclosure, with each second electroplating chamber having the second electrolyte containing cobalt ions, and with each second electroplating chamber adapted to electroplate a cobalt film onto a wafer at the second deposition rate; and

at least two robots within the enclosure, with one robot adapted to move wafers from the first electroplating chambers to the second electroplating chambers.

9. The processing system of claim 8 having three of the first electroplating chambers and one of the second electroplating chambers.

10. The processing system of claim 1 further including a controller electrically linked to the first and second electroplating chambers and to the robot, with the controller having an algorithm adapted to control operations of the chambers and the robot.

11. The processing system of claim 1 comprising a first wafer cleaning chamber, two first electroplating chambers, and a second electroplating chamber in a first column within the enclosure, and a second wafer cleaning chamber, two first electroplating chambers, and a second electroplating chamber in a second column within the enclosure, and with the robot movable linearly in a channel between the first and second columns.

12. A processing method comprising:

A] placing a wafer into a first electroplating chamber having a first electrolyte containing cobalt ions;

B] electroplating a first cobalt film onto the wafer at a first deposition rate;

C] rinsing and drying the wafer;

D] placing the wafer into a second electroplating chamber having a second electrolyte containing cobalt ions; and

E] electroplating a second cobalt film onto the wafer at a second deposition rate two to twenty times faster than the first deposition rate.

13. The method of claim 12 wherein the first and second electroplating chambers are within a single enclosure, and further including annealing the wafer within the enclosure after step B and before step C.

14. The method of claim 13 further including plasma or thermally pretreating the wafer within the enclosure.

15. The method of claim 12 further including annealing the wafer after step B and then repeating step B at least once.

16. The method of claim 12 wherein in step B the first electrolyte touches an entire down-facing surface of the wafer.

17. The method of claim 16 wherein in step D, the second electrolyte is sealed off from electrical contacts at a perimeter of the wafer.

18. The method of claim 12 further including annealing the wafer after step D.

19. The method of claim 12 wherein the first electrolyte is different from the second electrolyte.

20. A processing system comprising:

a first subsystem having at least one first electroplating chamber containing a first electrolyte containing cobalt ions, with the first electroplating chamber adapted to electroplate a cobalt film onto a wafer at a first deposition rate; and

at least one second subsystem having a second electroplating chamber holding a second electrolyte containing cobalt ions, with the second electroplating chamber adapted to electroplate a cobalt film onto a wafer at a second deposition rate, and with the second deposition rate faster than the first deposition rate.

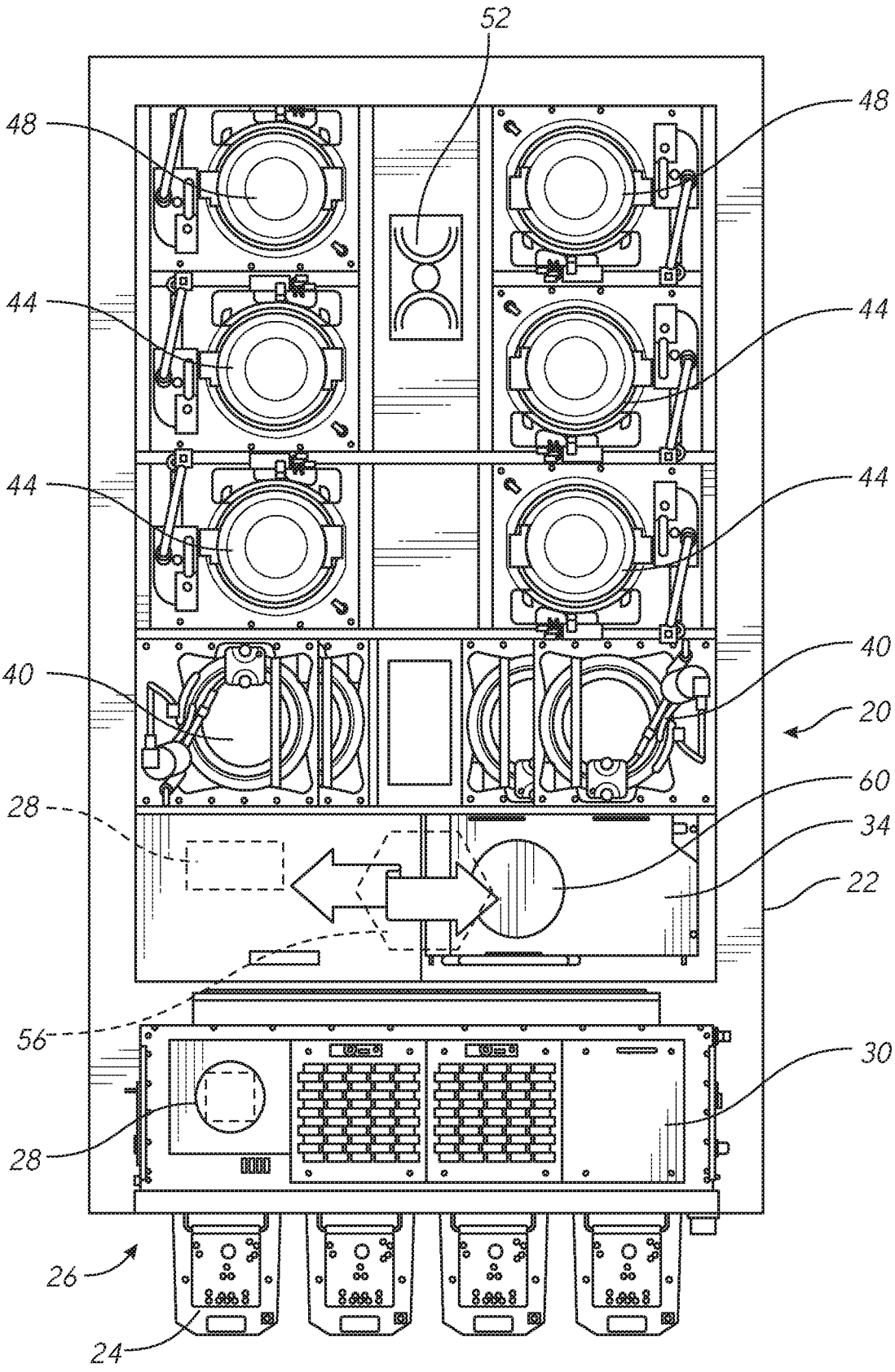


FIG. 1

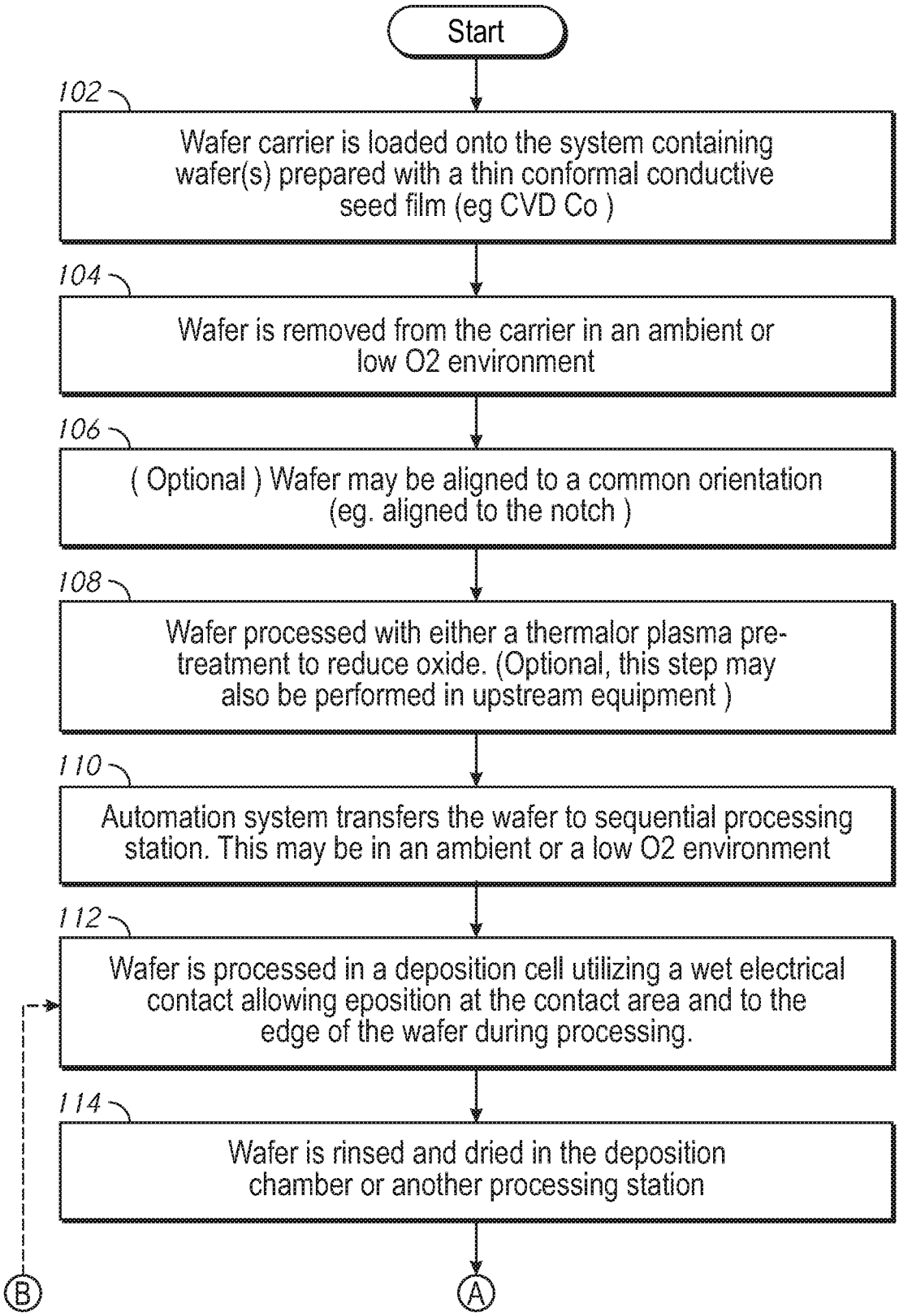

Start
102
Wafer carrier is loaded onto the system containing wafer(s) prepared with a thin conformal conductive seed film (eg CVD Co)
104
Wafer is removed from the carrier in an ambient or low O2 environment
106
(Optional) Wafer may be aligned to a common orientation (eg. aligned to the notch)
108
Wafer processed with either a thermalor plasma pre-treatment to reduce oxide. (Optional, this step may also be performed in upstream equipment)
110
Automation system transfers the wafer to sequential processing station. This may be in an ambient or a low O2 environment
112
Wafer is processed in a deposition cell utilizing a wet electrical contact allowing eposition at the contact area and to the edge of the wafer during processing.
114
Wafer is rinsed and dried in the deposition chamber or another processing station
B
A

FIG. 2

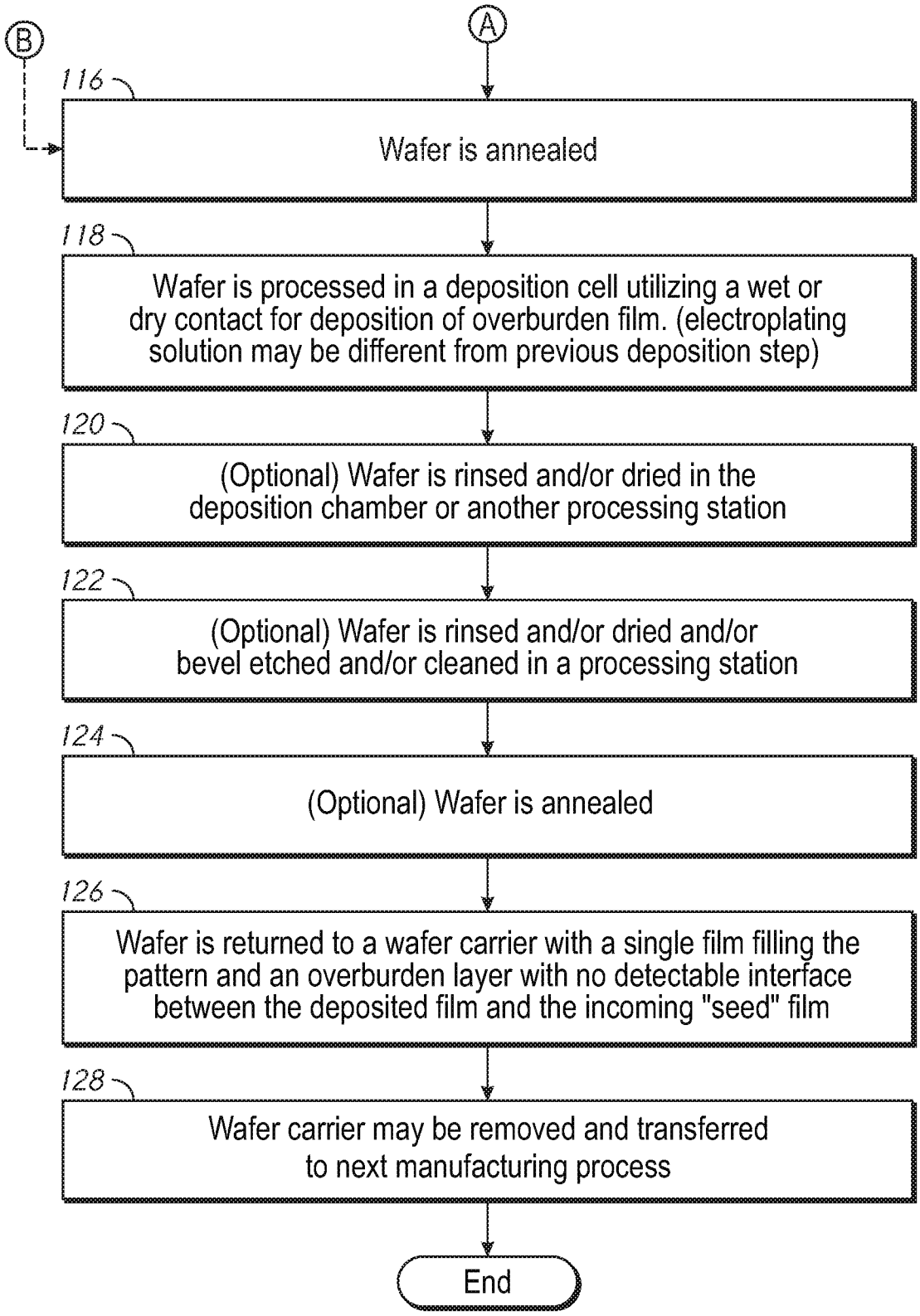


FIG. 2 (Continued)

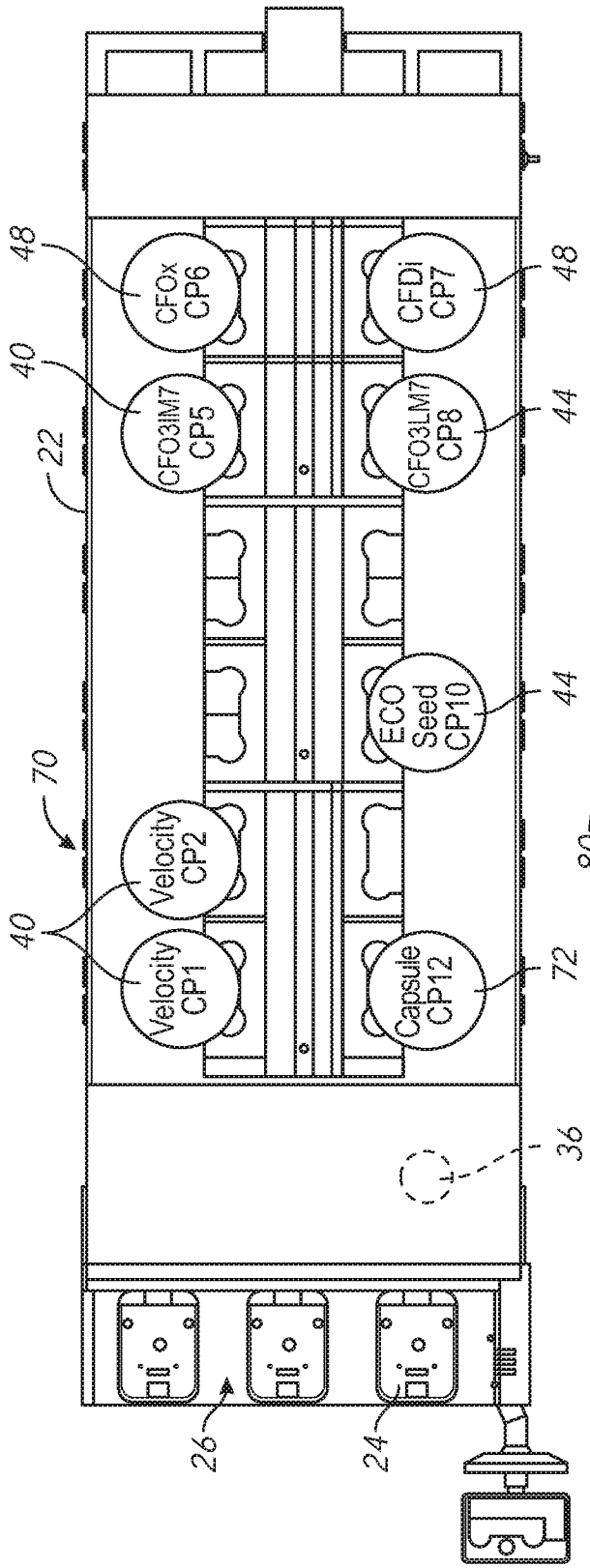

CFOx CP6
CFDi CP7
CFO3IM7 CP5
CFO3LM7 CP8
ECO Seed CP10
Velocity CP2
Velocity CP1
Capsule CP12
48
48
40
44
22
44
70
40
72
36
26
24

FIG. 3

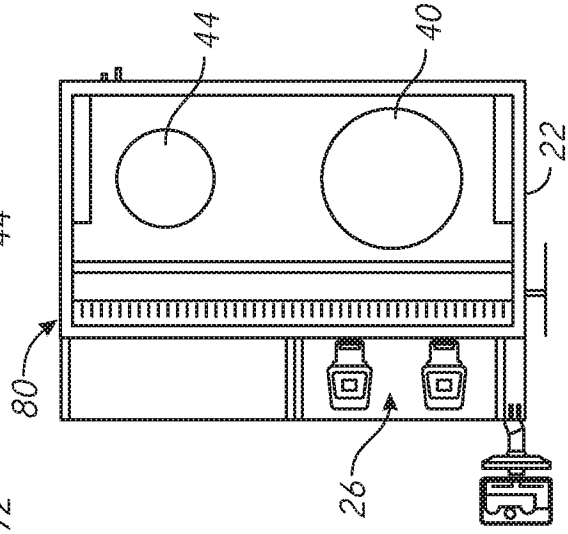

44
40
22
80
26

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/067903

A. CLASSIFICATION OF SUBJECT MATTER

H01L 21/288(2006.01)i, H01L 21/677(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L 21/288; C25D 3/38; H01L 21/28; C23C 18/16; H01L 21/683; C23C 18/18; H01L 31/042; H01L 21/677

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: electroplating, cobalt, deposition rate, cleaning, electrolyte

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	JP 2004-346399 A (EBARA CORP.) 09 December 2004 See paragraphs [0042]-[0044], claims 1, 10 and figure 2.	1-20
A	US 2005-0081744 A1 (JOHN L. KLOCKE et al.) 21 April 2005 See paragraphs [0062]-[0072], claim 1 and figures 8(a)-9(b).	1-20
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A	KR 10-2008-0010801 A (DONGBU ELECTRONICS CO., LTD.) 31 January 2008 See paragraphs [0022]-[0042], claims 1, 5 and figures 3-5.	1-20

☐ 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
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"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
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INTERNATIONAL SEARCH REPORT

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