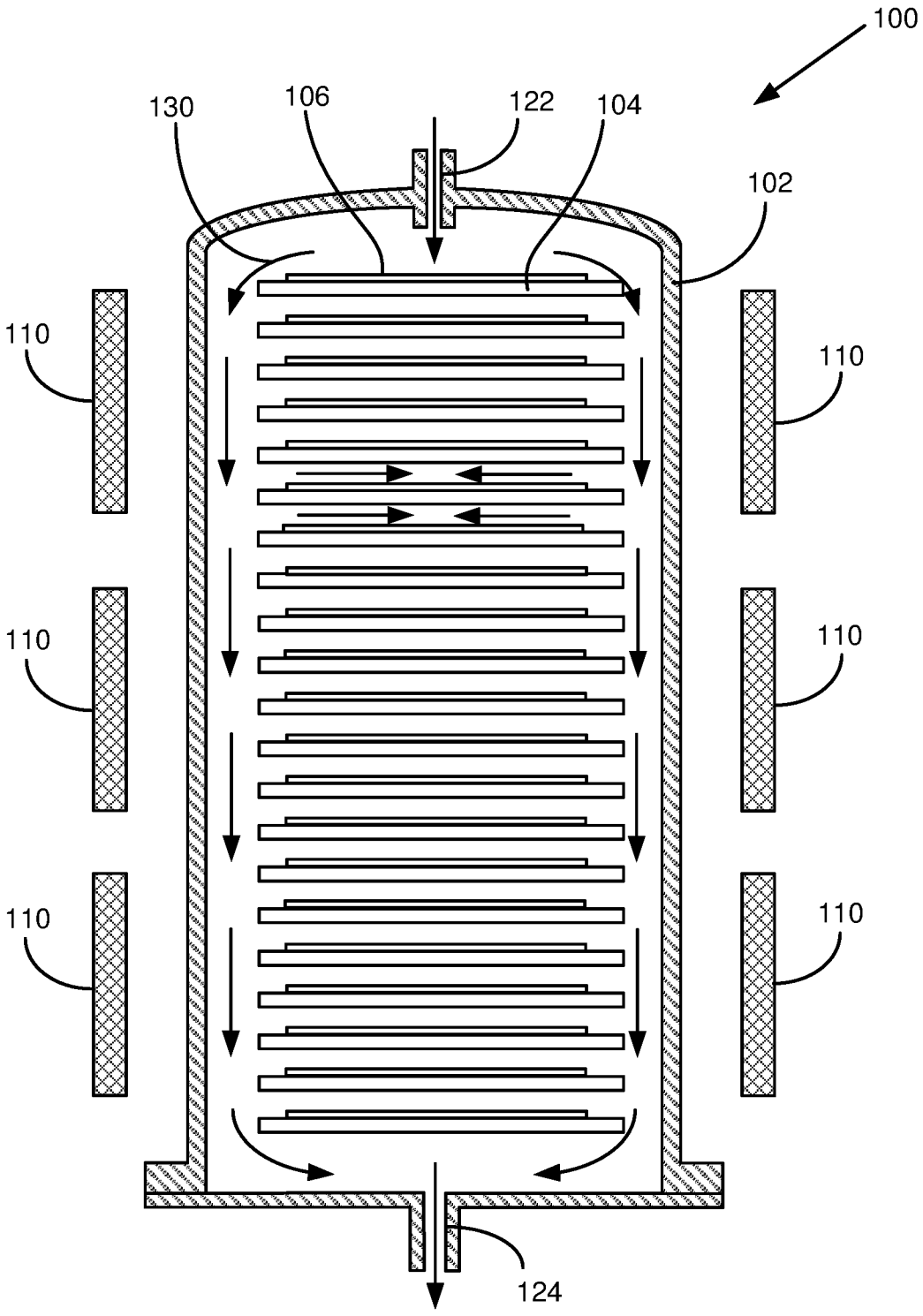


FIG. 1

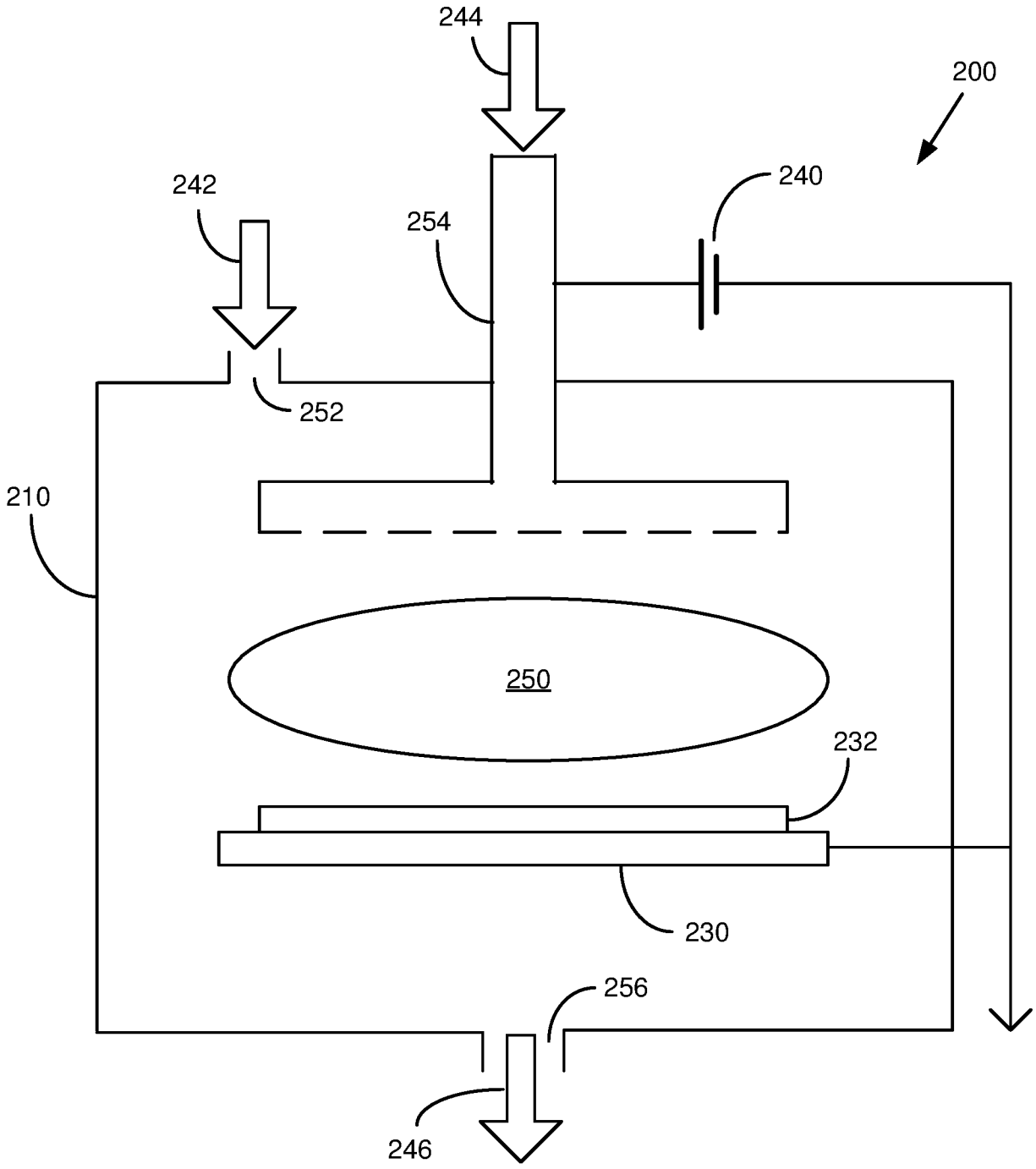


FIG. 2

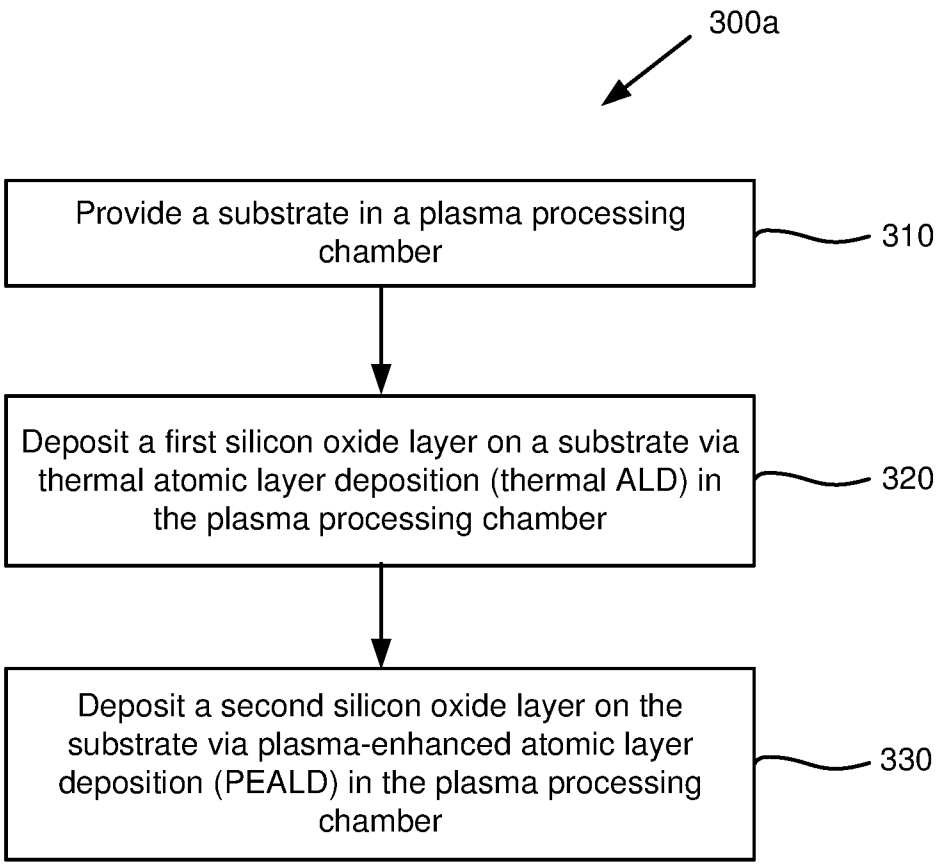

300a
Provide a substrate in a plasma processing chamber
310
Deposit a first silicon oxide layer on a substrate via thermal atomic layer deposition (thermal ALD) in the plasma processing chamber
320
Deposit a second silicon oxide layer on the substrate via plasma-enhanced atomic layer deposition (PEALD) in the plasma processing chamber
330

FIG. 3A

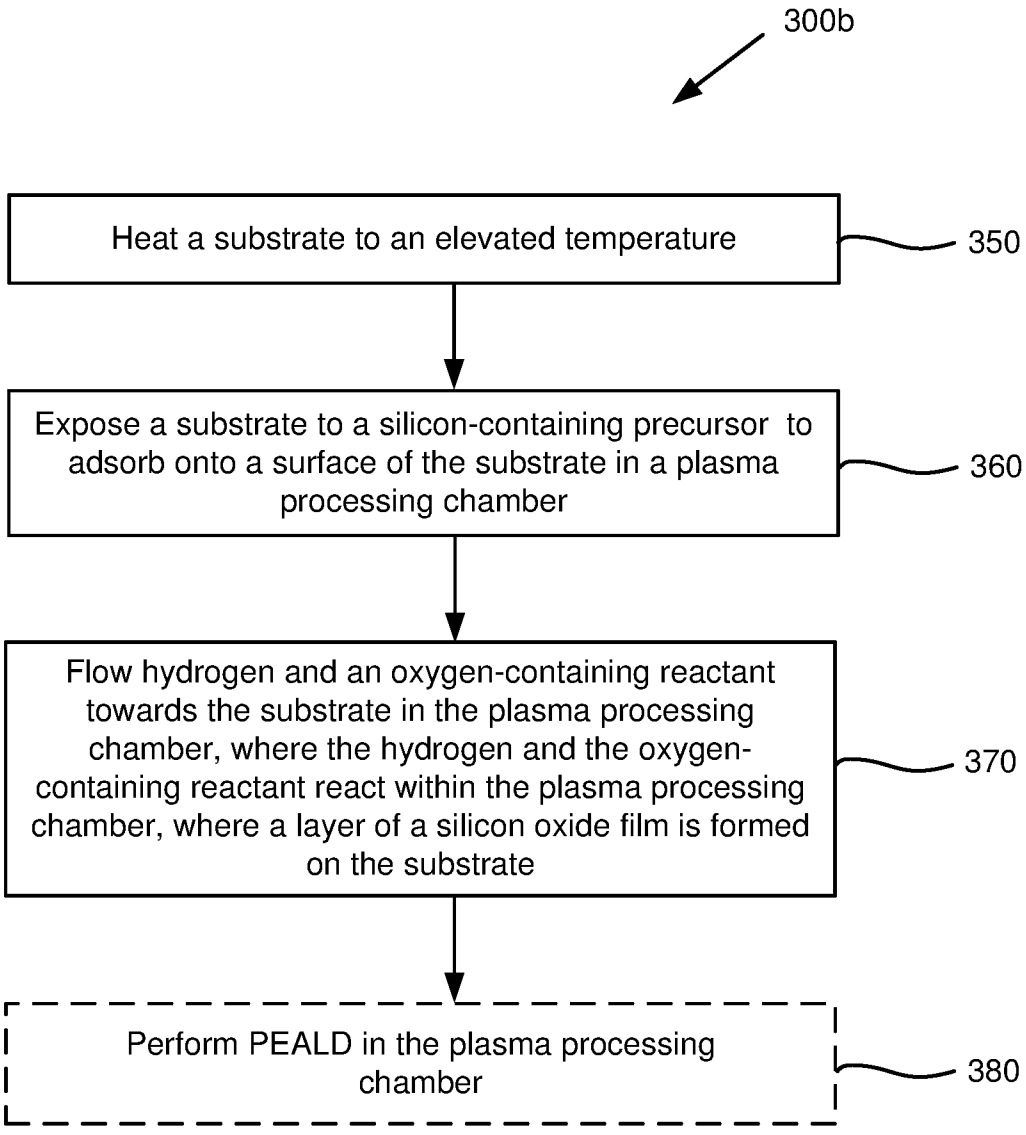

300b
Heat a substrate to an elevated temperature
350
Expose a substrate to a silicon-containing precursor to adsorb onto a surface of the substrate in a plasma processing chamber
360
Flow hydrogen and an oxygen-containing reactant towards the substrate in the plasma processing chamber, where the hydrogen and the oxygen-containing reactant react within the plasma processing chamber, where a layer of a silicon oxide film is formed on the substrate
370
Perform PEALD in the plasma processing chamber
380

FIG. 3B

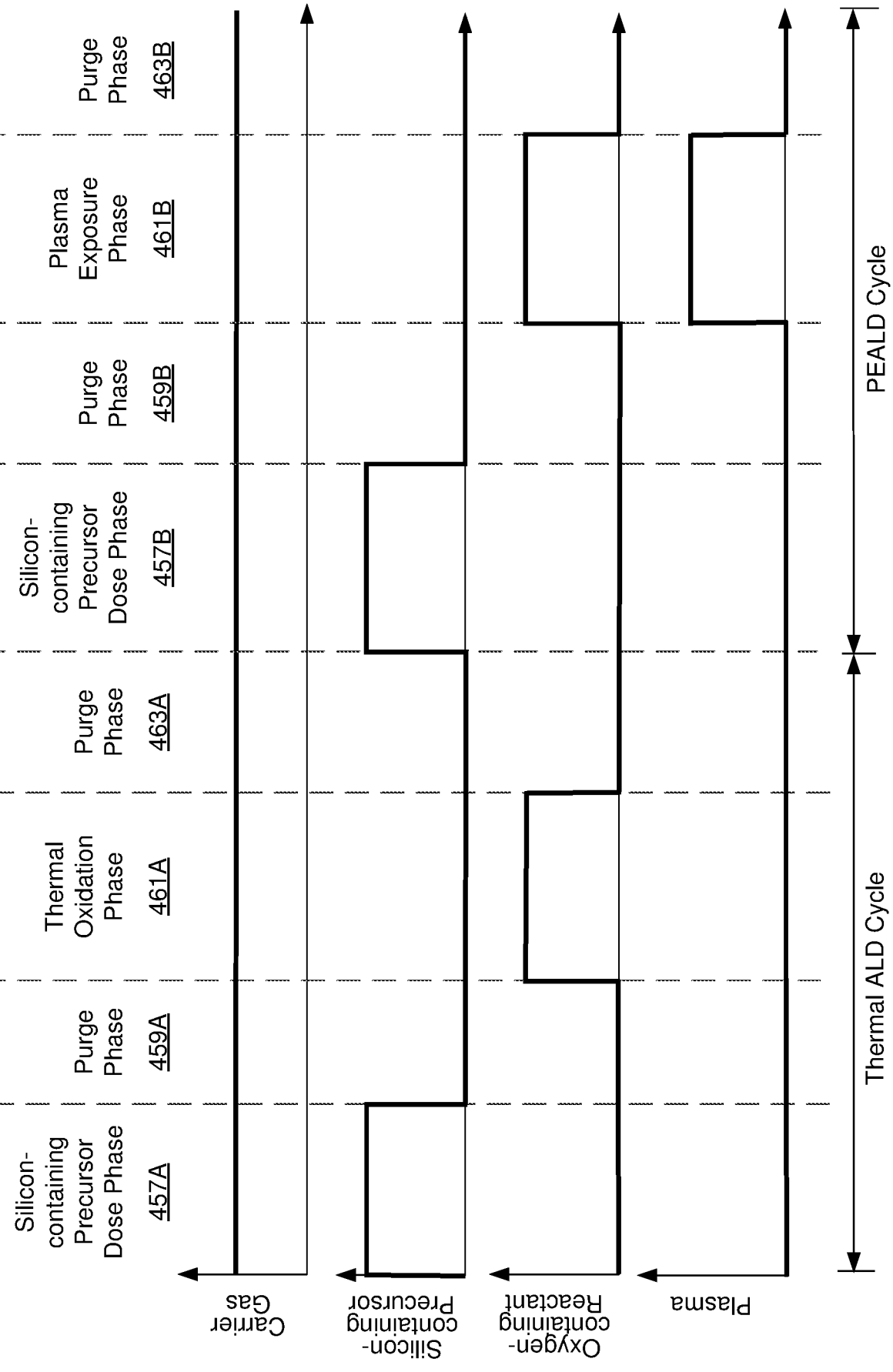

Carrier Gas
Silicon-containing Precursor
Oxygen-containing Reactant
Plasma
Silicon-containing Precursor Dose Phase 457A
Purge Phase 459A
Thermal Oxidation Phase 461A
Purge Phase 463A
Silicon-containing Precursor Dose Phase 457B
Purge Phase 459B
Plasma Exposure Phase 461B
Purge Phase 463B
Thermal ALD Cycle 410A
PEALD Cycle 410B

FIG. 4

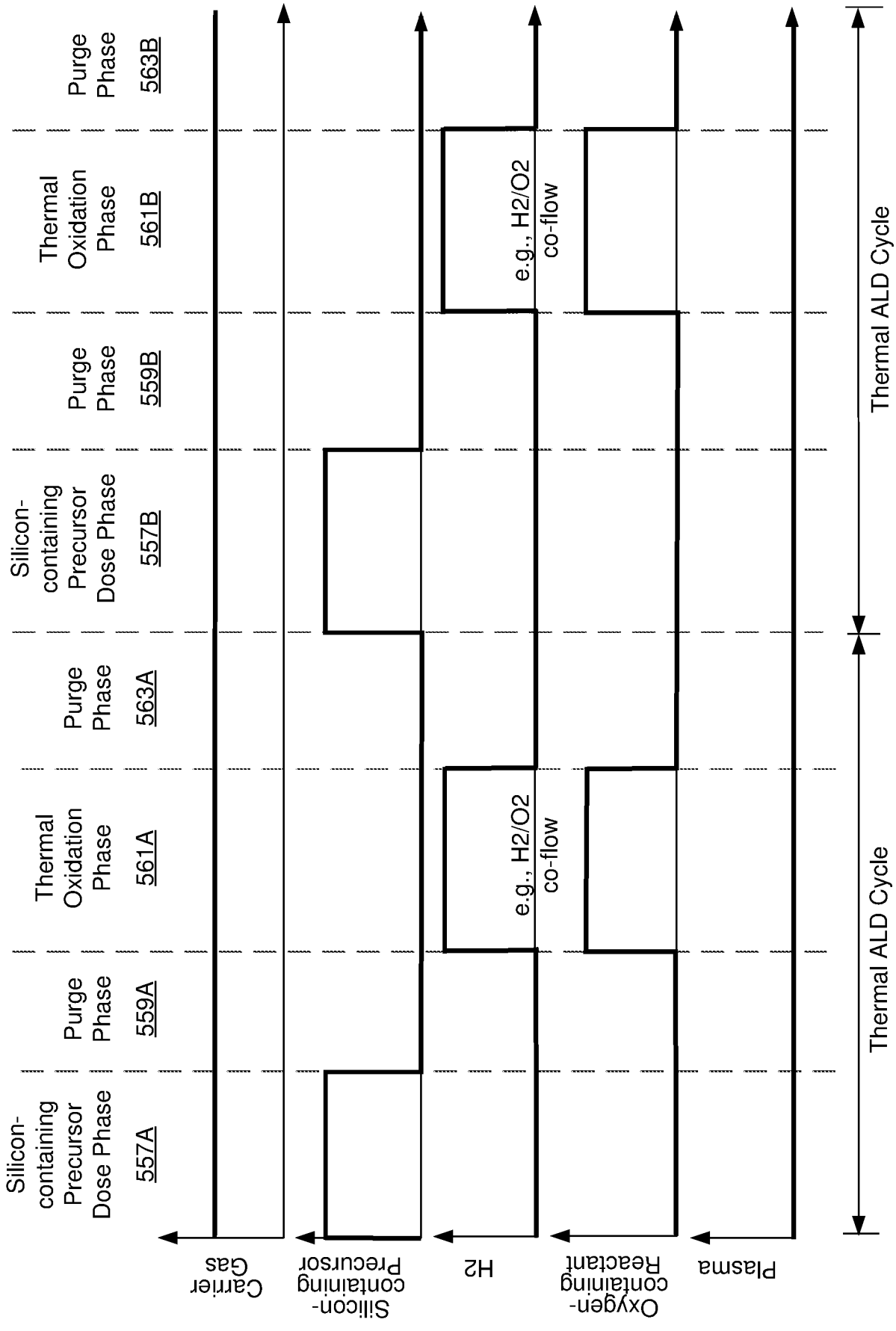

Silicon-containing Precursor Dose Phase 557A
Purge Phase 559A
Thermal Oxidation Phase 561A
Purge Phase 563A
Silicon-containing Precursor Dose Phase 557B
Purge Phase 559B
Thermal Oxidation Phase 561B
Purge Phase 563B
Carrier Gas
Silicon-containing Precursor
H2
Oxygen-containing Reactant
Plasma
e.g., H2/O2 co-flow
e.g., H2/O2 co-flow
Thermal ALD Cycle 510A
Thermal ALD Cycle 510B

FIG. 5

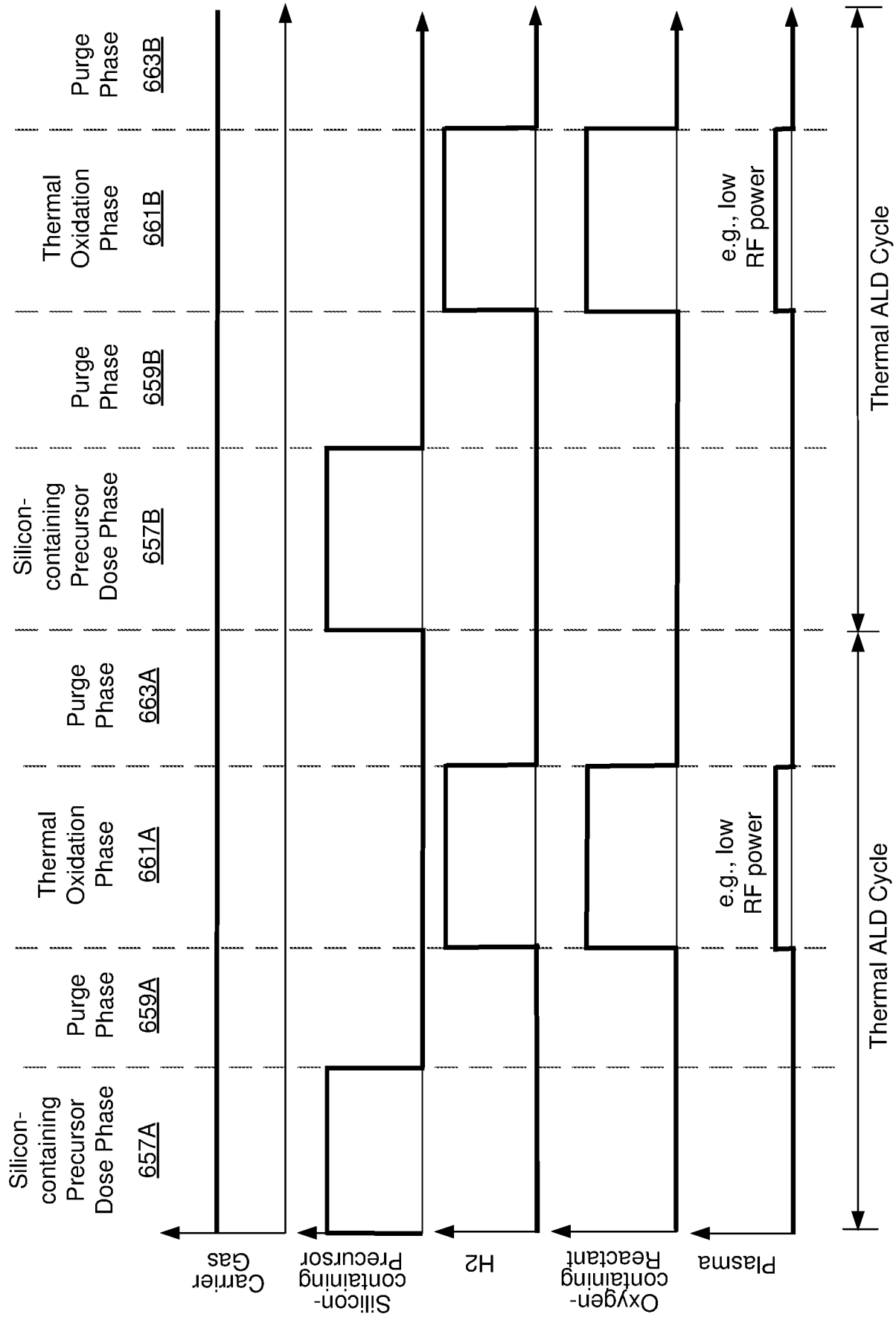

Silicon-containing Precursor Dose Phase 657A
Purge Phase 659A
Thermal Oxidation Phase 661A
Purge Phase 663A
Silicon-containing Precursor Dose Phase 657B
Purge Phase 659B
Thermal Oxidation Phase 661B
Purge Phase 663B
Carrier Gas
Silicon-containing Precursor
H2
Oxygen-containing Reactant
Plasma
e.g., low RF power
e.g., low RF power
Thermal ALD Cycle 610A
Thermal ALD Cycle 610B

FIG. 6

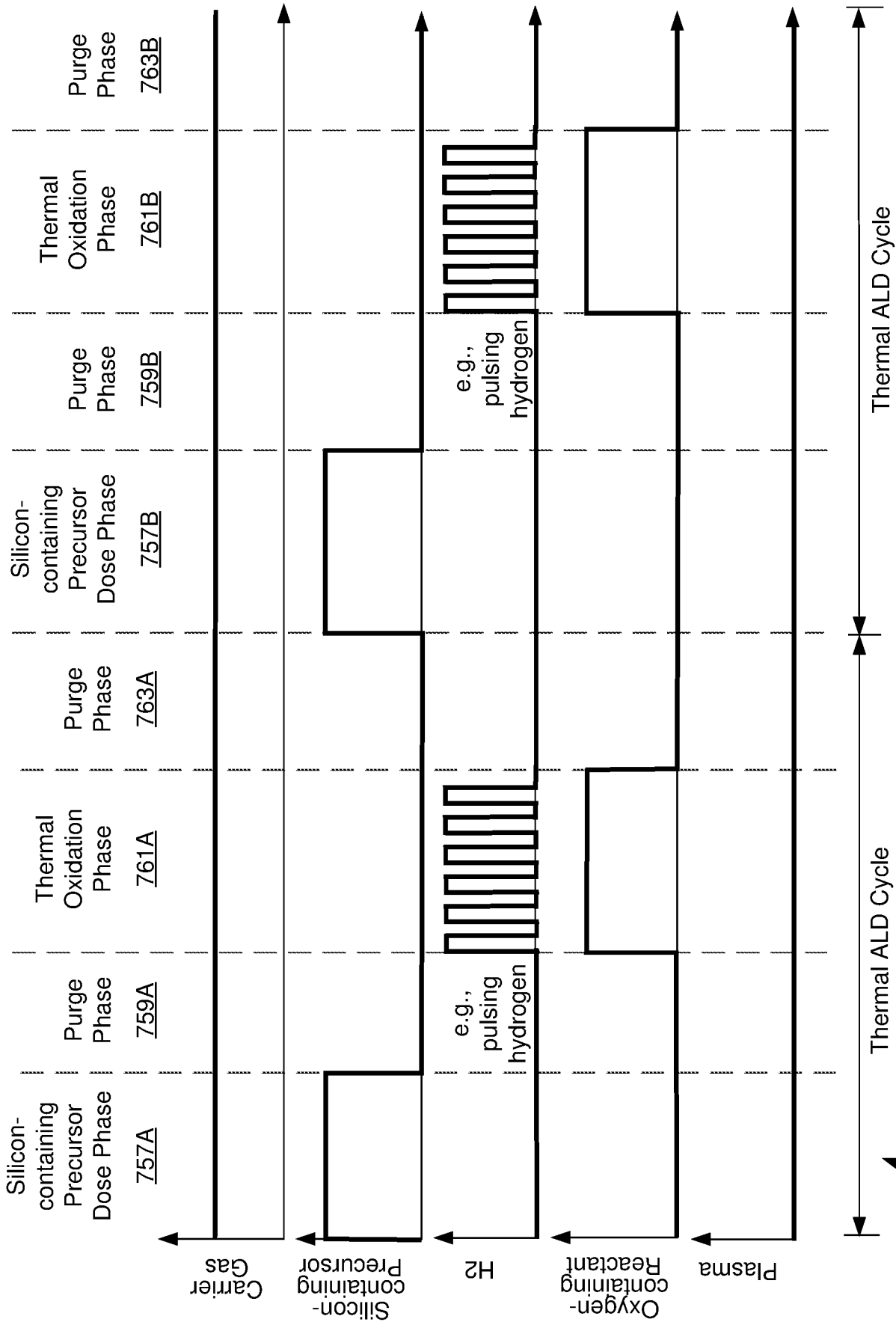

Carrier Gas
Silicon-containing Precursor
H2
Oxygen-containing Reactant
Plasma
Silicon-containing Precursor Dose Phase
Z57A
Purge Phase
Z59A
Thermal Oxidation Phase
Z61A
Purge Phase
Z63A
Silicon-containing Precursor Dose Phase
Z57B
Purge Phase
Z59B
Thermal Oxidation Phase
Z61B
Purge Phase
Z63B
e.g., pulsing hydrogen
e.g., pulsing hydrogen
Thermal ALD Cycle
Z10A
Thermal ALD Cycle
Z10B
700

FIG. 7

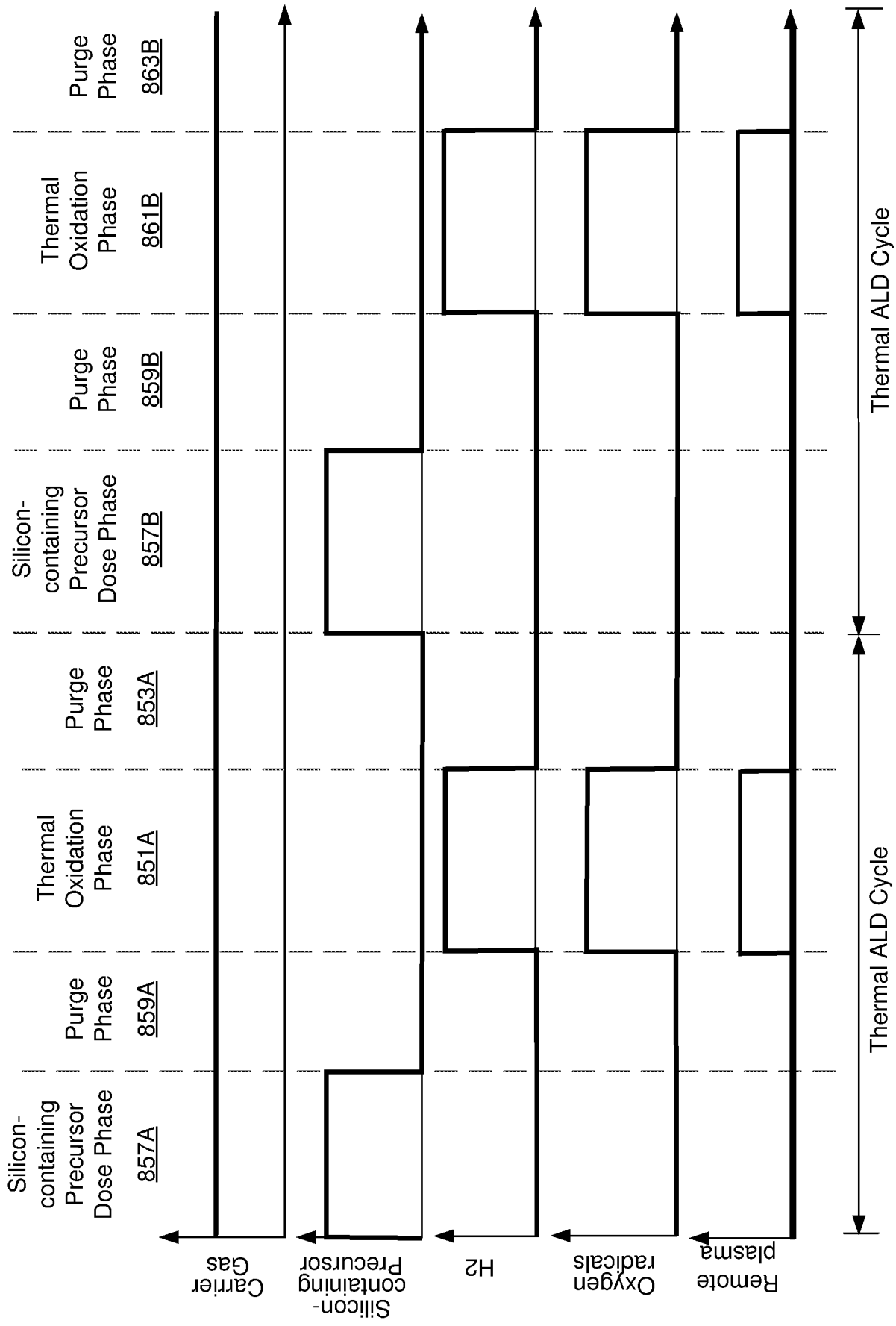

Carrier Gas
Silicon-containing Precursor
H2
Oxygen radicals
Remote plasma
Silicon-containing Precursor Dose Phase 857A
Purge Phase 859A
Thermal Oxidation Phase 851A
Purge Phase 853A
Silicon-containing Precursor Dose Phase 857B
Purge Phase 859B
Thermal Oxidation Phase 861B
Purge Phase 863B
Thermal ALD Cycle 810A
Thermal ALD Cycle 810B

FIG. 8

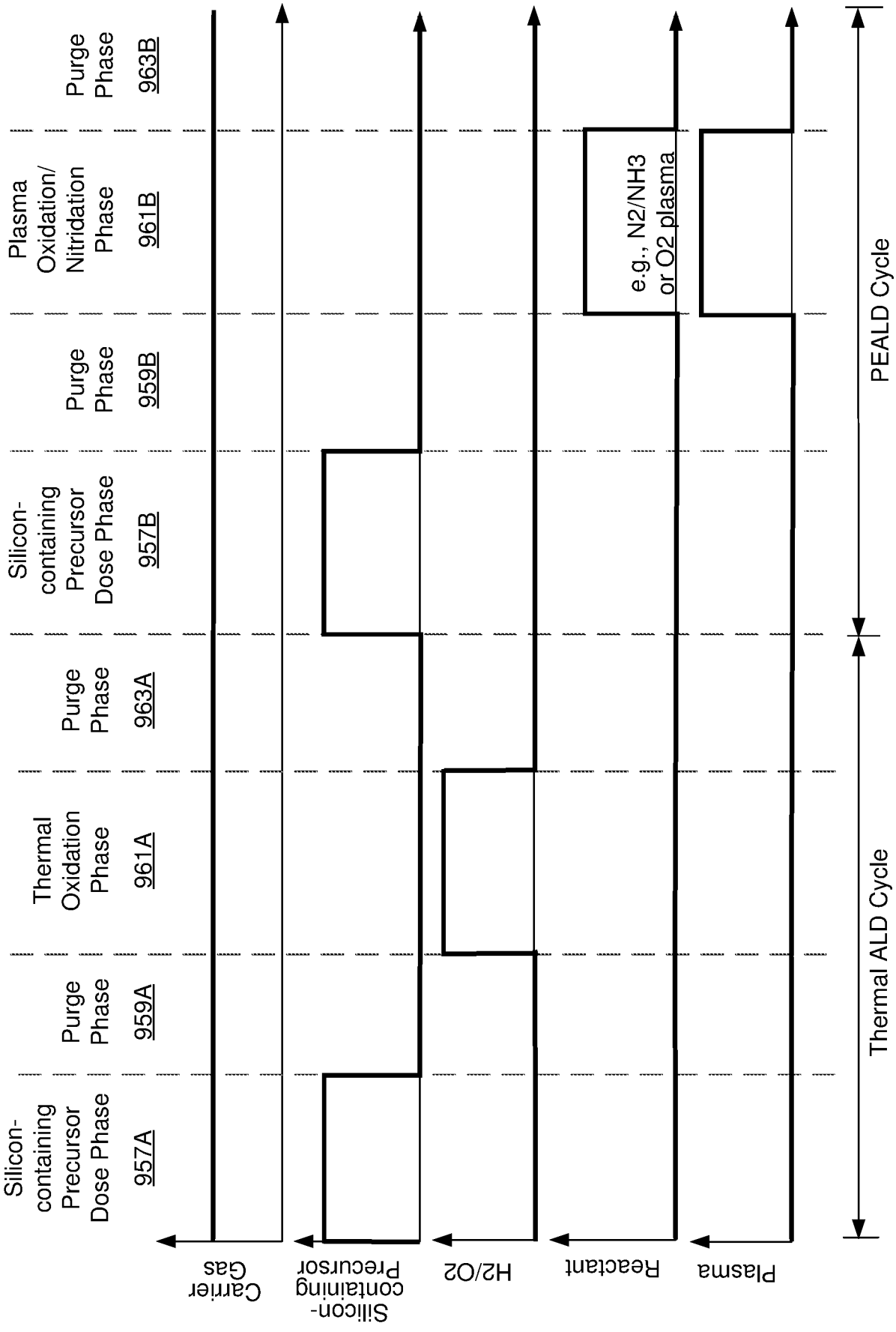

Silicon-containing Precursor Dose Phase
957A
Purge Phase
959A
Thermal Oxidation Phase
961A
Purge Phase
963A
Silicon-containing Precursor Dose Phase
957B
Purge Phase
959B
Plasma Oxidation/ Nitridation Phase
961B
Purge Phase
963B
Thermal ALD Cycle
910A
PEALD Cycle
910B
Carrier Gas
Silicon-containing Precursor
H2/O2
Reactant
e.g., N2/NH3 or O2 plasma
Plasma

FIG. 9

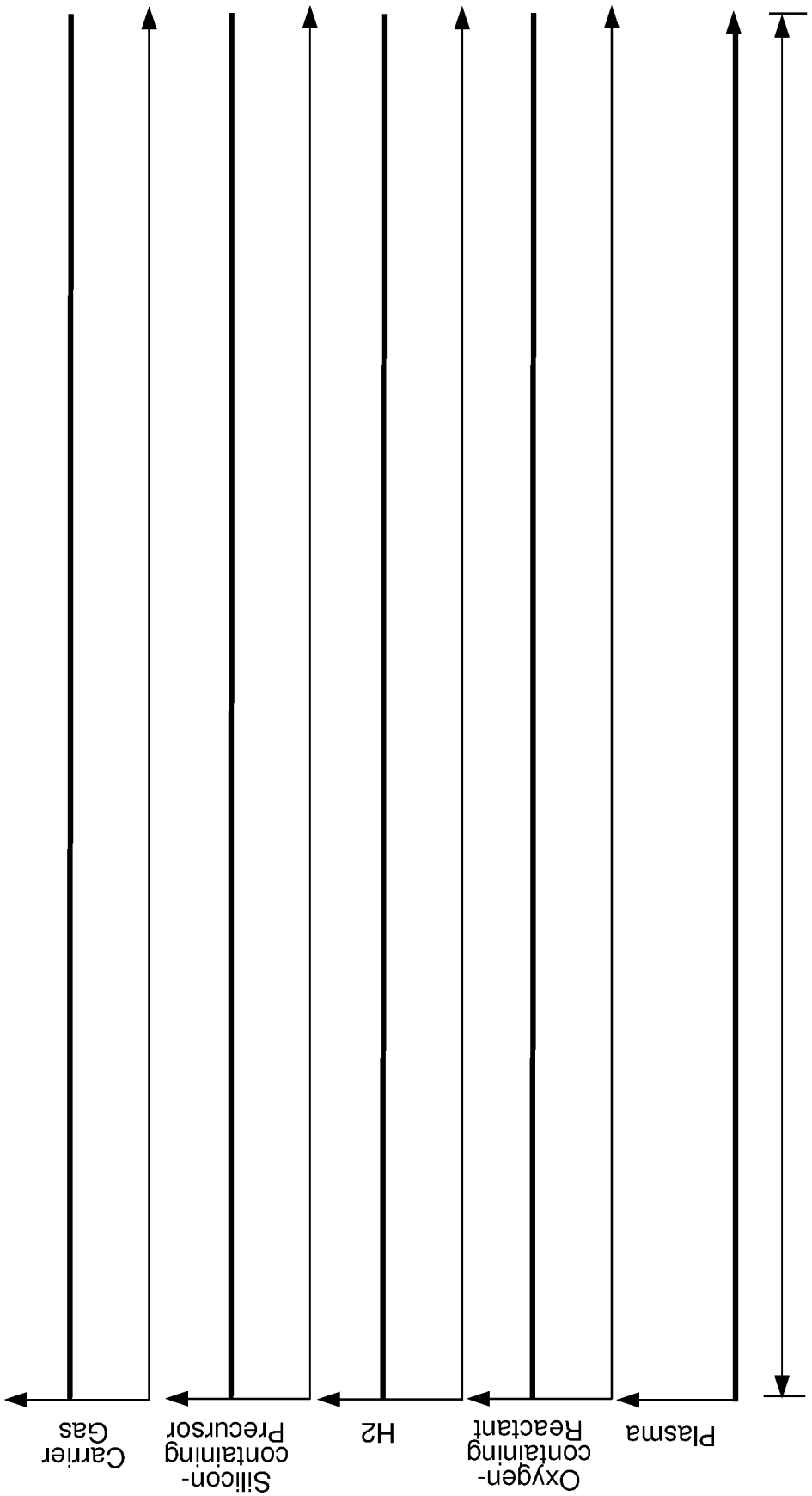

Plasma
Oxygen-containining Reactant
H2
Silicon-containing Precursor
Carrier Gas
Thermal CVD
1010

FIG. 10

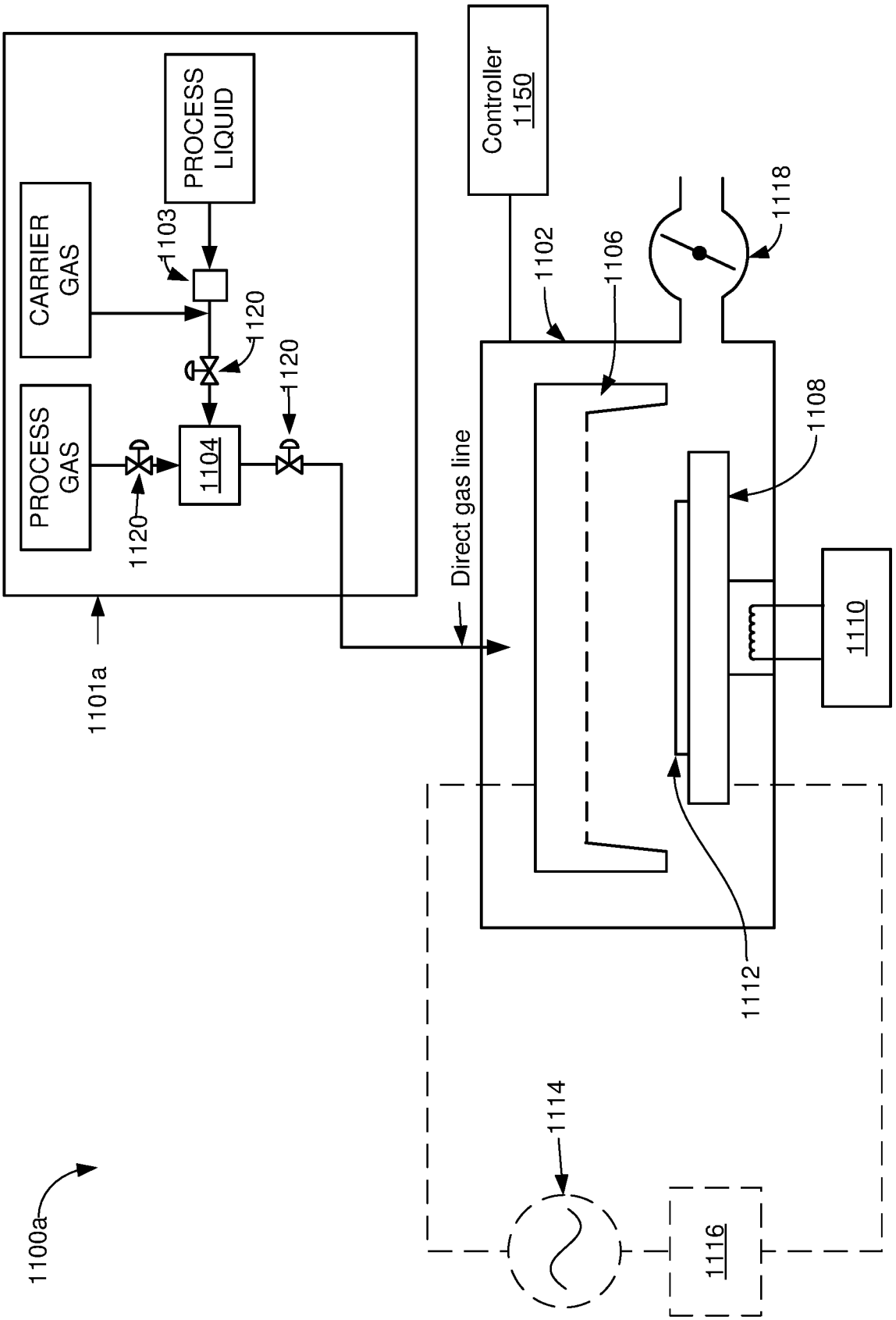

Controller
1150
PROCESS
LIQUID
CARRIER
GAS
PROCESS
GAS
1103
1120
1120
1120
1104
1101a
1100a
Direct gas line
1102
1106
1118
1108
1110
1112
1114
1116

FIG. 11

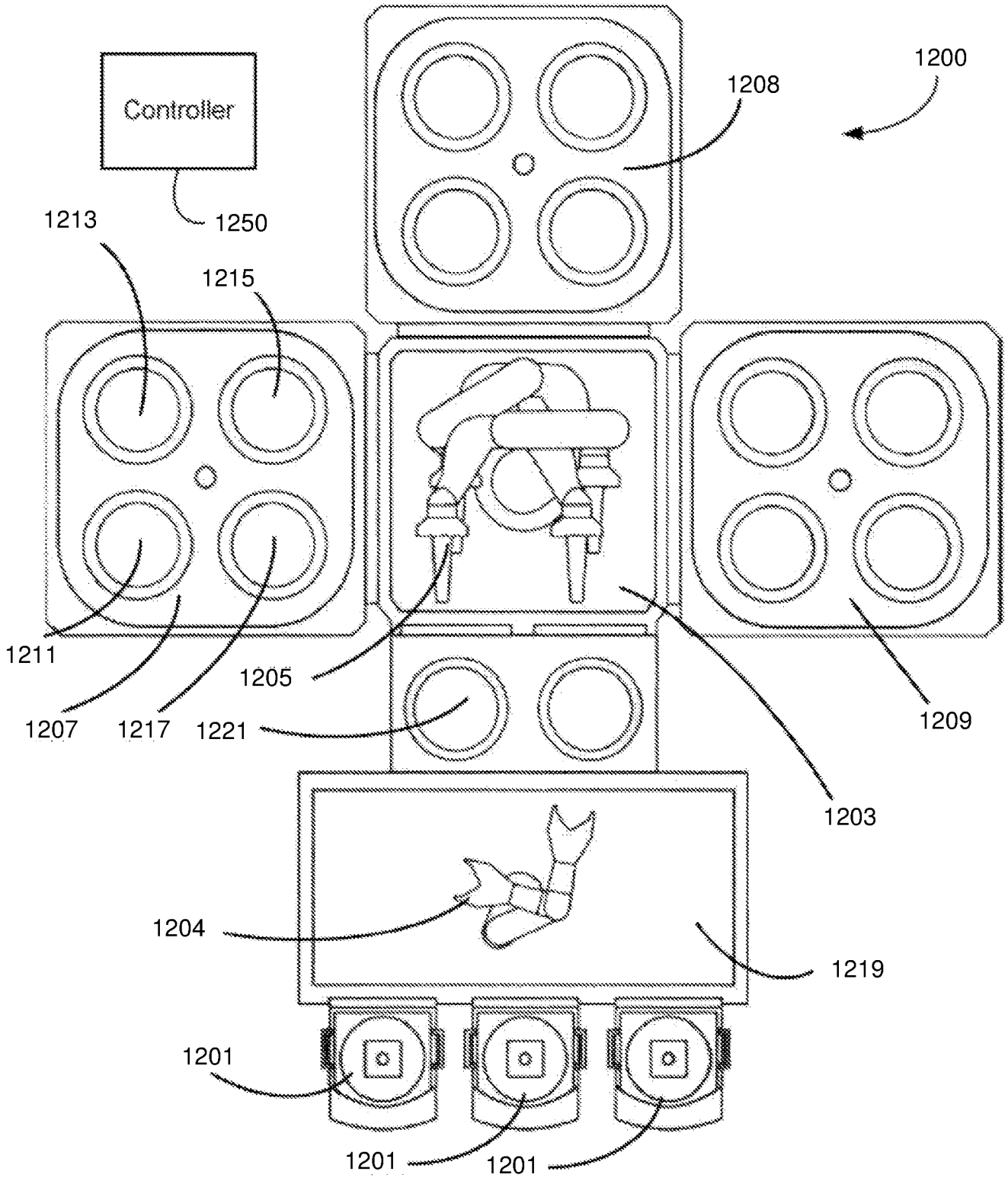

Controller
1250
1200
1208
1213
1215
1211
1207
1217
1221
1205
1209
1203
1204
1219
1201
1201
1201

FIG. 12

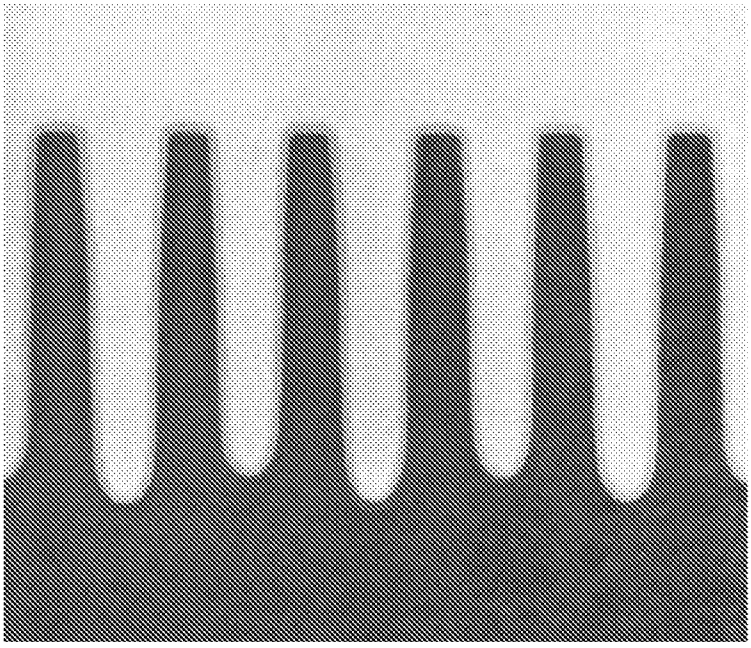


FIG. 13