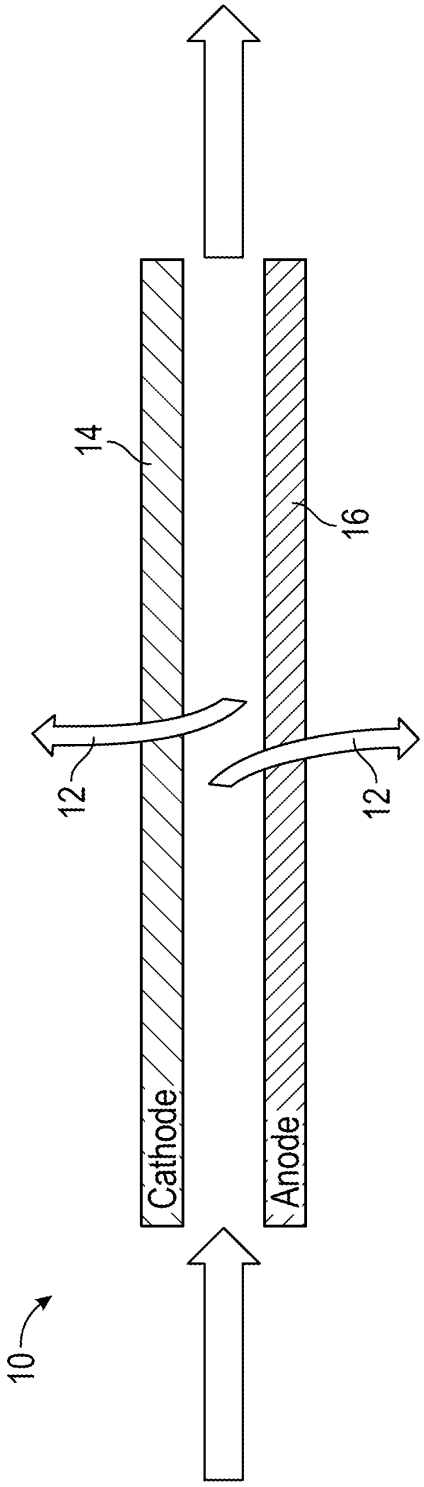


FIG. 1

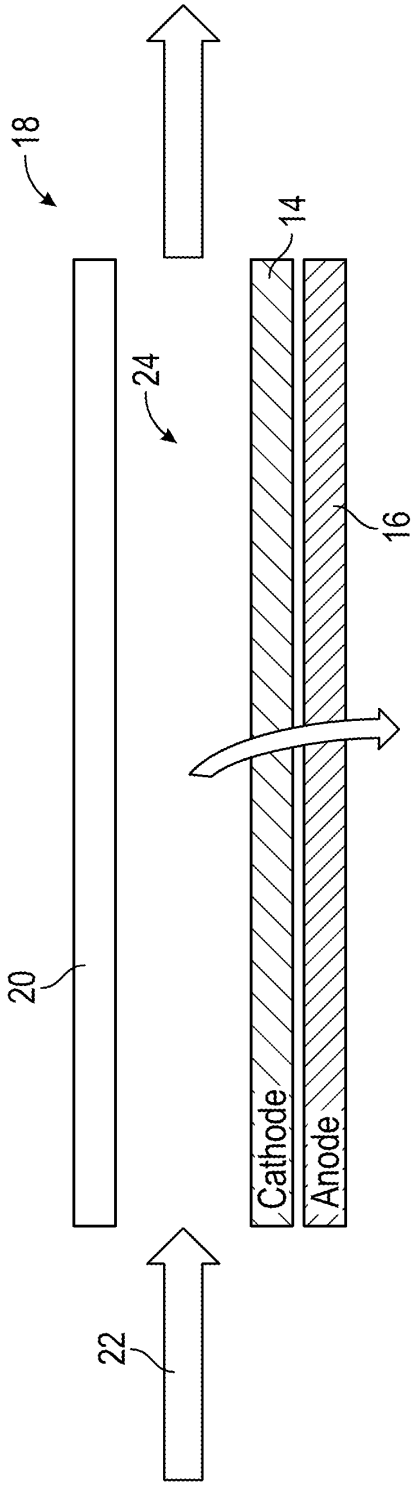


FIG. 2

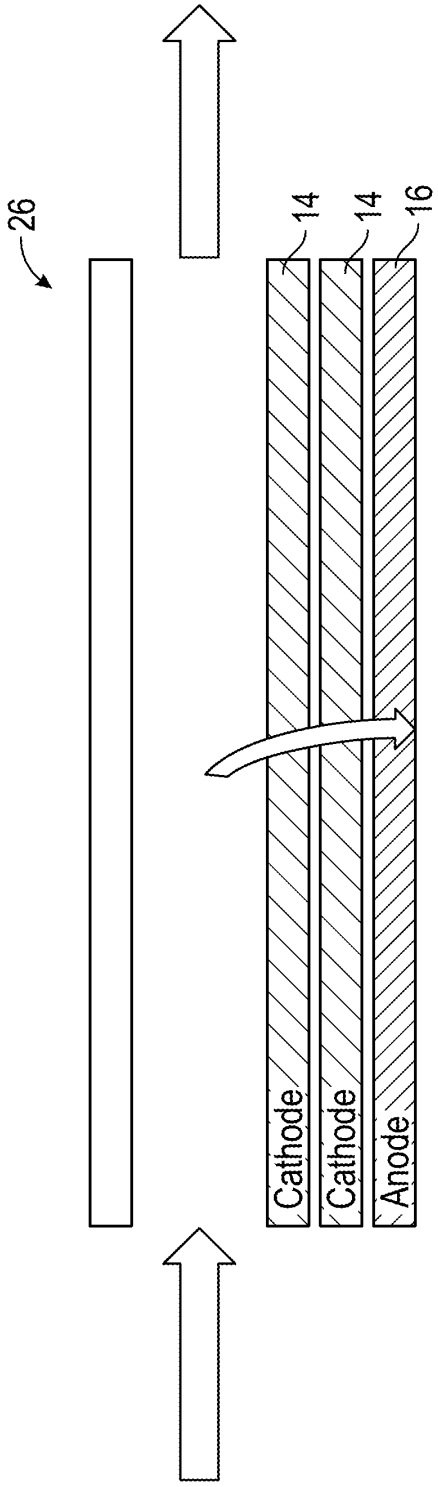

26
14
14
16
Cathode
Cathode
Anode

FIG. 3

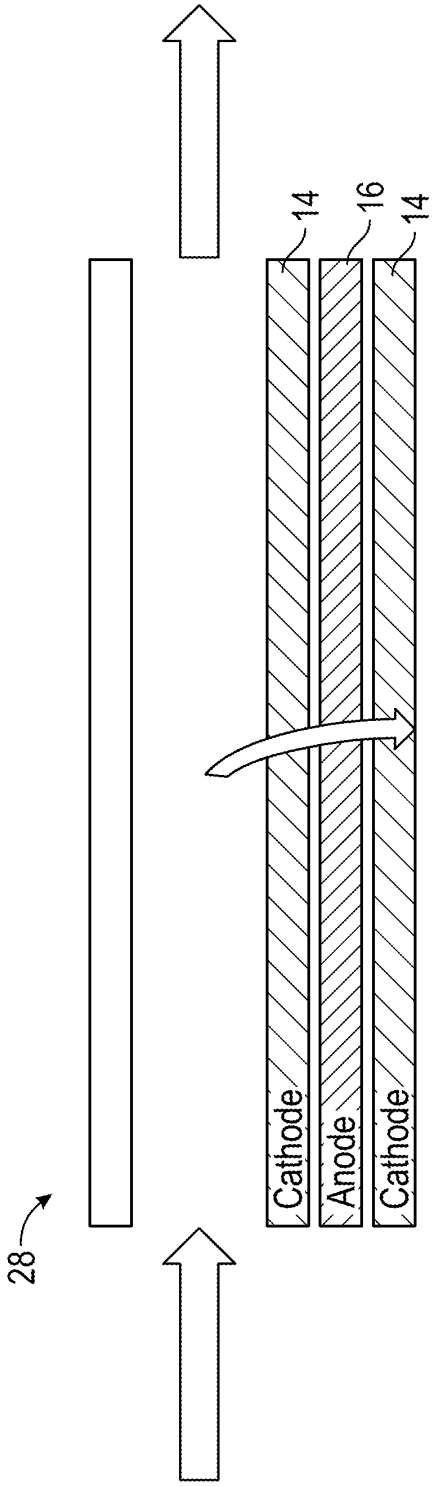

28
14
16
14
Cathode
Anode
Cathode

FIG. 4

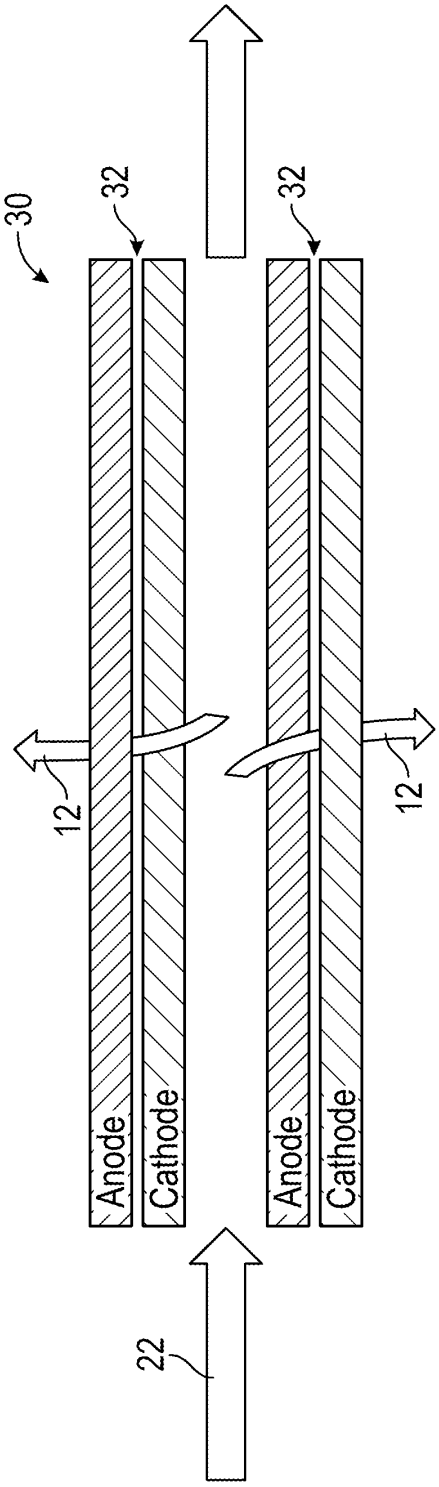

30
32
32
Anode
Cathode
Anode
Cathode
12
12
22

FIG. 5

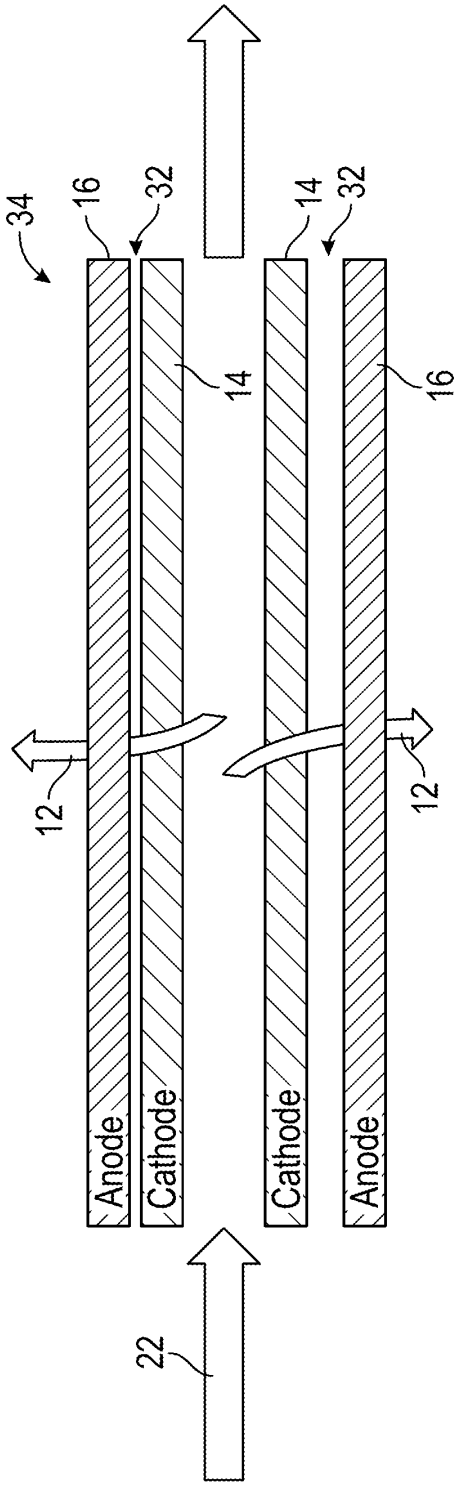

34
16
32
14
32
14
16
Anode
Cathode
Cathode
Anode
12
12
22

FIG. 6

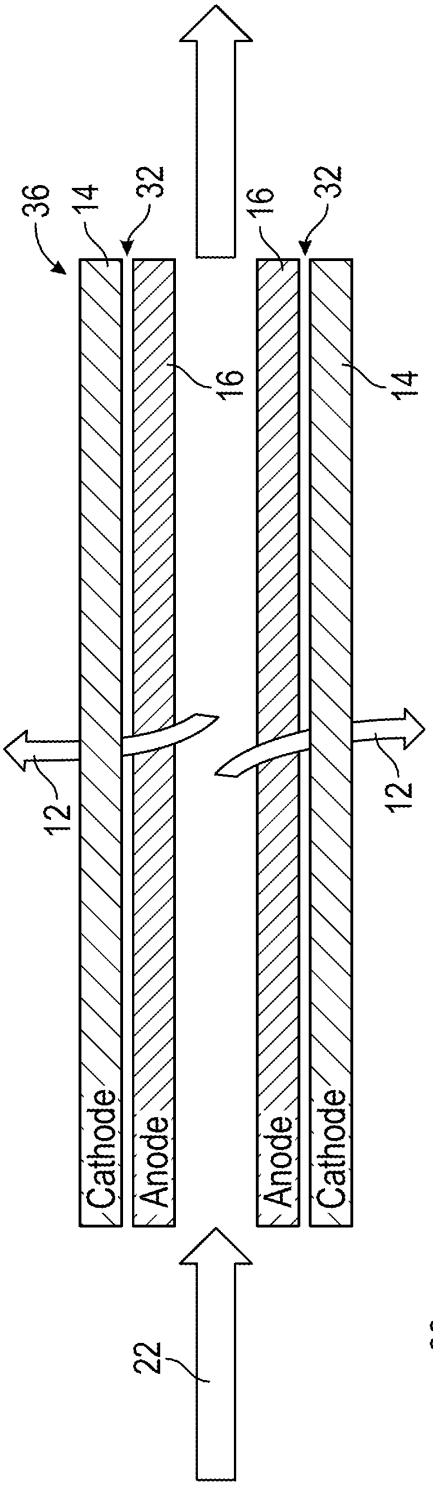

36
14
32
16
32
16
14
12
12
Cathode
Anode
Anode
Cathode
22

FIG. 7

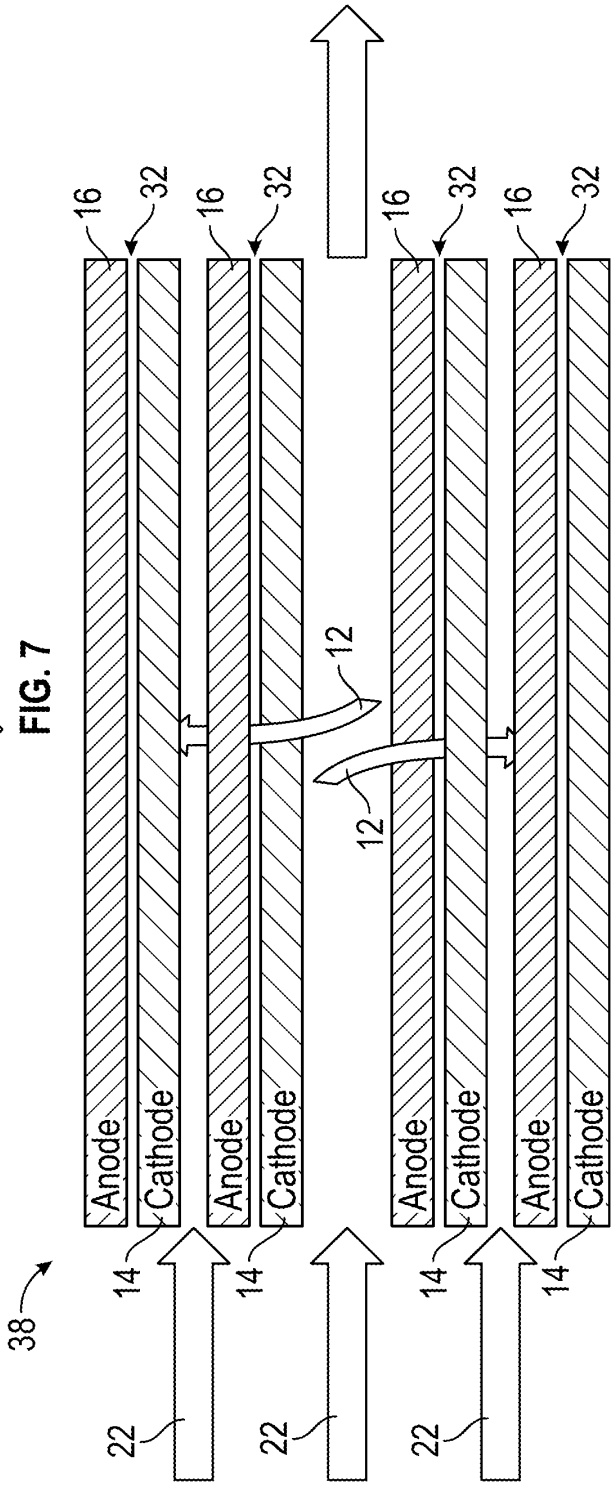

16
32
16
32
16
32
16
32
12
12
Anode
Cathode
Anode
Cathode
Anode
Cathode
Anode
Cathode
38
14
14
14
14
22
22
22

FIG. 8

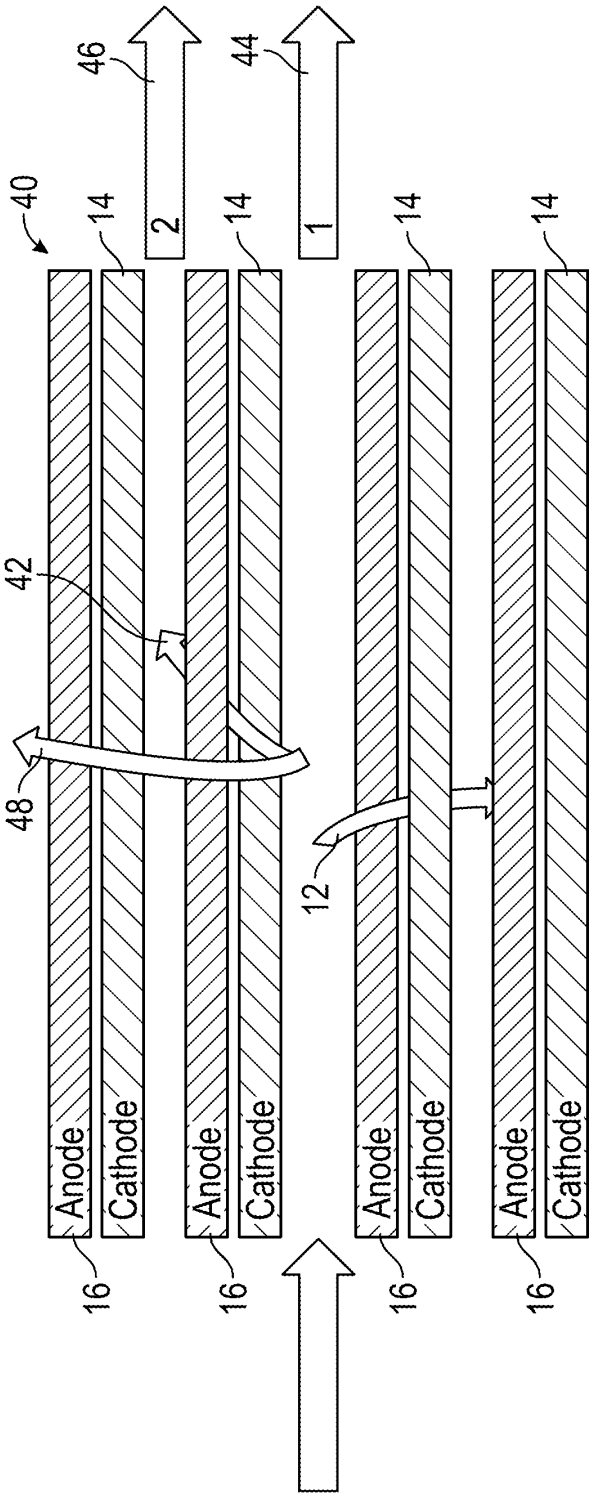

40
14
14
14
14
46
44
2
1
42
48
12
Anode
Cathode
Anode
Cathode
Anode
Cathode
Anode
Cathode
16
16
16
16

FIG. 9

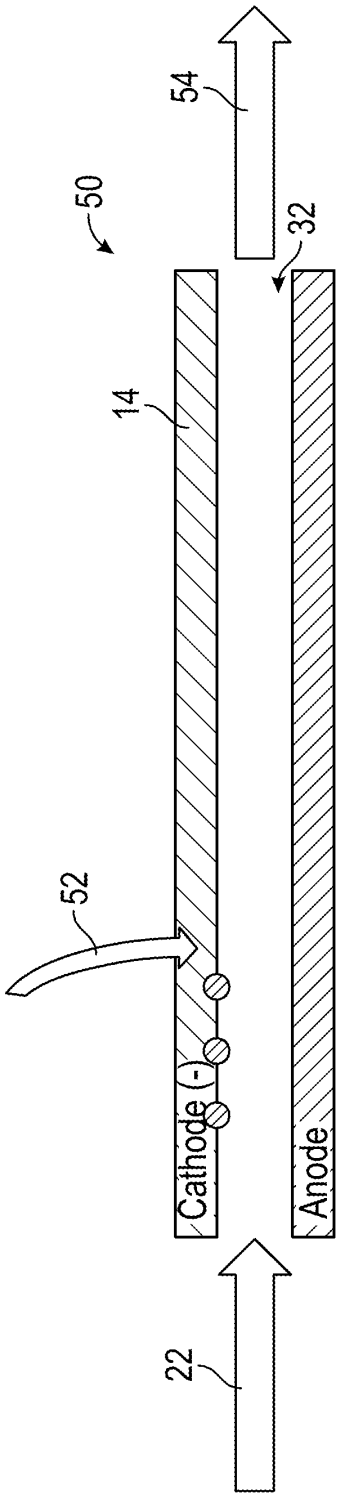

50
54
32
14
52
Cathode (-)
Anode
22

FIG. 10

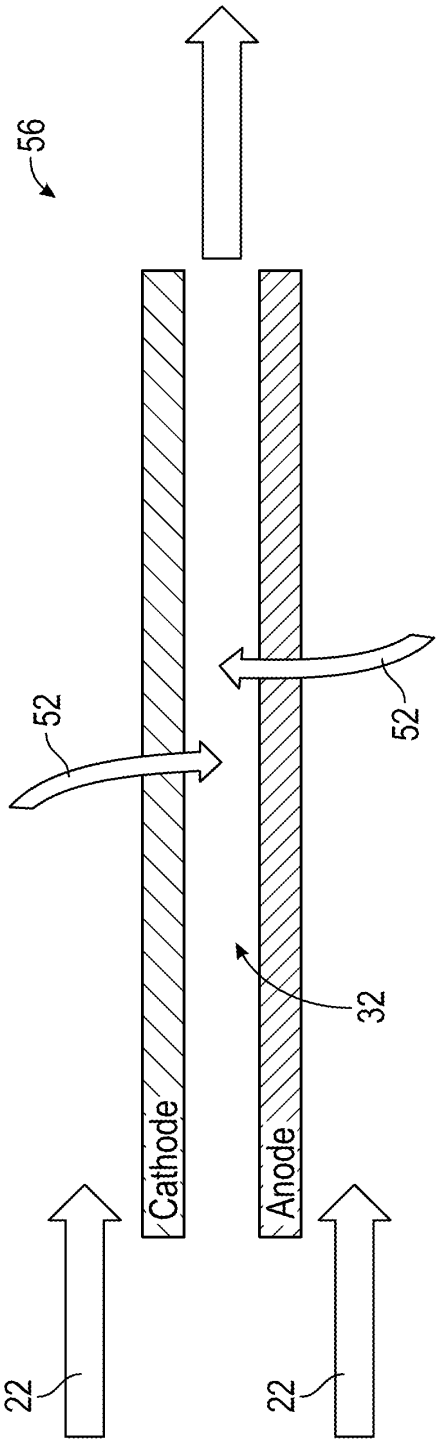

56
52
52
32
Cathode
Anode
22
22

FIG. 11

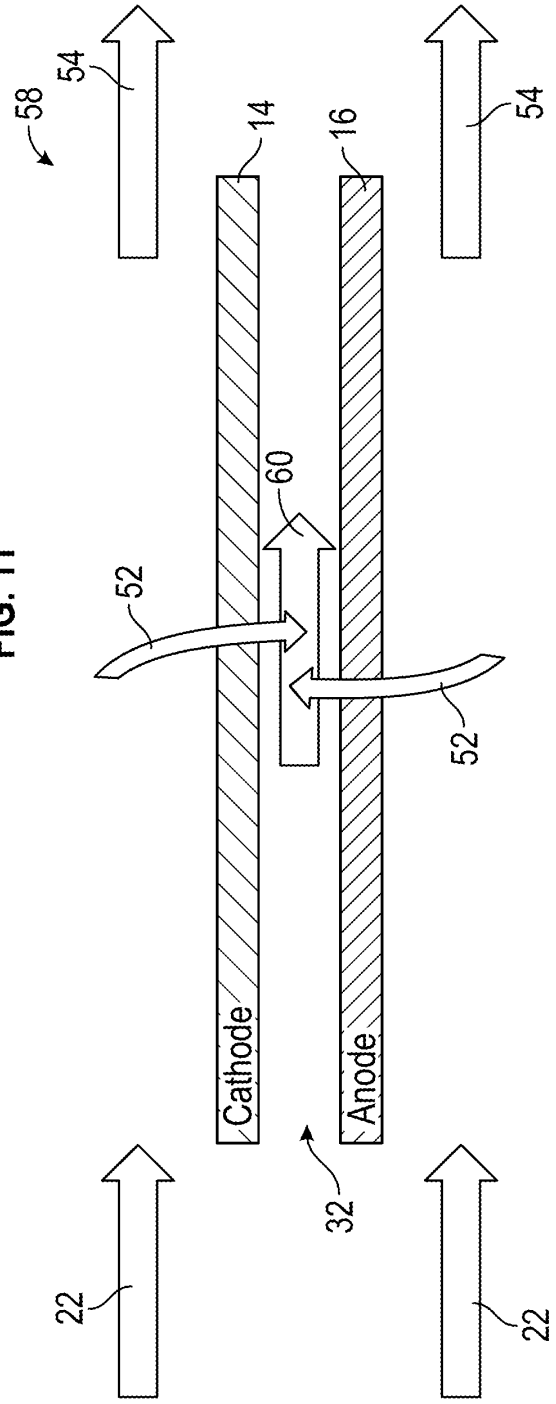

58
54
14
16
54
60
52
52
32
Cathode
Anode
22
22

FIG. 12

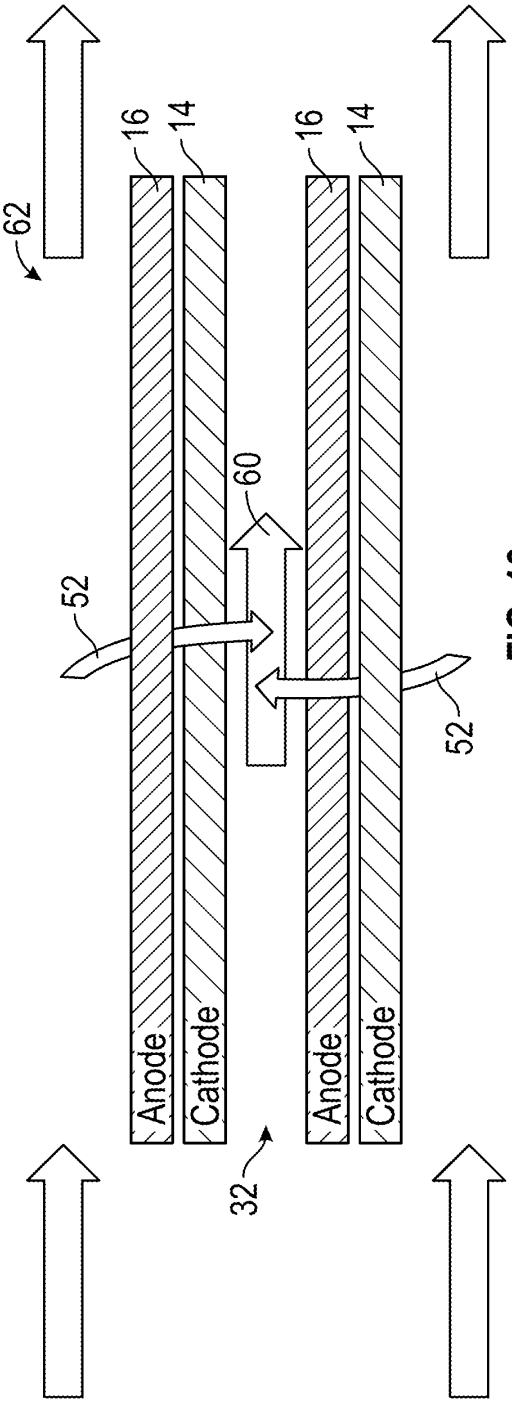

62
16
14
16
14
60
52
52
Anode
Cathode
Anode
Cathode
32

FIG. 13

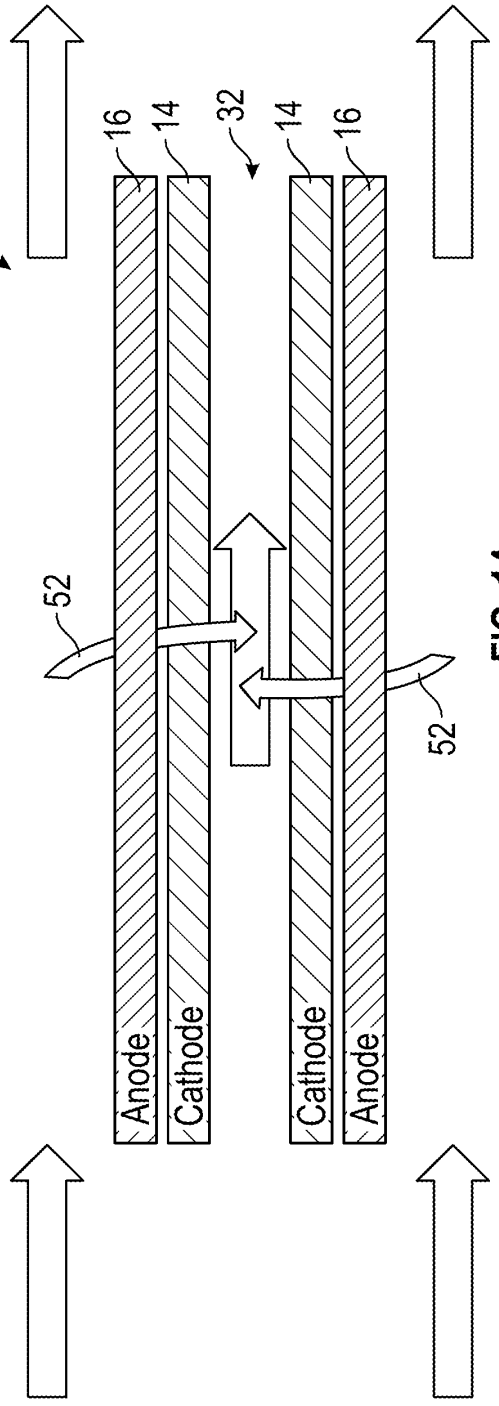

64
16
14
32
14
16
52
52
Anode
Cathode
Cathode
Anode

FIG. 14

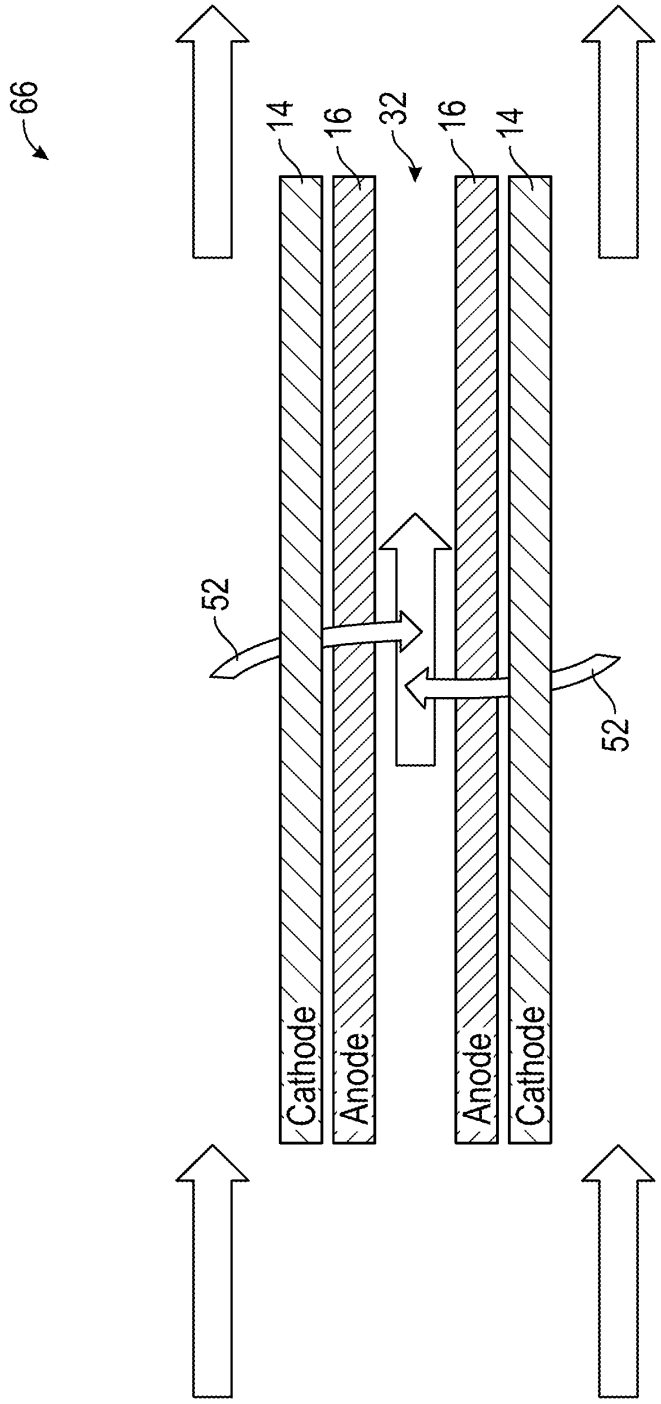


FIG. 15

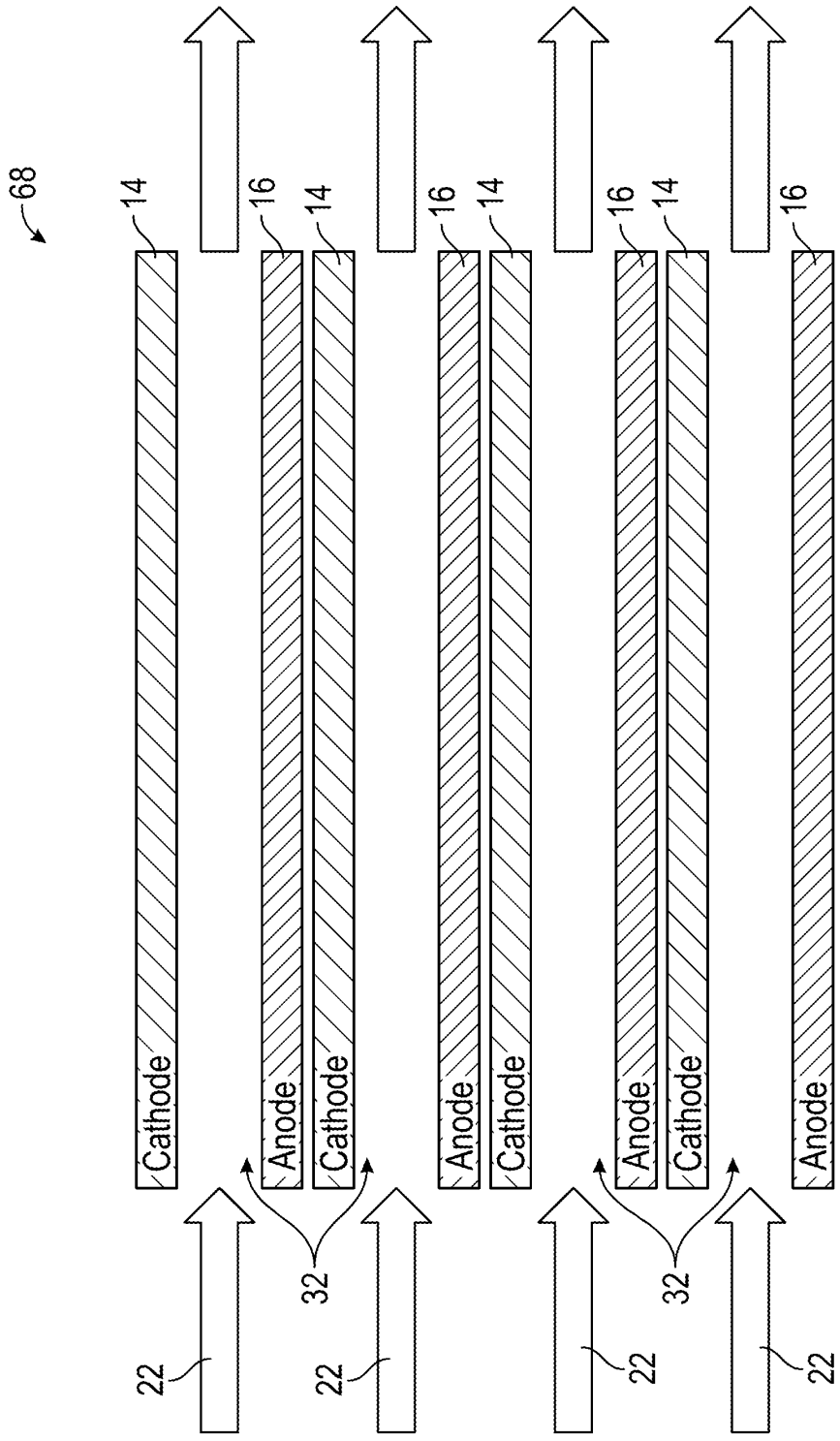

68
14
16
14
16
14
16
14
16
Cathode
Anode
Cathode
Anode
Cathode
Anode
Cathode
Anode
32
32
22
22
22
22

FIG. 16

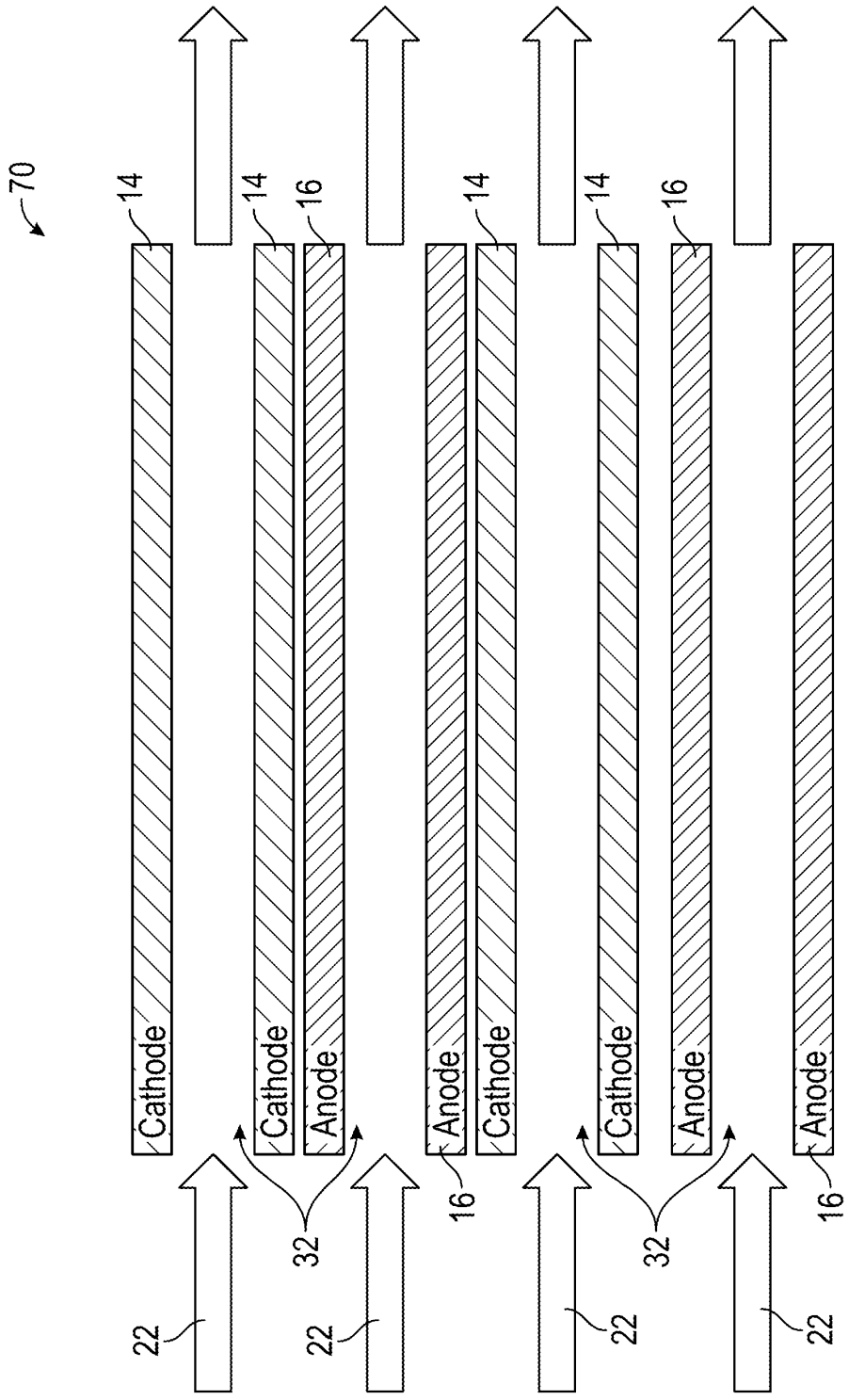

70
14
14
16
14
14
16
Cathode
Cathode
Anode
Anode
Cathode
Cathode
Anode
Anode
16
16
32
32
22
22
22
22

FIG. 17

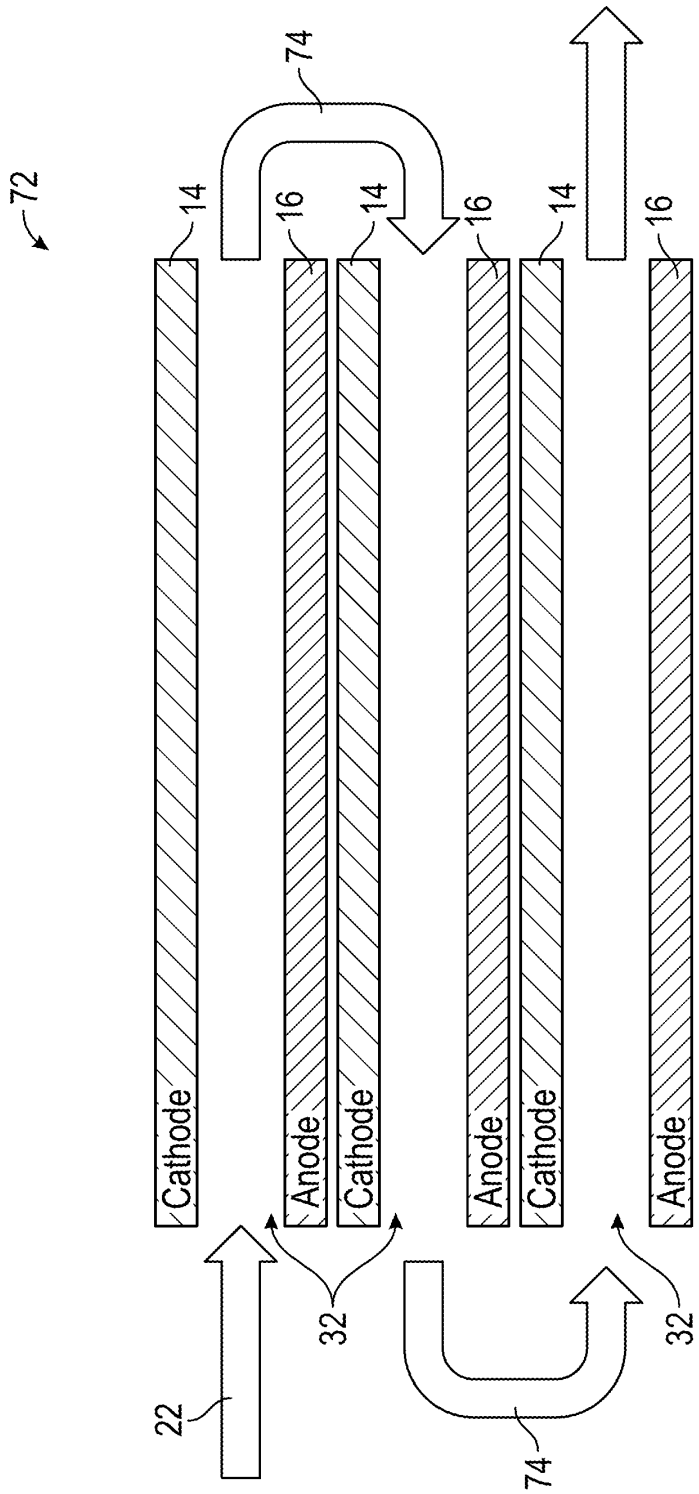

72
74
14
16
14
16
14
16
Cathode
Anode
Cathode
Anode
Cathode
Anode
22
32
32
74

FIG. 18

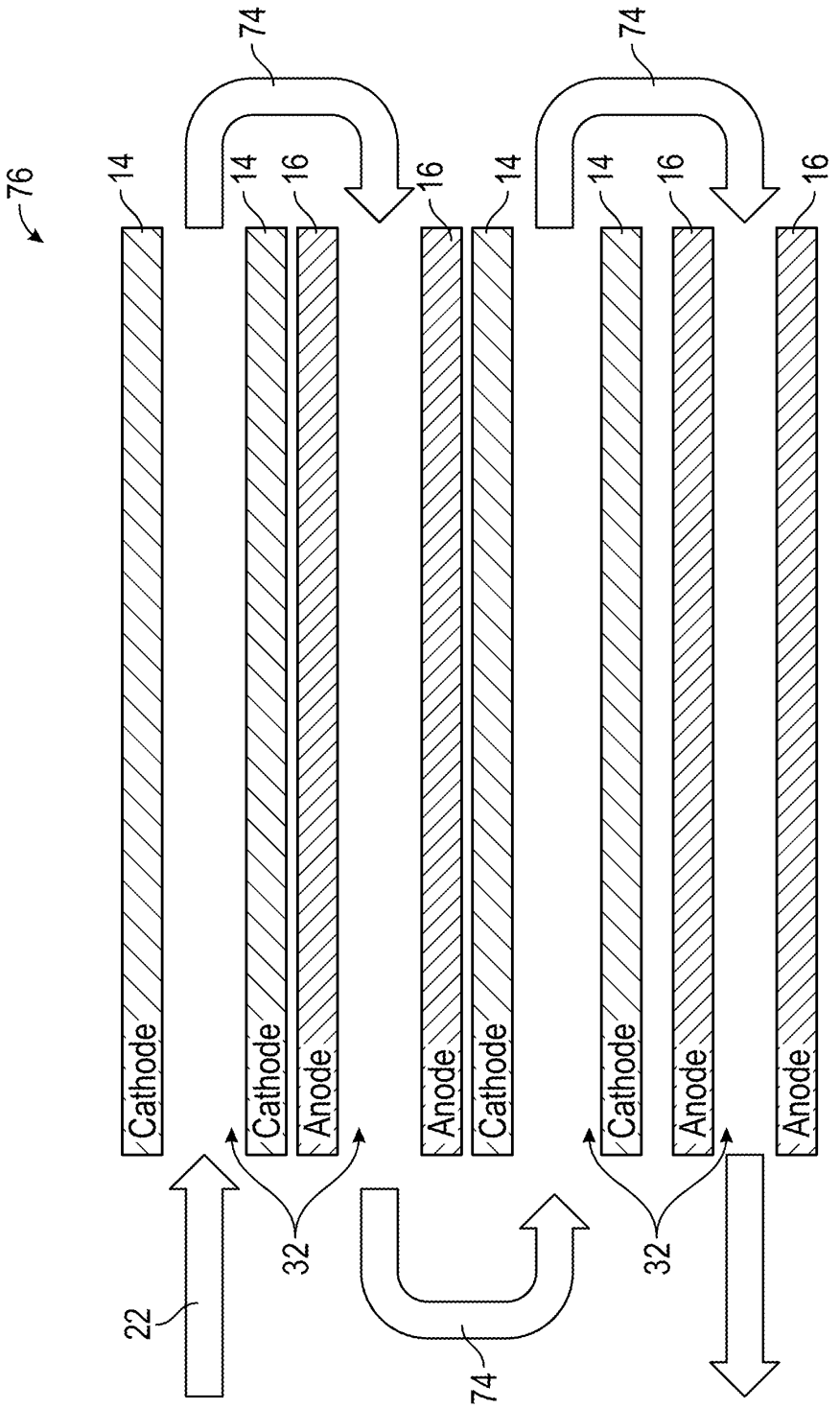

76
14
14
16
74
16
14
14
16
74
16
Cathode
Cathode
Anode
Anode
Cathode
Cathode
Anode
Anode
22
32
74
32

FIG. 19

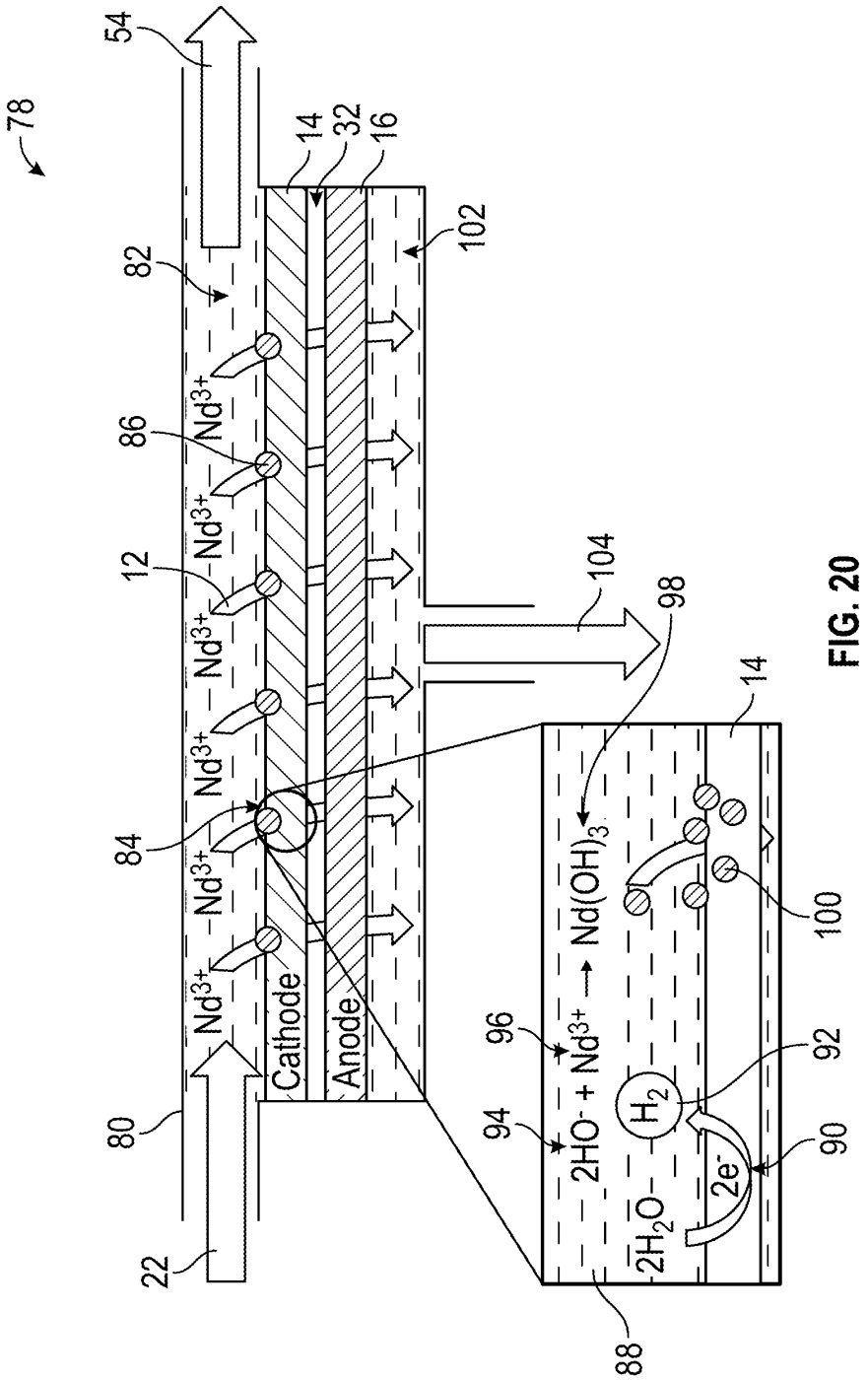

78
54
14
32
16
102
82
86
12
84
80
22
Nd3+
Cathode
Anode
104
98
14
100
96
92
94
90
88
2HO- + Nd3+ → Nd(OH)3
H2
2H2O
2e-

FIG. 20

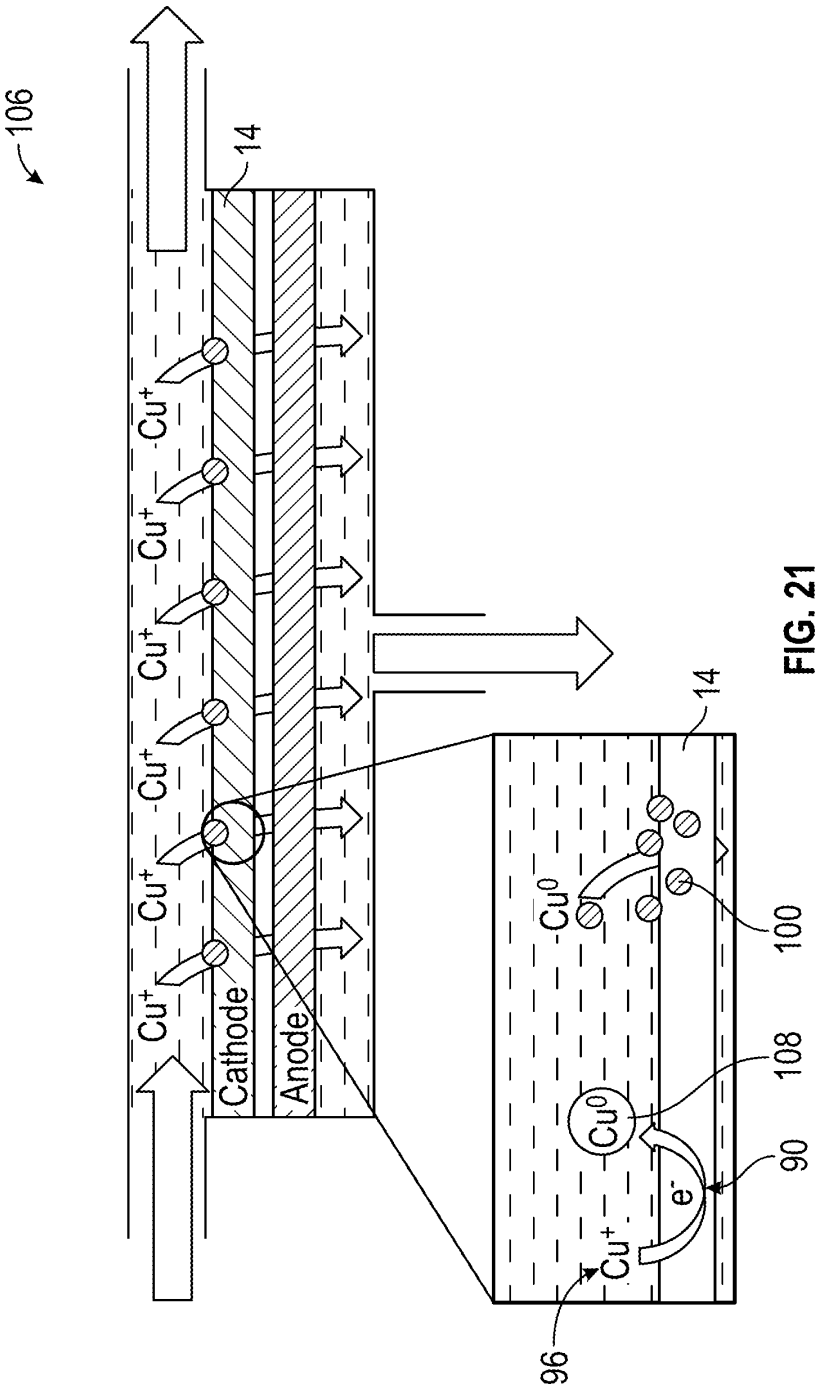

106
14
Cu+
Cu+
Cu+
Cu+
Cu+
Cu+
Cathode
Anode
14
Cu0
100
108
Cu0
90
e-
Cu+
96

FIG. 21

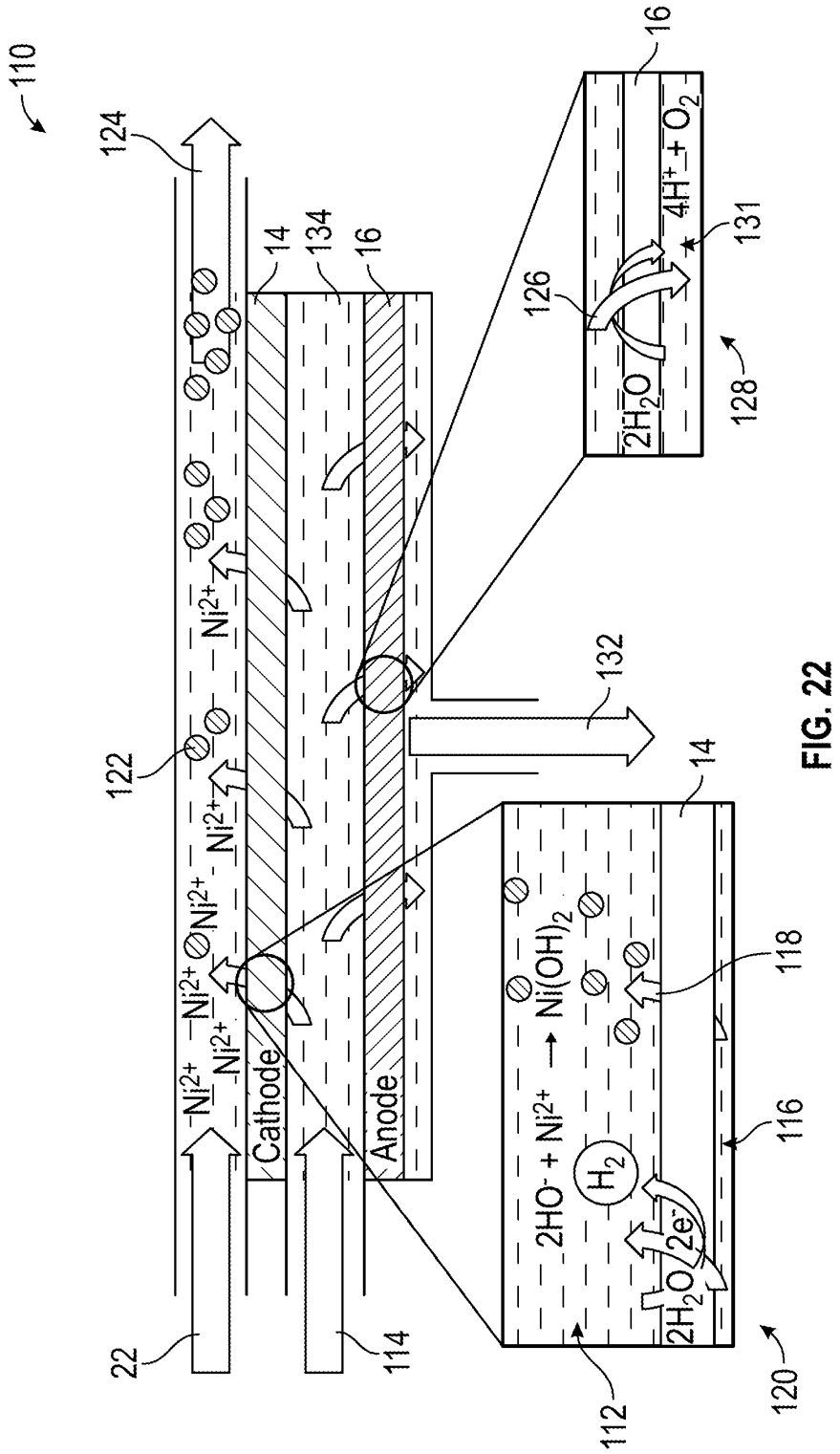

110
124
14
134
16
16
126
131
128
$2H_2O$
$4H^+ + O_2$
132
122
Ni^{2+}
Cathode
Anode
14
$2HO^- + Ni^{2+} \rightarrow Ni(OH)_2$
118
H_2
116
$2H_2O$
$2e^-$
22
114
112
120

FIG. 22

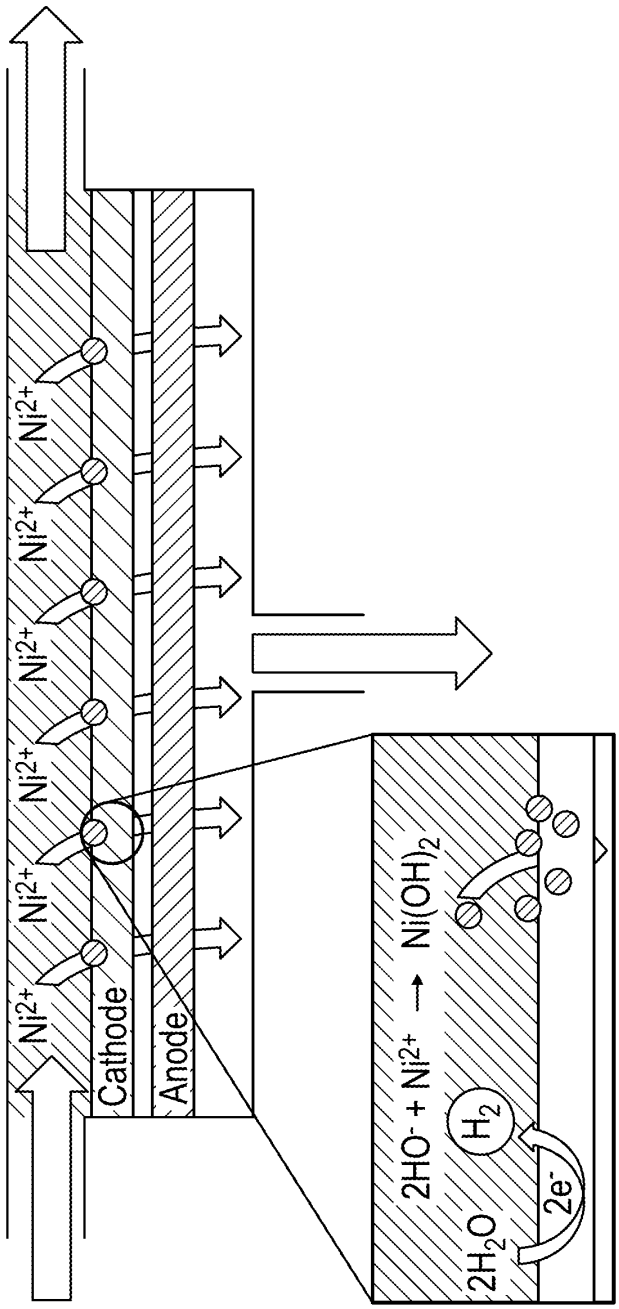


FIG. 23

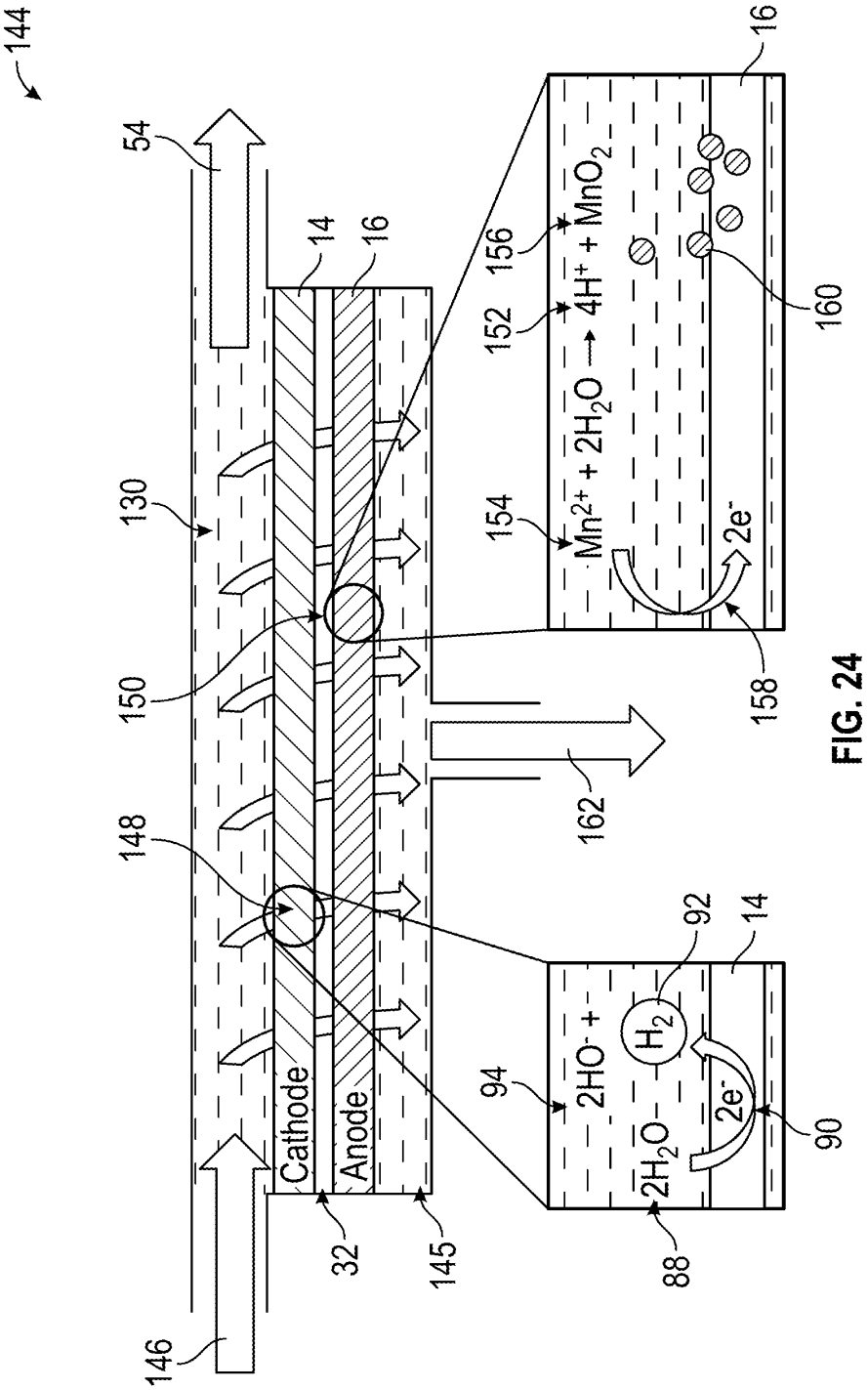

144
54
14
16
130
150
148
146
32
145
Cathode
Anode
156
152
154
160
158
162
16
$Mn^{2+} + 2H_2O \rightarrow 4H^+ + MnO_2$
$2e^-$
92
14
94
90
88
$2HO^- + -$
H_2
$2H_2O$
$2e^-$

FIG. 24

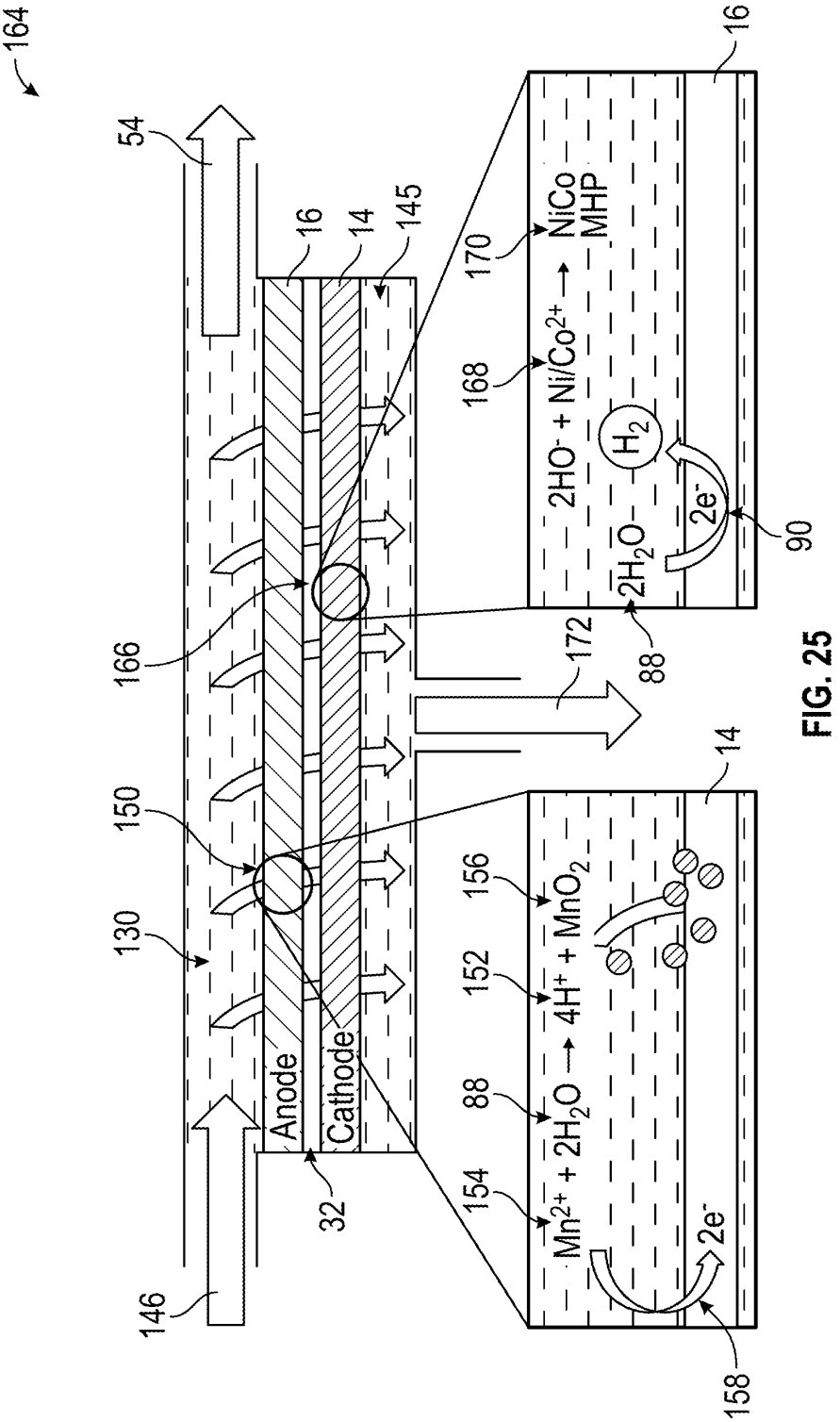

164
54
16
14
145
170
NiCo MHP
168
2HO⁻ + Ni/Co²⁺ →
H₂
2H₂O
2e⁻
90
88
172
166
150
130
156
MnO₂
152
4H⁺ +
88
2H₂O →
154
Mn²⁺ +
2e⁻
158
Anode
Cathode
32
146

FIG. 25

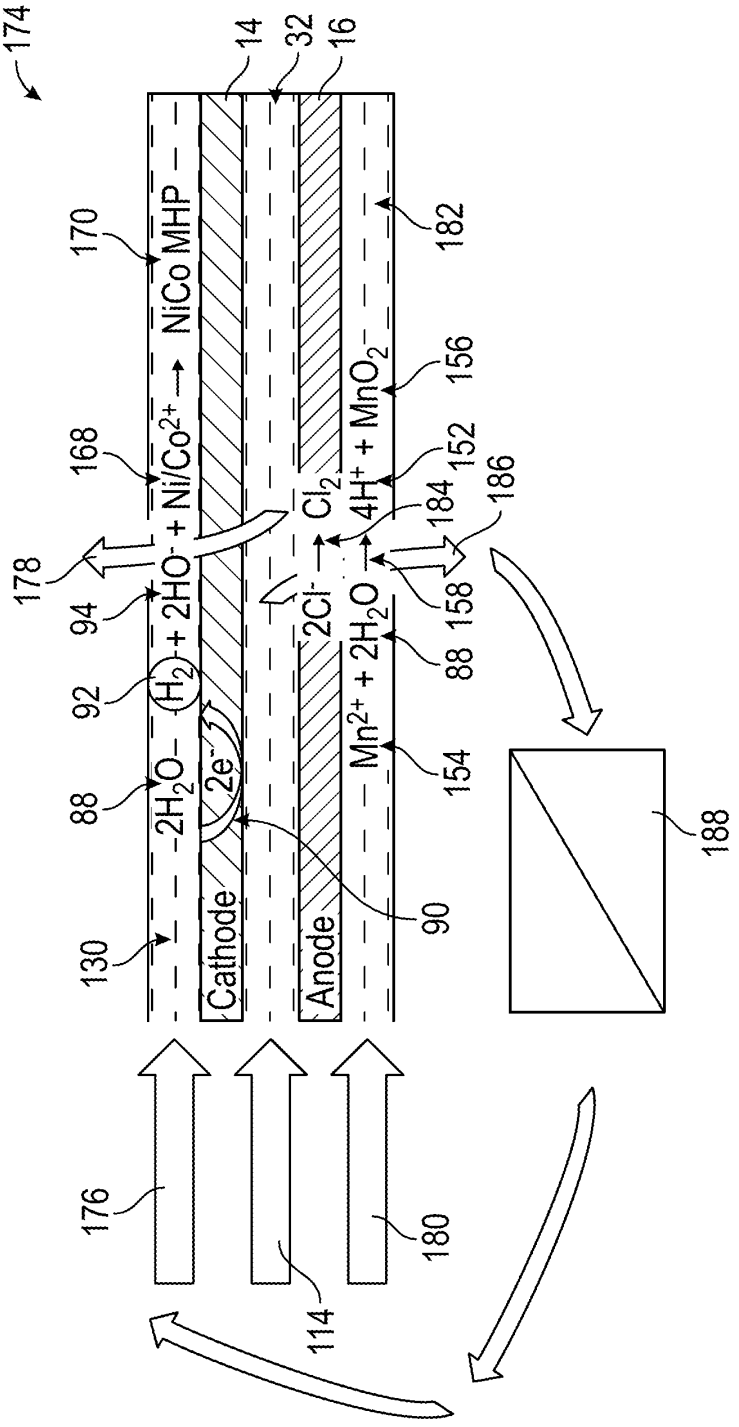

174
14
32
16
170
182
NiCo MHP
156
168
152
186
184
178
94
158
92
88
154
188
130
90
Cathode
Anode
176
180
114

FIG. 26

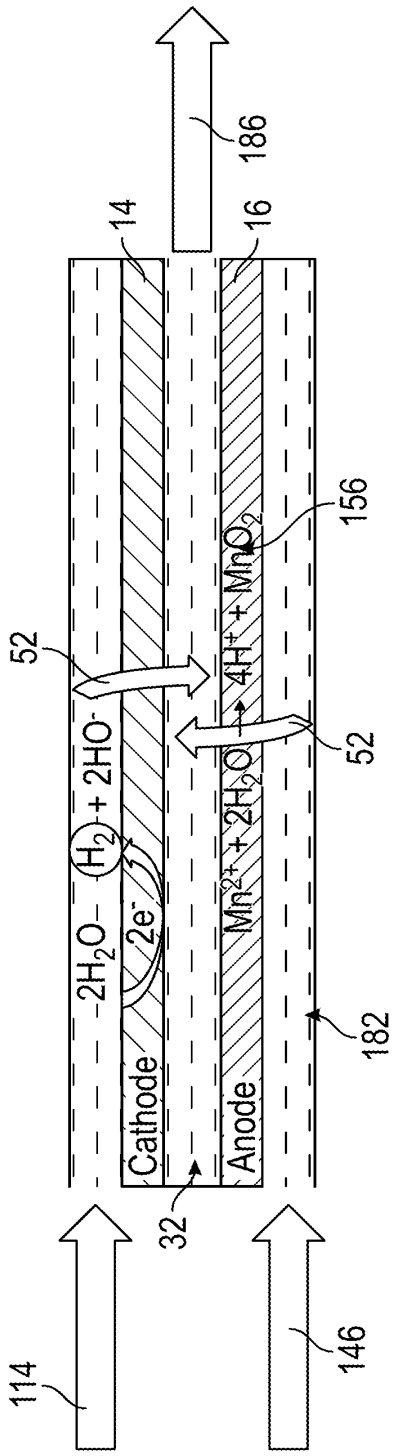

190
186
14
16
156
MnO_2
52
$4H^+ + MnO_2$
52
$2HO^-$
H_2
$2e^-$
$2H_2O$
$Mn^{2+} + 2H_2O$
182
Cathode
Anode
32
114
146

FIG. 27

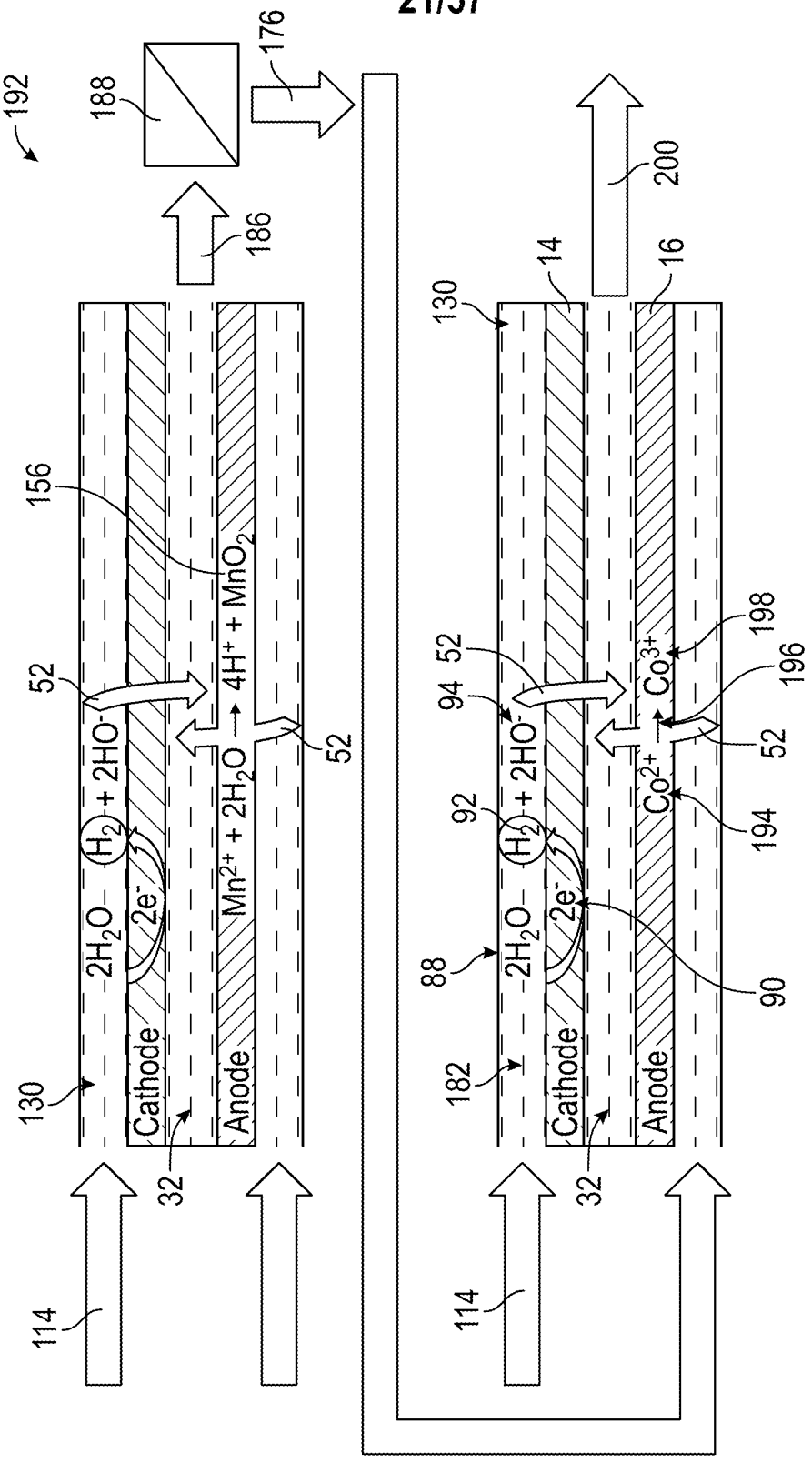

192
188
176
186
200
14
16
130
156
52
94
198
196
MnO_2
$4H^+ + MnO_2 \rightarrow Mn^{2+} + 2H_2O$
Co^{3+}
Co^{2+}
$(H_2) + 2HO^-$
$-2H_2O$
$2e^-$
92
88
90
194
182
Cathode
Anode
32
114

FIG. 28

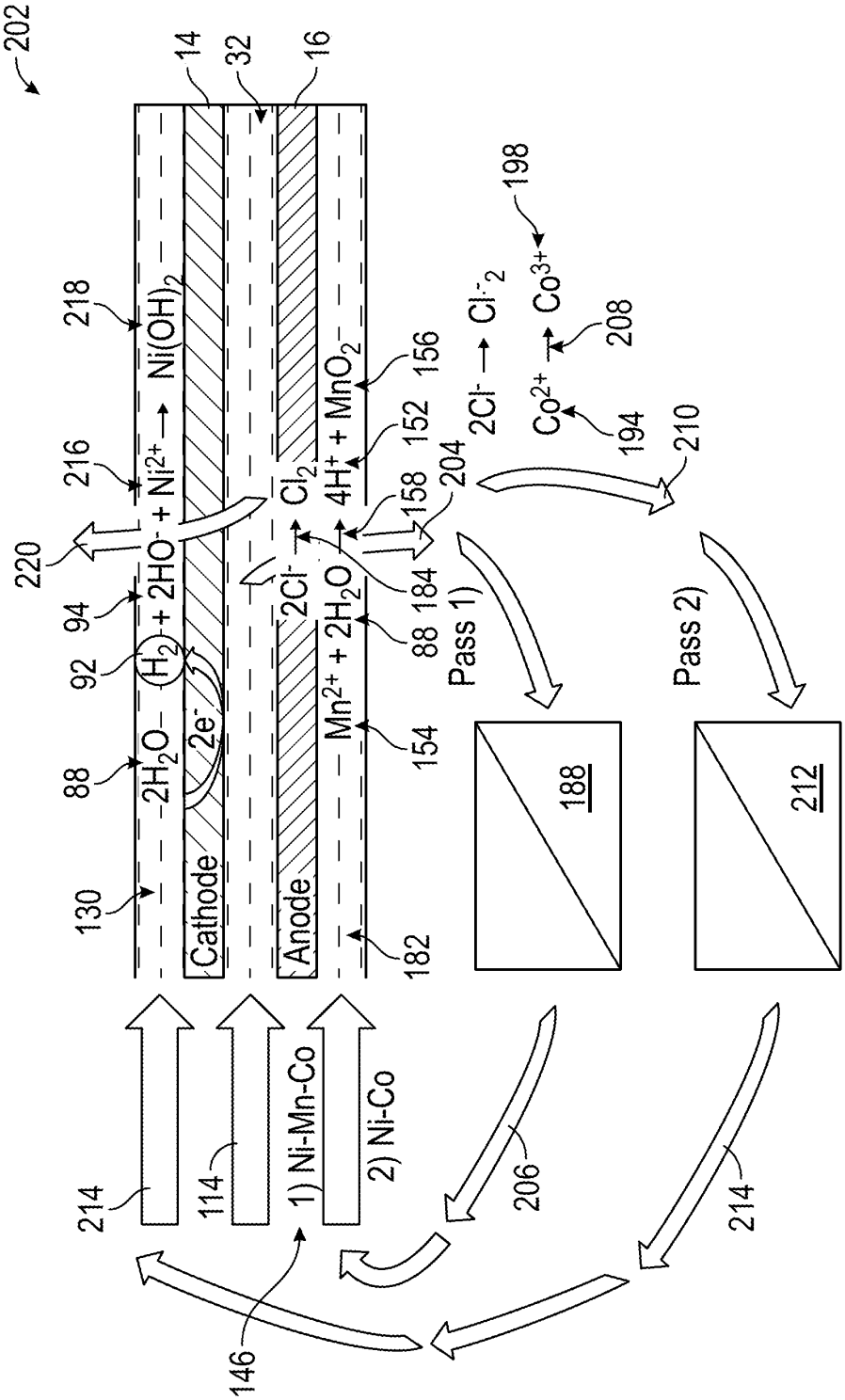

202
14
32
16
218
216
220
94
92
88
130
$2H_2O$
(H_2)
$+ 2HO^- + Ni^{2+} \rightarrow Ni(OH)_2$
2e-
Cathode
Cl_2
$2Cl^-$
Anode
$4H^+ + MnO_2$
$Mn^{2+} + 2H_2O$
156
152
158
184
154
182
$2Cl^- \rightarrow Cl^-_2$
198
Co^{3+}
208
Co^{2+}
194
204
210
Pass 1)
Pass 2)
188
212
214
114
1) Ni-Mn-Co
2) Ni-Co
206
146

FIG. 29

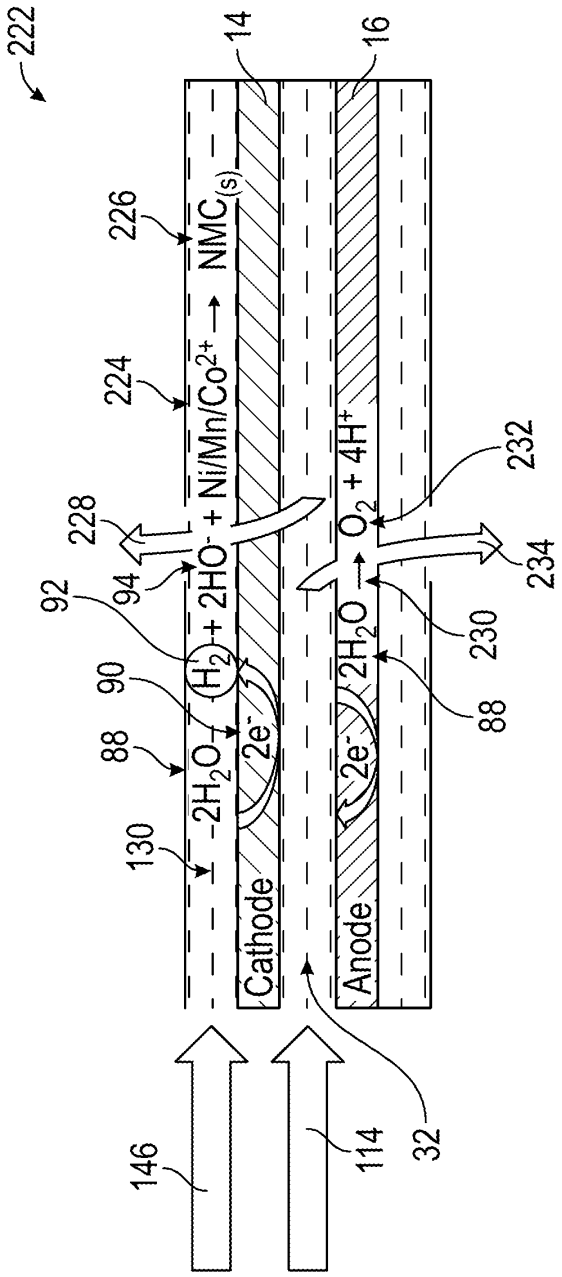

222
14
16
226
$NMC_{(s)}$
$Ni/Mn/Co^{2+}$
224
$O_2 + 4H^+$
232
228
$2HO^-$
234
92
94
(H_2)
230
$2H_2O$
90
$2e^-$
88
$2H_2O$
$2e^-$
88
130
Cathode
Anode
146
114
32

FIG. 30

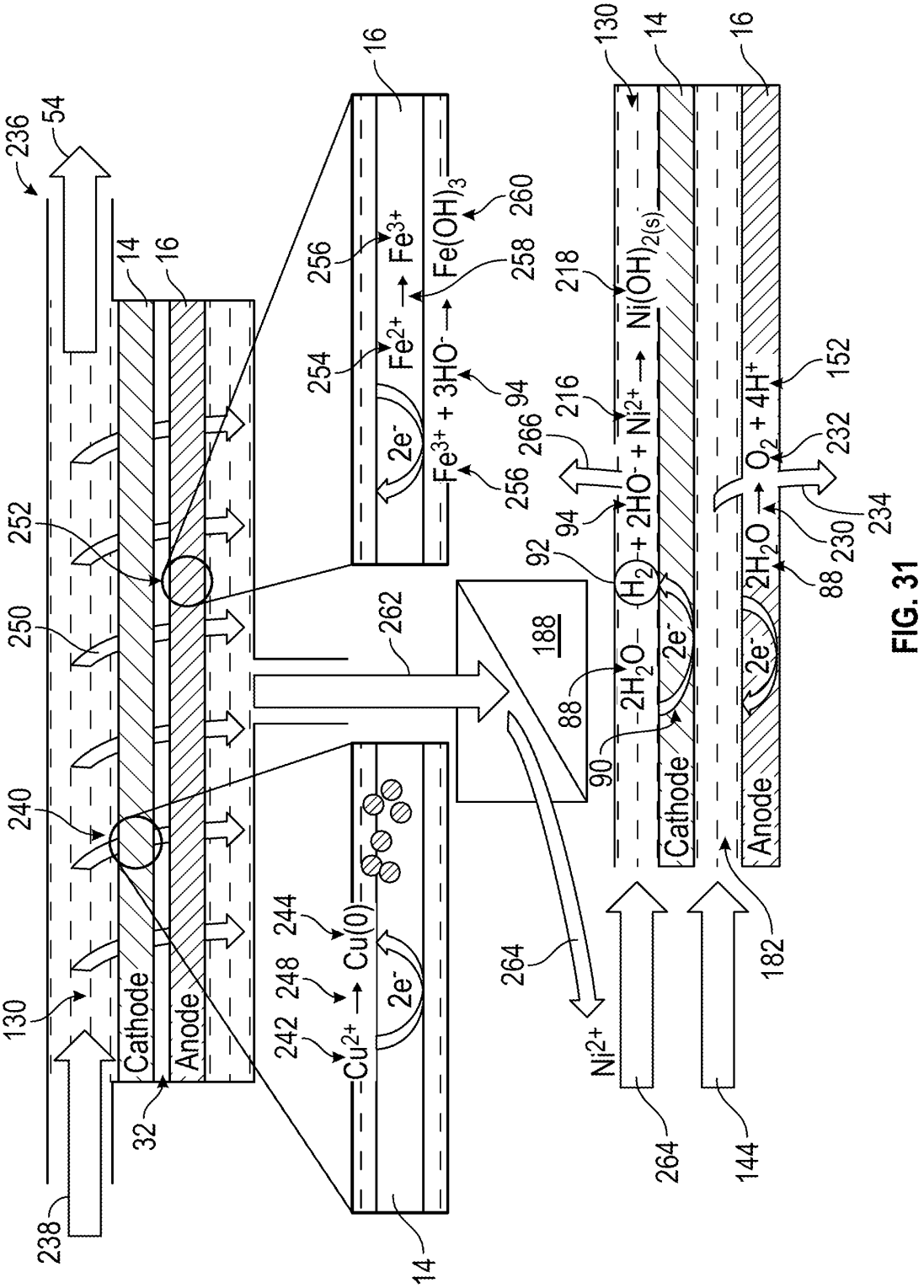

236
54
14
16
252
250
240
130
Cathode
Anode
32
238
16
256
Fe^{3+}
$Fe(OH)_3$
260
258
254
Fe^{2+}
$Fe^{3+} + 3HO^-$
94
2e⁻
256
266
262
188
14
244
Cu(0)
248
242
Cu^{2+}
2e⁻
264
Ni^{2+}
130
14
16
218
$Ni(OH)_{2(s)}$
216
$Ni^{2+} + 2HO^-$
152
$O_2 + 4H^+$
232
234
230
88
92
(H_2)
94
$2H_2O$
2e⁻
90
88
Cathode
Anode
$2H_2O$
2e⁻
182
264
144

FIG. 31

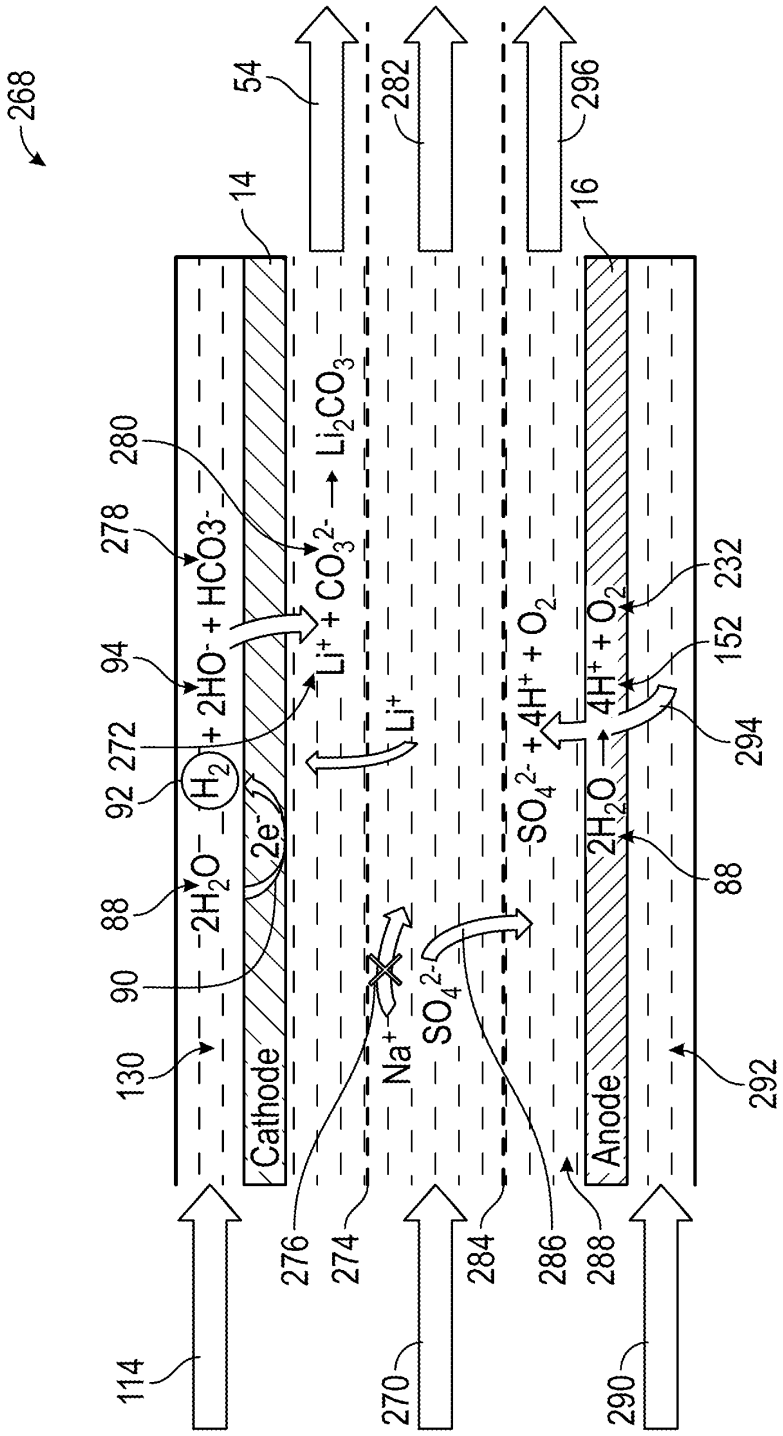

268
54
282
296
14
16
280
278
94
272
92
88
90
130
114
270
290
276
274
284
286
288
292
294
152
232
Cathode
Anode
Li_2CO_3
CO_3^{2-}
$HCO3^-$
$2HO^-$
H_2
$2H_2O$
$2e^-$
Li^+
Na^+
SO_4^{2-}
$-SO_4^{2-} + 4H^+ + O_2$
$4H^+ + O_2$
$2H_2O$

FIG. 32

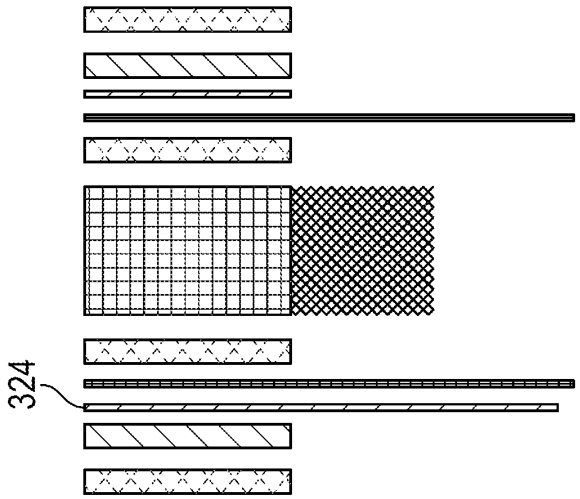


FIG. 34

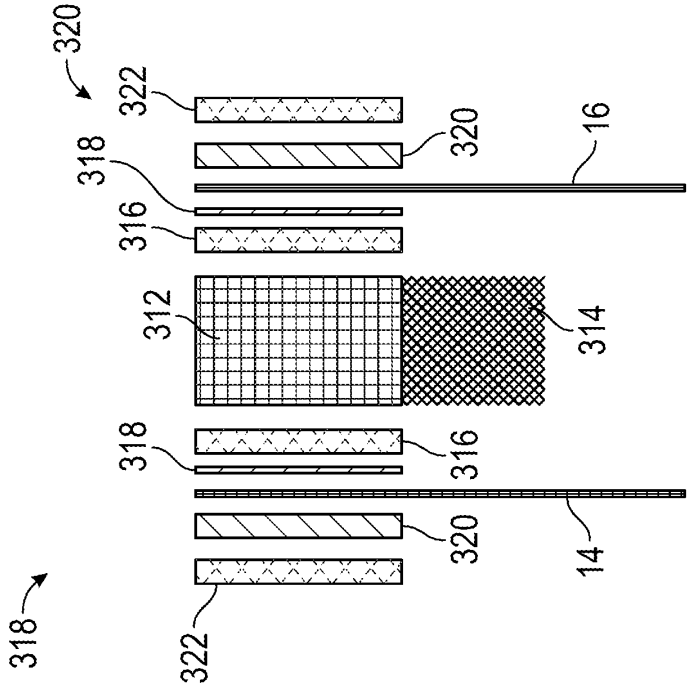


FIG. 33

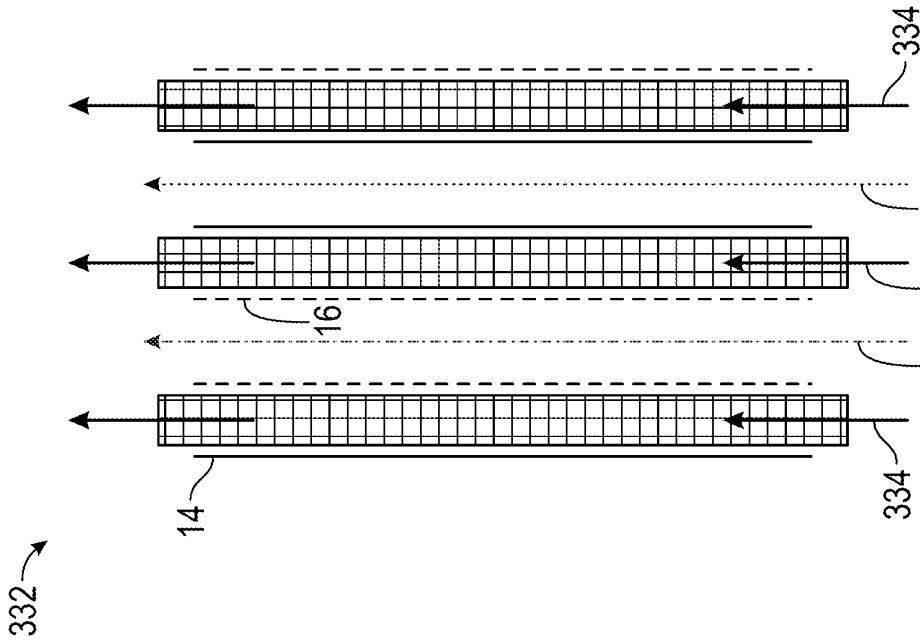

334
330
334
16
330
14
334
332

FIG. 36

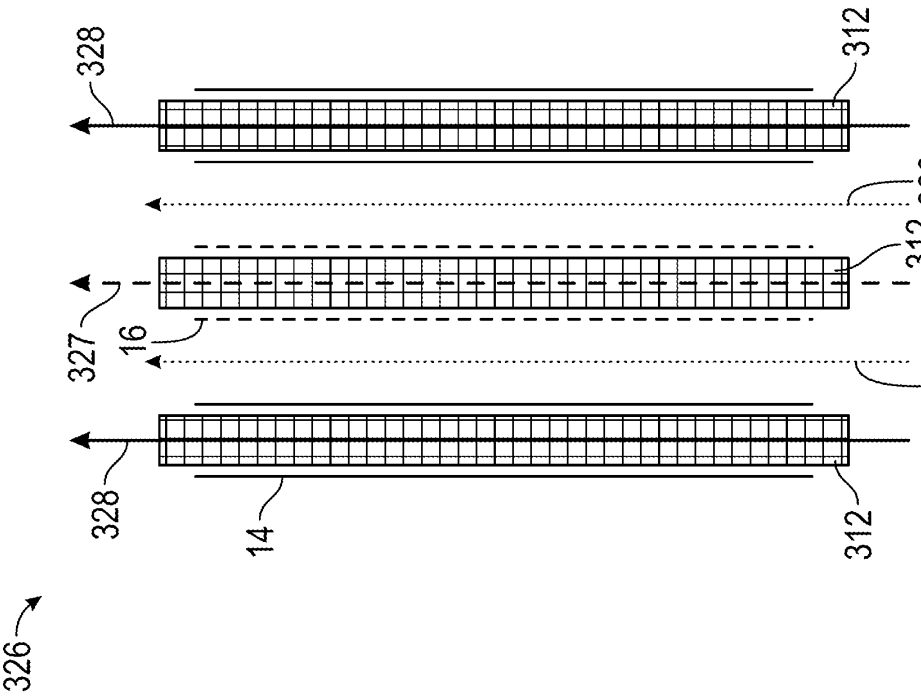

328
312
330
312
327
16
330
328
14
312
326

FIG. 35

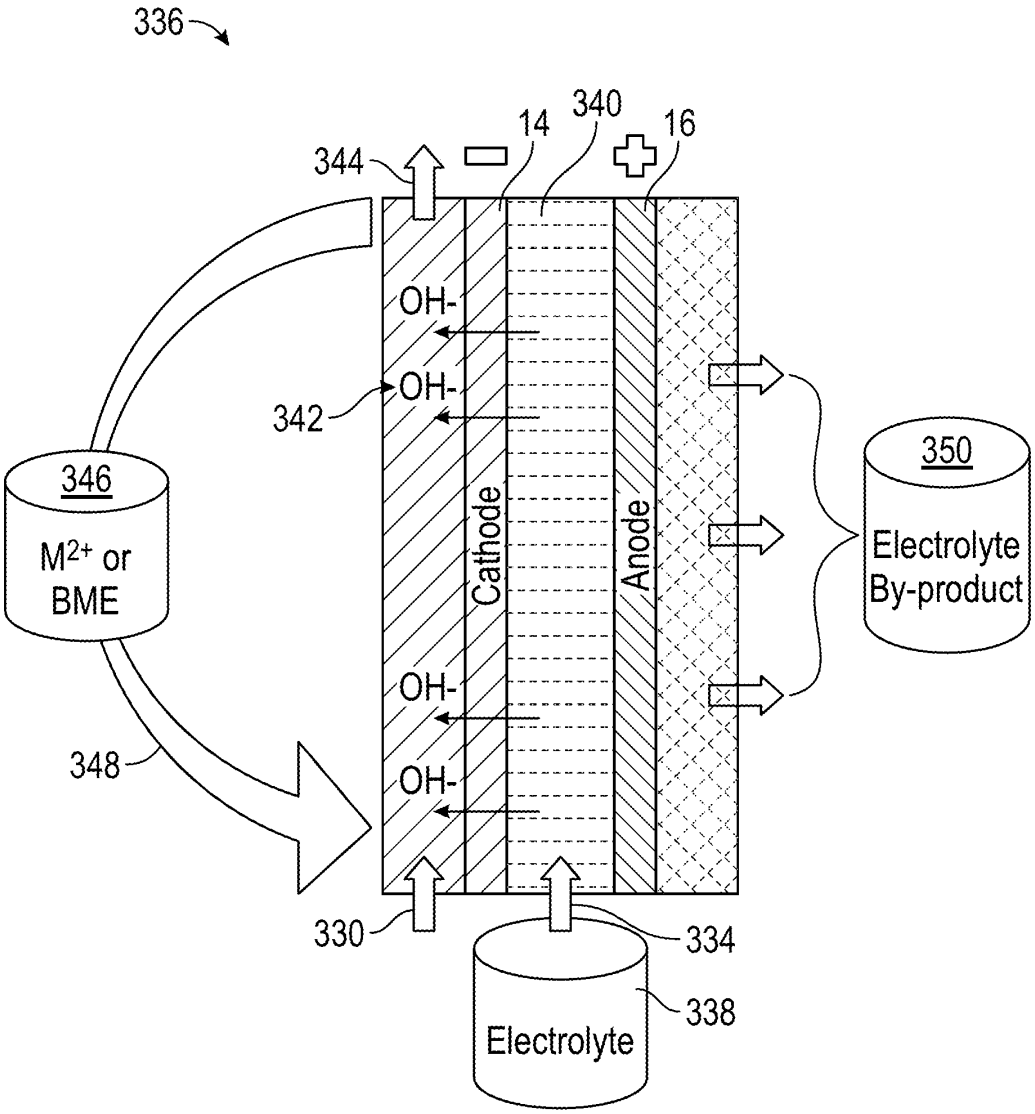

336
344
14
340
16
OH-
OH-
342
346
M2+ or
BME
Cathode
Anode
350
Electrolyte
By-product
OH-
OH-
348
330
334
338
Electrolyte

FIG. 37

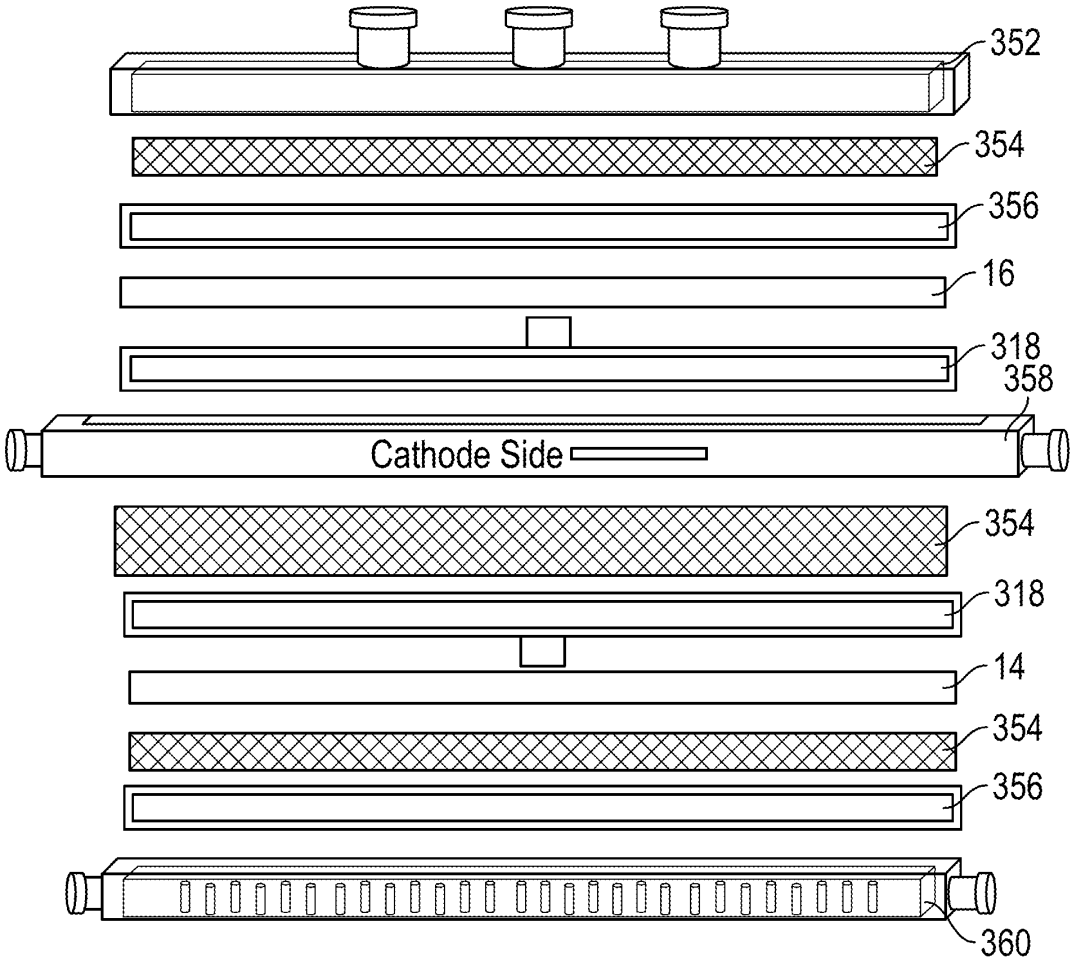


FIG. 38

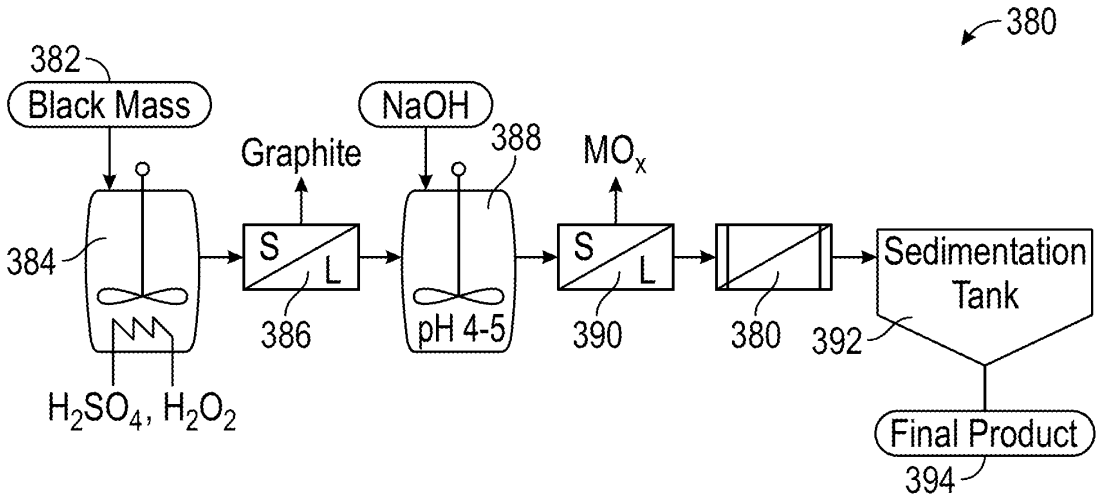

380
382
Black Mass
NaOH
Graphite
388
MOx
384
S
L
S
L
Sedimentation Tank
386
pH 4-5
390
380
392
H2SO4, H2O2
Final Product
394

FIG. 39

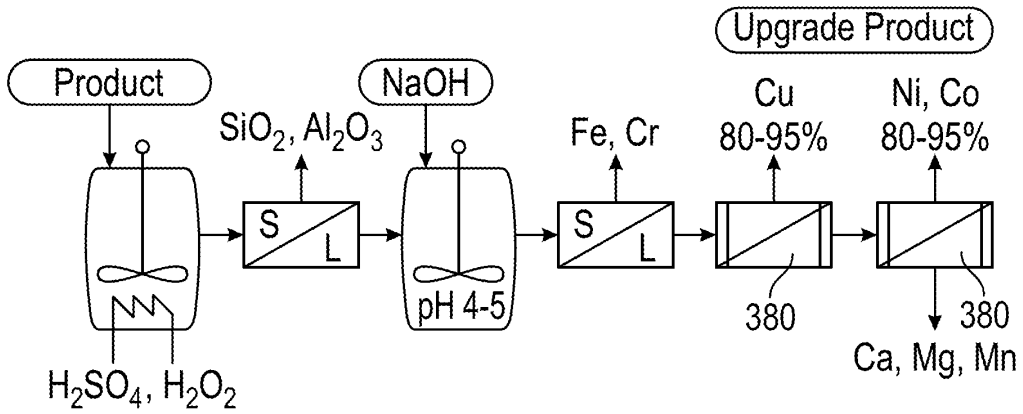

Upgrade Product
Product
NaOH
Cu
80-95%
Ni, Co
80-95%
SiO2, Al2O3
Fe, Cr
S
L
S
L
pH 4-5
380
380
Ca, Mg, Mn
H2SO4, H2O2

FIG. 40

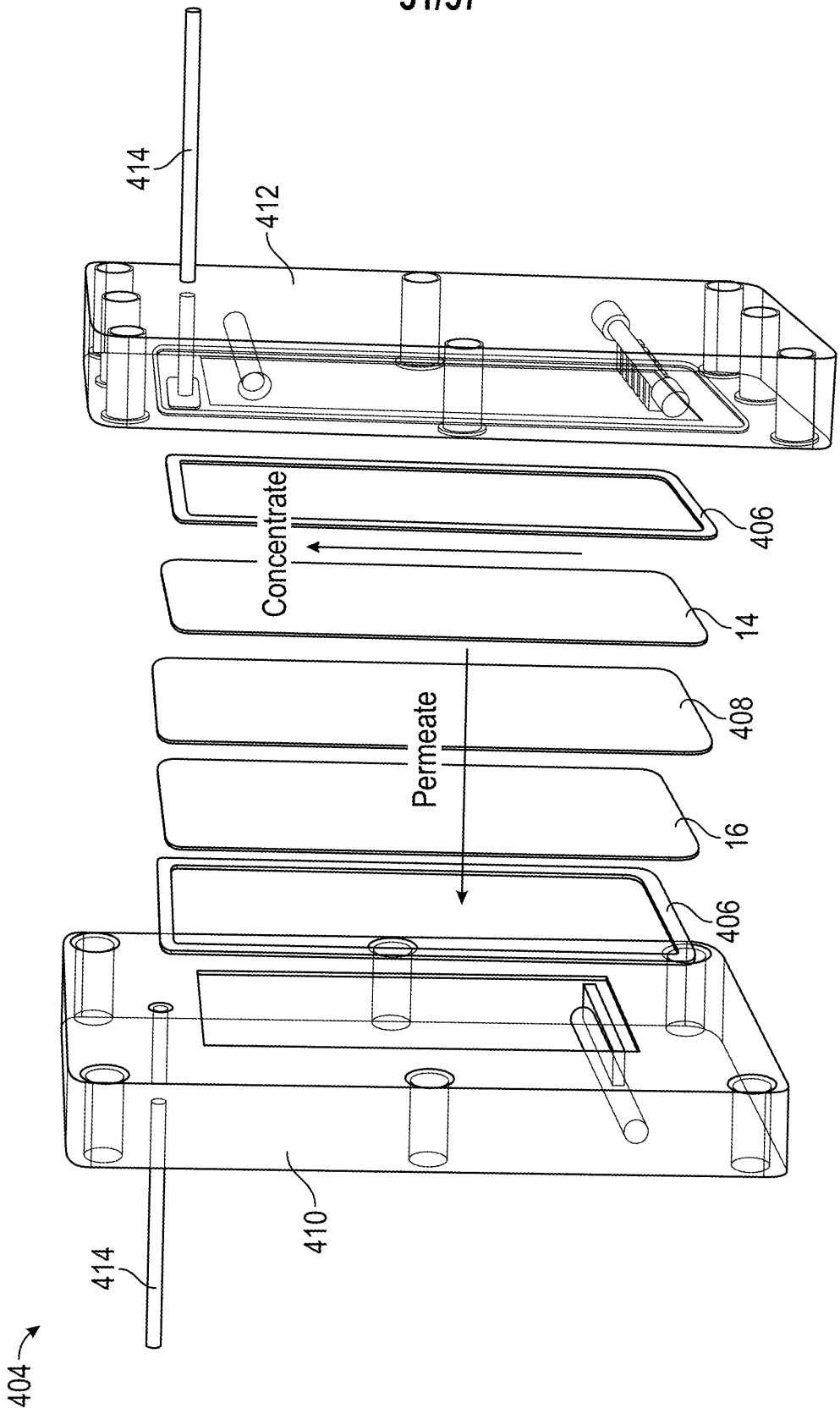


FIG. 41

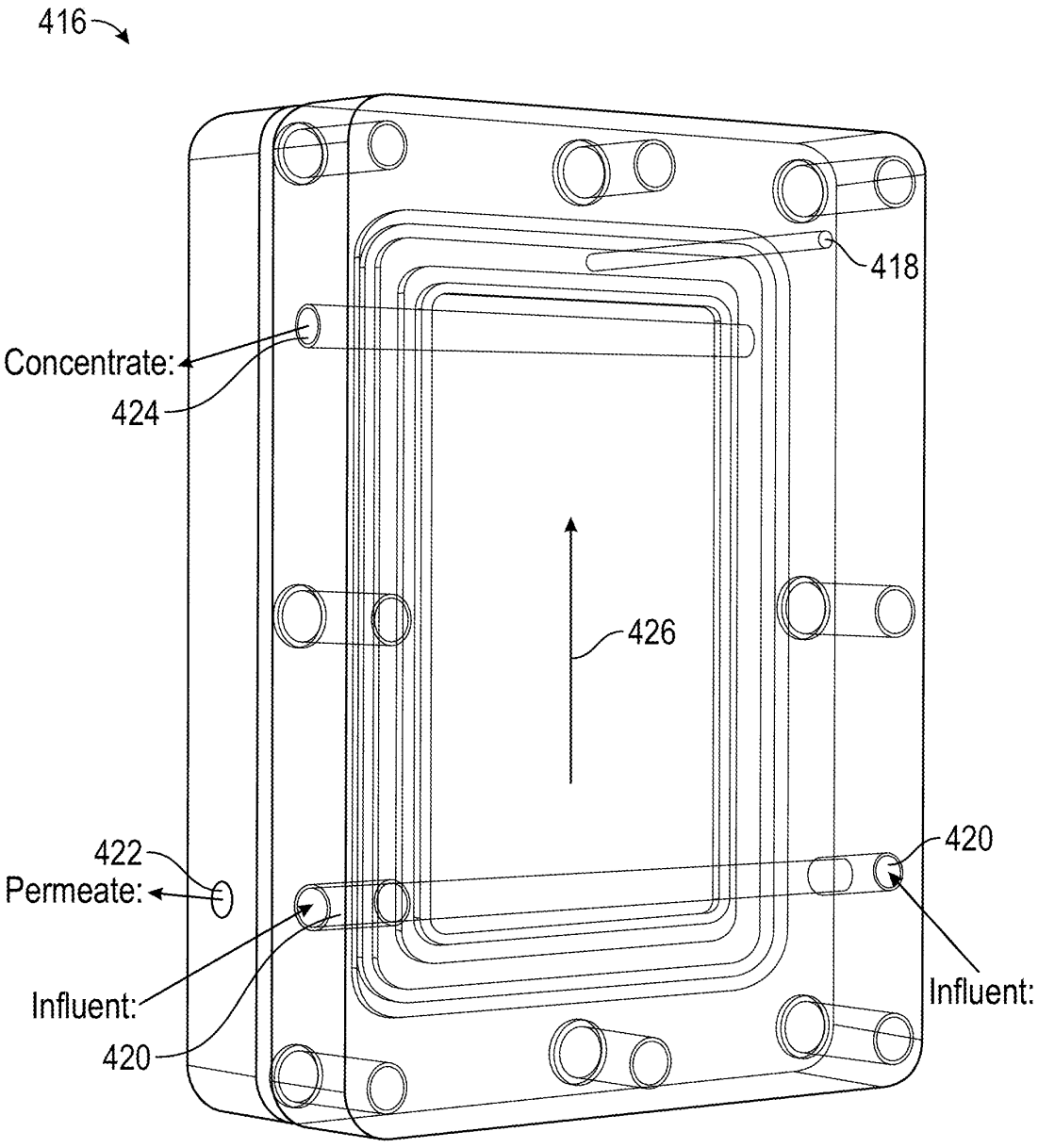

416
418
Concentrate:
424
426
422
Permeate:
420
Influent:
420
Influent:

FIG. 42

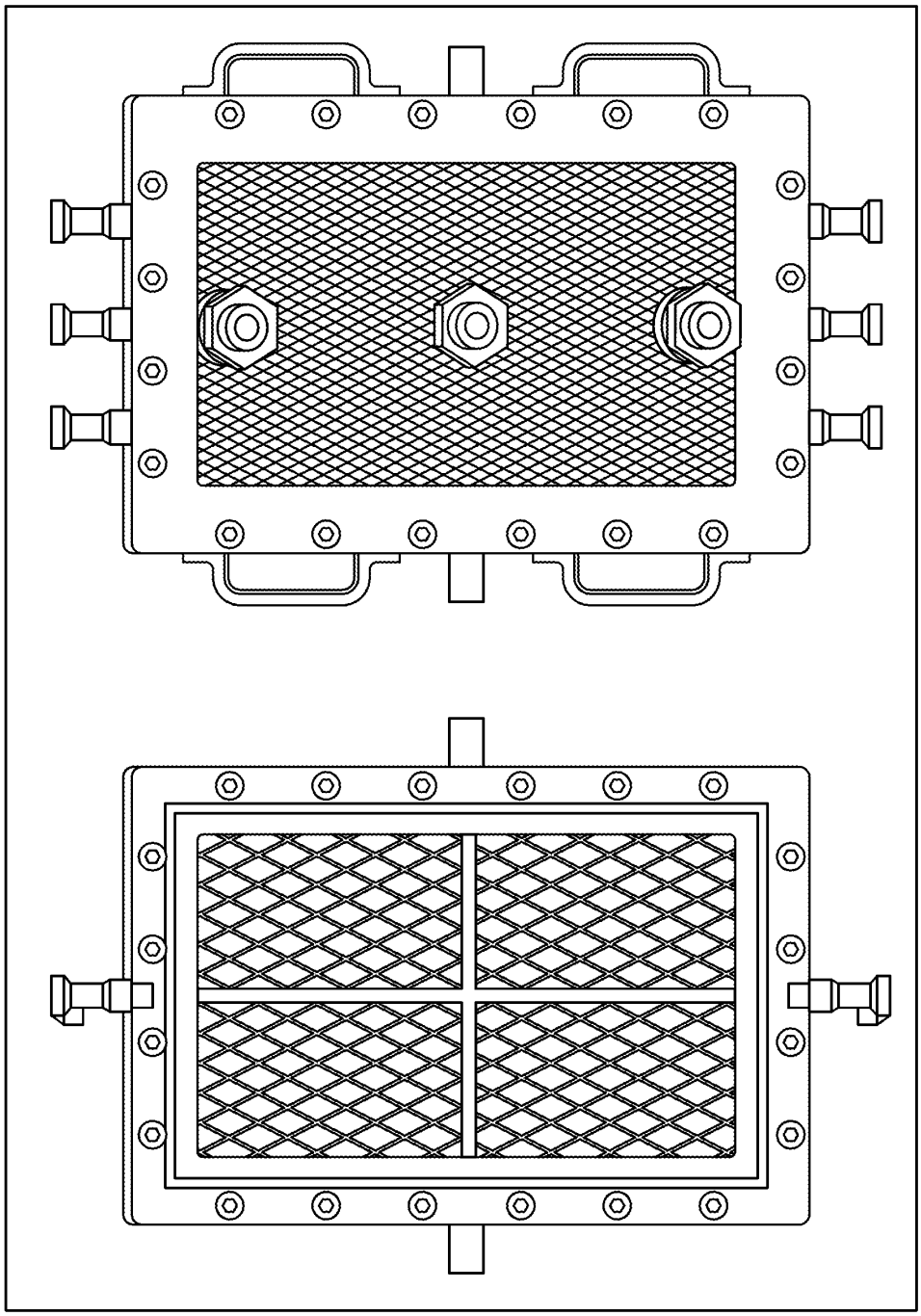


FIG. 43

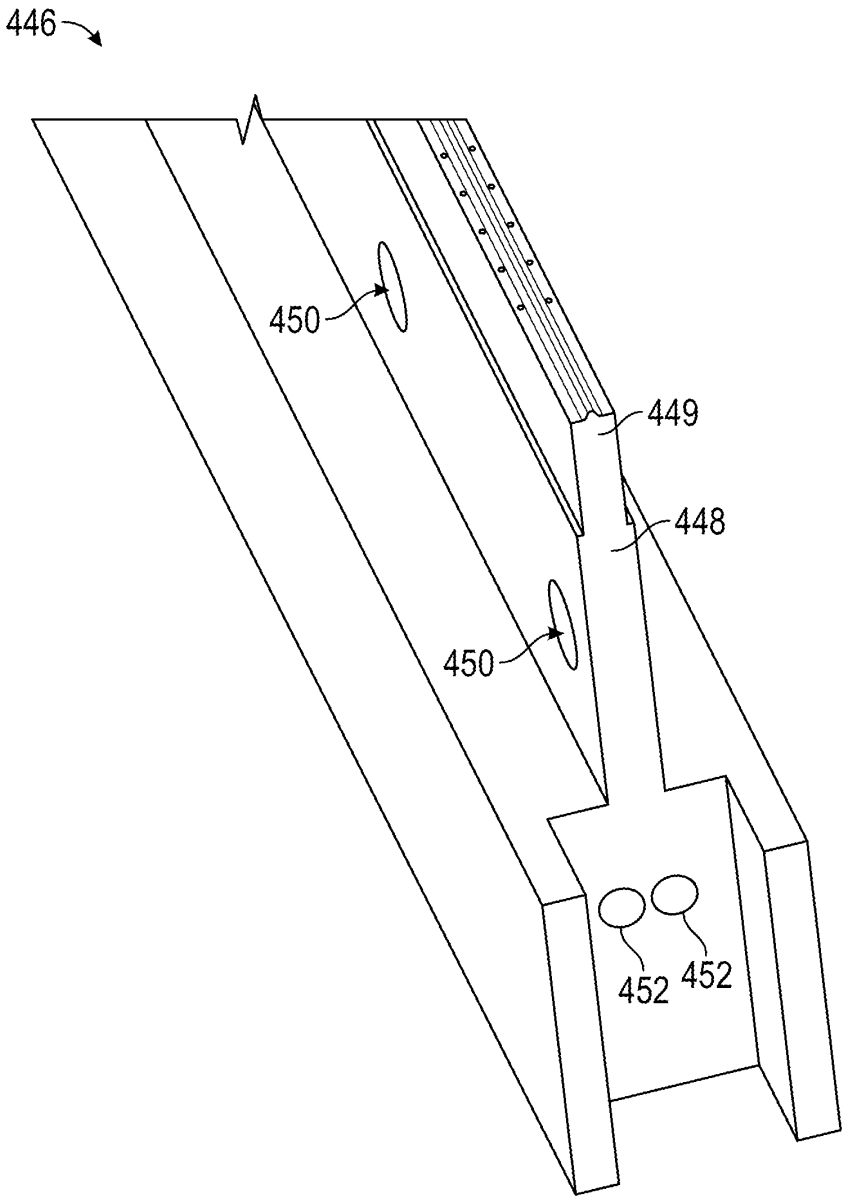


FIG. 44

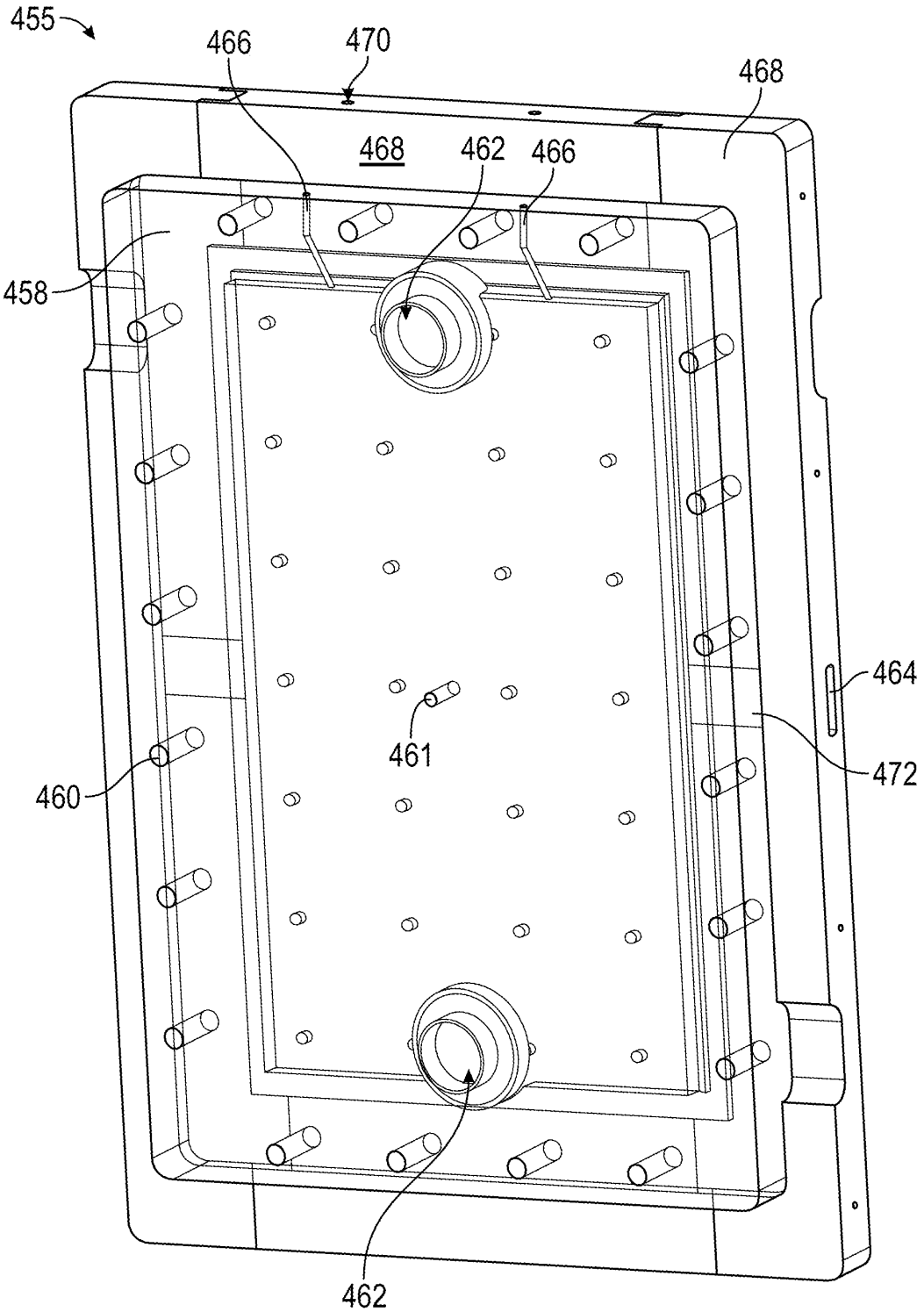


FIG. 45

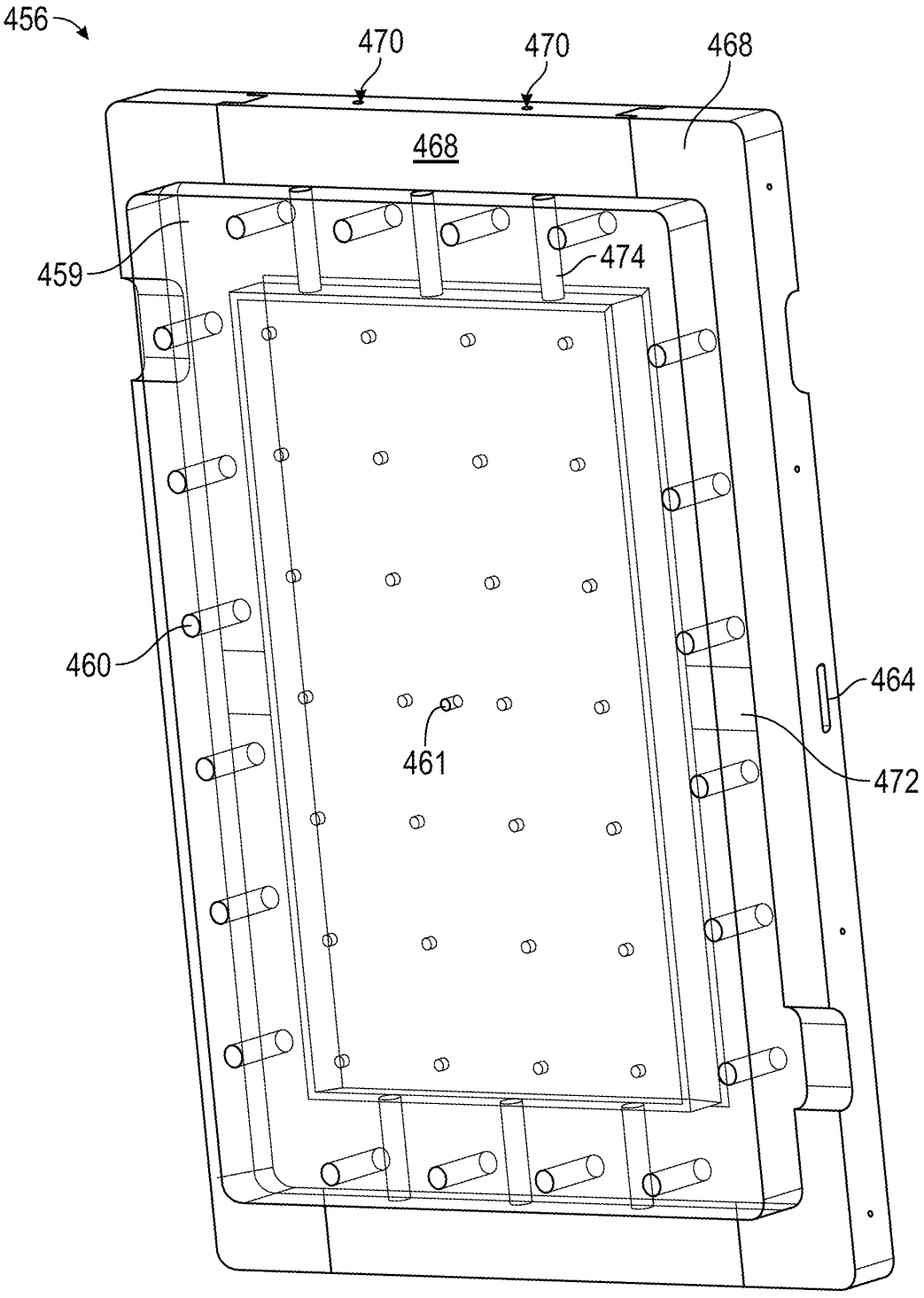


FIG. 46

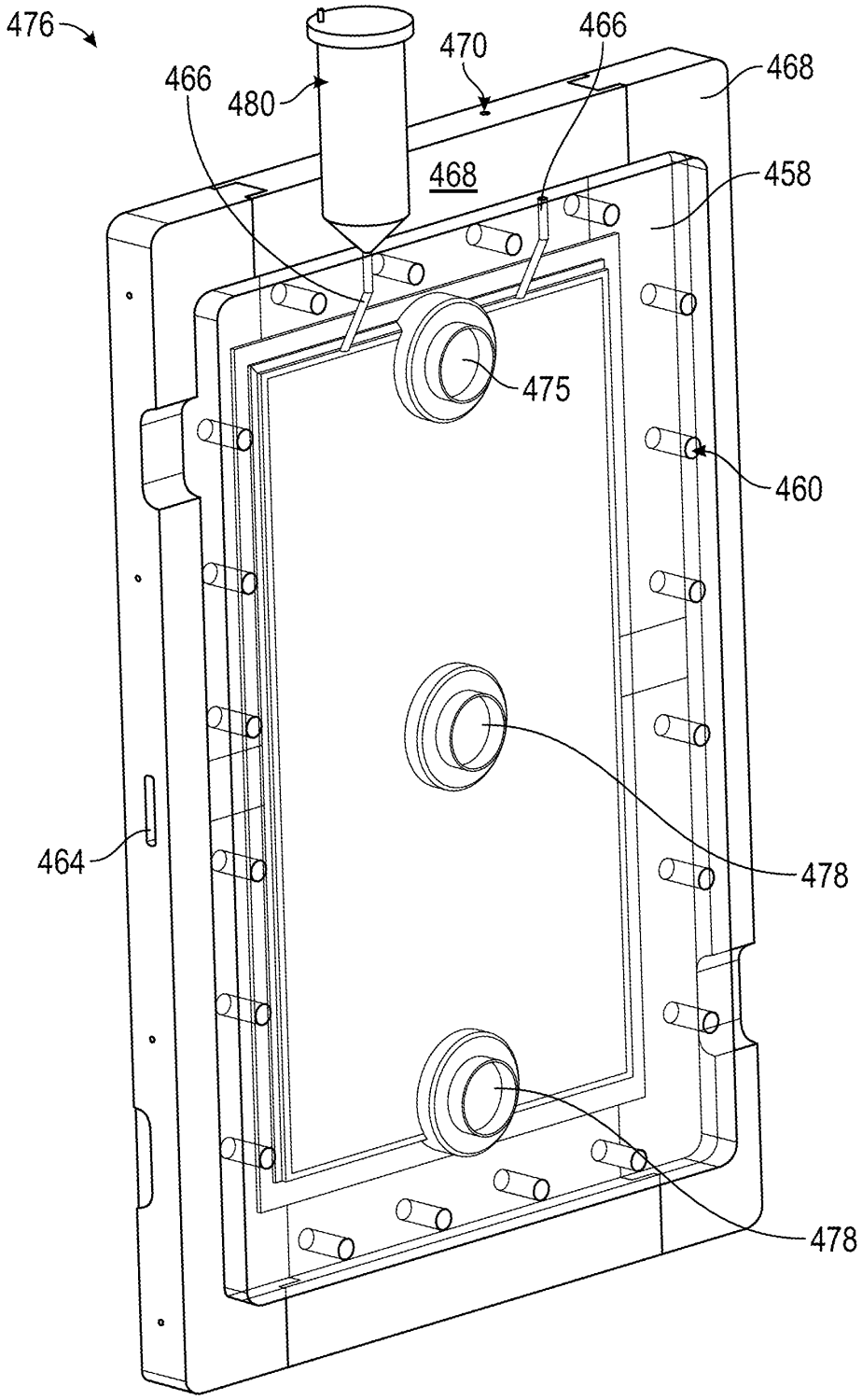


FIG. 47

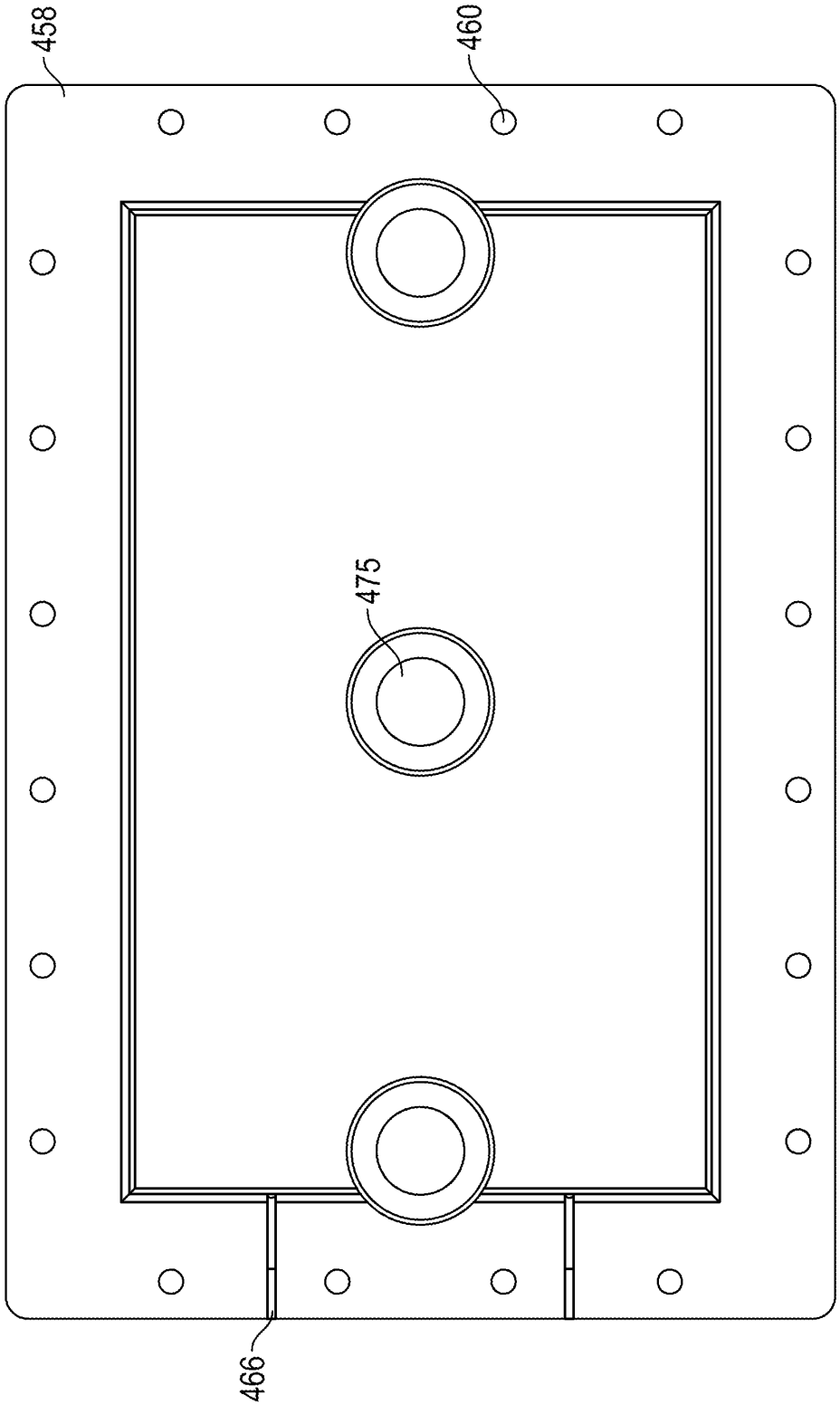


FIG. 48

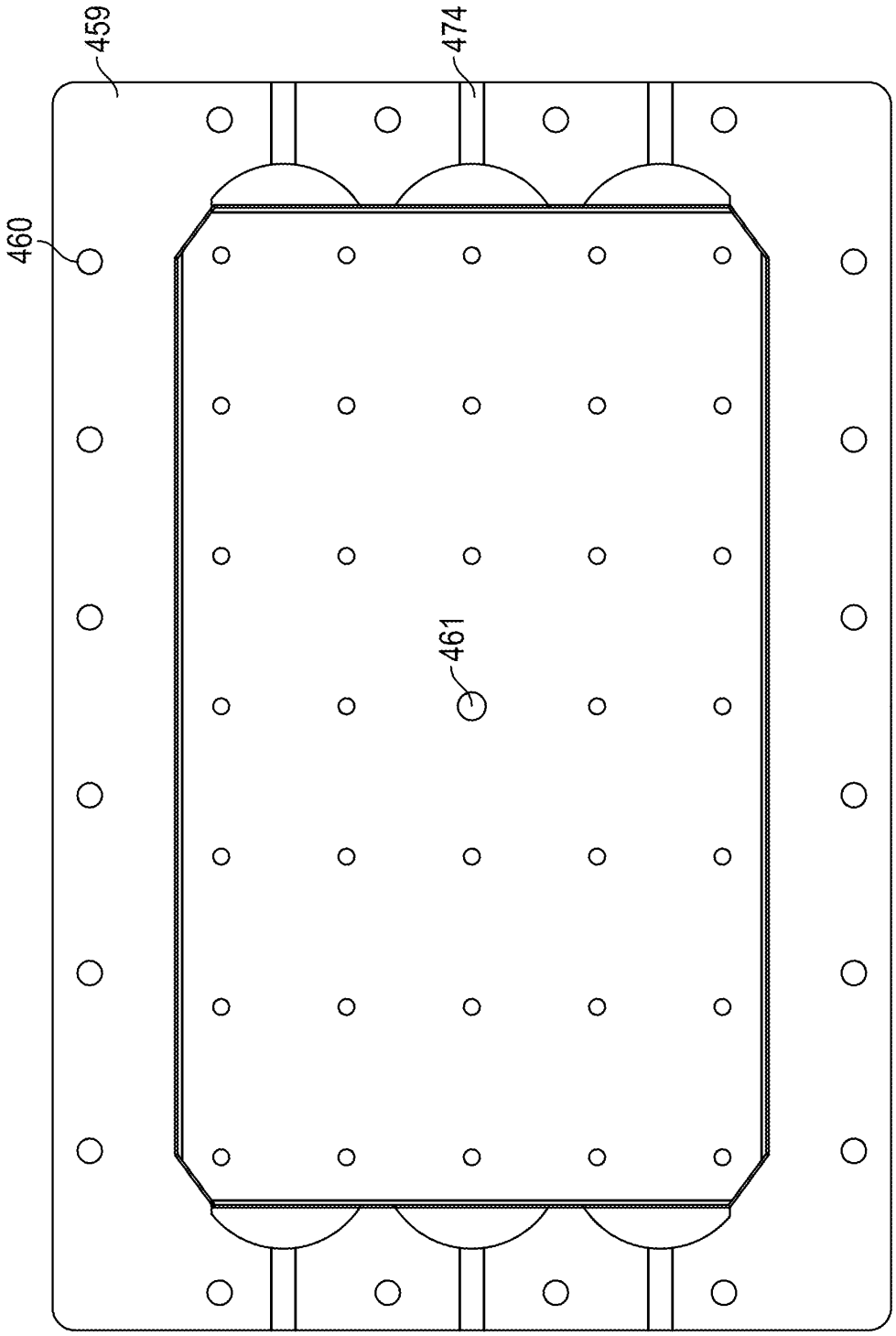


FIG. 49

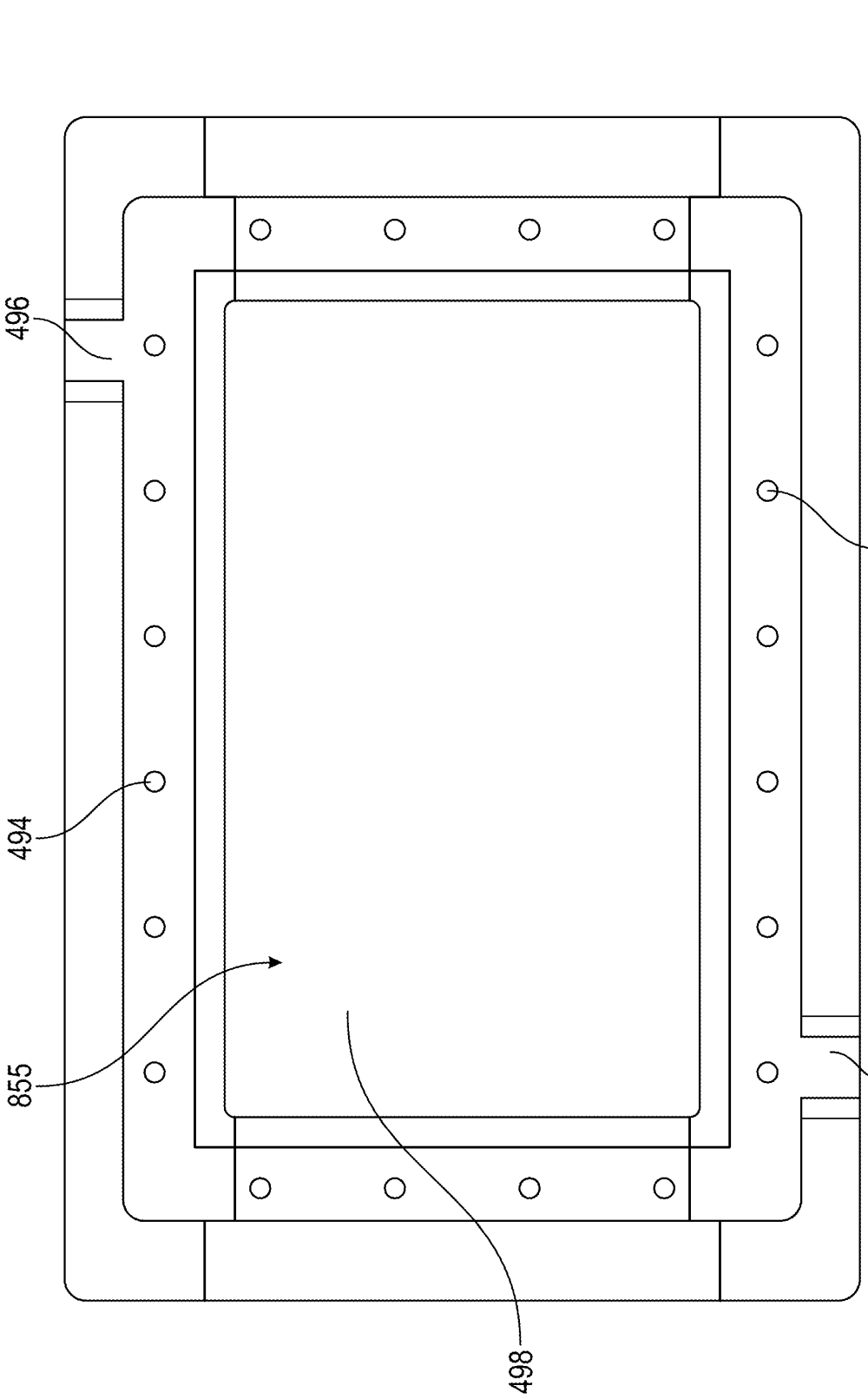


FIG. 50

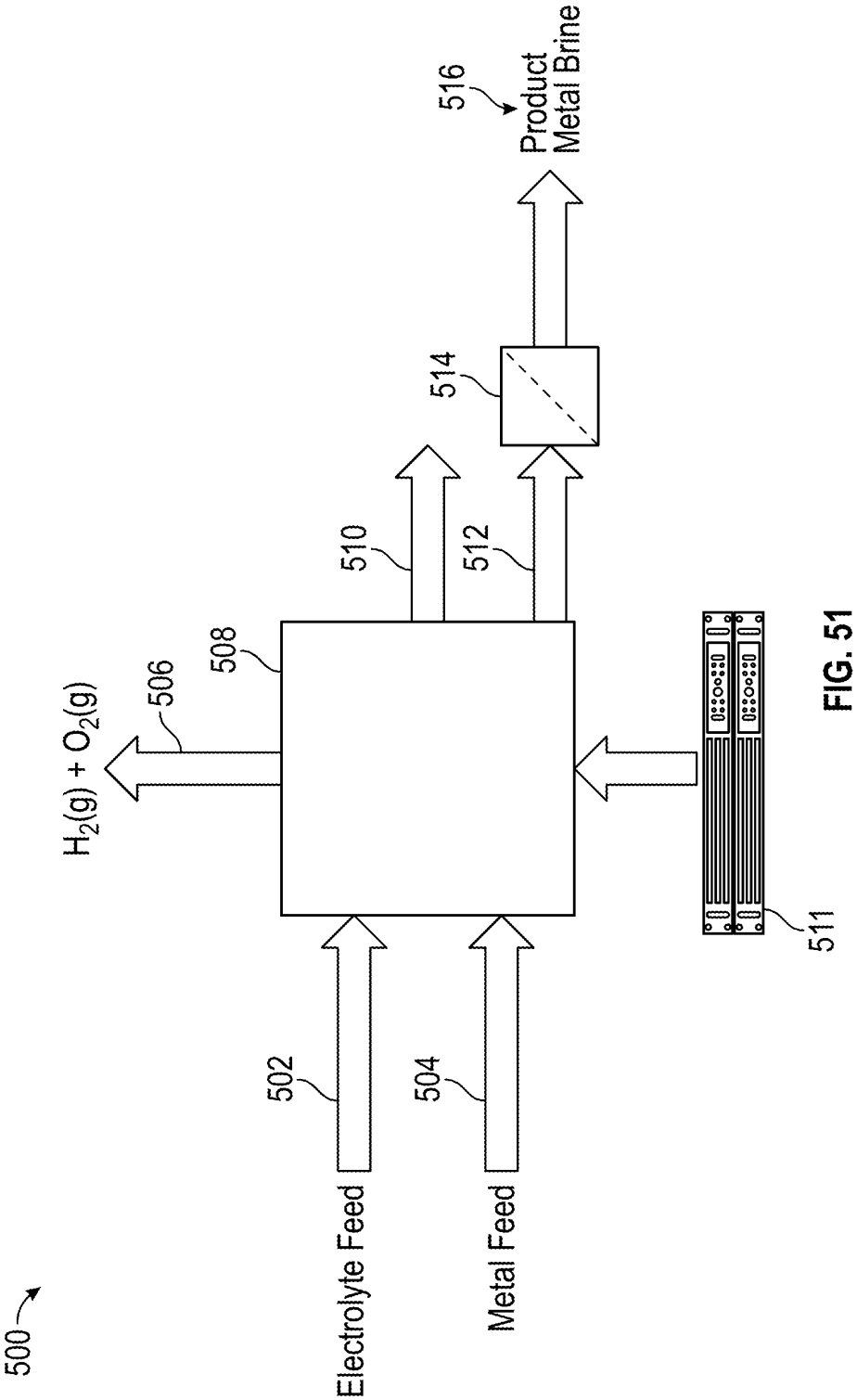

500
Electrolyte Feed
Metal Feed
502
504
$H_2(g) + O_2(g)$
506
508
510
512
514
516
Product Metal Brine
511

FIG. 51

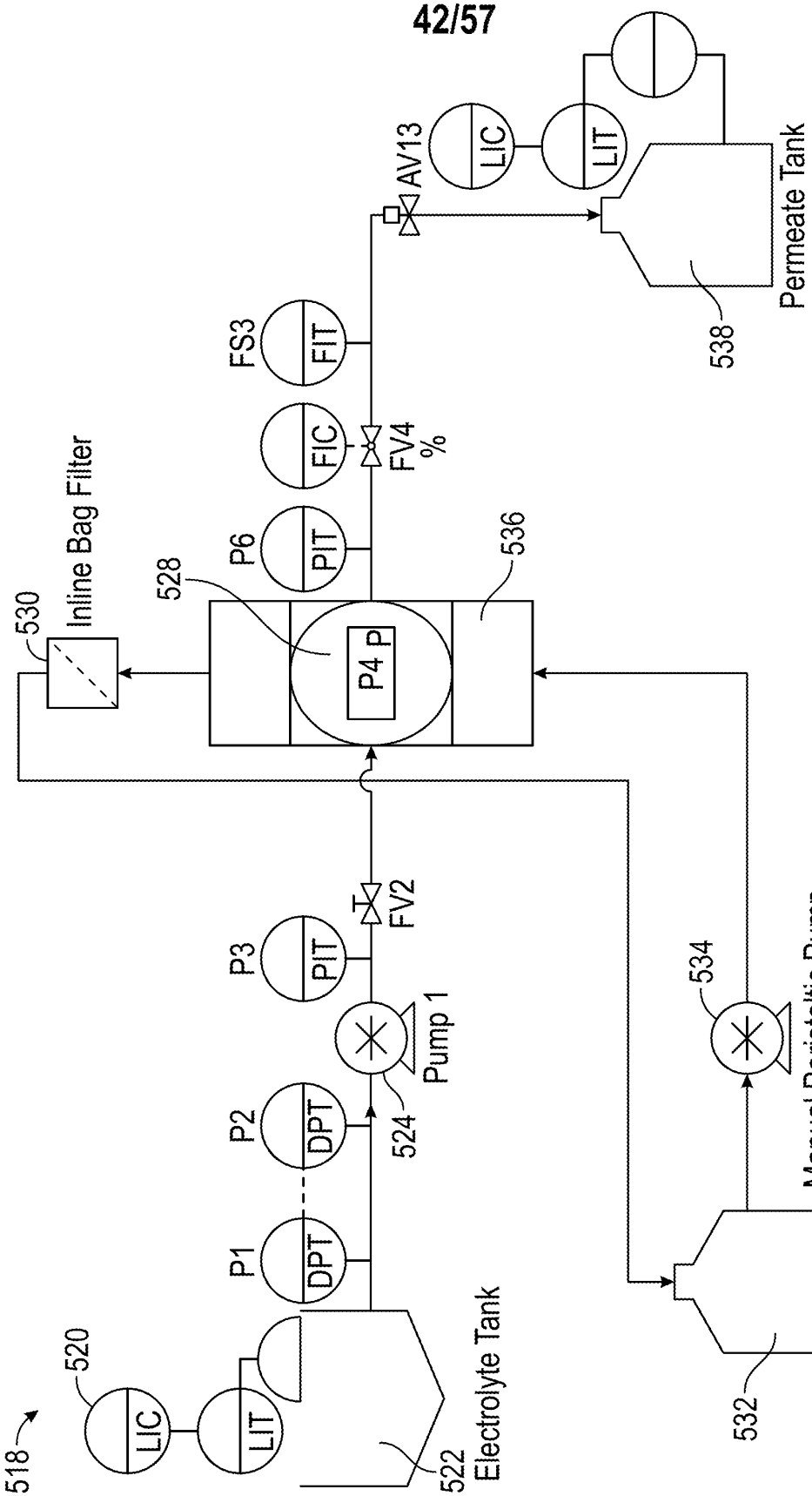

518
520
LIC
LIT
522
Electrolyte Tank
P1
DPT
P2
DPT
524
Pump 1
P3
PIT
FV2
528
P4 P
536
P6
PIT
FIC
FV4
%
FS3
FIT
530
Inline Bag Filter
AV13
LIC
LIT
538
Permeate Tank
532
Metal Feed Tank
534
Manual Peristaltic Pump

FIG. 52

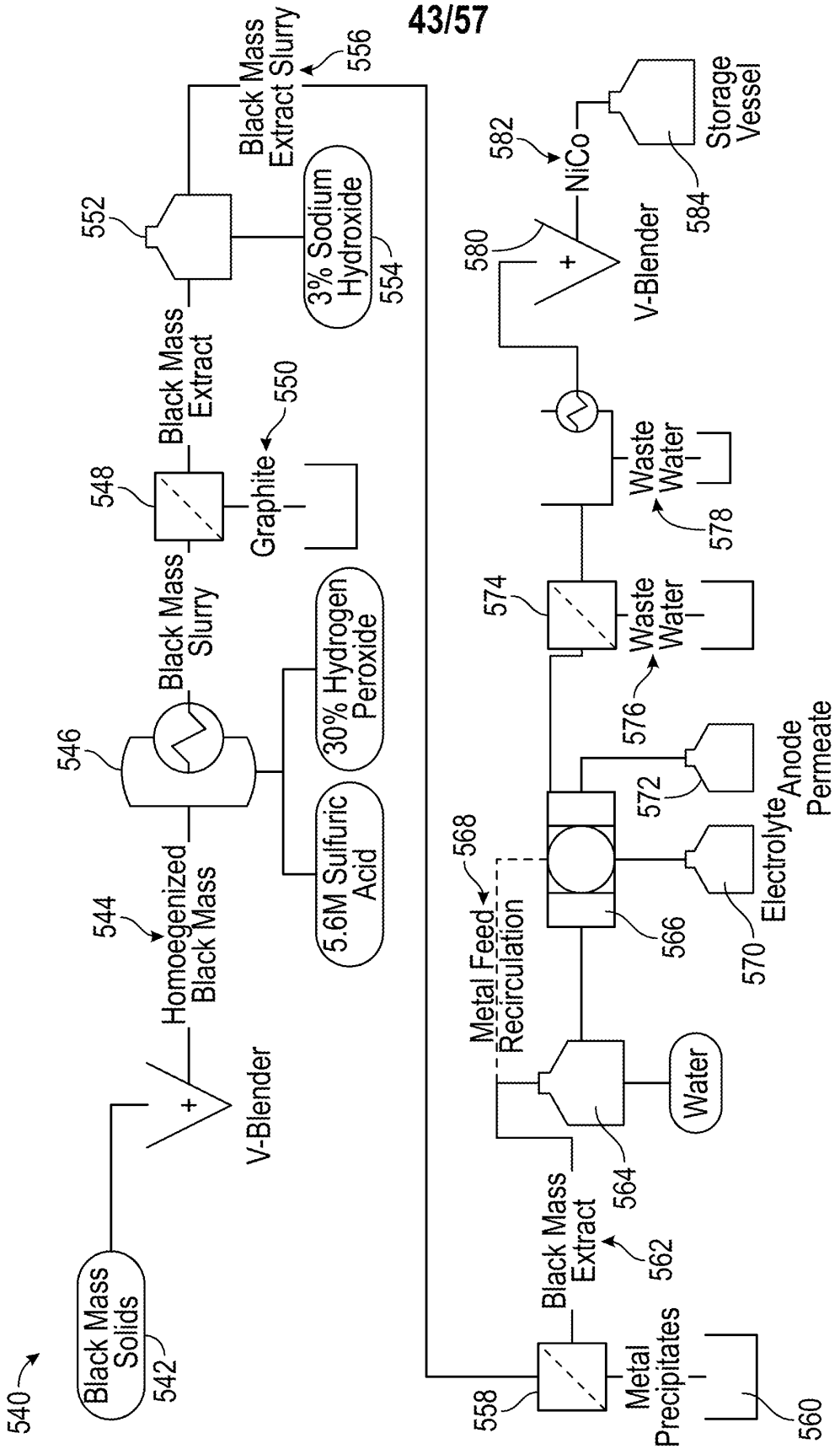

540
Black Mass Solids
542
V-Blender
Homoegenized Black Mass
544
5.6M Sulfuric Acid
30% Hydrogen Peroxide
546
Black Mass Slurry
548
Graphite
550
Black Mass Extract
552
3% Sodium Hydroxide
554
Black Mass Extract Slurry
556
558
Metal Precipitates
560
Black Mass Extract
562
564
Water
Metal Feed Recirculation
568
566
Electrolyte
570
Anode Permeate
572
574
Waste Water
576
Waste Water
578
580
V-Blender
582
NiCo
584
Storage Vessel

FIG. 53

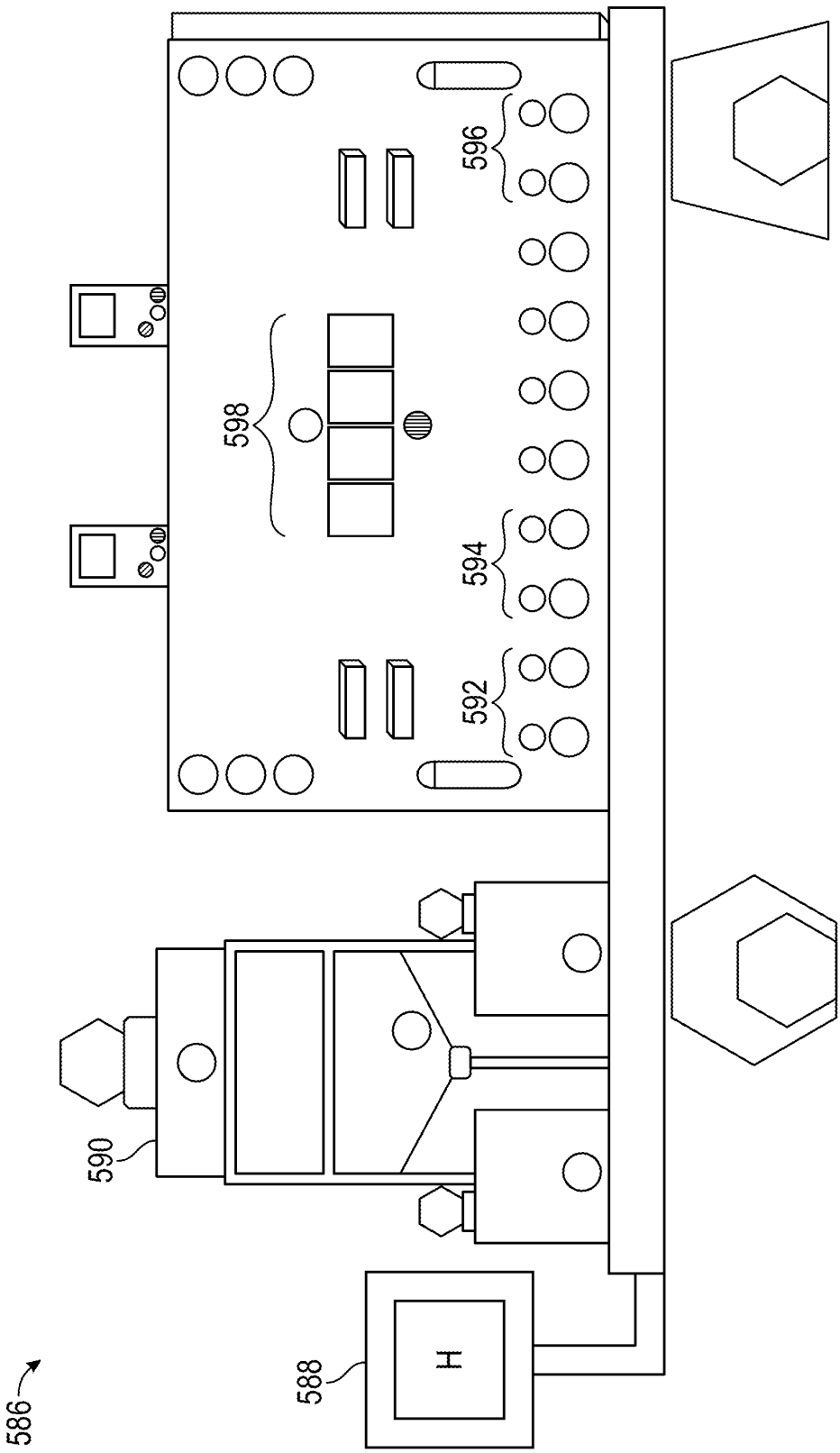


FIG. 54

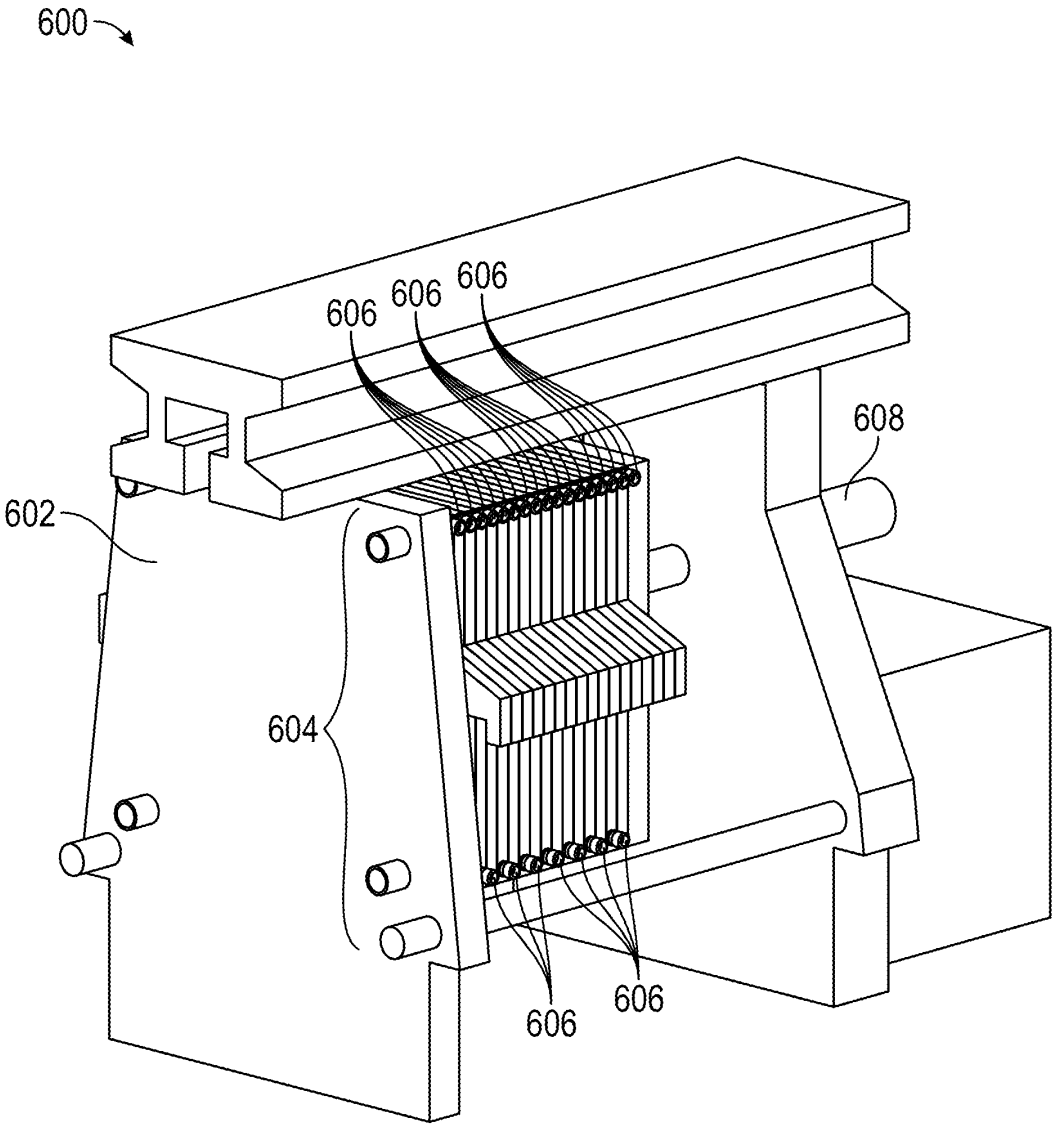


FIG. 55

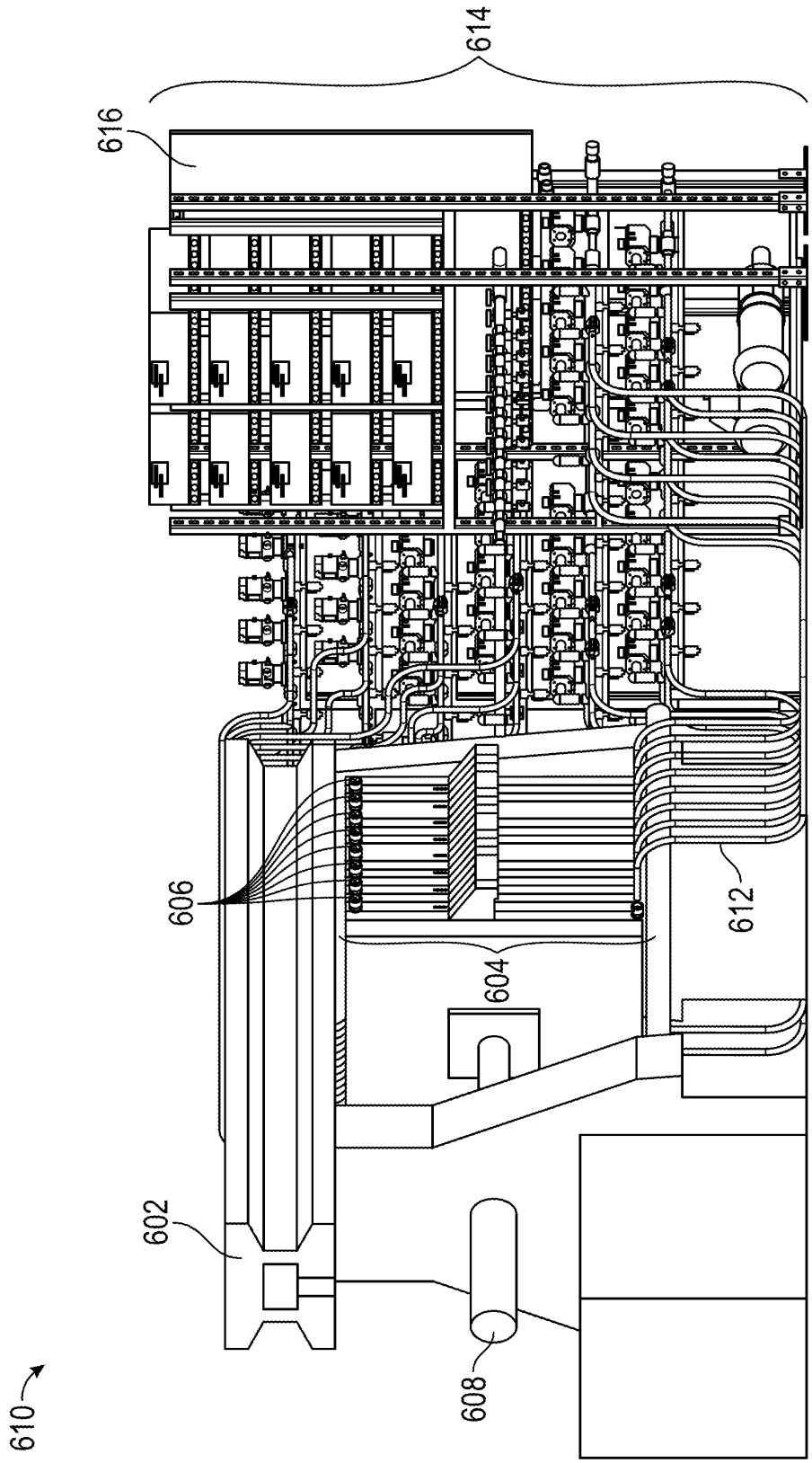


FIG. 56

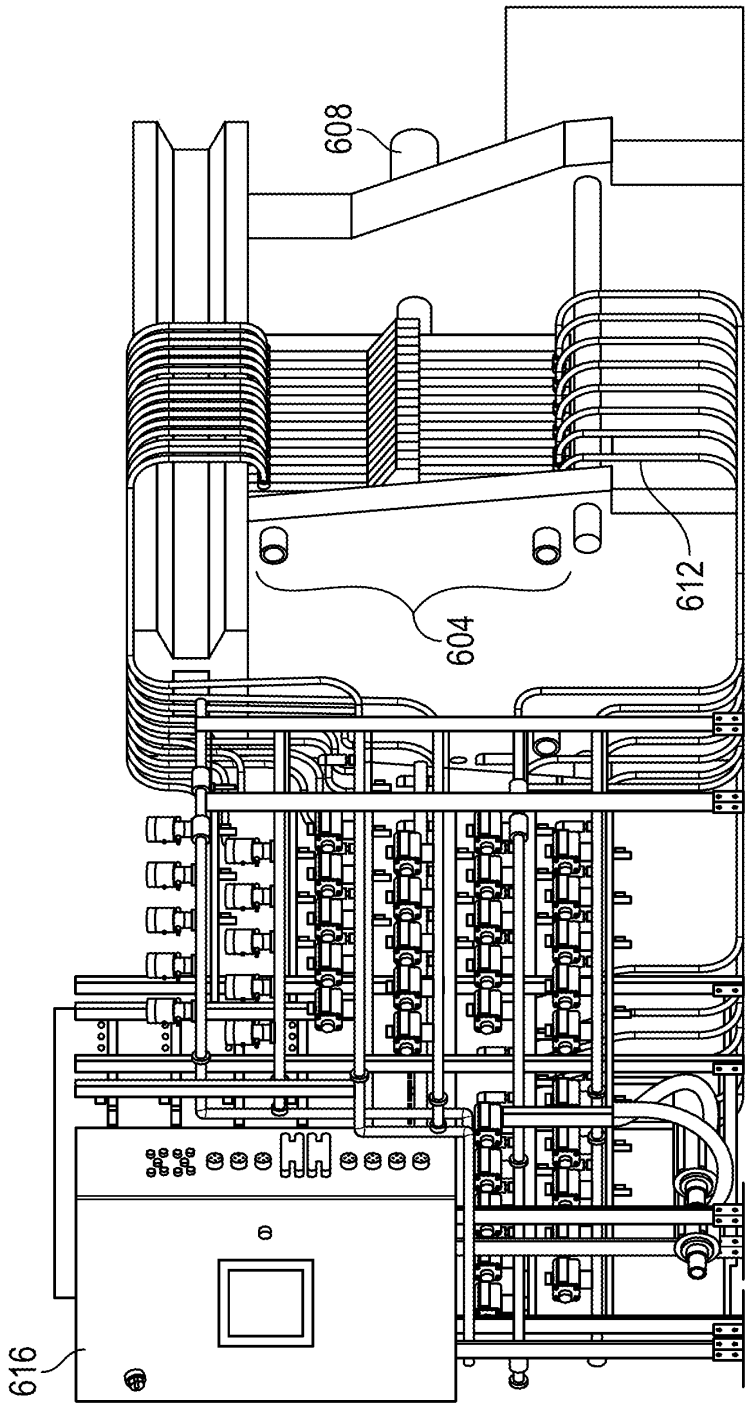


FIG. 57

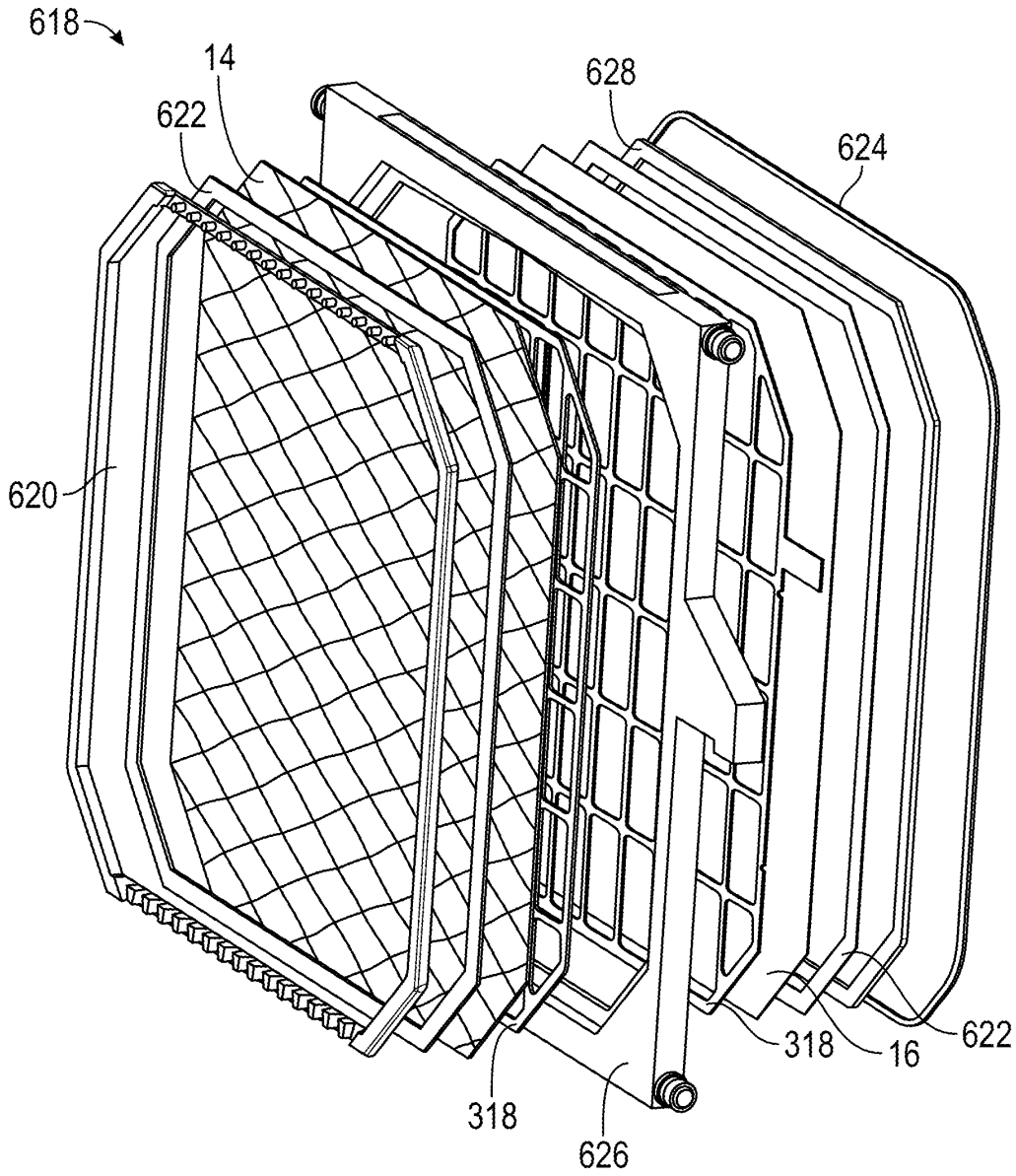


FIG. 58

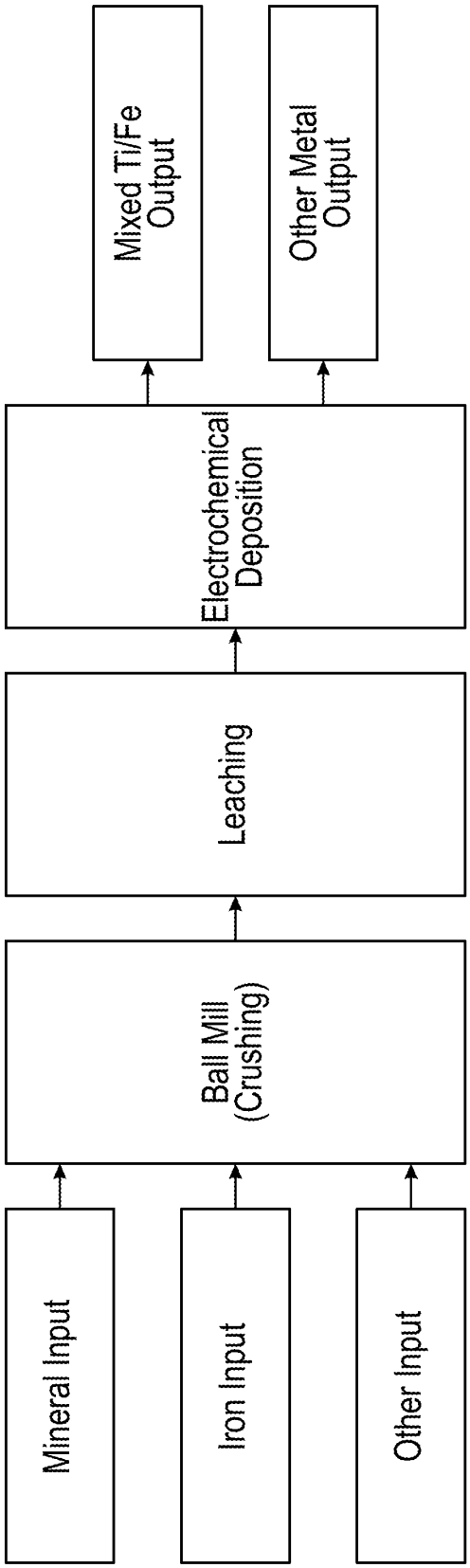

Mixed Ti/Fe Output
Other Metal Output
Electrochemical Deposition
Leaching
Ball Mill (Crushing)
Mineral Input
Iron Input
Other Input

FIG. 59

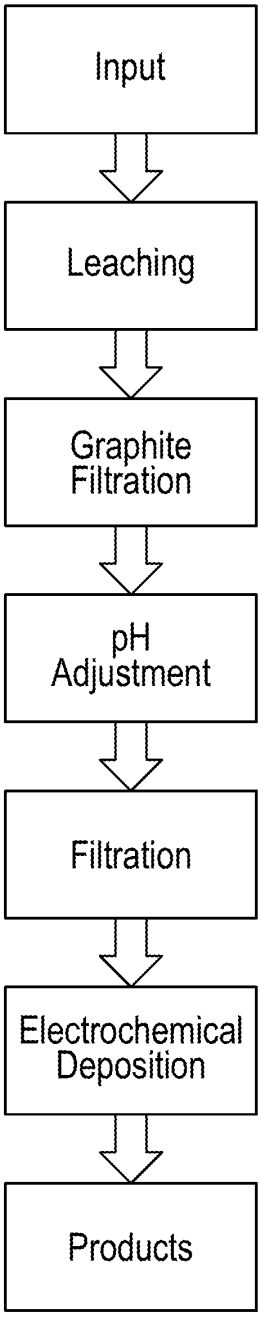

Input
Leaching
Graphite Filtration
pH Adjustment
Filtration
Electrochemical Deposition
Products

FIG. 60

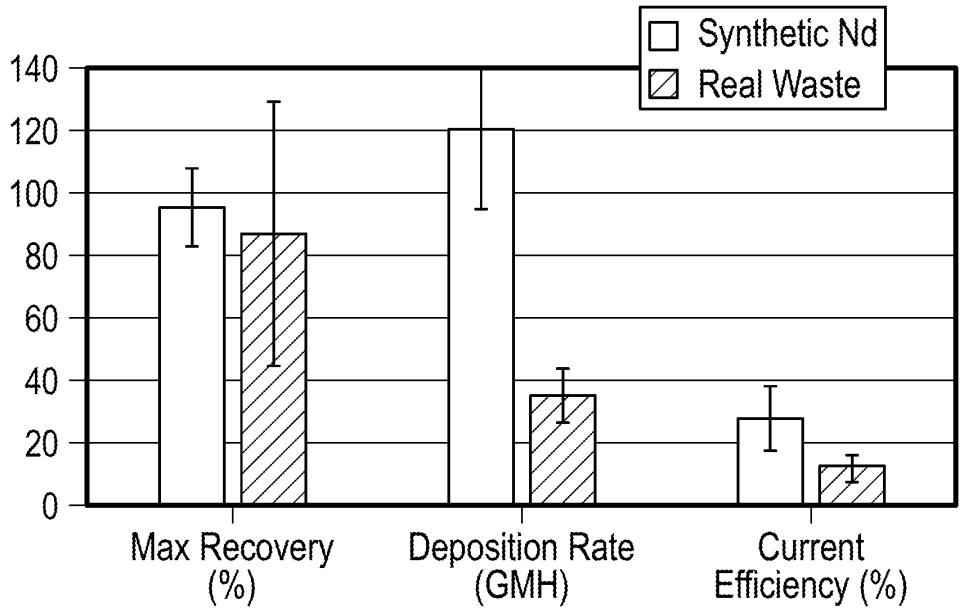

Synthetic Nd
Real Waste
140
120
100
80
60
40
20
0
Max Recovery (%)
Deposition Rate (GMH)
Current Efficiency (%)

FIG. 61

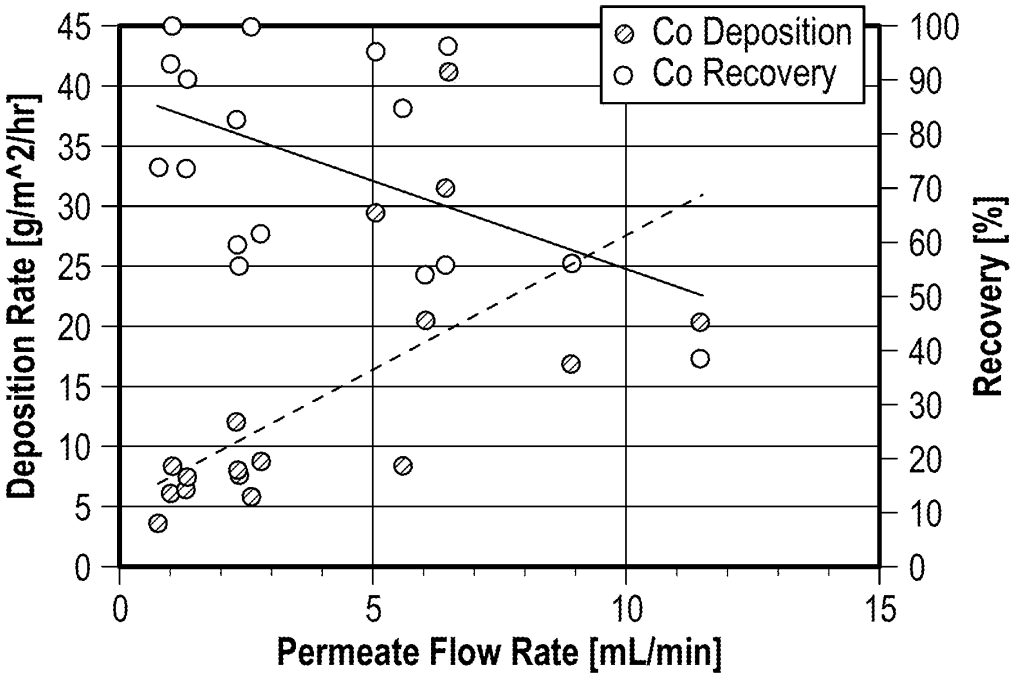

Co Deposition
Co Recovery
Deposition Rate [g/m^2/hr]
Recovery [%]
Permeate Flow Rate [mL/min]
0
5
10
15
0
10
20
30
40
45
50
60
70
80
90
100

FIG. 62

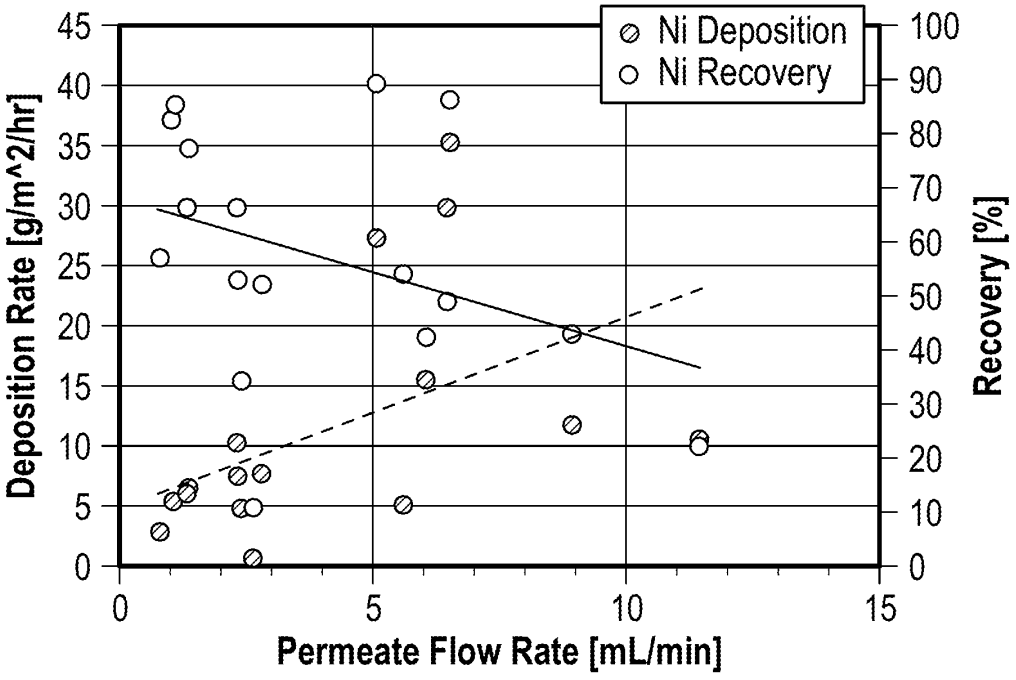

Ni Deposition
Ni Recovery
Deposition Rate [g/m^2/hr]
Recovery [%]
Permeate Flow Rate [mL/min]
0
5
10
15
0
10
20
30
40
45
50
60
70
80
90
100

FIG. 63

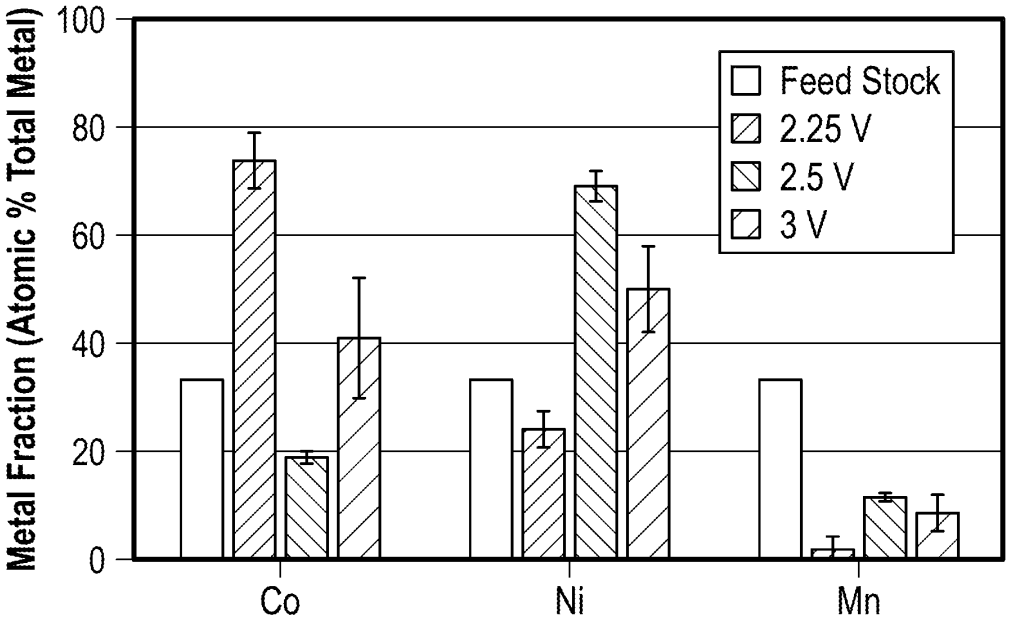

Metal Fraction (Atomic % Total Metal)
100
80
60
40
20
0
Feed Stock
2.25 V
2.5 V
3 V
Co
Ni
Mn

FIG. 64

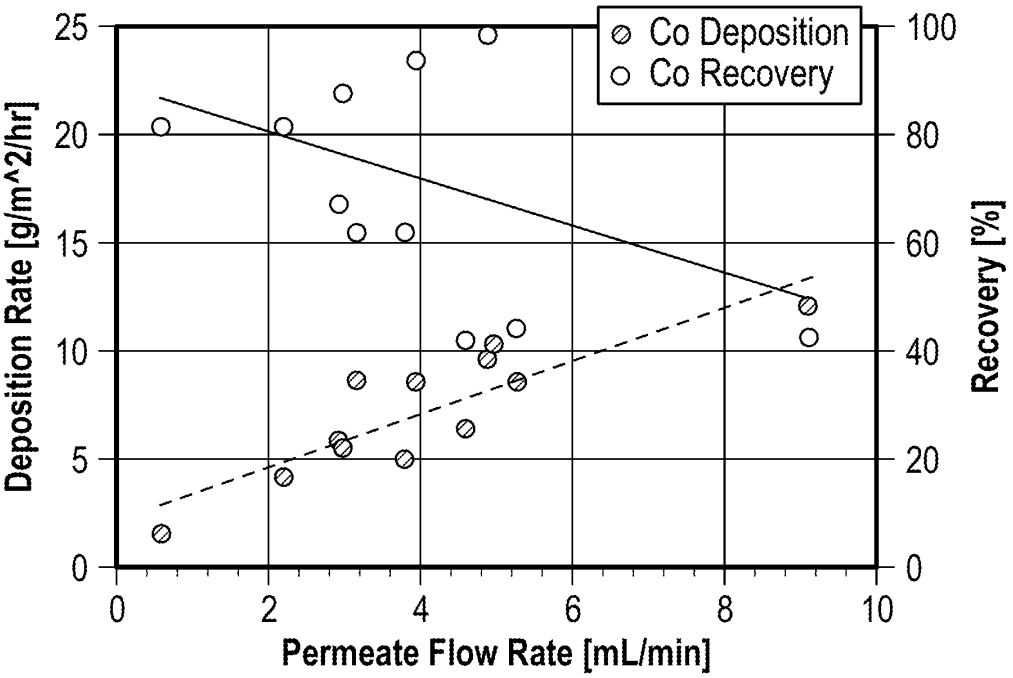

Deposition Rate [g/m^2/hr]
25
20
15
10
5
0
Co Deposition
Co Recovery
100
80
60
40
20
0
Recovery [%]
0
2
4
6
8
10
Permeate Flow Rate [mL/min]

FIG. 65

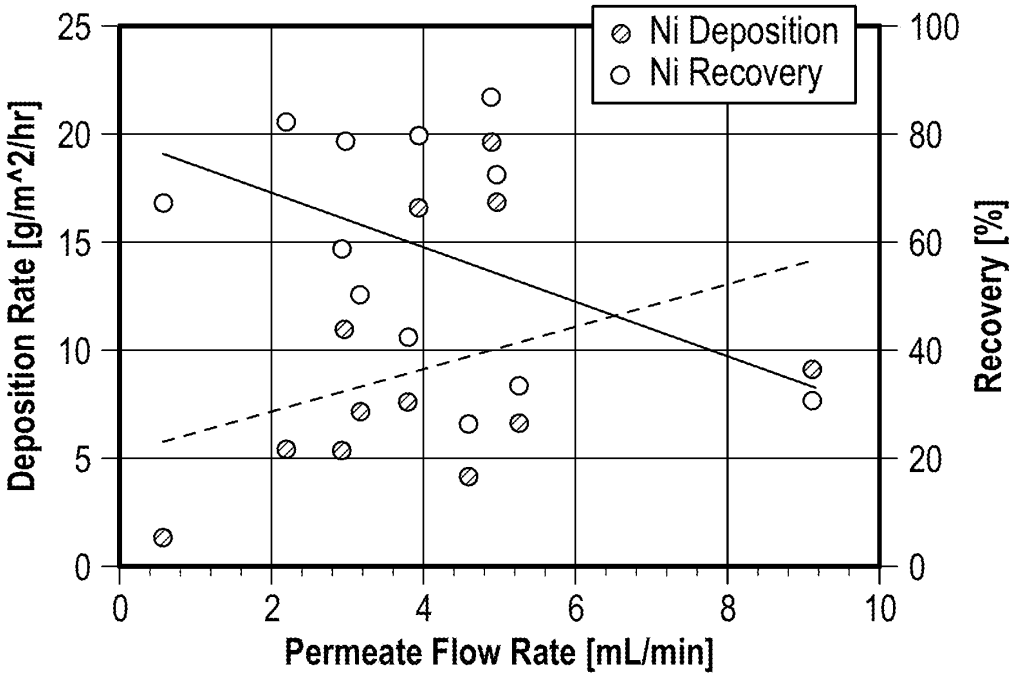

Ni Deposition
Ni Recovery
Deposition Rate [g/m^2/hr]
Recovery [%]
Permeate Flow Rate [mL/min]
0
5
10
15
20
25
0
20
40
60
80
100
0
2
4
6
8
10

FIG. 66

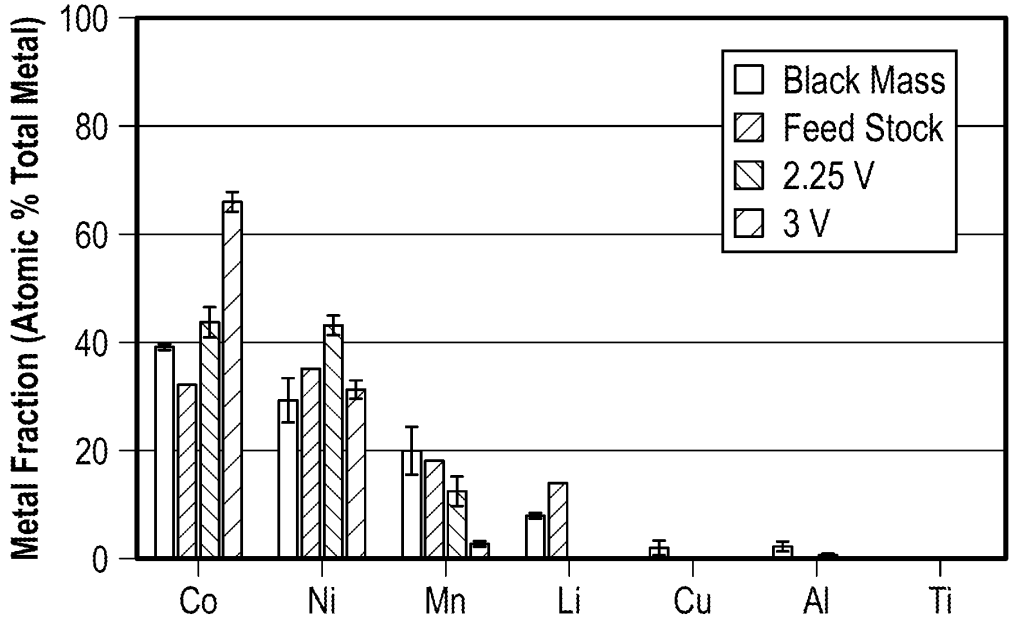

Black Mass
Feed Stock
2.25 V
3 V
Metal Fraction (Atomic % Total Metal)
0
20
40
60
80
100
Co
Ni
Mn
Li
Cu
Al
Ti

FIG. 67

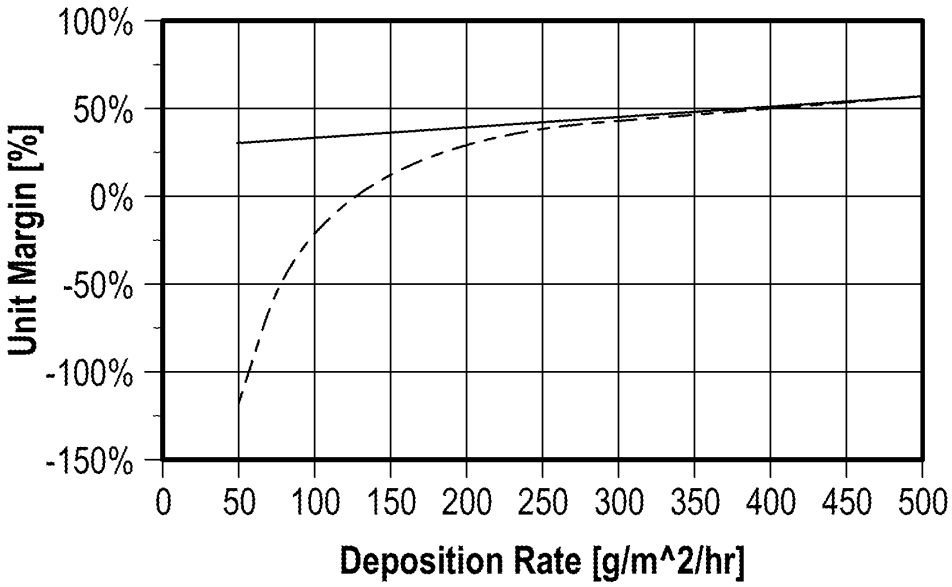

100%
50%
0%
-50%
-100%
-150%
Unit Margin [%]
0
50
100
150
200
250
300
350
400
450
500
Deposition Rate [g/m^2/hr]

FIG. 68

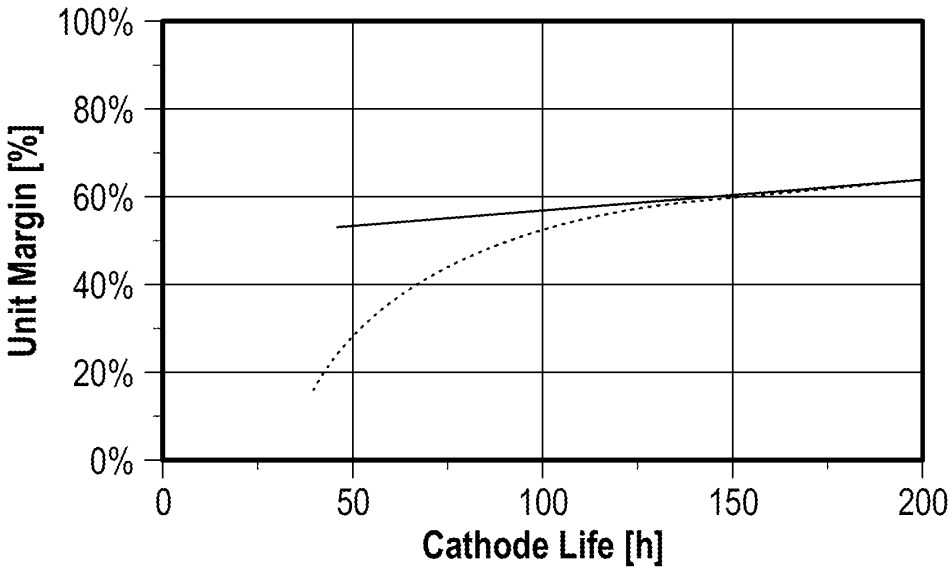

100%
80%
60%
40%
20%
0%
Unit Margin [%]
0
50
100
150
200
Cathode Life [h]

FIG. 69

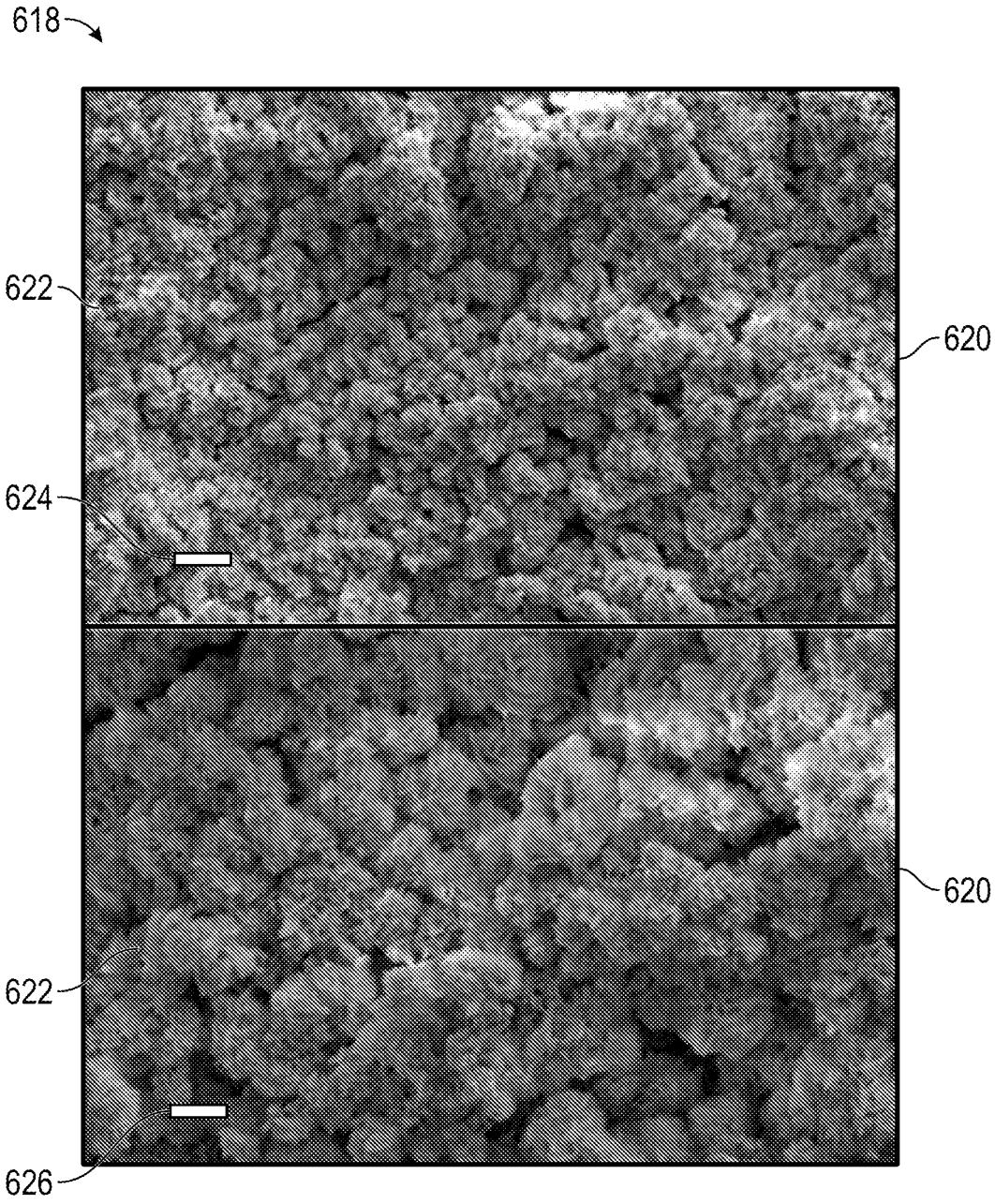


FIG. 70

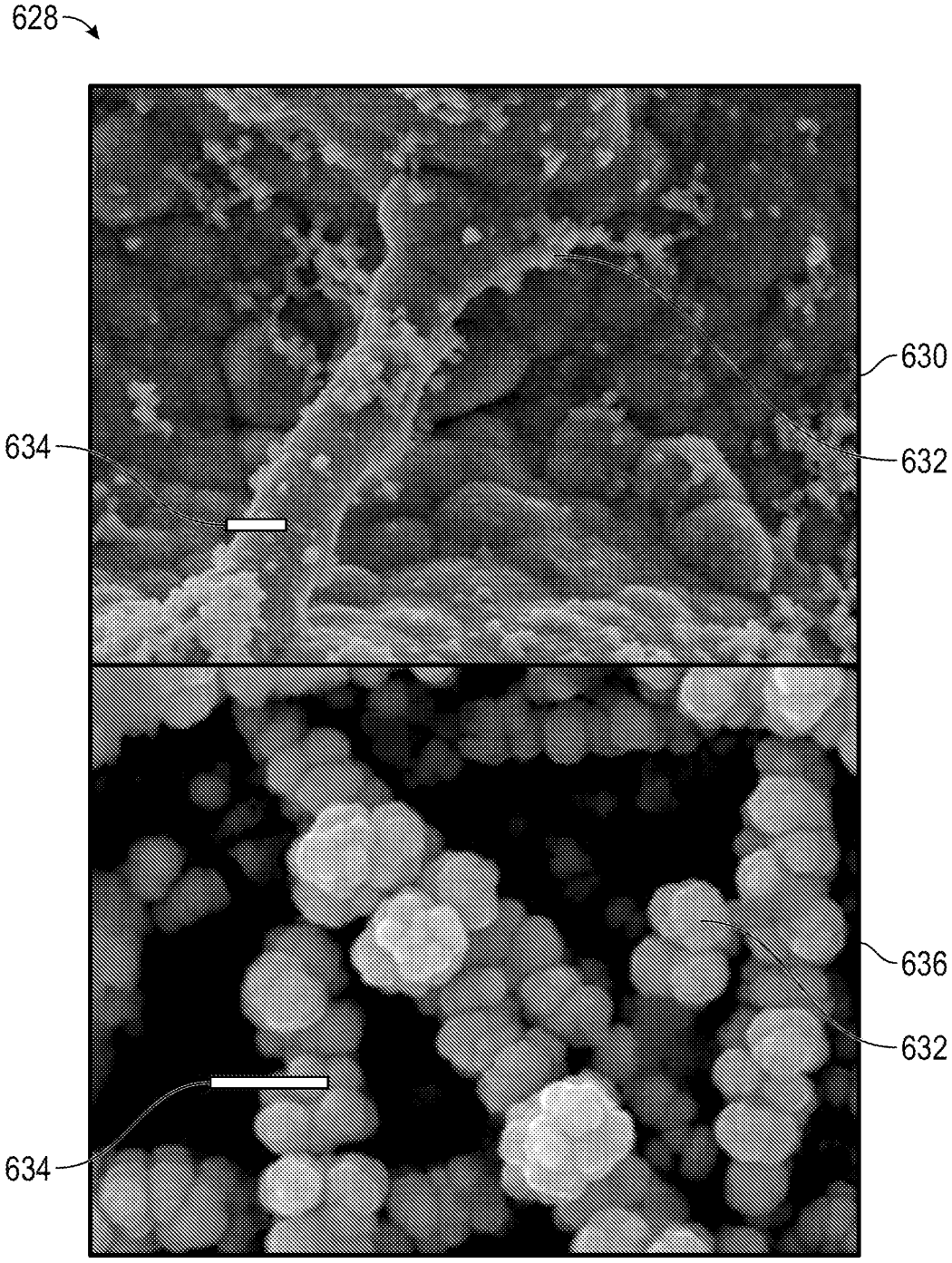


FIG. 71