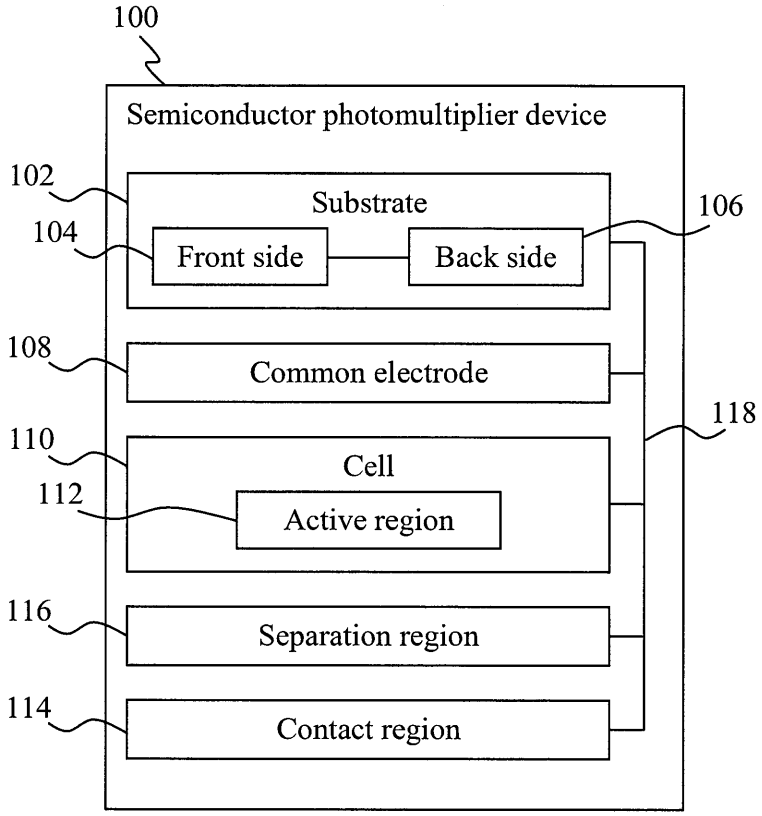

100
Semiconductor photomultiplier device
102
Substrate
106
104
Front side
Back side
108
Common electrode
118
110
Cell
112
Active region
116
Separation region
114
Contact region

FIG. 1A

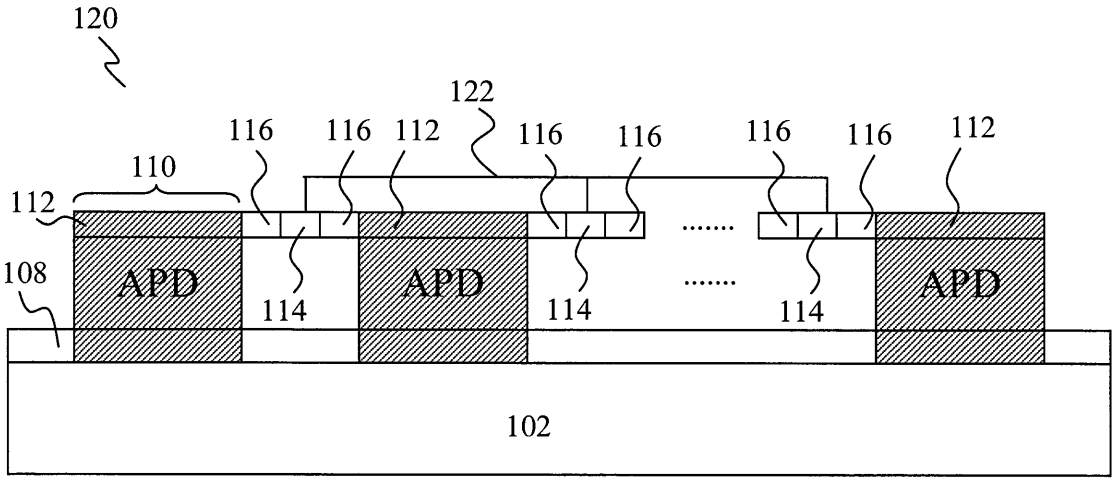

120
122
116
116
112
116
116
116
116
112
110
112
108
APD
APD
APD
114
114
114
102

FIG. 1B

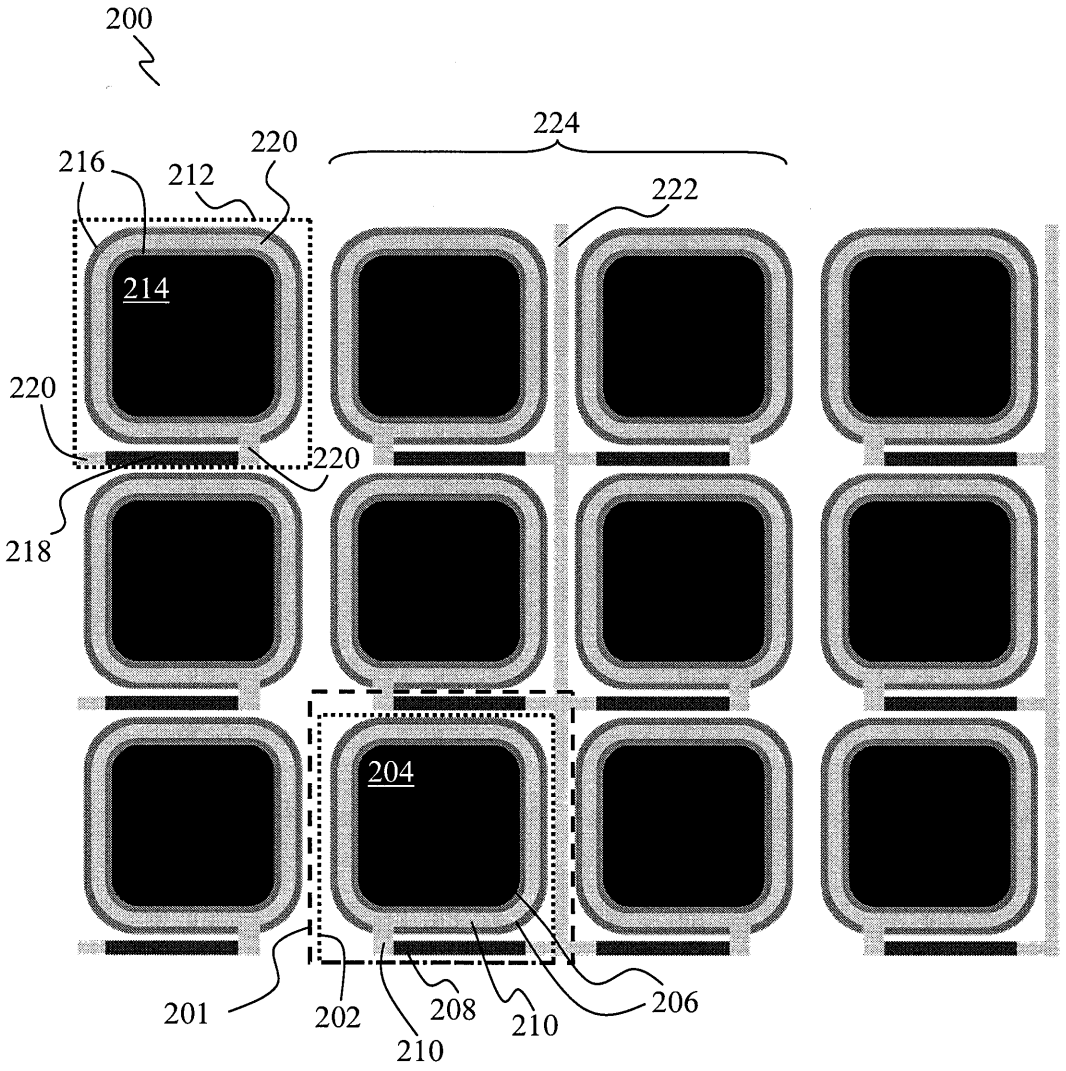

200
224
220
216
212
222
214
220
220
218
204
201
202
208
210
210
206

FIG. 2A

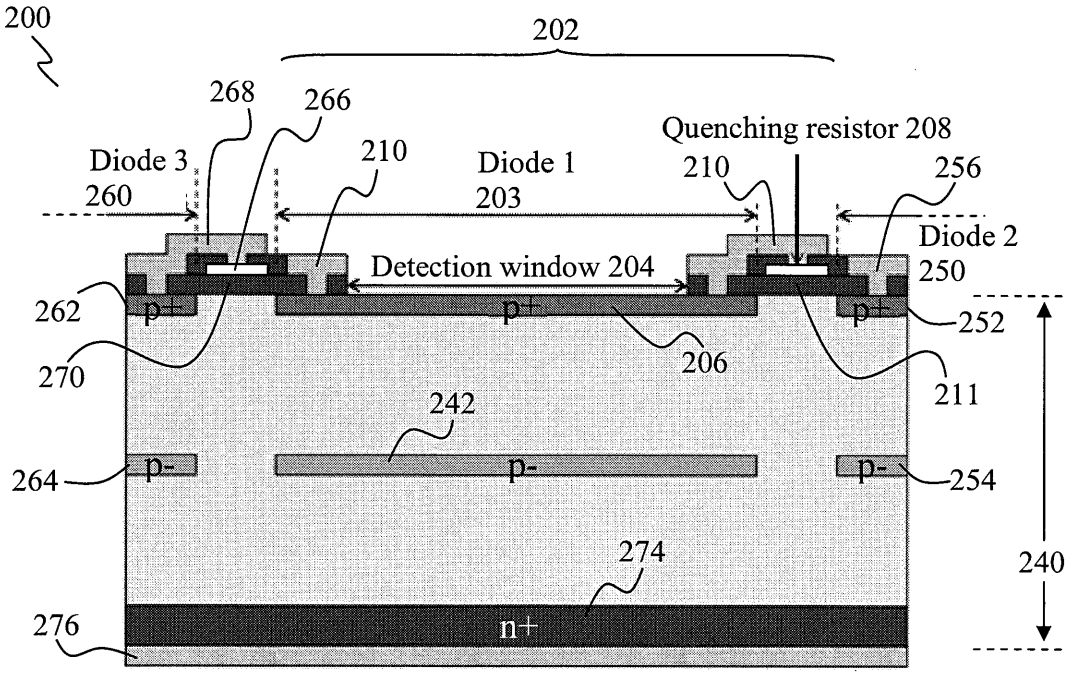

200
202
268
266
210
Quenching resistor 208
Diode 3
260
Diode 1
203
210
256
Diode 2
250
Detection window 204
262
p+
p+
p+
252
270
206
211
242
264
p-
p-
p-
254
274
240
276
n+

FIG. 2B

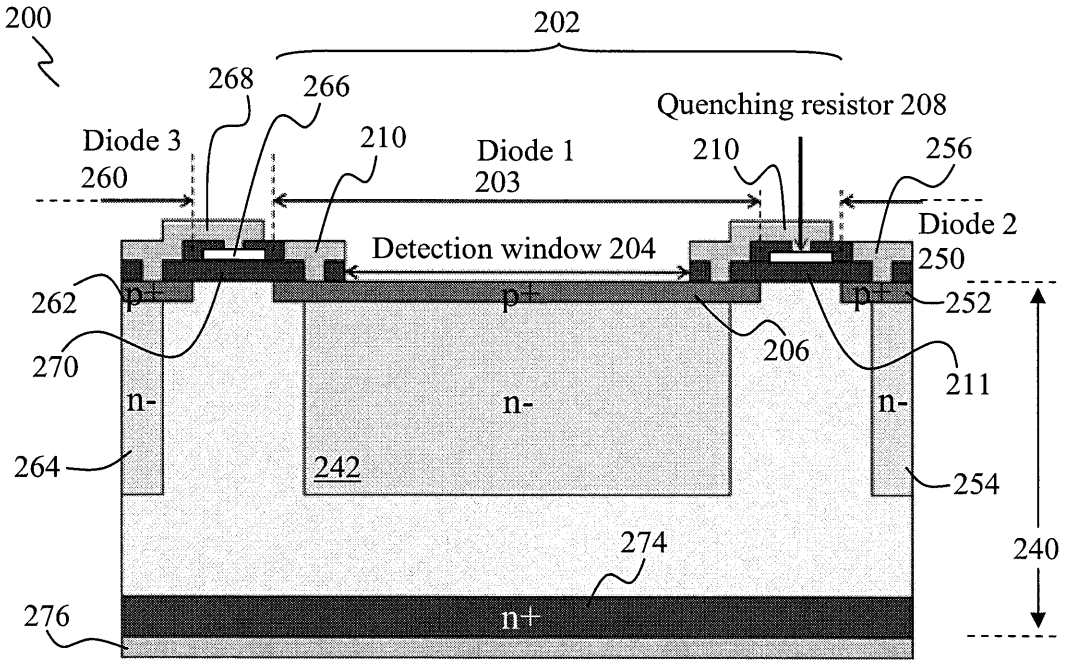

200
202
268
266
Quenching resistor 208
Diode 3
260
210
Diode 1
203
210
256
Diode 2
250
Detection window 204
262
p+
p+
p+
252
206
270
211
n-
n-
n-
264
242
254
274
240
276
n+

FIG. 2C

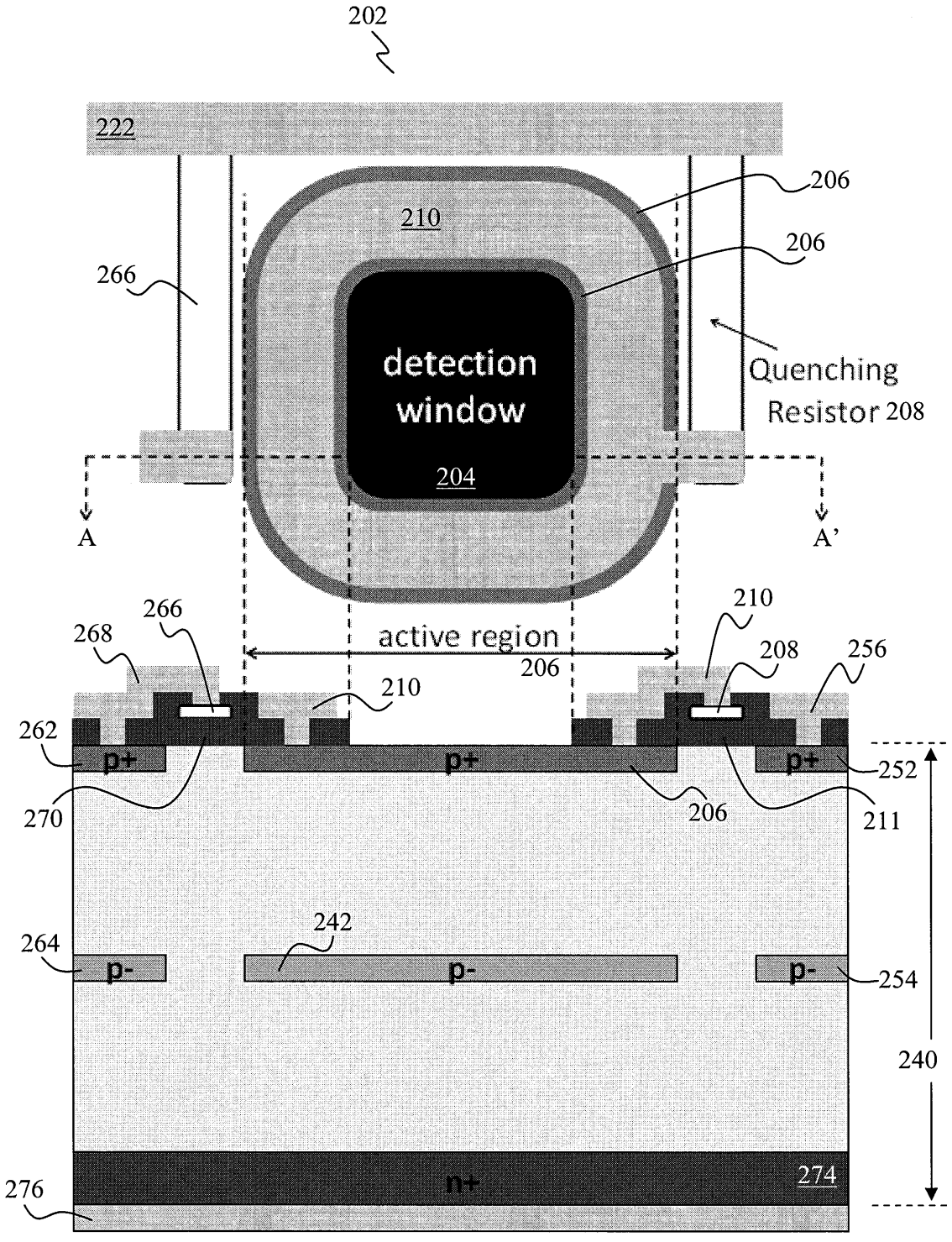

202
222
206
210
206
266
detection window
204
Quenching Resistor 208
A
A'
210
266
268
active region
206
208
256
210
262
p+
p+
p+
252
270
206
211
242
264
p-
p-
p-
254
240
n+
274
276

FIG. 2D

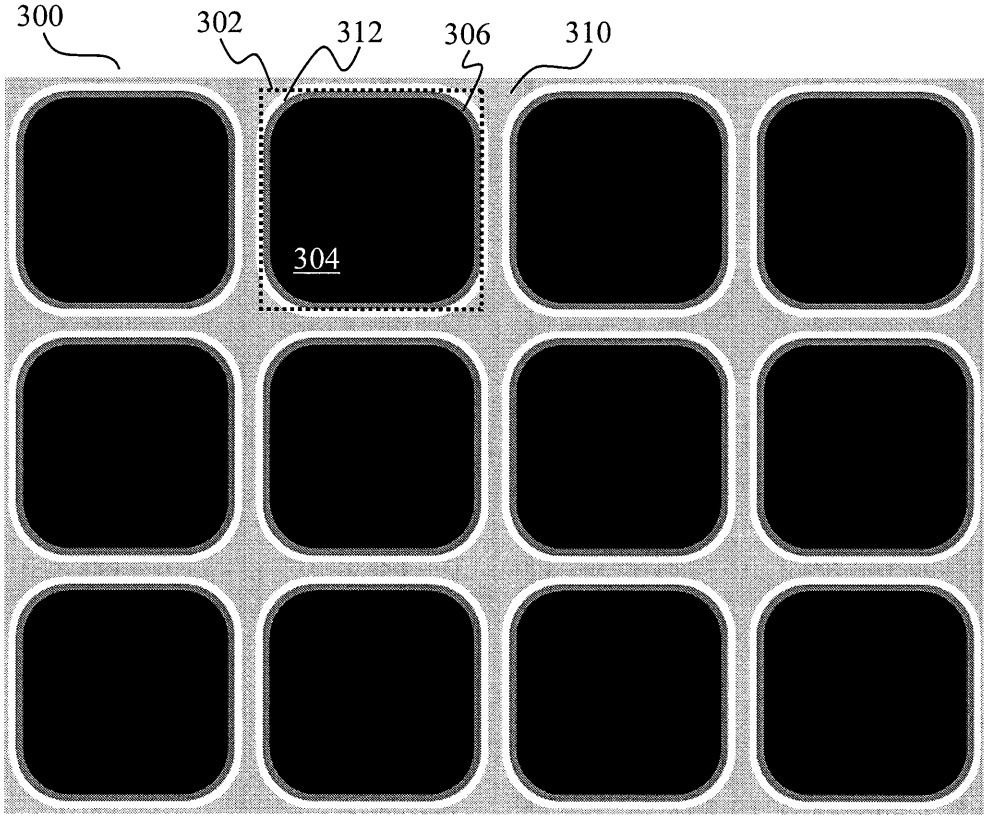

300
302
312
306
310
304

FIG. 3A

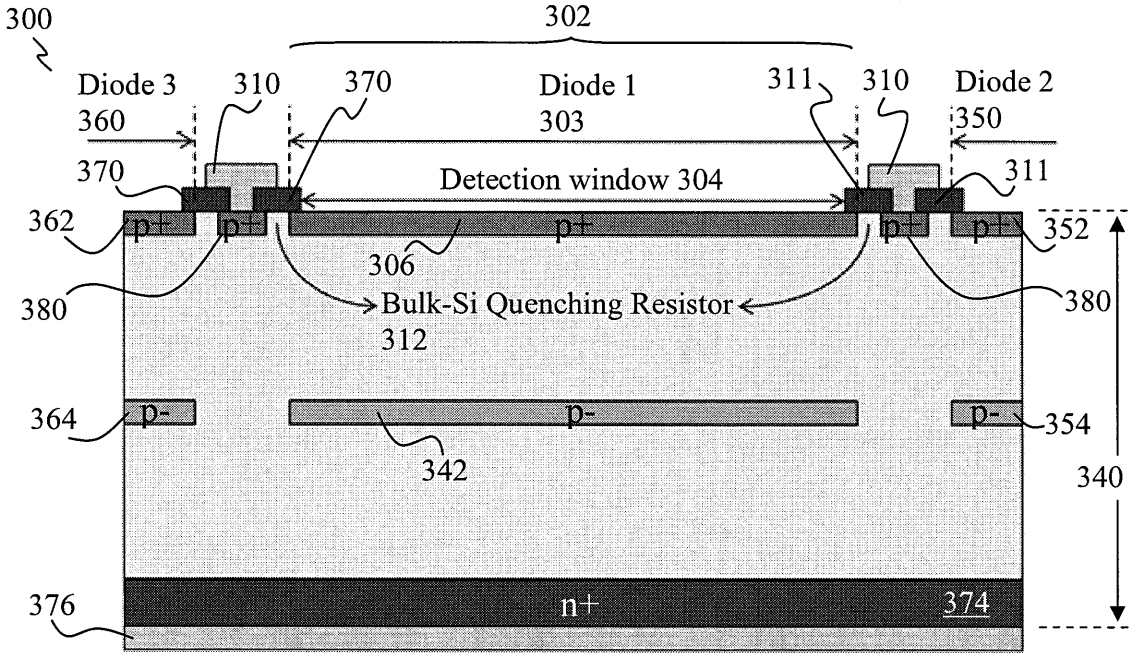

300
302
Diode 3
310
370
Diode 1
311
310
Diode 2
360
303
350
370
Detection window 304
311
362
p+
p+
p+
p+
p+
352
306
380
Bulk-Si Quenching Resistor
312
380
364
p-
p-
p-
354
342
340
376
n+
374

FIG. 3B

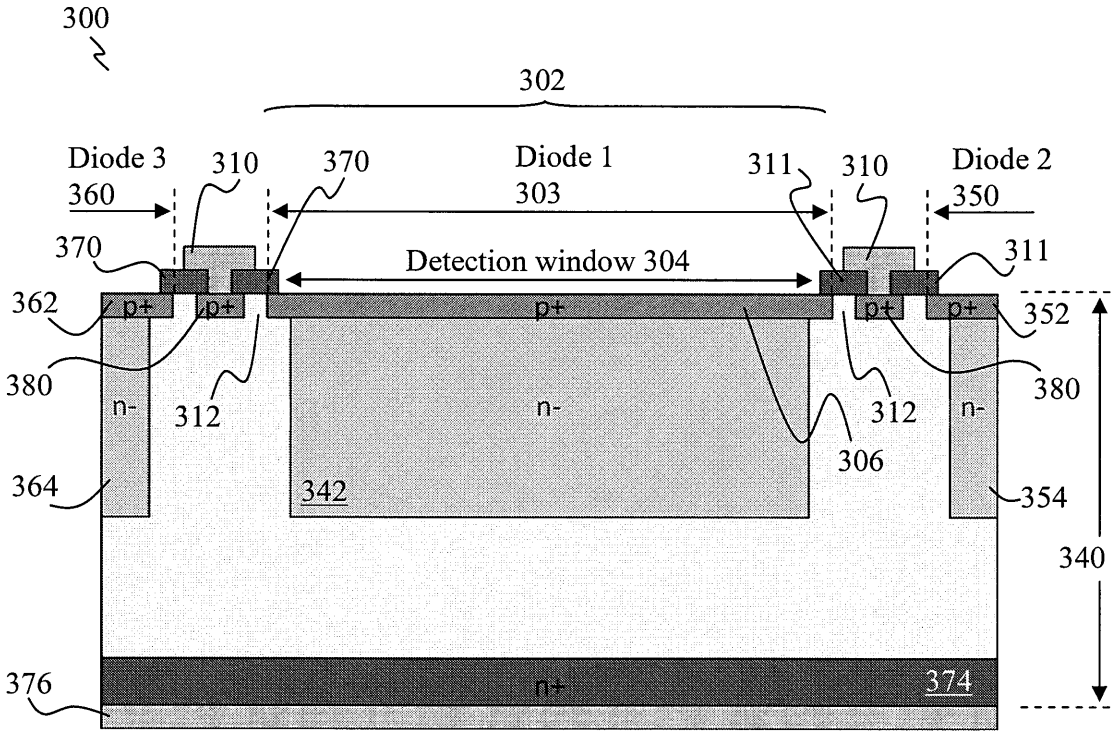

300
302
Diode 3
360
310
370
Diode 1
303
311
310
Diode 2
350
370
Detection window 304
311
362
p+
p+
p+
p+
p+
352
380
n-
312
n-
312
n-
380
306
364
342
354
340
376
n+
374

FIG. 3C

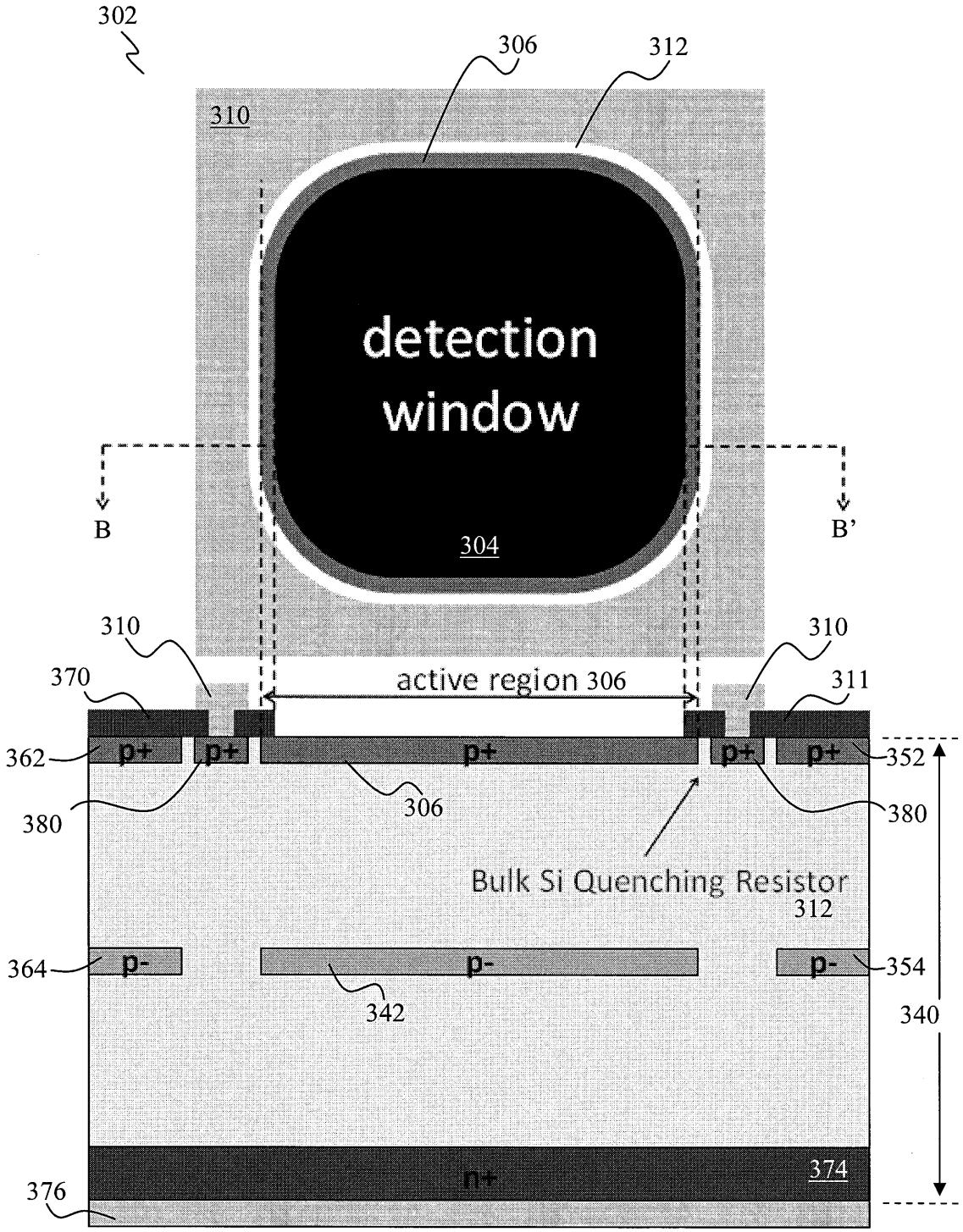

302
306
312
310
detection window
304
B
B'
310
310
370
active region 306
311
362
p+
p+
p+
p+
p+
352
380
306
380
Bulk Si Quenching Resistor
312
364
p-
p-
p-
354
342
340
n+
374
376

FIG. 3D

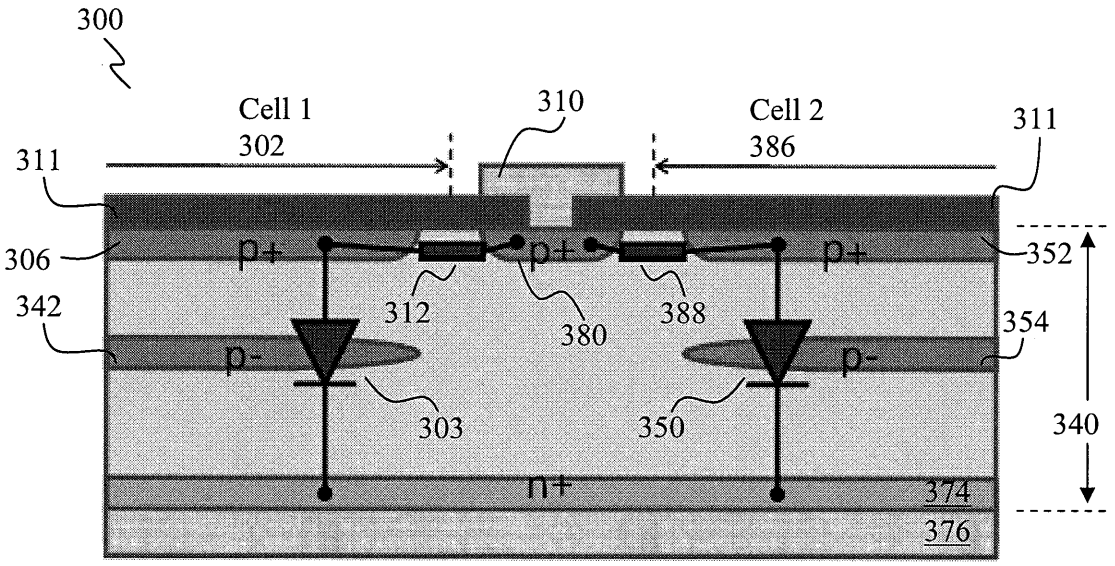

300
Cell 1
302
310
Cell 2
386
311
311
306
p+
p+
p+
352
342
312
380
388
354
p-
p-
303
350
340
n+
374
376

FIG. 3E

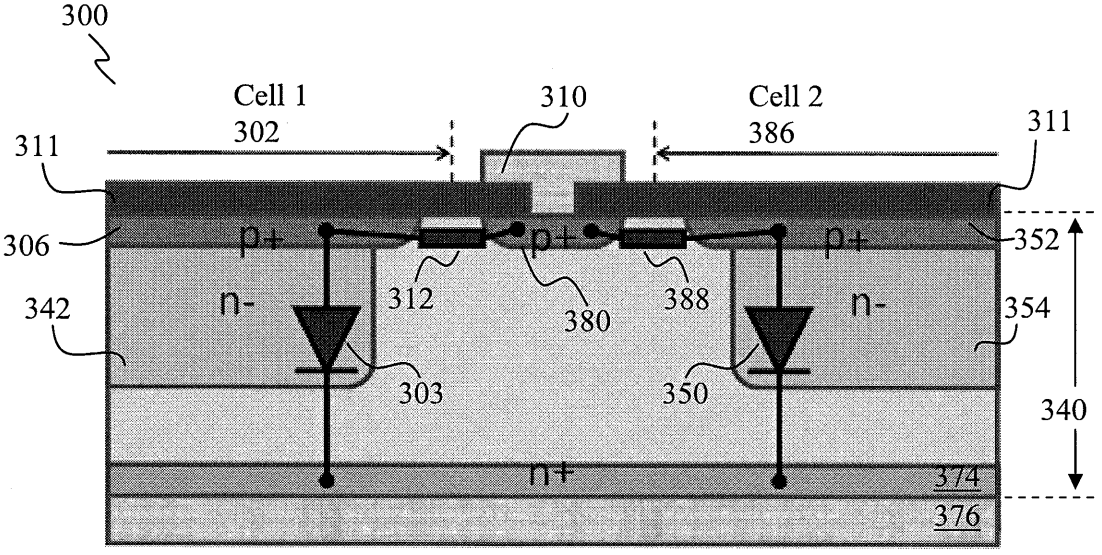

300
Cell 1
302
310
Cell 2
386
311
311
306
p+
p+
p+
352
342
n-
312
380
388
n-
354
303
350
340
n+
374
376

FIG. 3F

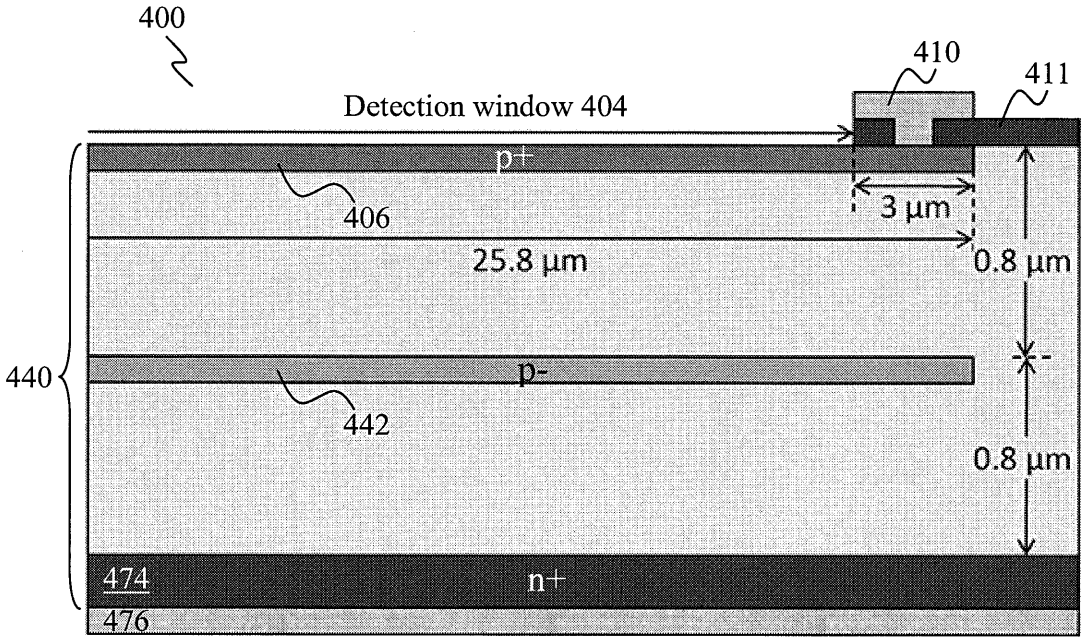

400
410
411
Detection window 404
p+
406
3 µm
25.8 µm
0.8 µm
440
p-
442
0.8 µm
474
n+
476

FIG. 4A

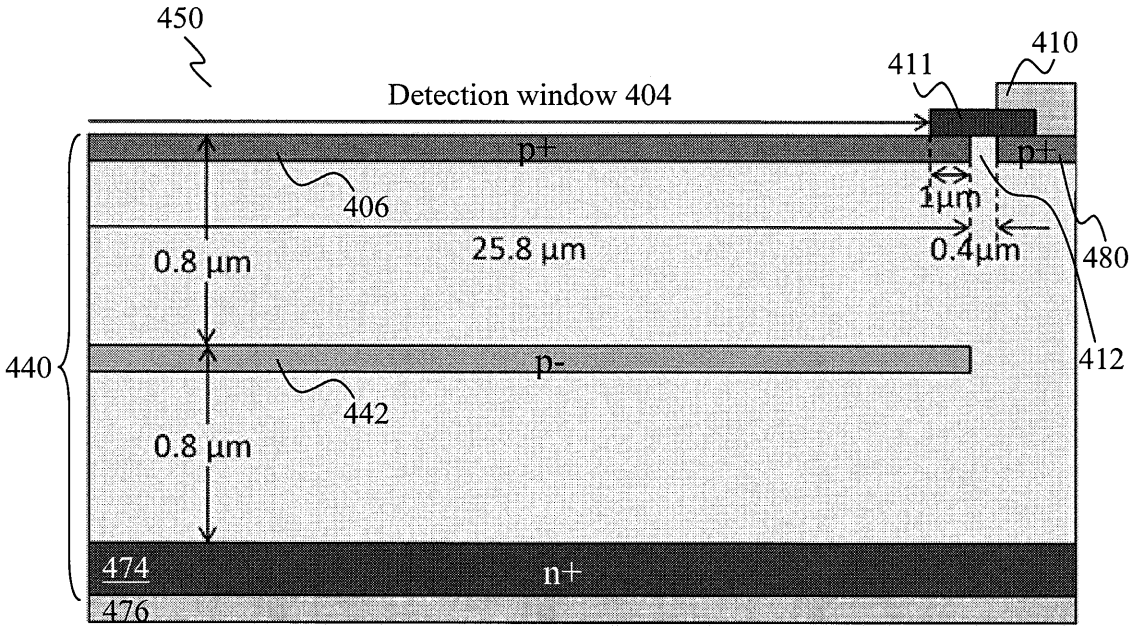

450
411
410
Detection window 404
p+
p+
406
1µm
0.4µm
480
0.8 µm
25.8 µm
440
p-
412
442
0.8 µm
474
n+
476

FIG. 4B

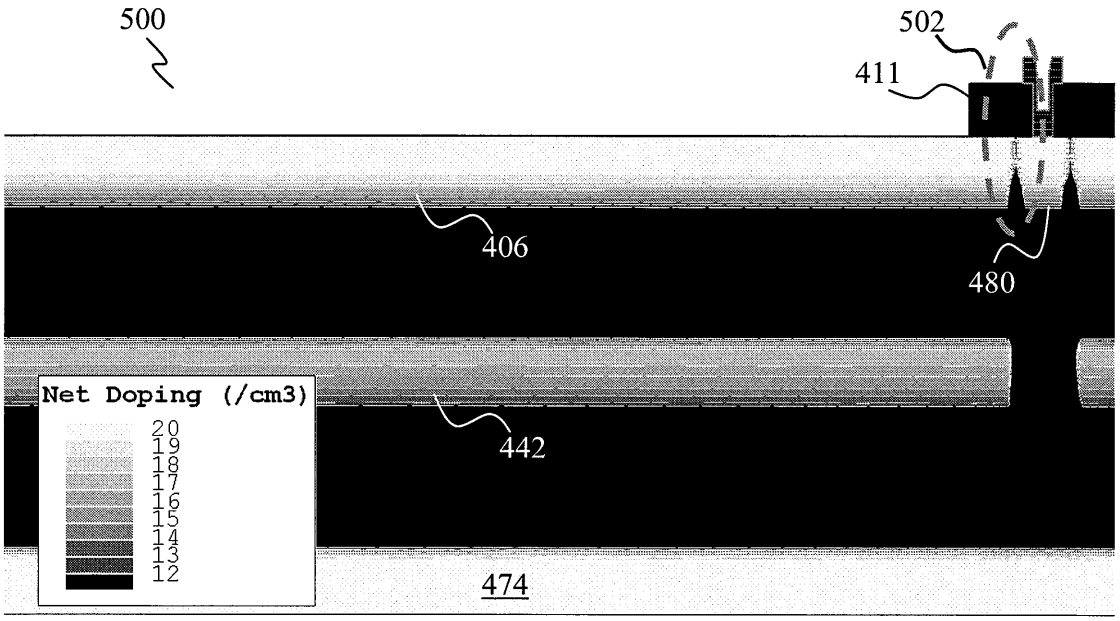

500
502
411
406
480
Net Doping (/cm3)
20
19
18
17
16
15
14
13
12
442
474

FIG. 5A

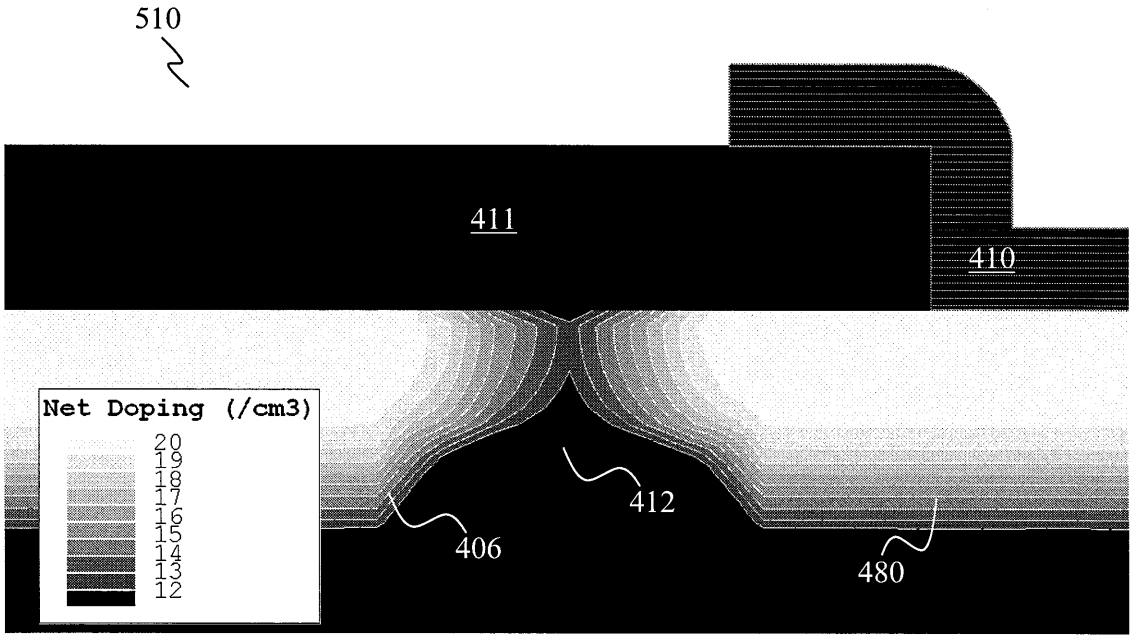

510
411
410
Net Doping (/cm3)
20
19
18
17
16
15
14
13
12
406
412
480

FIG. 5B

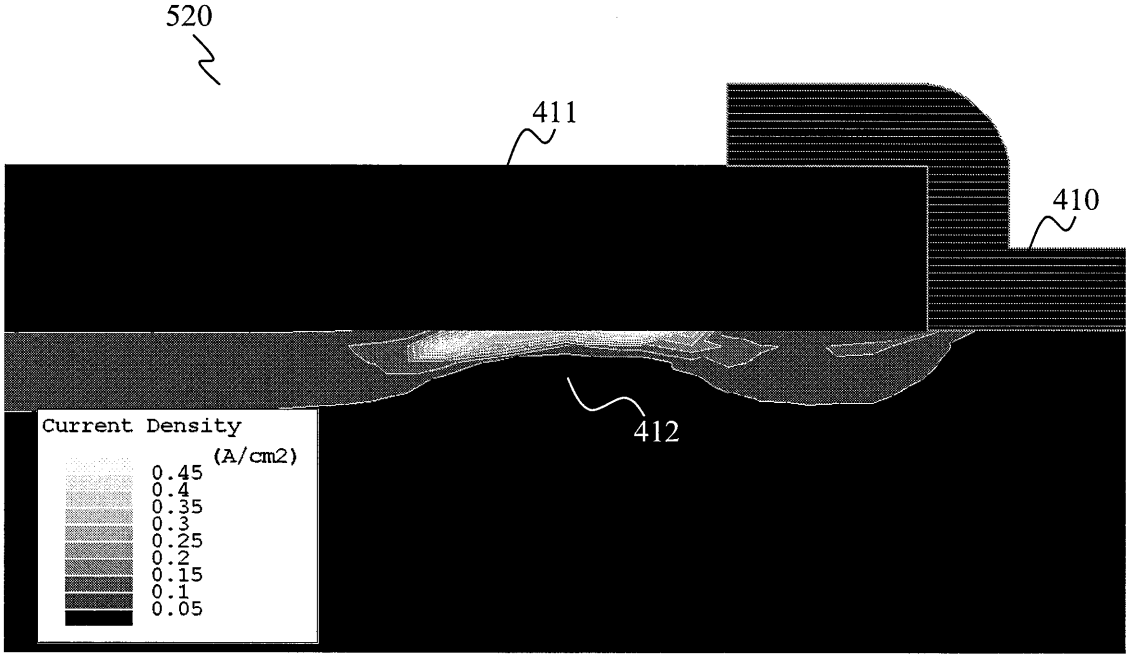

520
411
410
412
Current Density
(A/cm2)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05

FIG. 5C

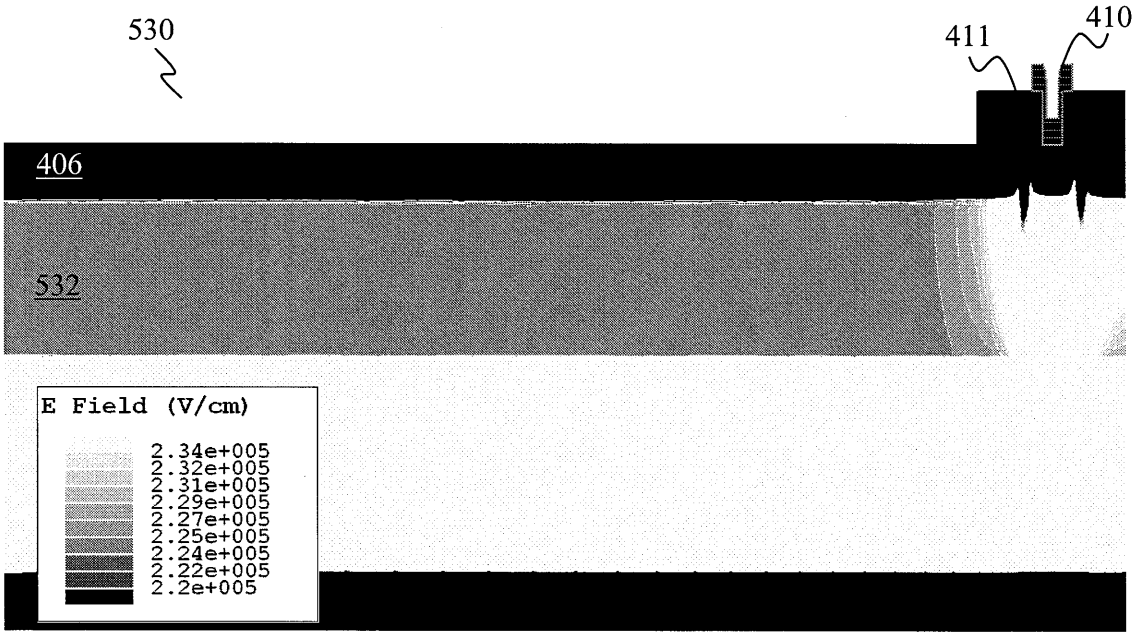

530
411
410
406
532
E Field (V/cm)
2.34e+005
2.32e+005
2.31e+005
2.29e+005
2.27e+005
2.25e+005
2.24e+005
2.22e+005
2.2e+005

FIG. 5D

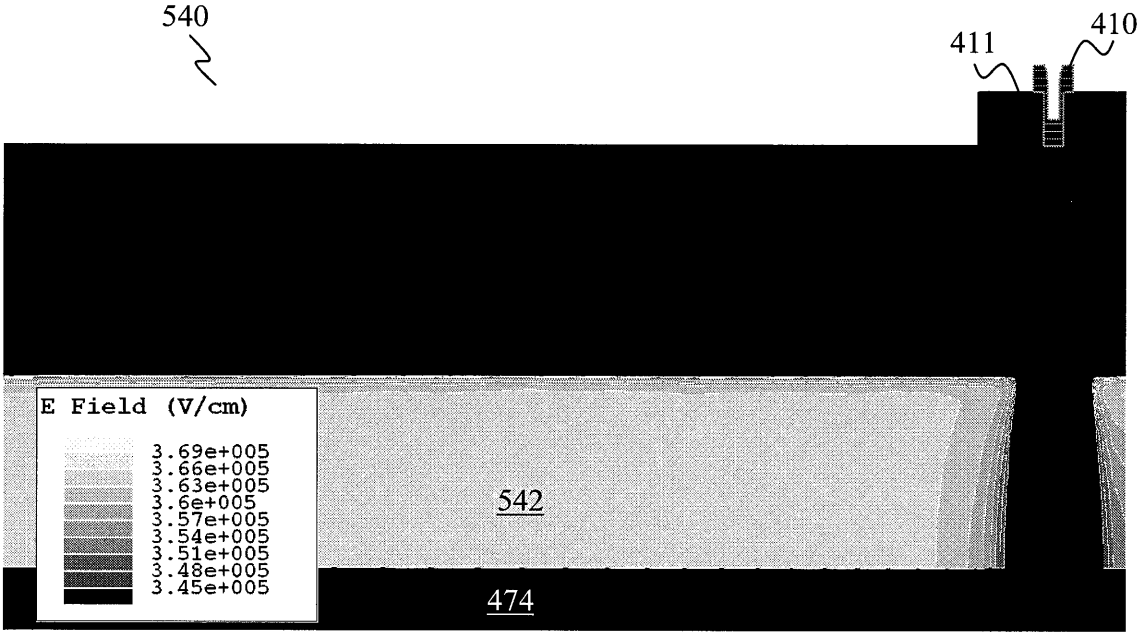

540
411
410
E Field (V/cm)
3.69e+005
3.66e+005
3.63e+005
3.6e+005
3.57e+005
3.54e+005
3.51e+005
3.48e+005
3.45e+005
542
474

FIG. 5E

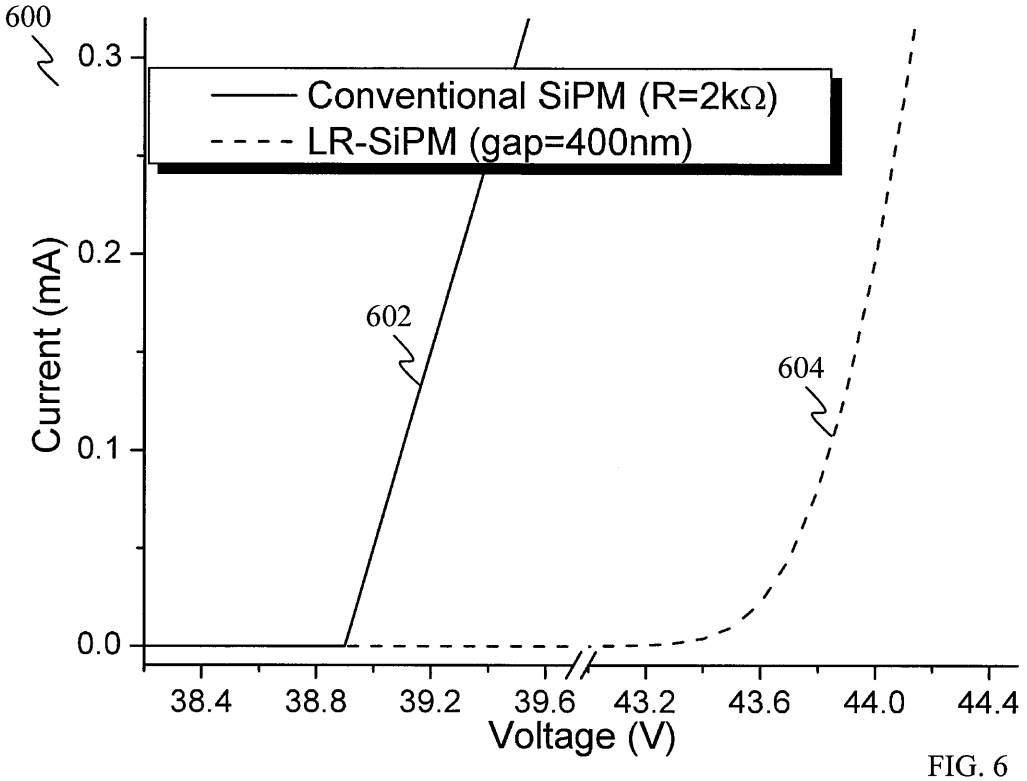

600
0.3
0.2
0.1
0.0
Current (mA)
Conventional SiPM (R=2kΩ)
LR-SiPM (gap=400nm)
602
604
38.4
38.8
39.2
39.6
43.2
43.6
44.0
44.4
Voltage (V)

FIG. 6

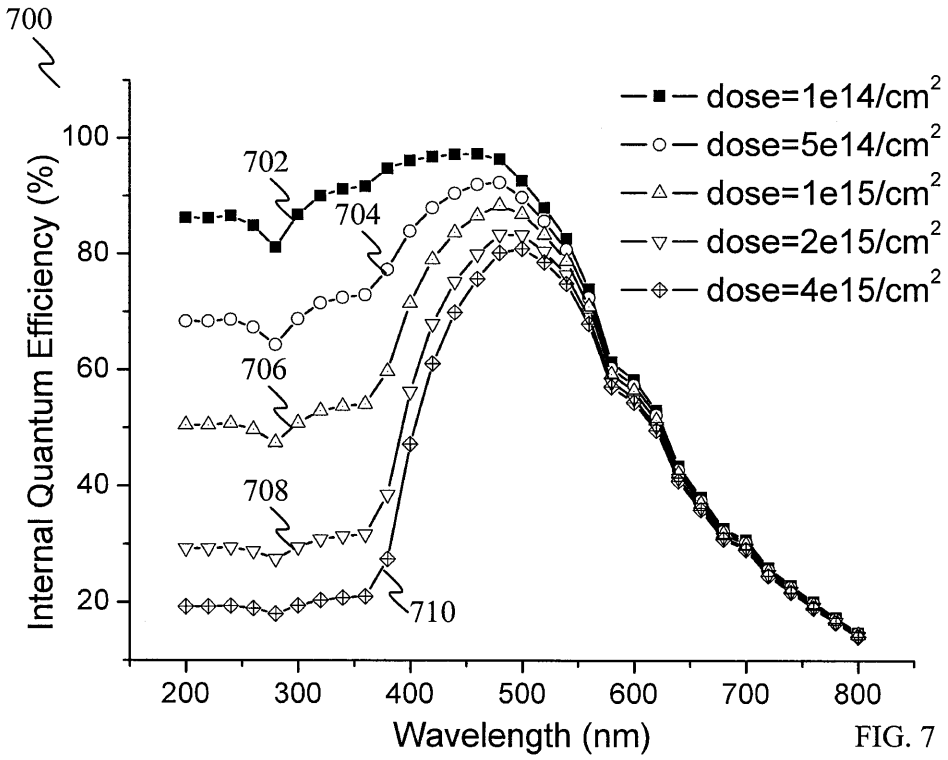

700
100
80
60
40
20
Internal Quantum Efficiency (%)
dose=1e14/cm2
dose=5e14/cm2
dose=1e15/cm2
dose=2e15/cm2
dose=4e15/cm2
702
704
706
708
710
200
300
400
500
600
700
800
Wavelength (nm)

FIG. 7

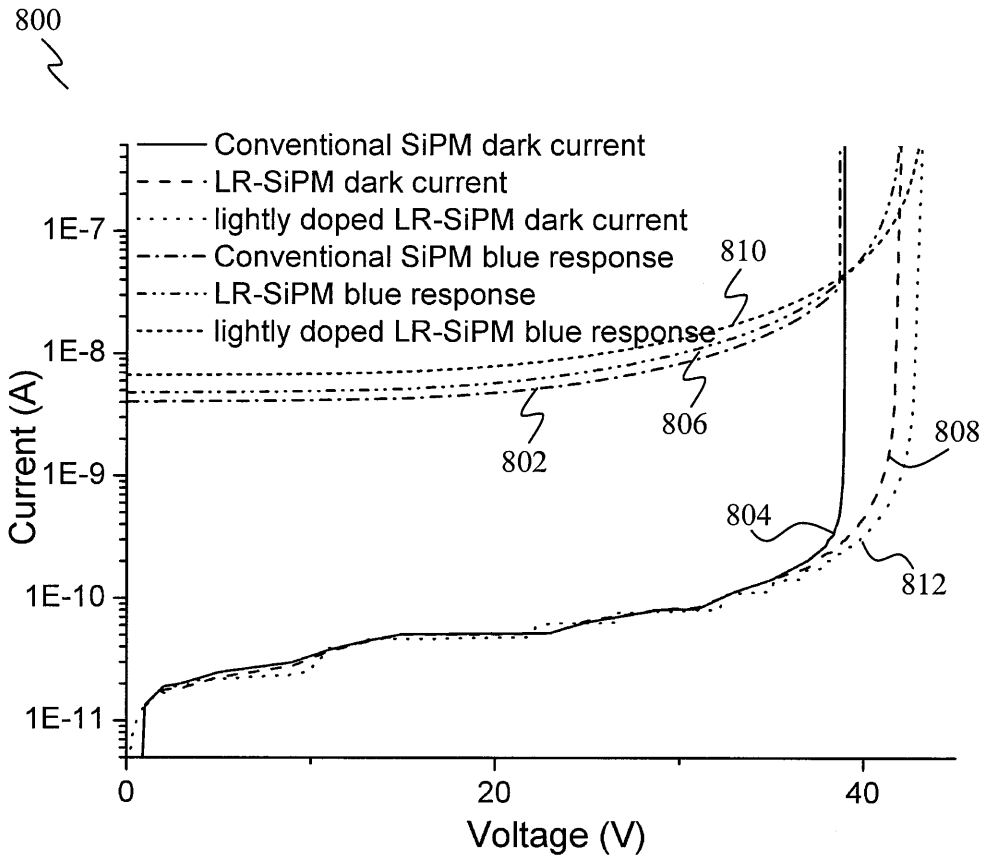

800
Conventional SiPM dark current
LR-SiPM dark current
lightly doped LR-SiPM dark current
Conventional SiPM blue response
LR-SiPM blue response
lightly doped LR-SiPM blue response
1E-7
1E-8
1E-9
1E-10
1E-11
Current (A)
0
20
40
Voltage (V)
802
804
806
808
810
812

FIG. 8

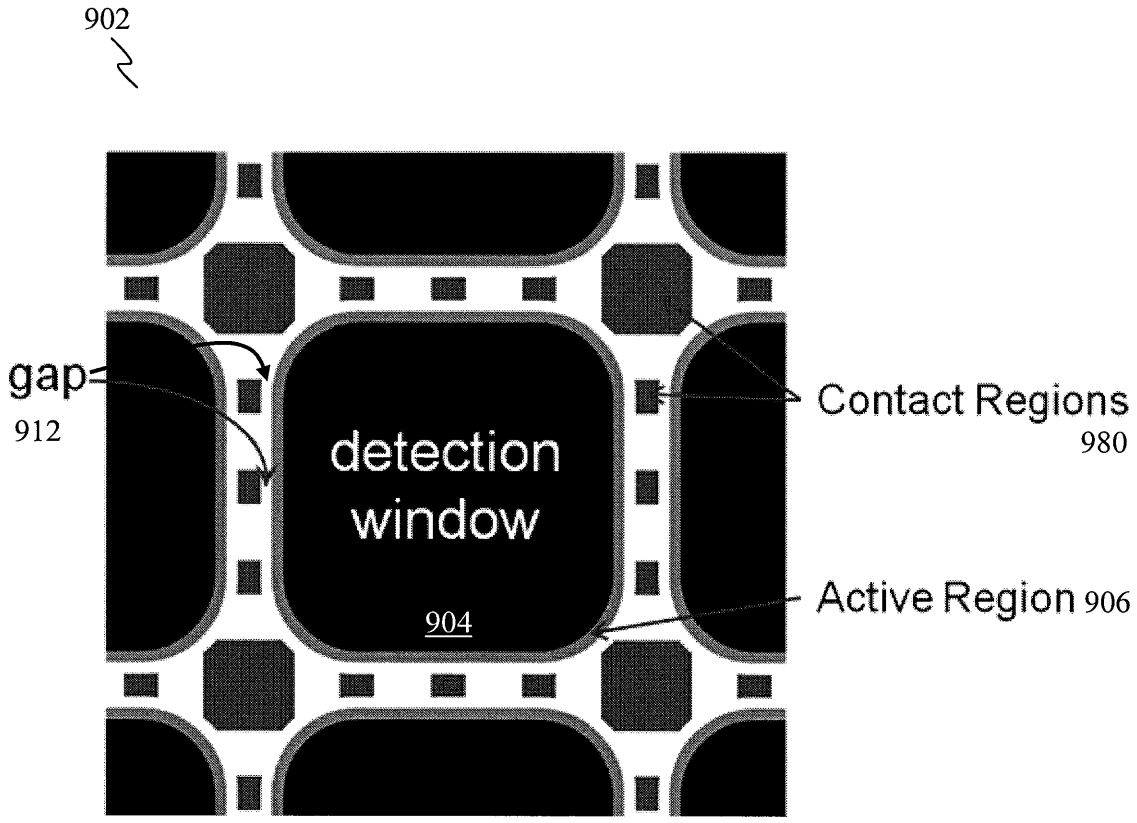

902
gap
912
detection
window
904
Contact Regions
980
Active Region 906

FIG. 9