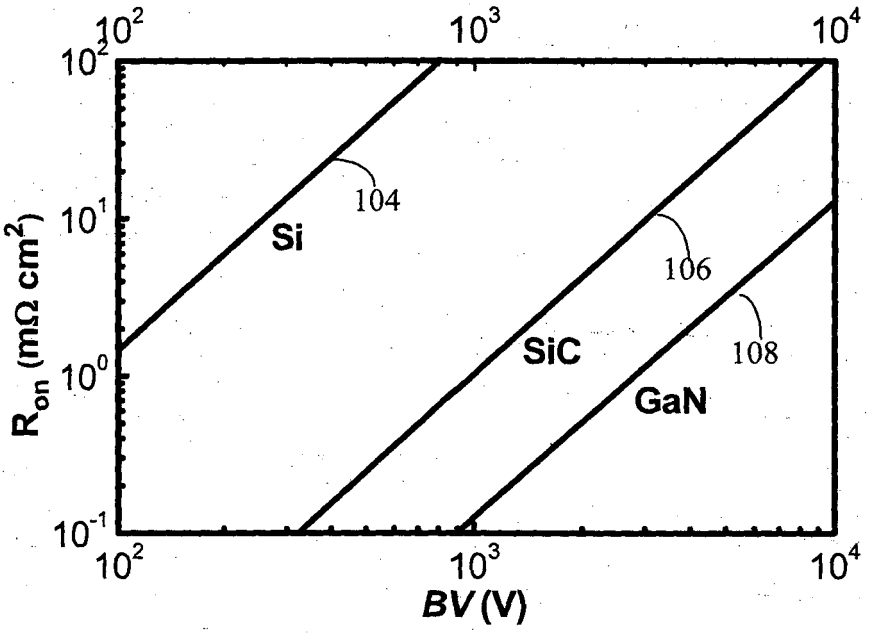
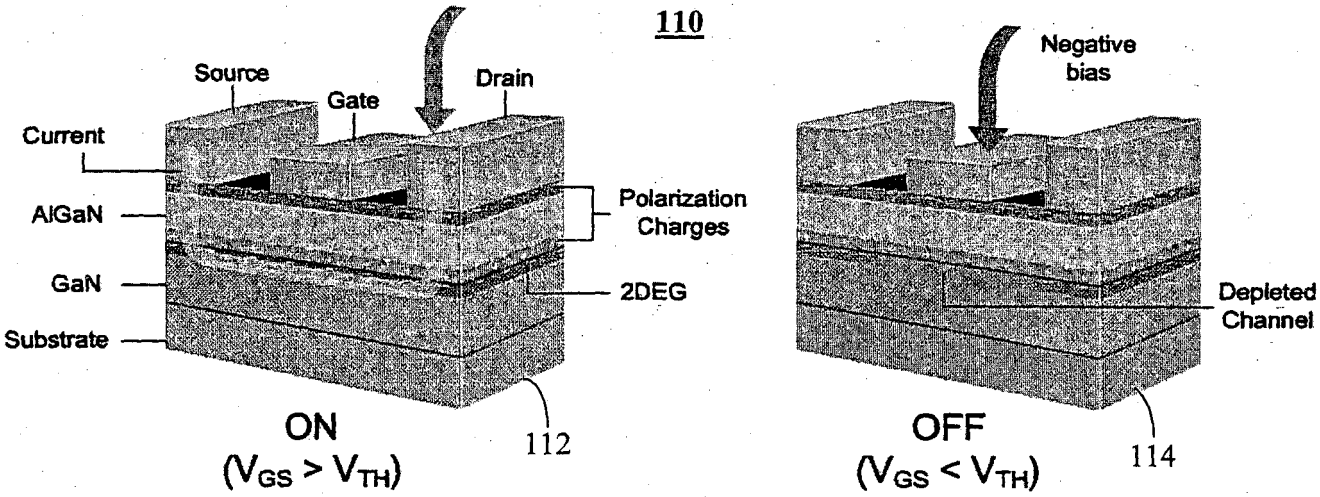


PRIOR ART

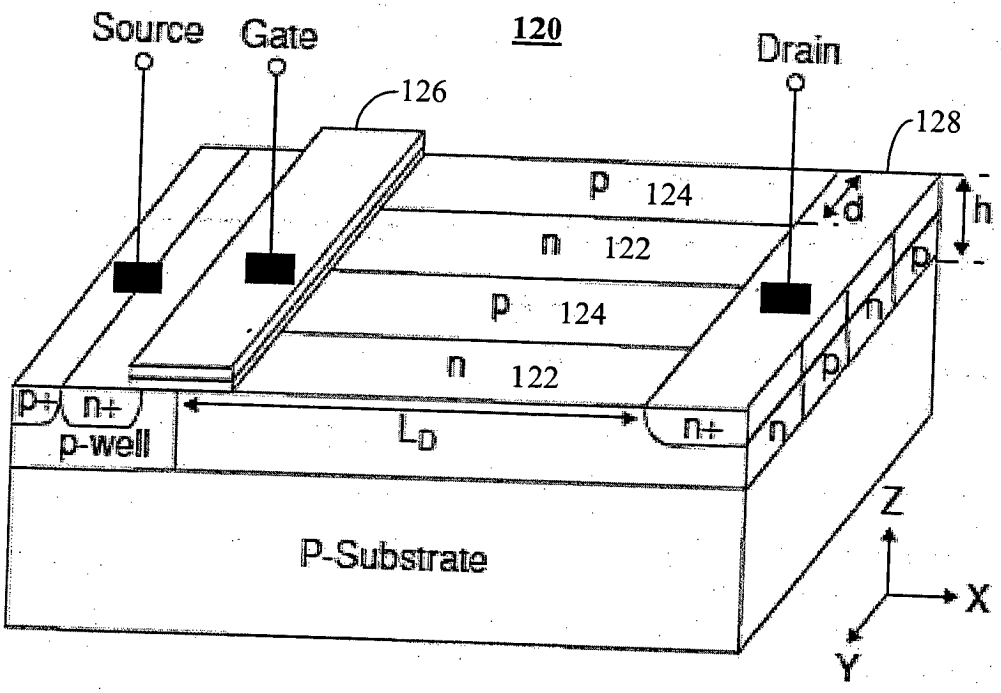
FIG. 1A



Normally-on (Depletion-mode): $V_{TH} < 0$

PRIOR ART

FIG. 1B



PRIOR ART

FIG. 1C

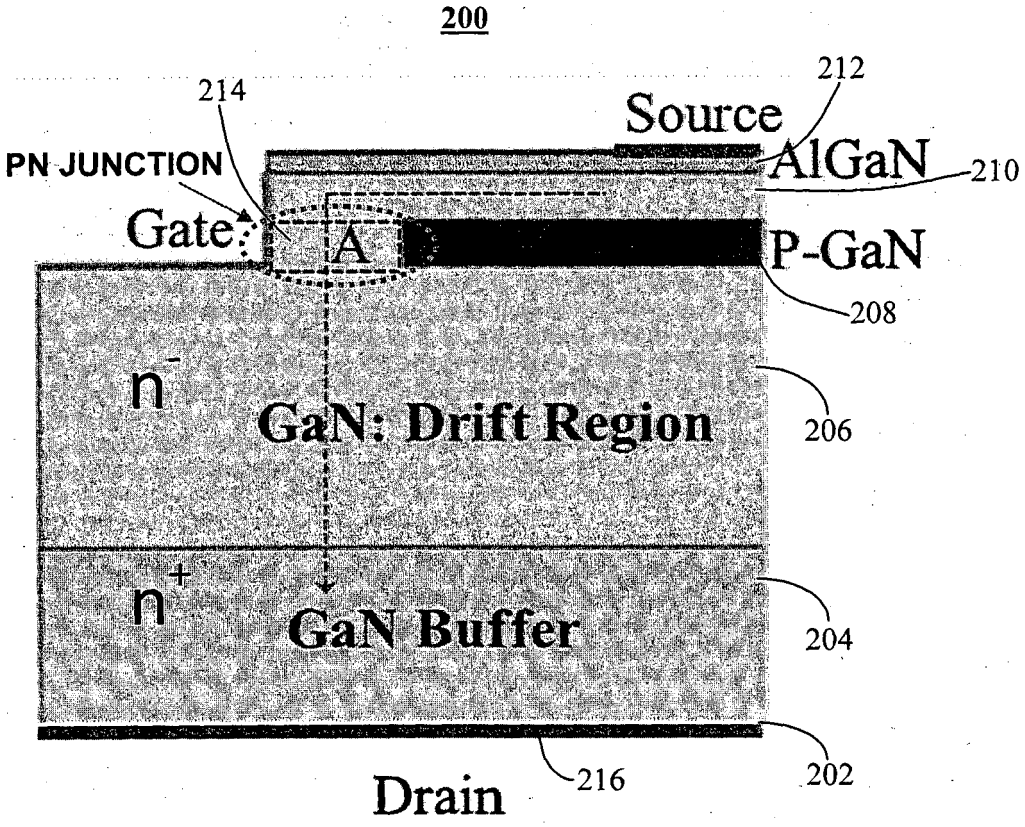

200
214
212
Source
PN JUNCTION
AlGaN
210
Gate
A
P-GaN
208
n⁻
GaN: Drift Region
206
n⁺
GaN Buffer
204
216
202
Drain

FIG. 2

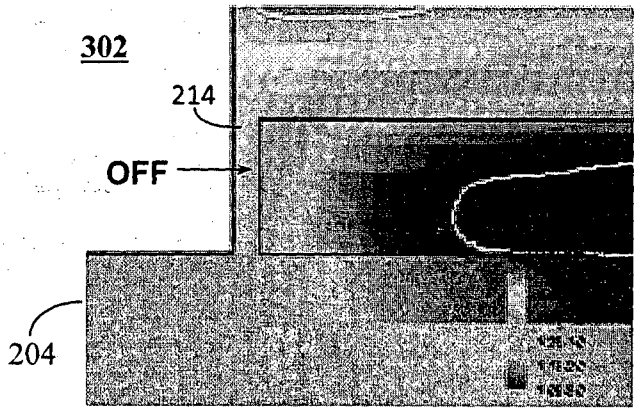


FIG. 3A

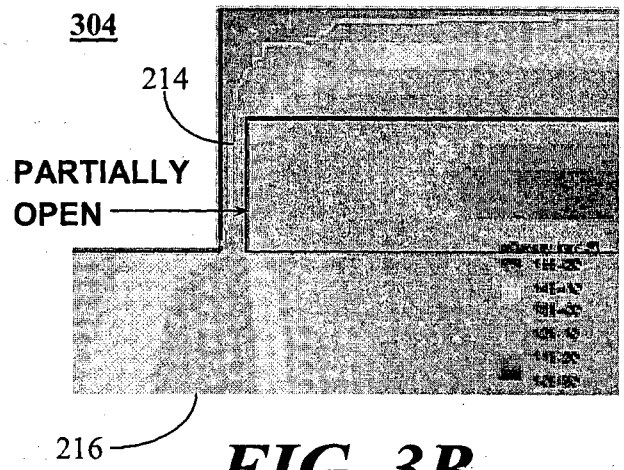


FIG. 3B

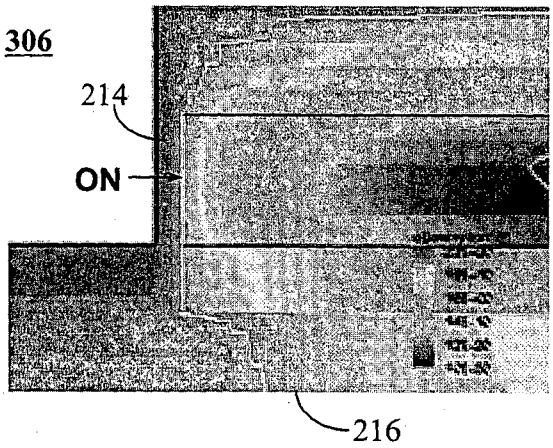


FIG. 3C

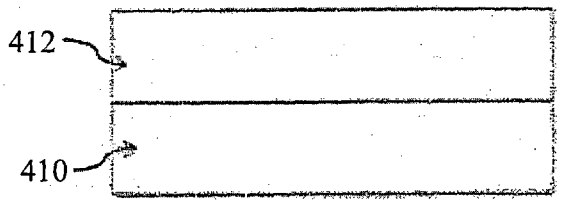


FIG. 4A

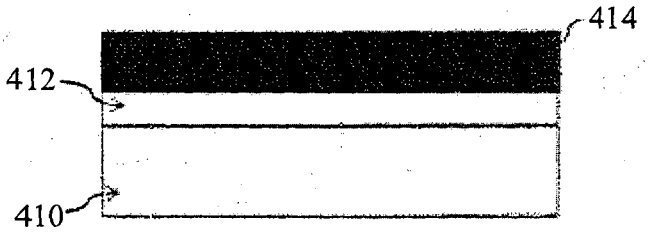


FIG. 4B

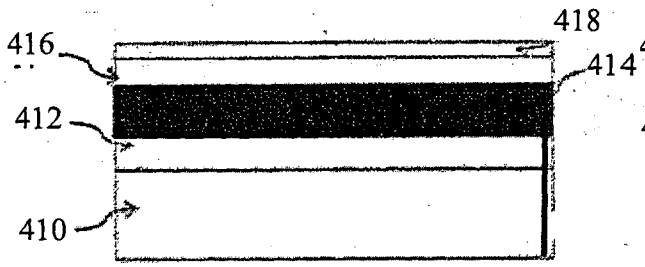


FIG. 4C

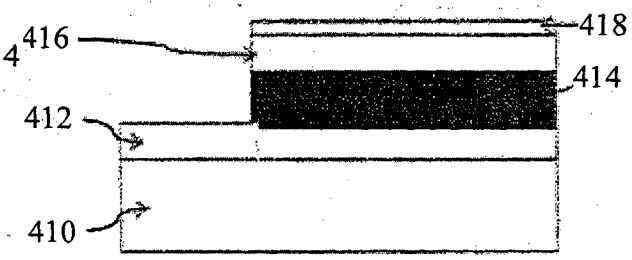


FIG. 4D

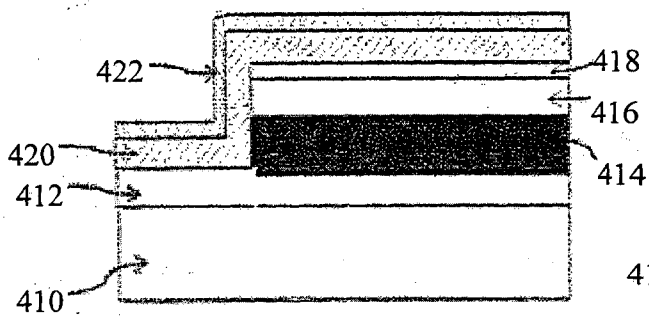


FIG. 4E

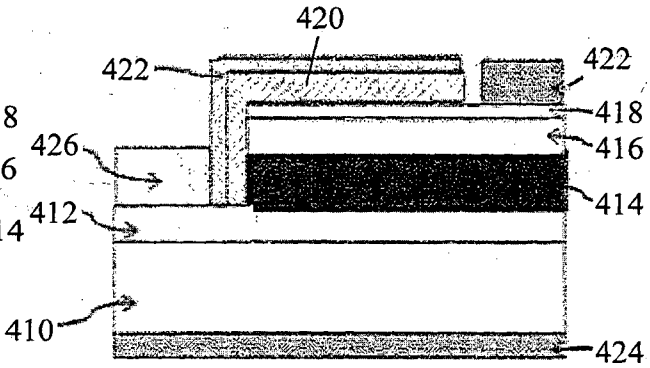


FIG. 4F

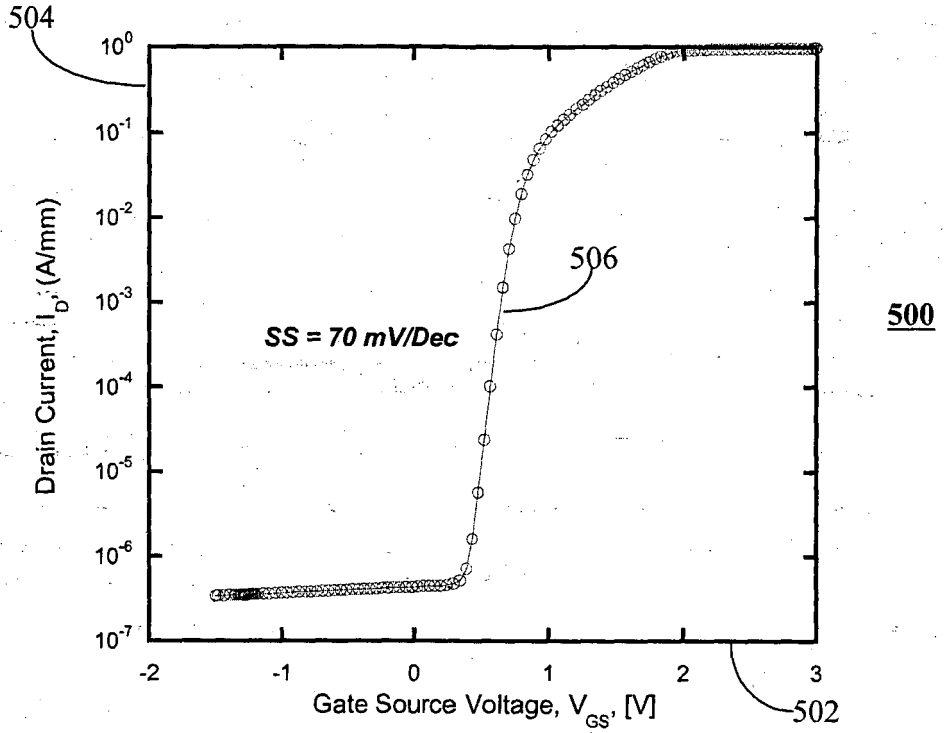

504
506
SS = 70 mV/Dec
500
Drain Current, I_D, (A/mm)
Gate Source Voltage, V_{GS}, [V]
502

FIG. 5A

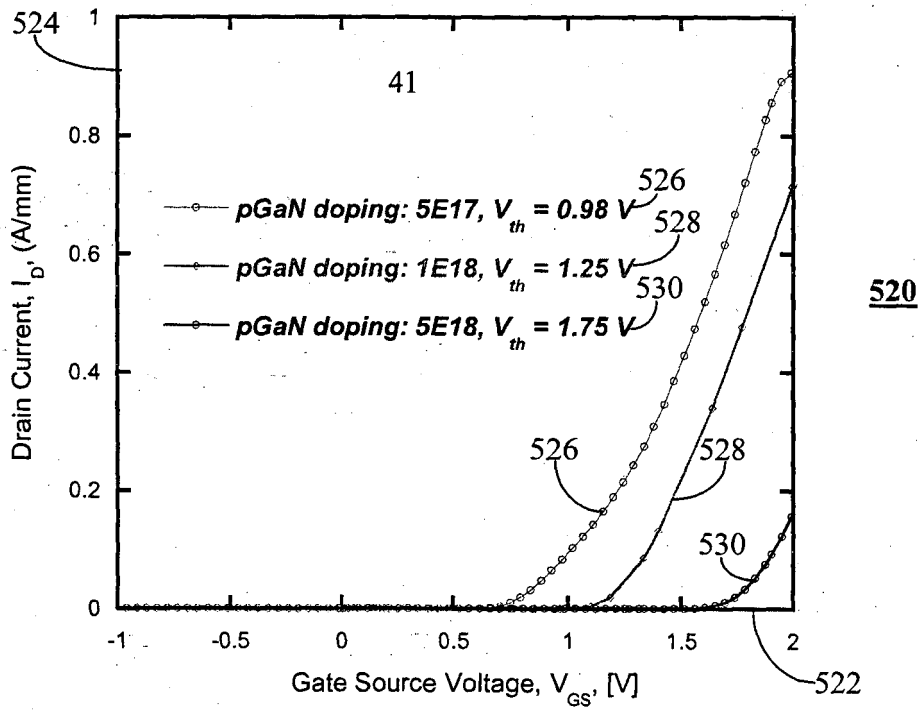

524
41
pGaN doping: 5E17, V_{th} = 0.98 V
pGaN doping: 1E18, V_{th} = 1.25 V
pGaN doping: 5E18, V_{th} = 1.75 V
526
528
530
520
Drain Current, I_D, (A/mm)
Gate Source Voltage, V_{GS}, [V]
522

FIG. 5B

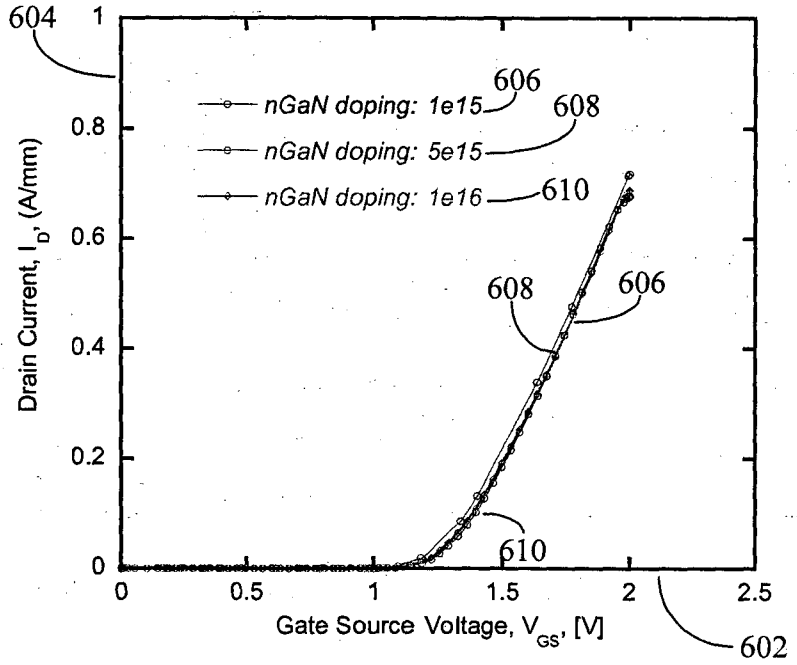

604
606
608
610
nGaN doping: 1e15
nGaN doping: 5e15
nGaN doping: 1e16
Drain Current, I_D, (A/mm)
Gate Source Voltage, V_{GS}, [V]
602
600

FIG. 6A

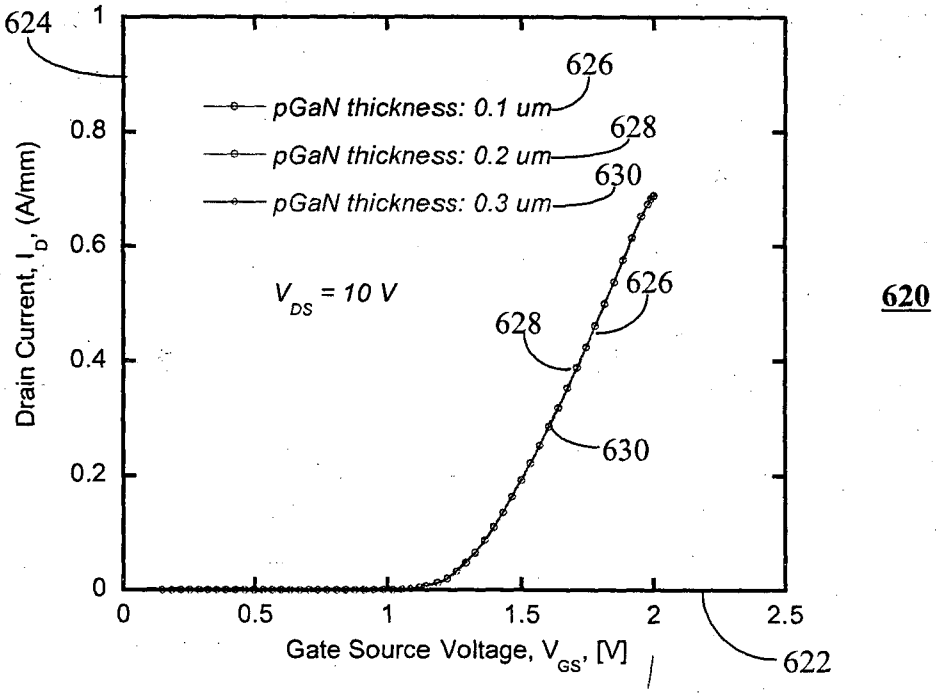

624
626
628
630
pGaN thickness: 0.1 um
pGaN thickness: 0.2 um
pGaN thickness: 0.3 um
V_{DS} = 10 V
Drain Current, I_D, (A/mm)
Gate Source Voltage, V_{GS}, [V]
622
620

FIG. 6B

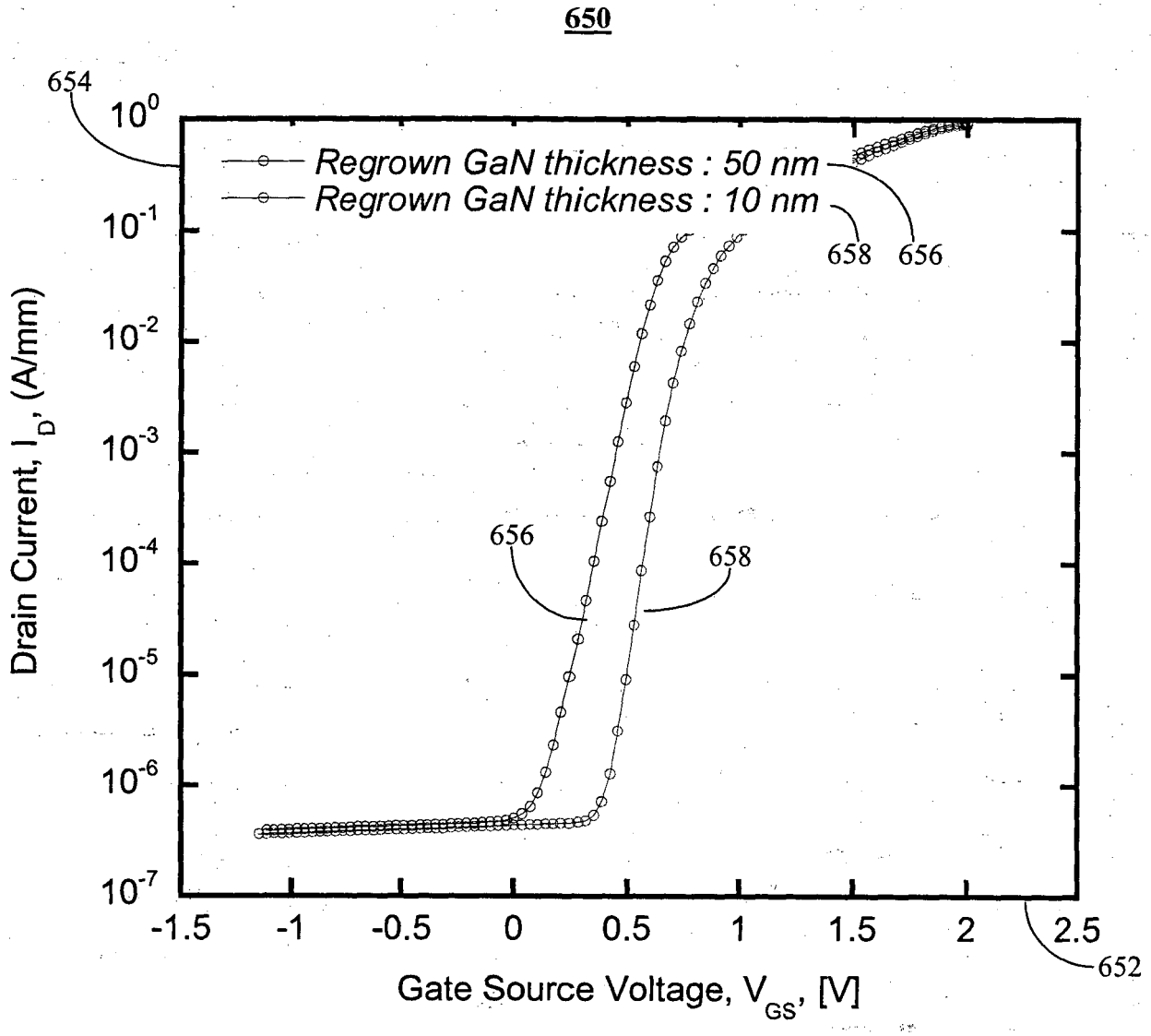

650
654
Regrown GaN thickness : 50 nm
Regrown GaN thickness : 10 nm
658
656
656
658
Drain Current, I_D, (A/mm)
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
652
Gate Source Voltage, V_{GS}, [V]

FIG. 6C

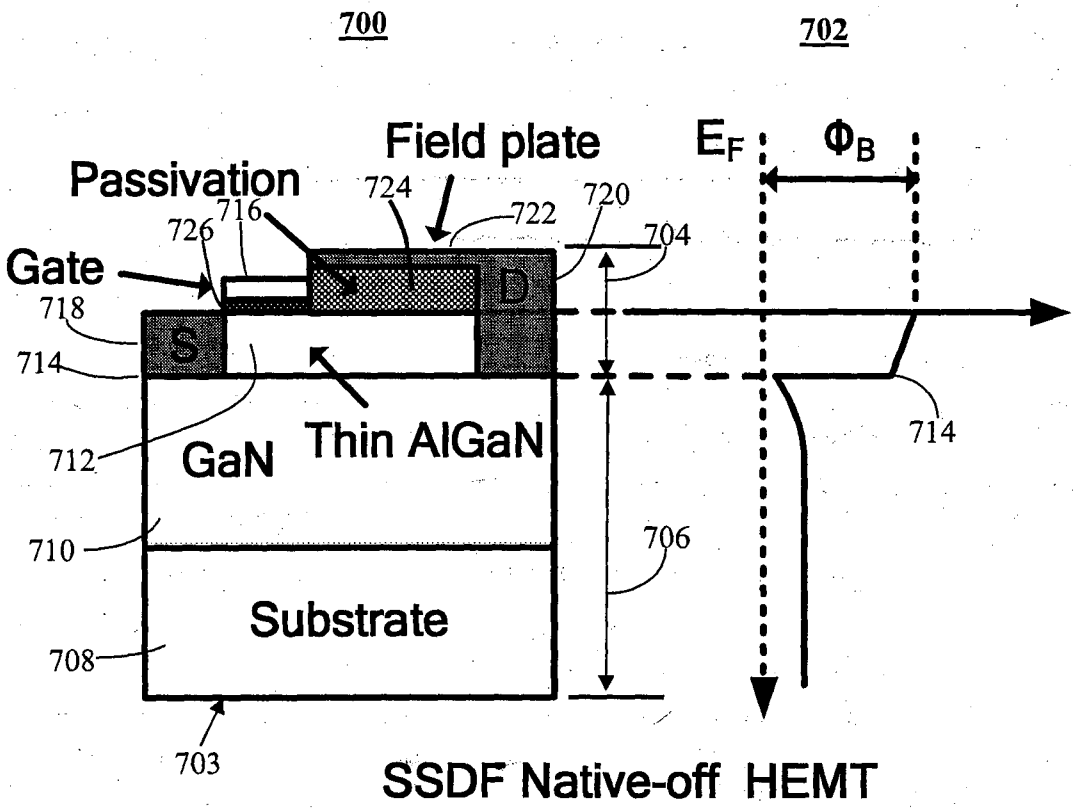

700
702
Field plate
E_F
Φ_B
Passivation
724
720
716
722
726
704
Gate
D
718
S
714
712
GaN
Thin AlGaN
714
710
706
Substrate
708
703
SSDF Native-off HEMT

FIG. 7

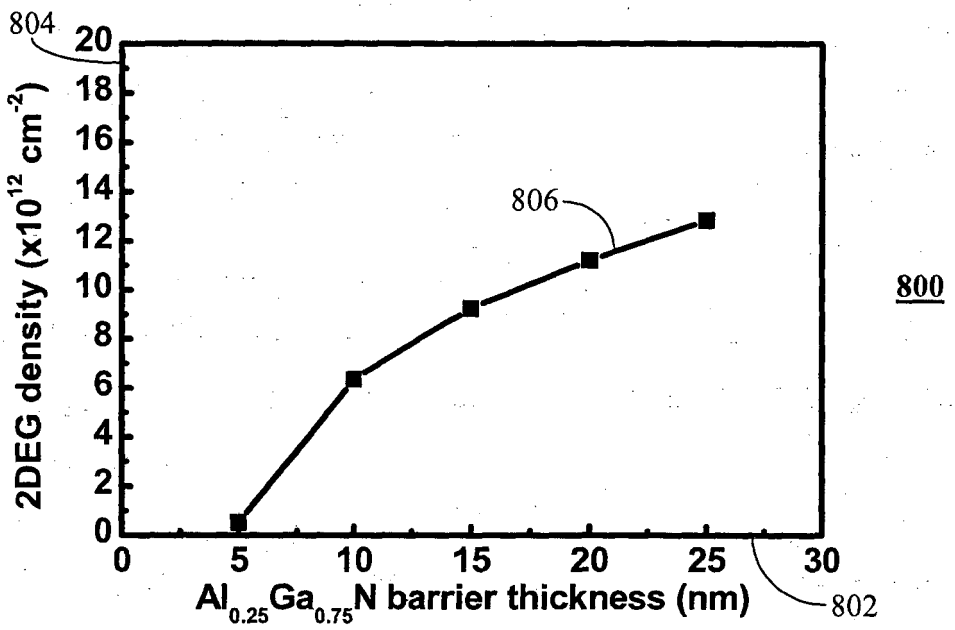

804
2DEG density (x10^12 cm^-2)
20
18
16
14
12
10
8
6
4
2
0
806
0
5
10
15
20
25
30
Al0.25Ga0.75N barrier thickness (nm)
802
800

FIG. 8A

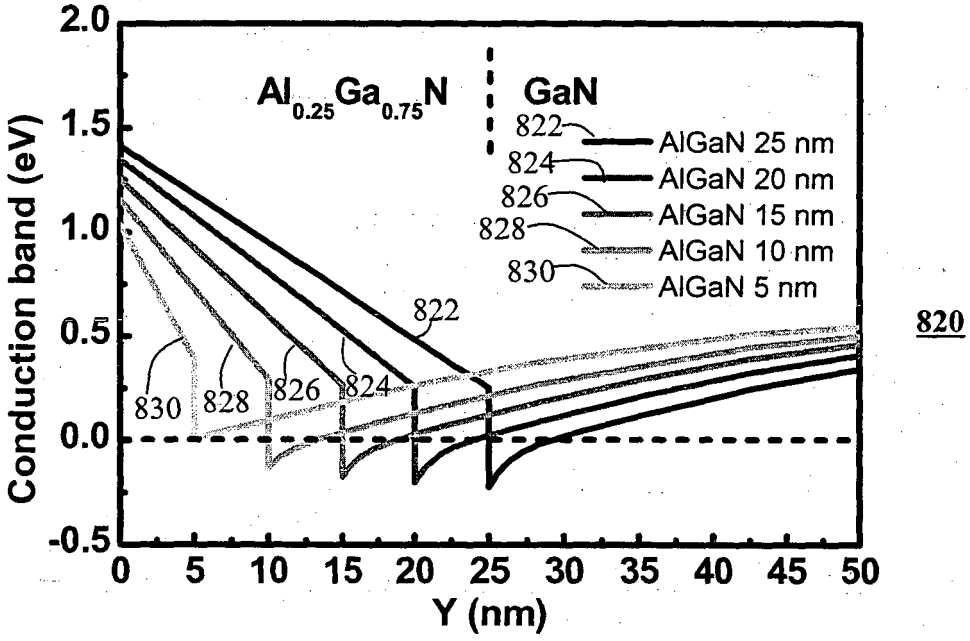

2.0
1.5
1.0
0.5
0.0
-0.5
Conduction band (eV)
Al0.25Ga0.75N
GaN
822
AlGaN 25 nm
824
AlGaN 20 nm
826
AlGaN 15 nm
828
AlGaN 10 nm
830
AlGaN 5 nm
822
830
828
826
824
0
5
10
15
20
25
30
35
40
45
50
Y (nm)
820

FIG. 8B

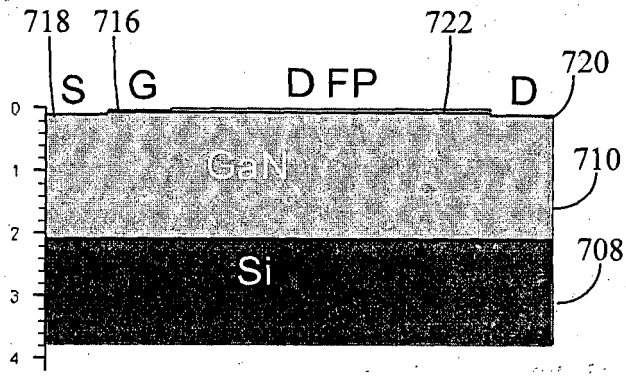
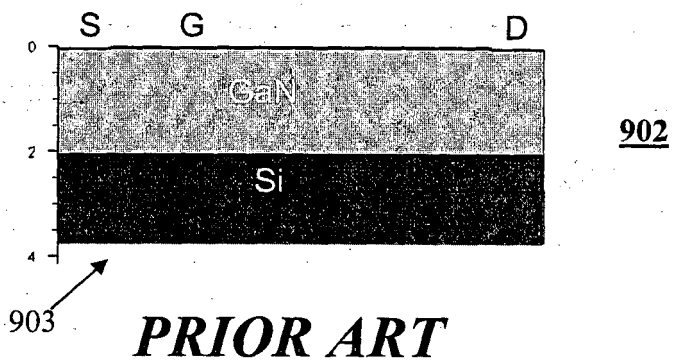


FIG. 9A



PRIOR ART

FIG. 9B

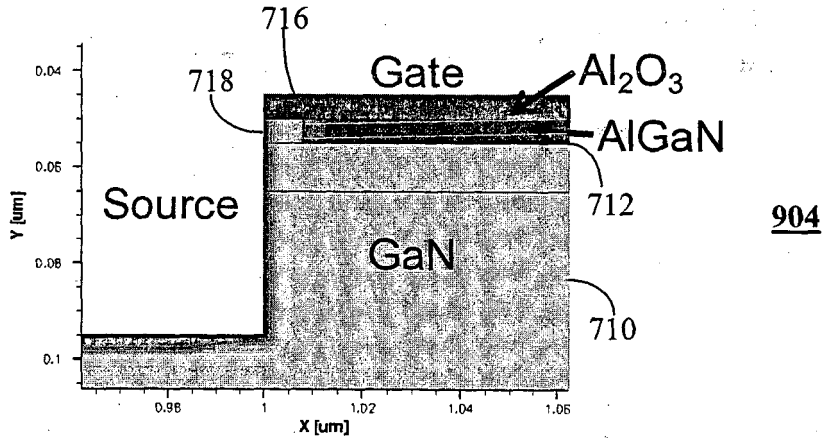


FIG. 9C

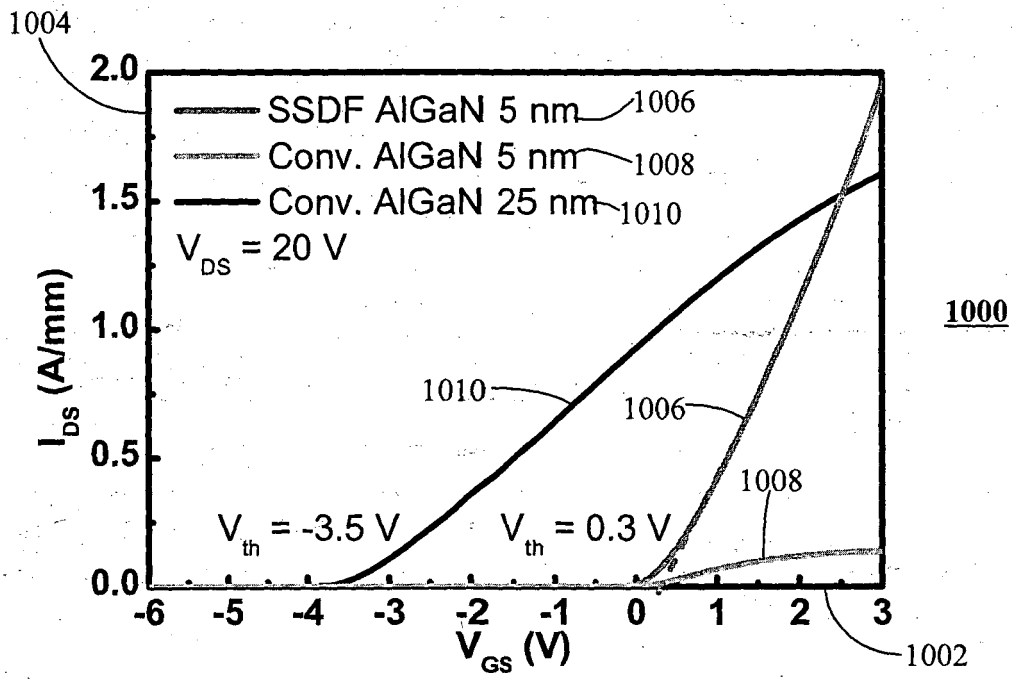

1004
2.0
1.5
1.0
0.5
0.0
SSDF AlGaN 5 nm
Conv. AlGaN 5 nm
Conv. AlGaN 25 nm
V_{DS} = 20 V
1006
1008
1010
I_{DS} (A/mm)
V_{th} = -3.5 V
V_{th} = 0.3 V
-6 -5 -4 -3 -2 -1 0 1 2 3
V_{GS} (V)
1000
1002

FIG. 10

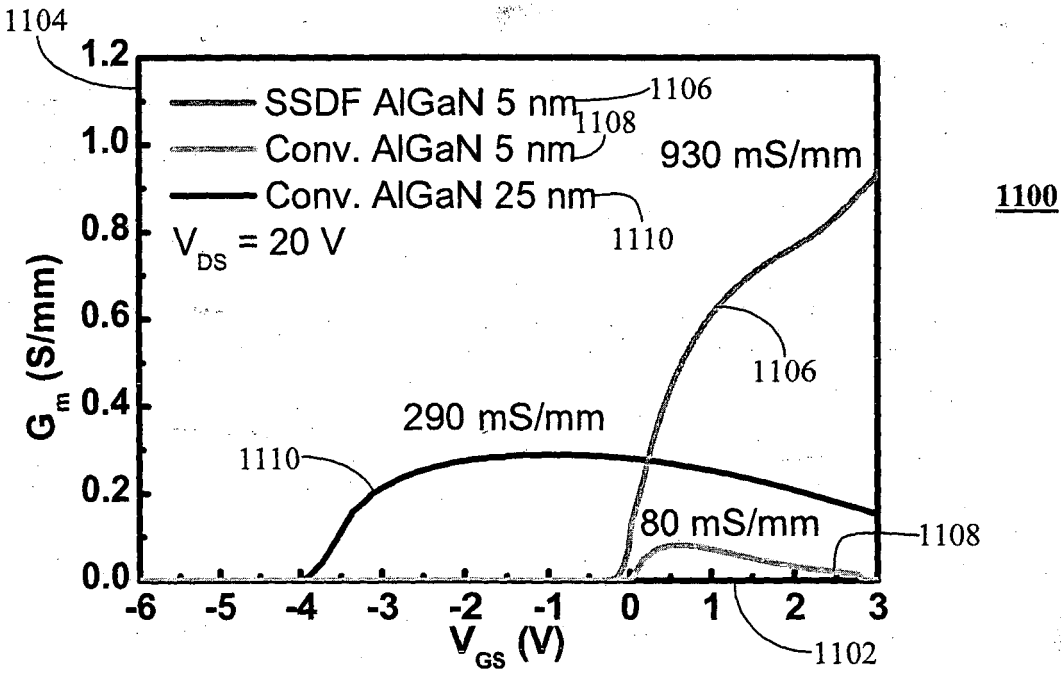

1104
1.2
1.0
0.8
0.6
0.4
0.2
0.0
SSDF AlGaN 5 nm
Conv. AlGaN 5 nm
Conv. AlGaN 25 nm
V_{DS} = 20 V
1106
1108
1110
930 mS/mm
290 mS/mm
80 mS/mm
G_m (S/mm)
-6 -5 -4 -3 -2 -1 0 1 2 3
V_{GS} (V)
1100
1102

FIG. 11

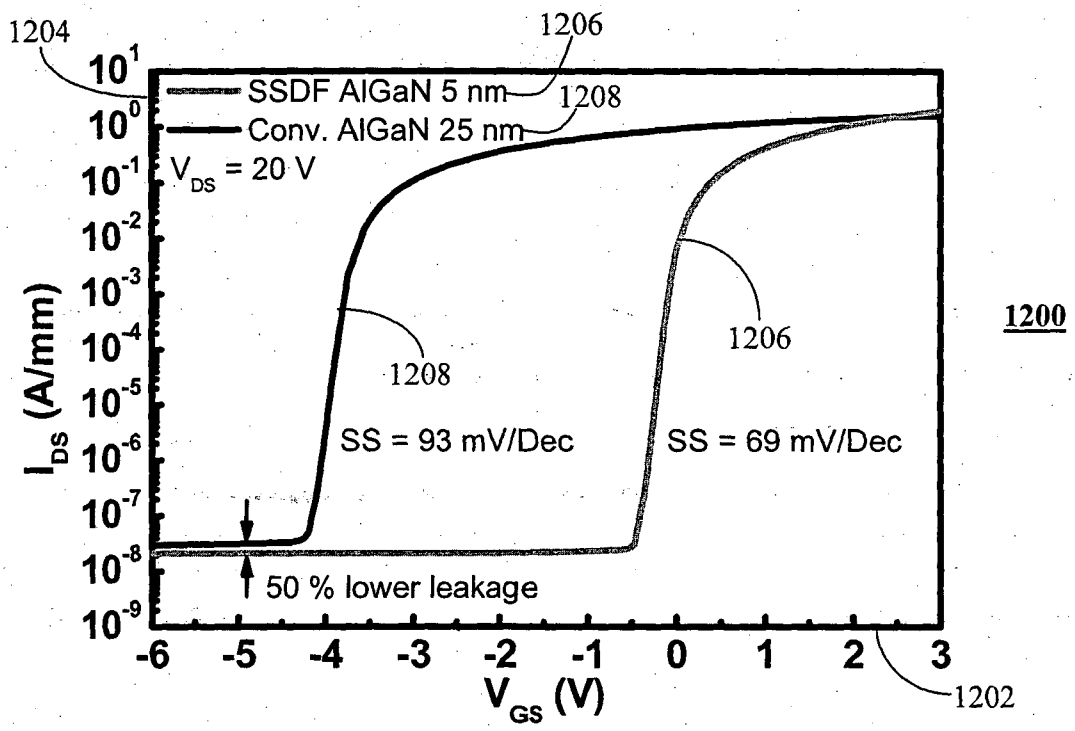

1204
1206
SSDF AlGaN 5 nm
1208
Conv. AlGaN 25 nm
V_{DS} = 20 V
I_{DS} (A/mm)
1208
1206
1200
SS = 93 mV/Dec
SS = 69 mV/Dec
50 % lower leakage
V_{GS} (V)
1202

FIG. 12

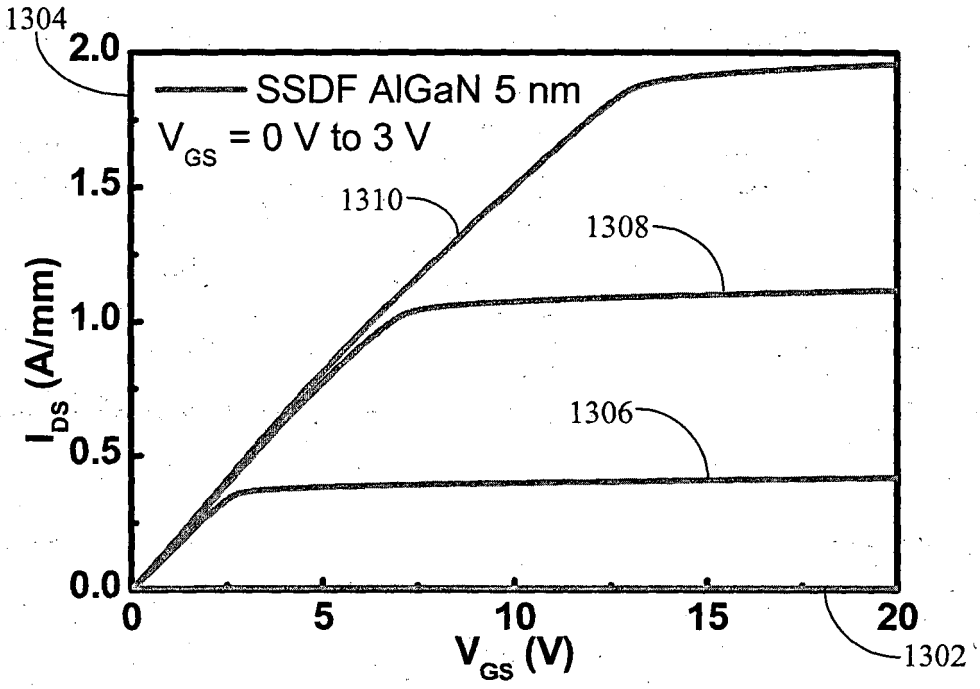

1304
SSDF AlGaN 5 nm
V_{GS} = 0 V to 3 V
1310
1308
1306
1300
I_{DS} (A/mm)
V_{GS} (V)
1302
2.0
1.5
1.0
0.5
0.0
0
5
10
15
20

FIG. 13

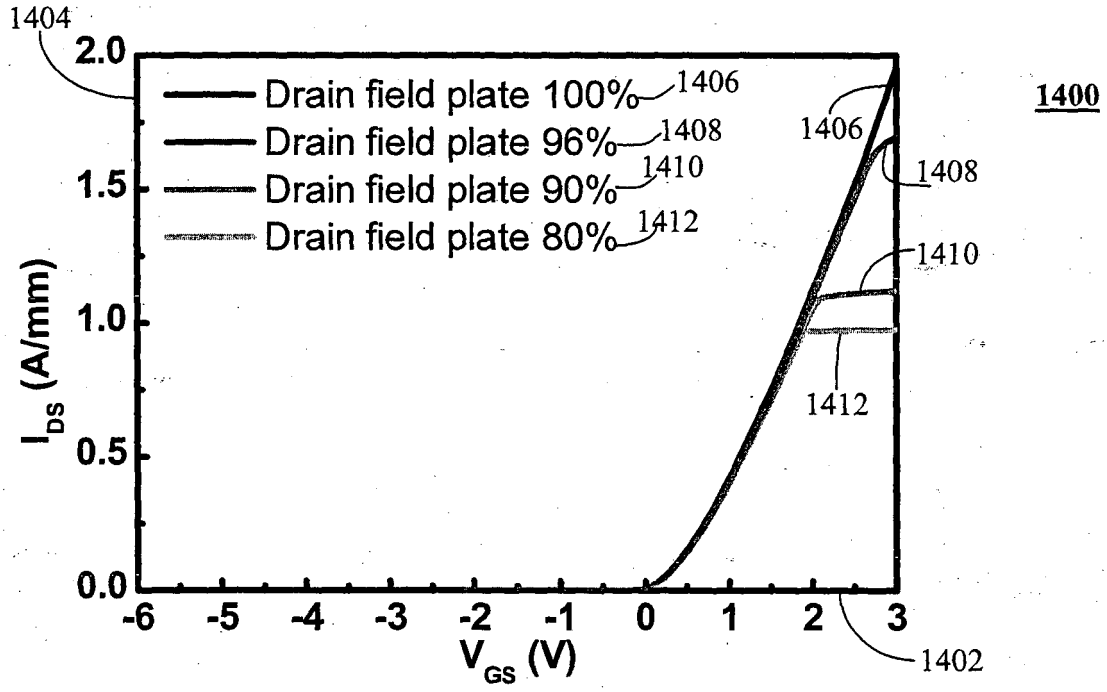

1404
Drain field plate 100%
Drain field plate 96%
Drain field plate 90%
Drain field plate 80%
1406
1408
1410
1412
1400
I_{DS} (A/mm)
V_{GS} (V)
1402
2.0
1.5
1.0
0.5
0.0
-6
-5
-4
-3
-2
-1
0
1
2
3

FIG. 14

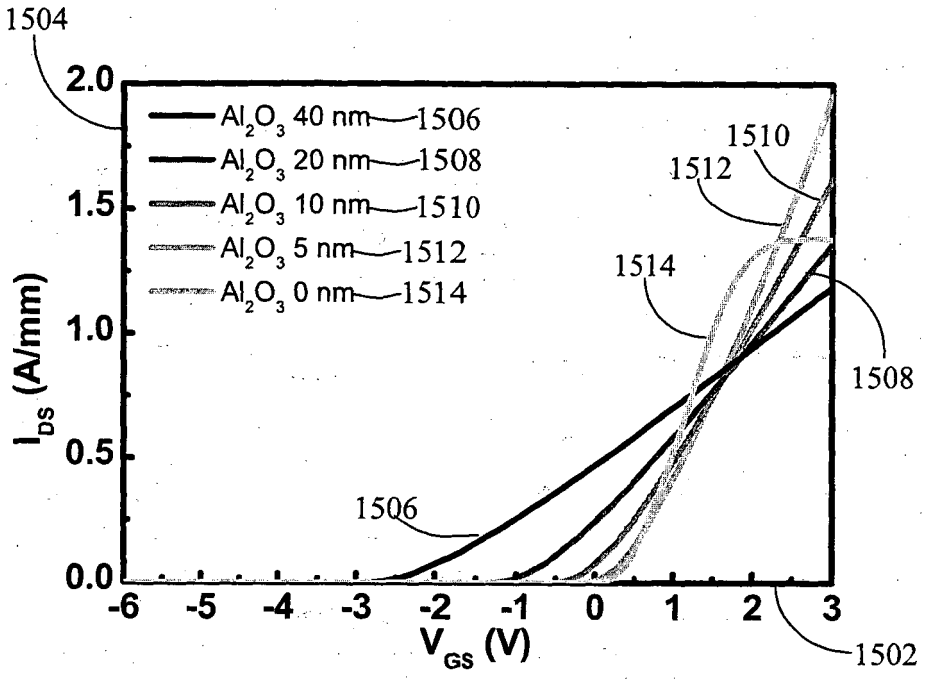


FIG. 15A

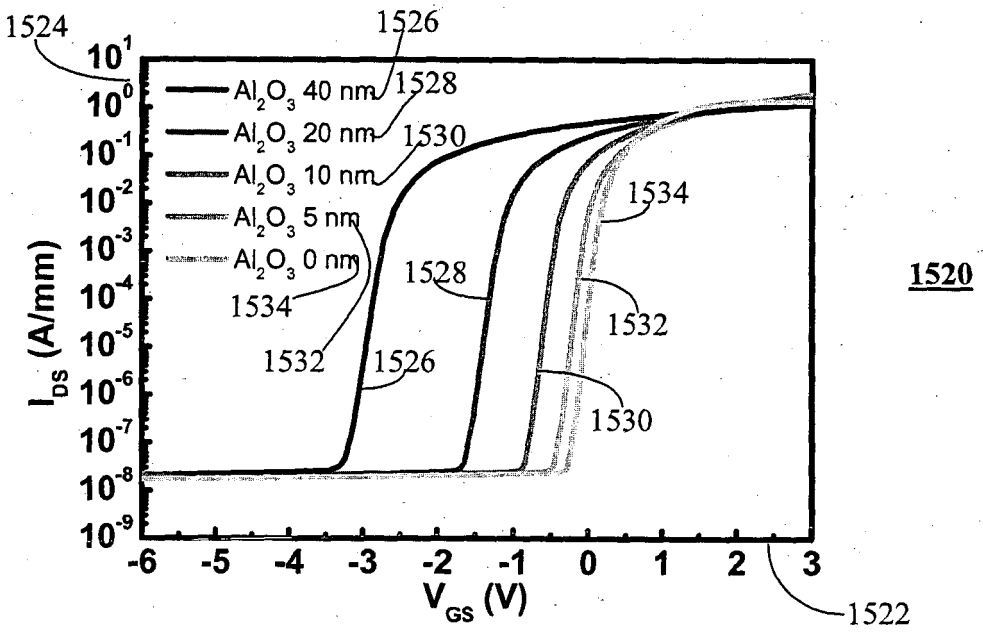


FIG. 15B

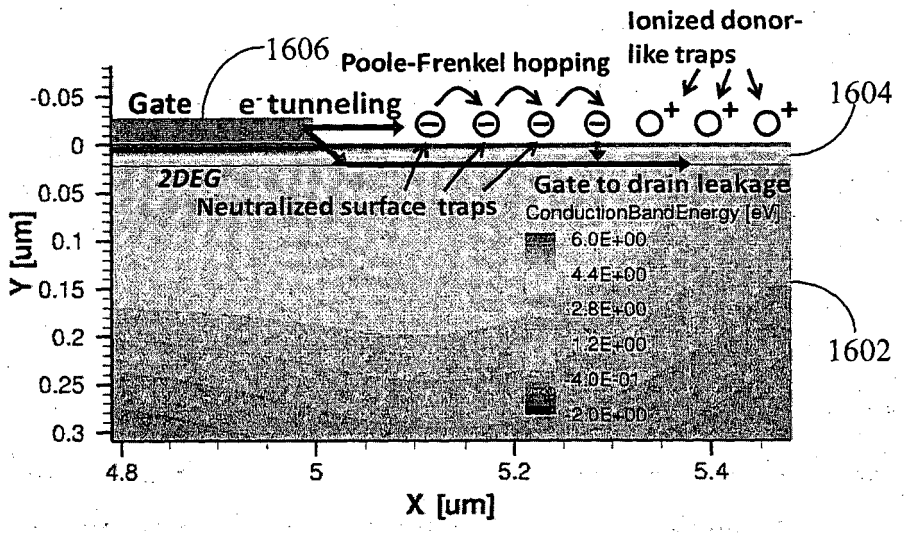


FIG. 16A

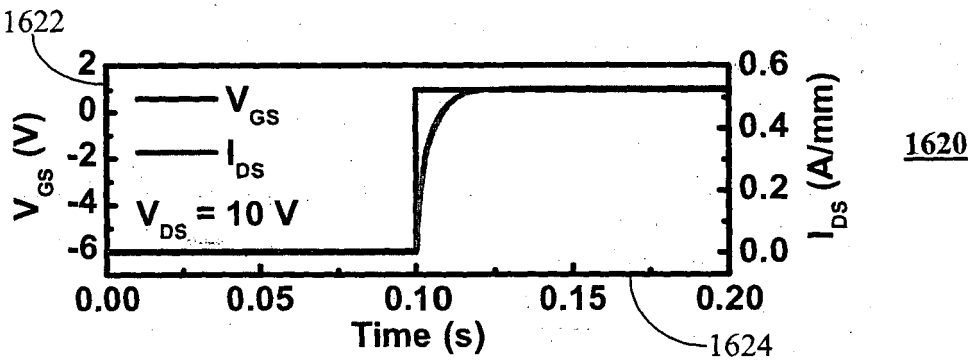


FIG. 16B

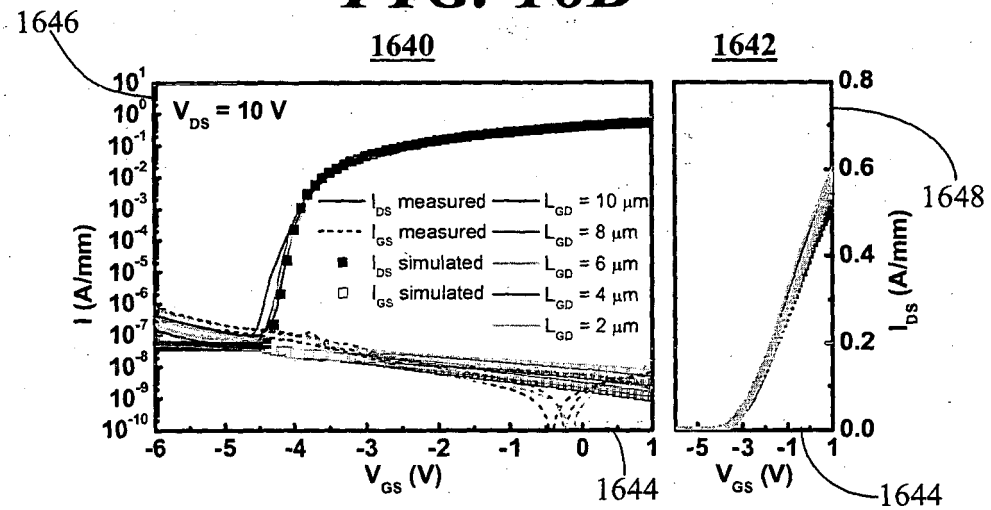


FIG. 16C

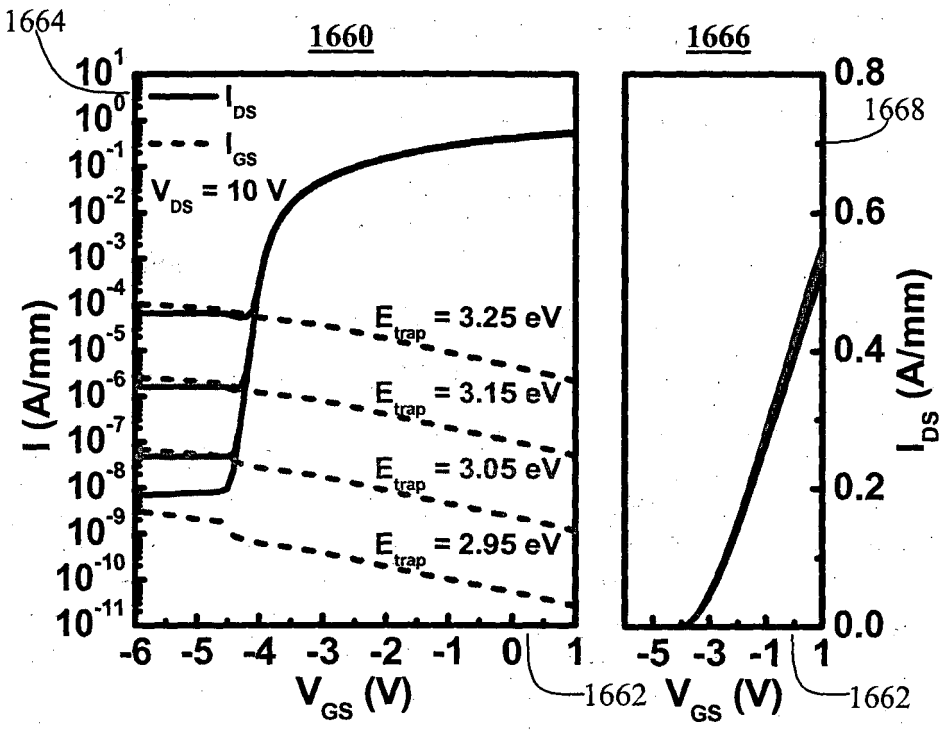


FIG. 16D

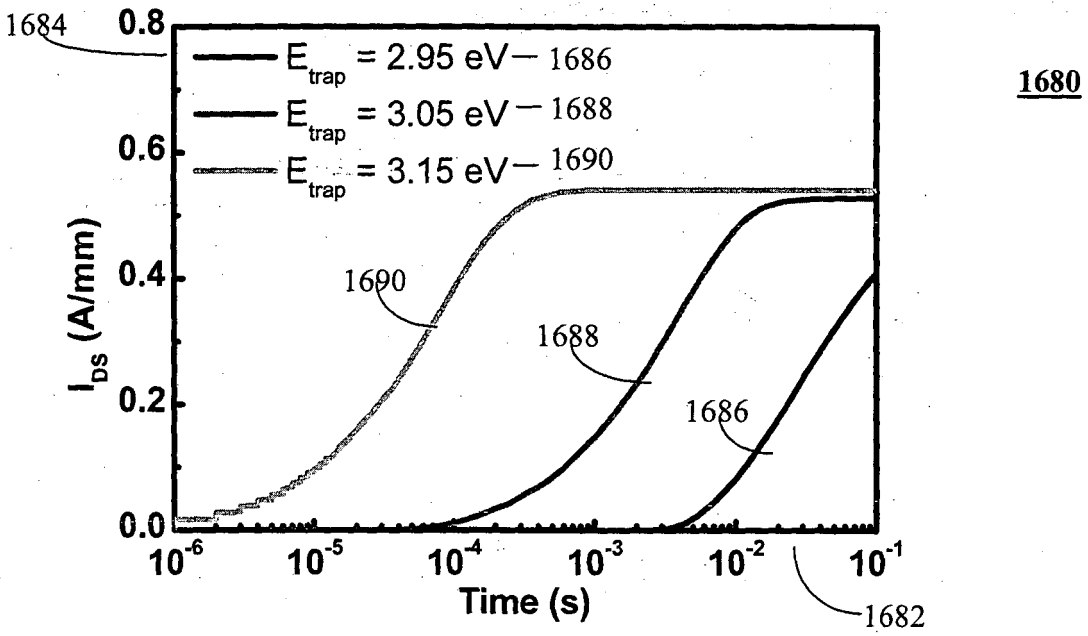


FIG. 16E

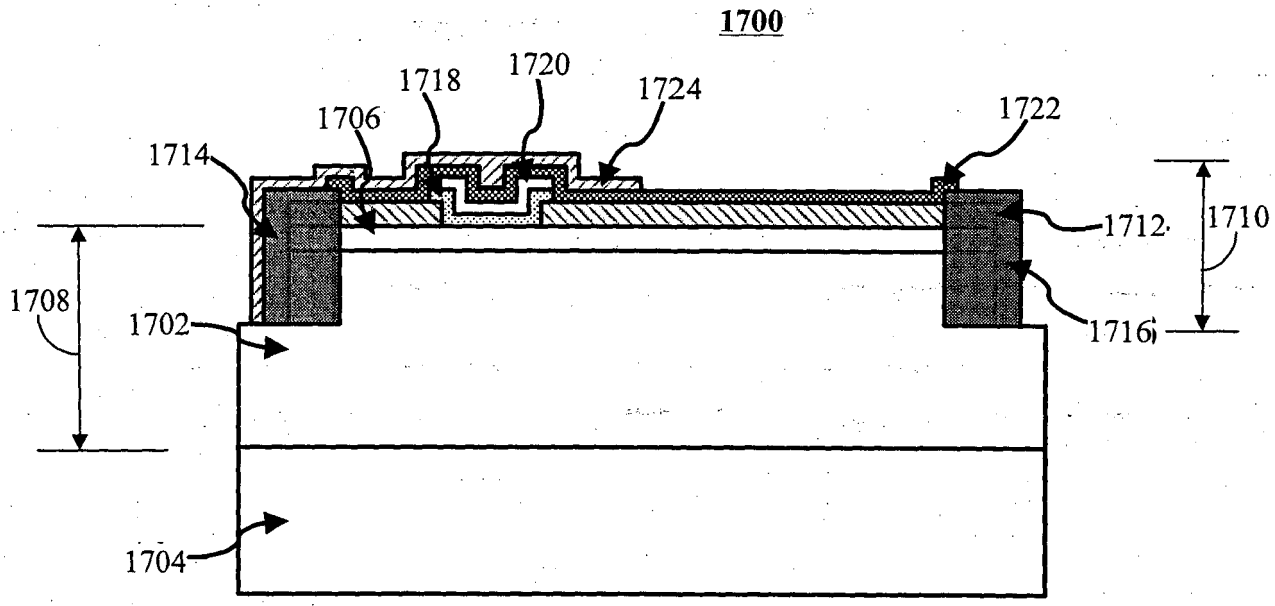

1700
1718
1720
1724
1706
1722
1714
1712
1710
1708
1702
1716
1704

FIG. 17

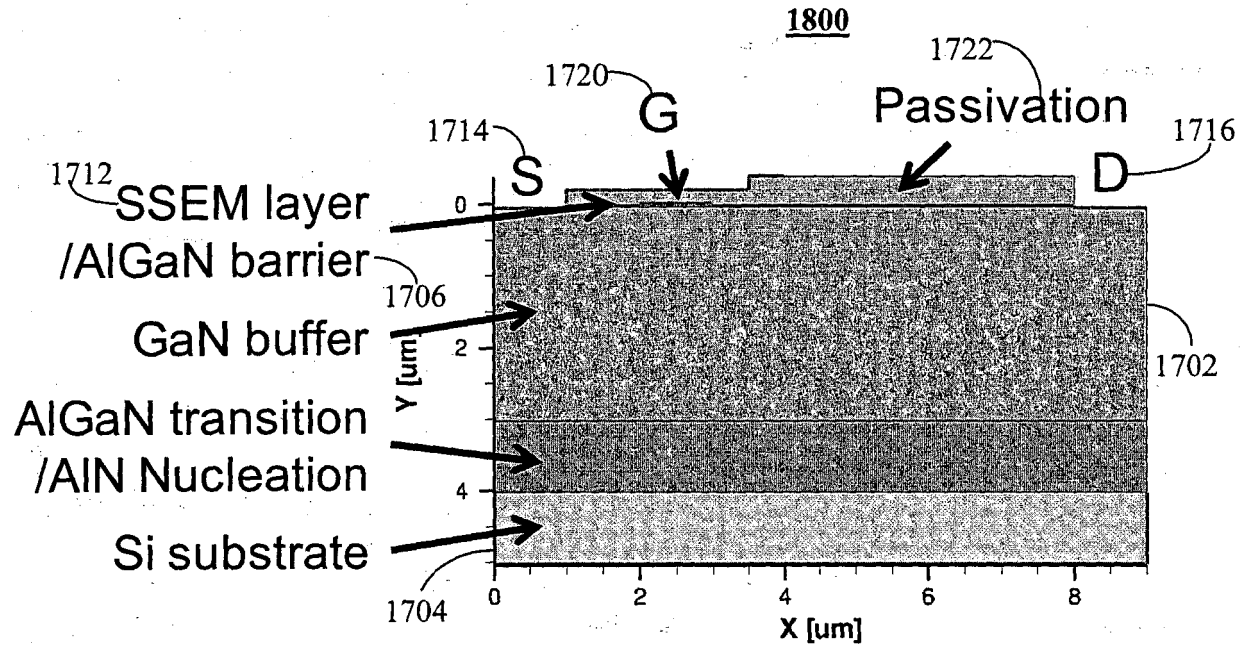


FIG. 18A

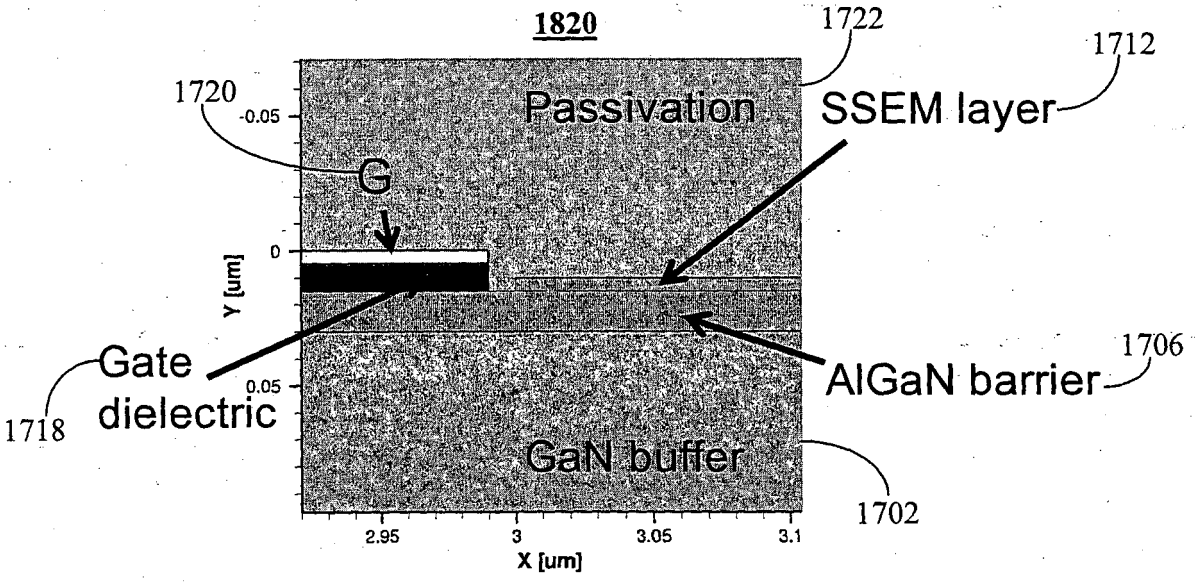


FIG. 18B

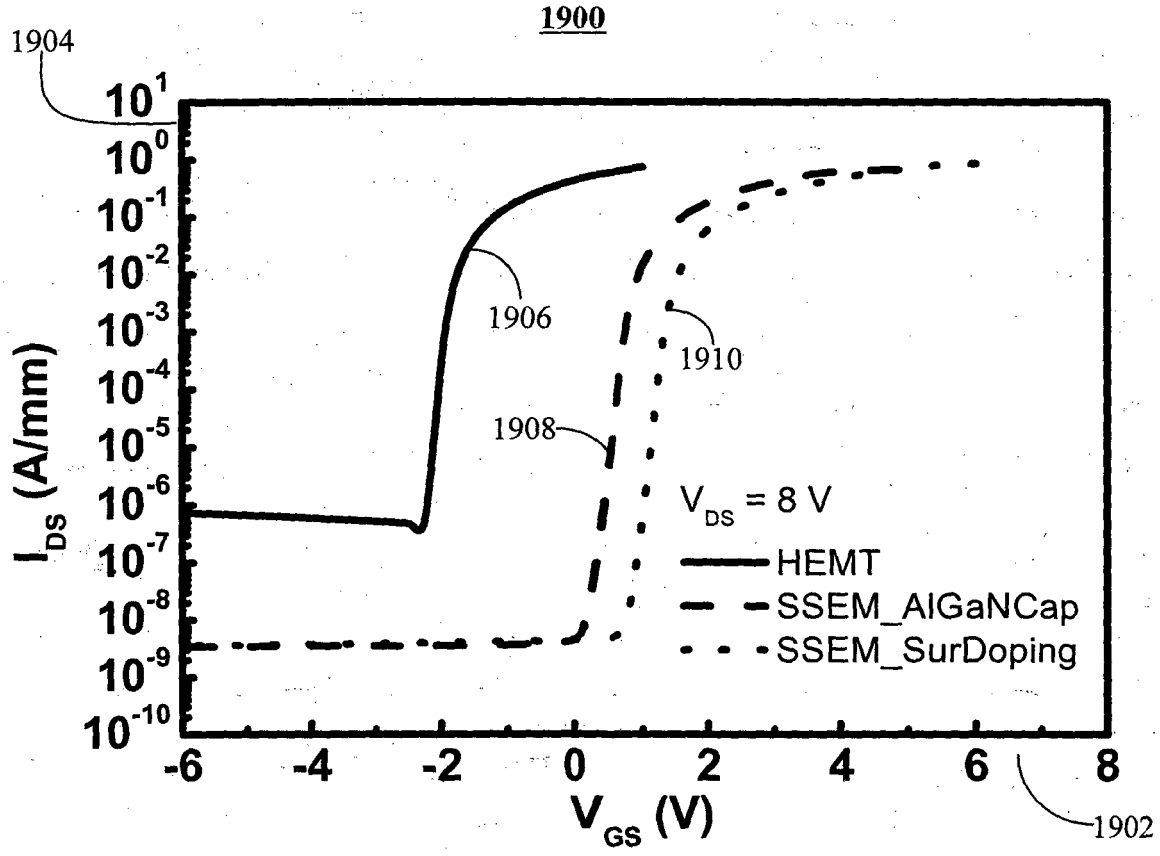

1900
1904
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
I_{DS} (A/mm)
1906
1910
1908
V_{DS} = 8 V
HEMT
SSEM_AlGaNCap
SSEM_SurDoping
-6
-4
-2
0
2
4
6
8
V_{GS} (V)
1902

FIG. 19

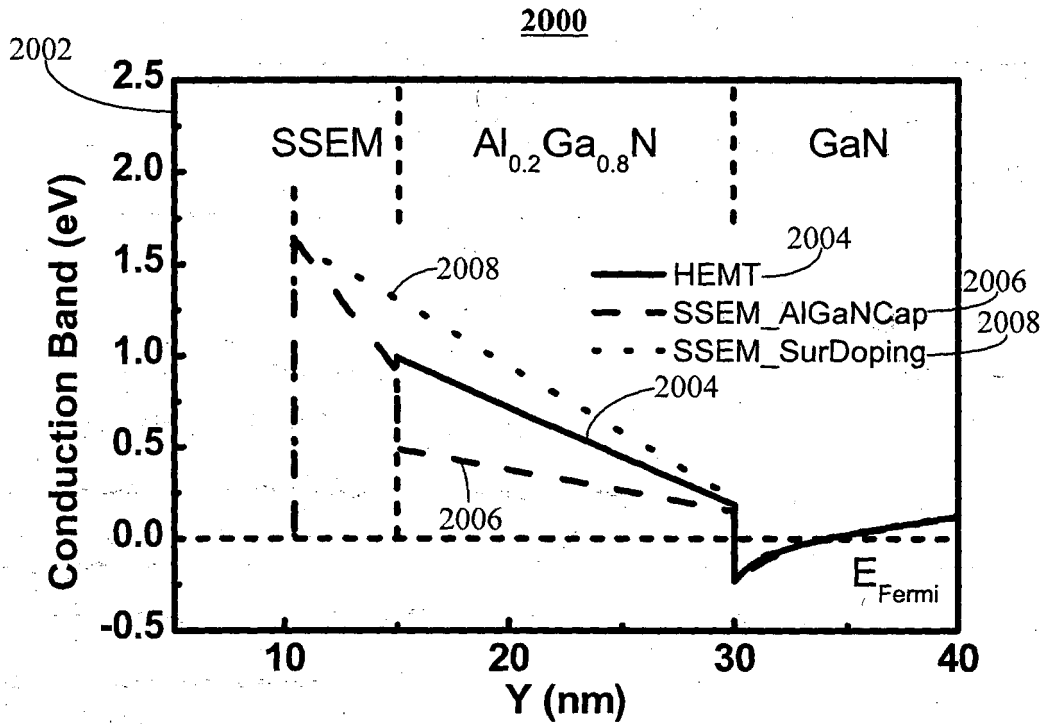

2000
2002
SSEM
$Al_{0.2}Ga_{0.8}N$
GaN
Conduction Band (eV)
Y (nm)
HEMT
SSEM_AlGaNCap
SSEM_SurDoping
2004
2006
2008
E_{Fermi}

FIG. 20

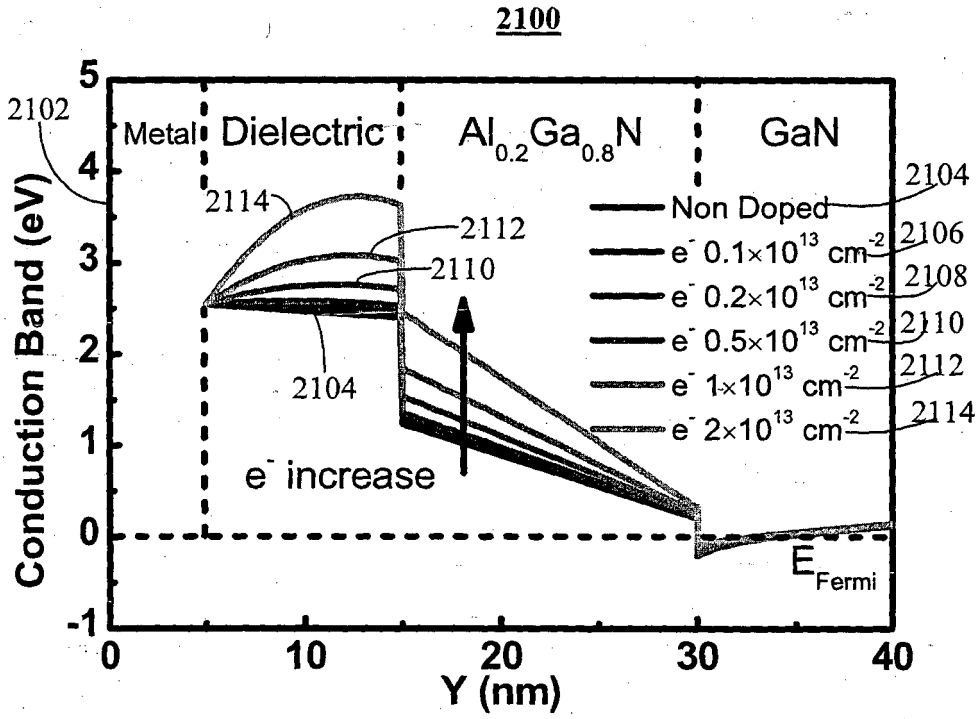

2100
2102
Metal
Dielectric
$Al_{0.2}Ga_{0.8}N$
GaN
Conduction Band (eV)
Y (nm)
Non Doped
$e^- 0.1\times10^{13}$ cm^{-2}
$e^- 0.2\times10^{13}$ cm^{-2}
$e^- 0.5\times10^{13}$ cm^{-2}
$e^- 1\times10^{13}$ cm^{-2}
$e^- 2\times10^{13}$ cm^{-2}
2104
2106
2108
2110
2112
2114
e^- increase
E_{Fermi}

FIG. 21

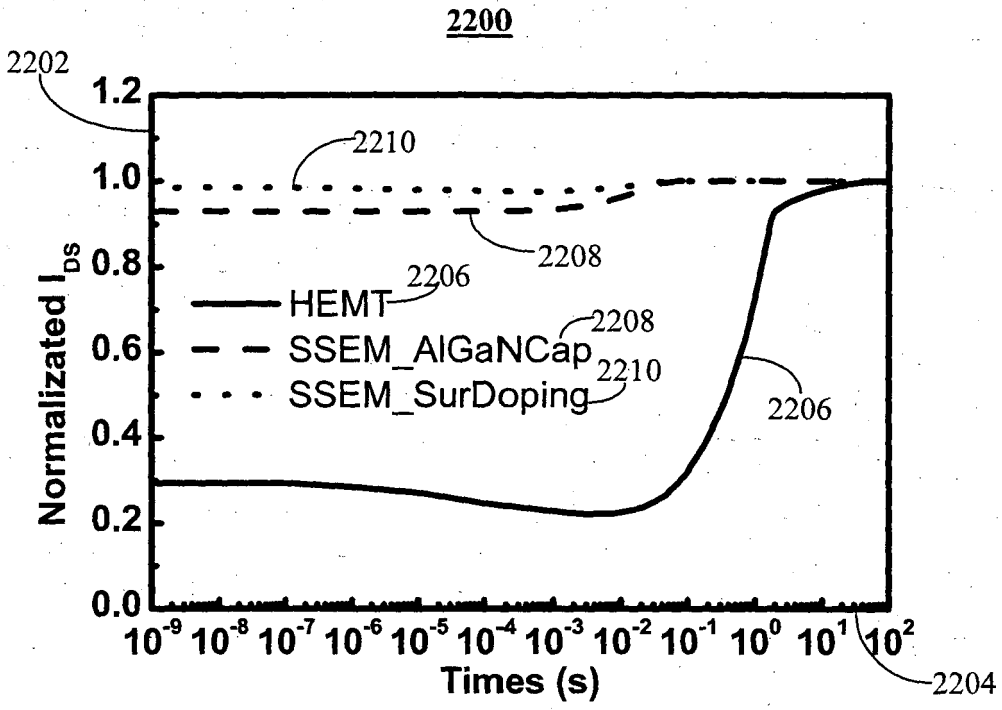

2200
2202
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Normalizated I_{DS}
2210
2208
2206
HEMT
SSEM_AlGaNCap
SSEM_SurDoping
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1} 10^{2}
Times (s)
2204

FIG. 22

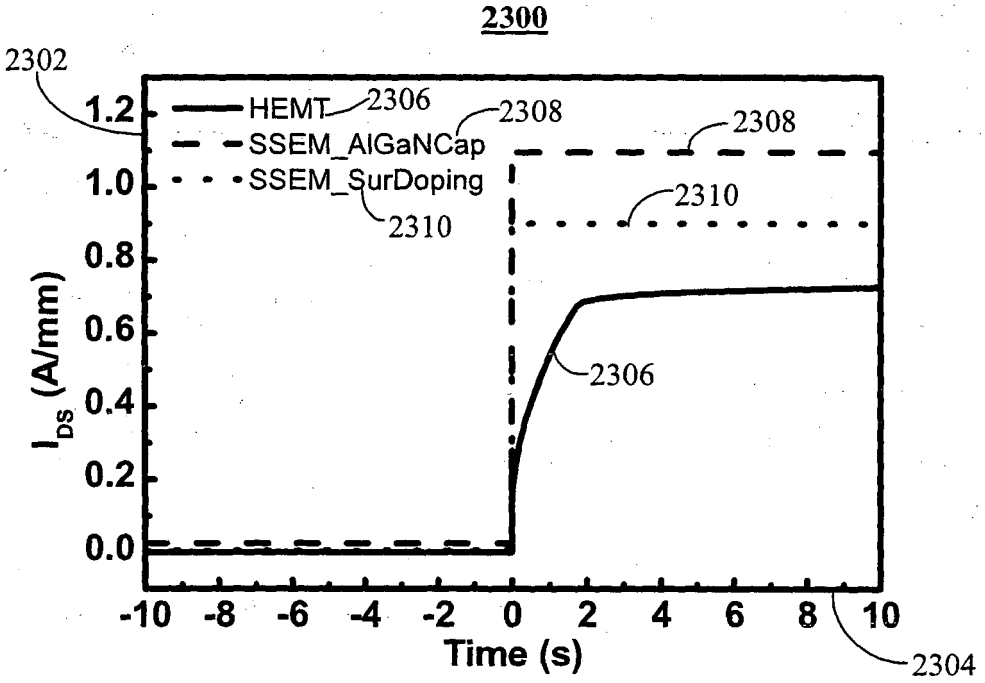

2300
2302
1.2
1.0
0.8
0.6
0.4
0.2
0.0
I_{DS} (A/mm)
HEMT
2306
2308
SSEM_AlGaNCap
SSEM_SurDoping
2310
-10 -8 -6 -4 -2 0 2 4 6 8 10
Time (s)
2304

FIG. 23

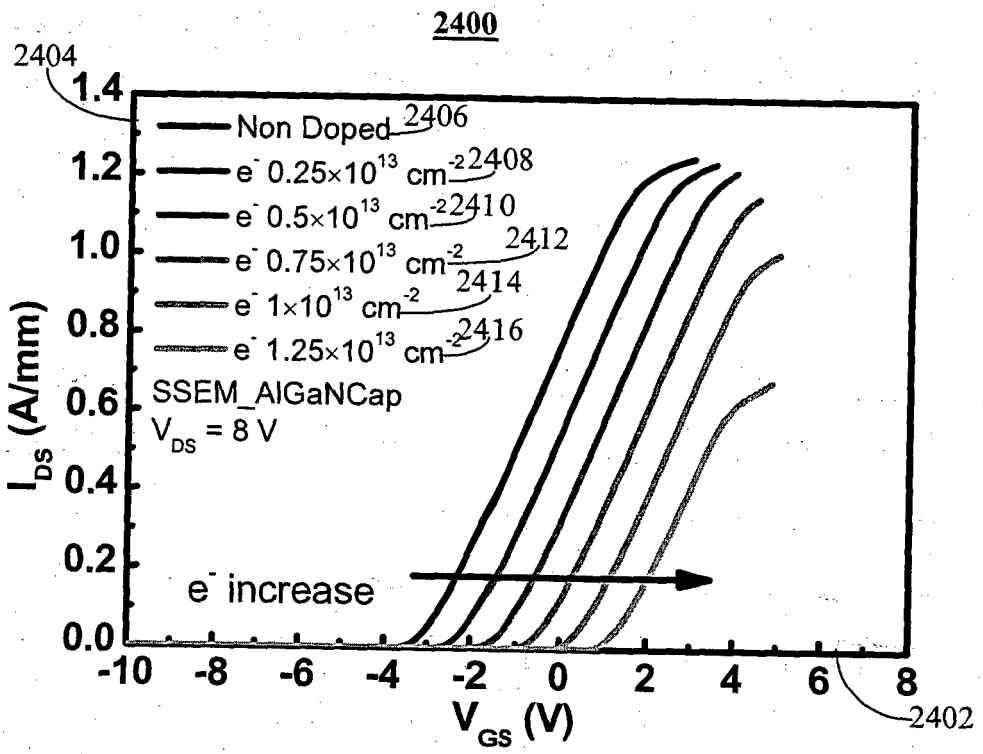

2400
2404
Non Doped 2406
e⁻ 0.25×10¹³ cm⁻² 2408
e⁻ 0.5×10¹³ cm⁻² 2410
e⁻ 0.75×10¹³ cm⁻² 2412
e⁻ 1×10¹³ cm⁻² 2414
e⁻ 1.25×10¹³ cm⁻² 2416
SSEM_AlGaNCap
V_DS = 8 V
e⁻ increase
I_DS (A/mm)
V_GS (V)
2402

FIG. 24

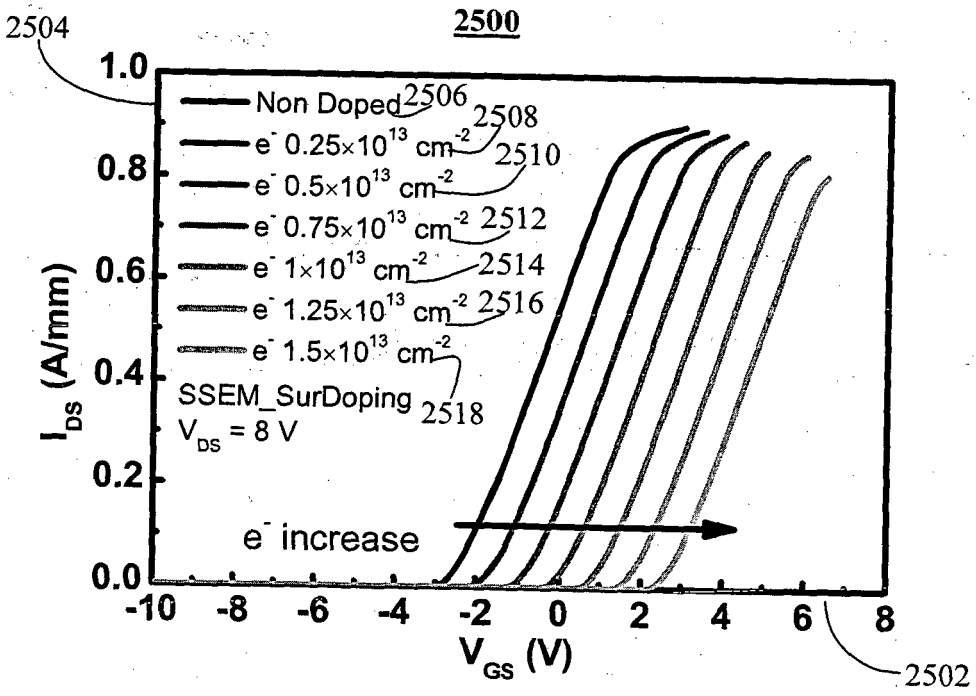

2500
2504
Non Doped 2506
e⁻ 0.25×10¹³ cm⁻² 2508
e⁻ 0.5×10¹³ cm⁻² 2510
e⁻ 0.75×10¹³ cm⁻² 2512
e⁻ 1×10¹³ cm⁻² 2514
e⁻ 1.25×10¹³ cm⁻² 2516
e⁻ 1.5×10¹³ cm⁻² 2518
SSEM_SurDoping
V_DS = 8 V
e⁻ increase
I_DS (A/mm)
V_GS (V)
2502

FIG. 25

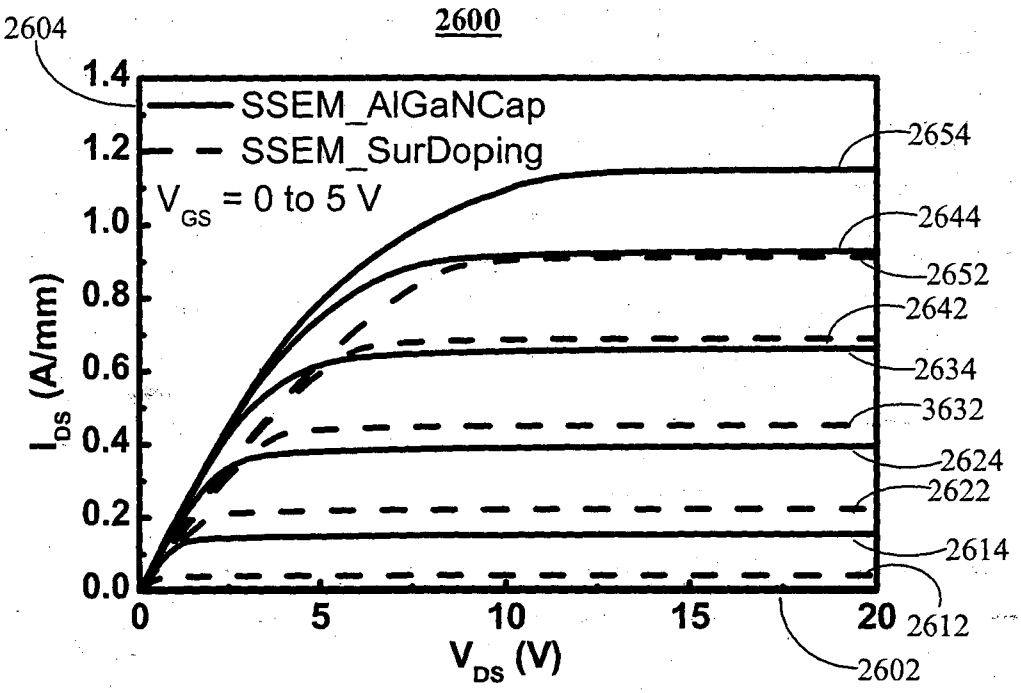

2600
2604
SSEM_AlGaNCap
SSEM_SurDoping
V_{GS} = 0 to 5 V
I_{DS} (A/mm)
V_{DS} (V)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
2654
2644
2652
2642
2634
3632
2624
2622
2614
2612
2602

FIG. 26

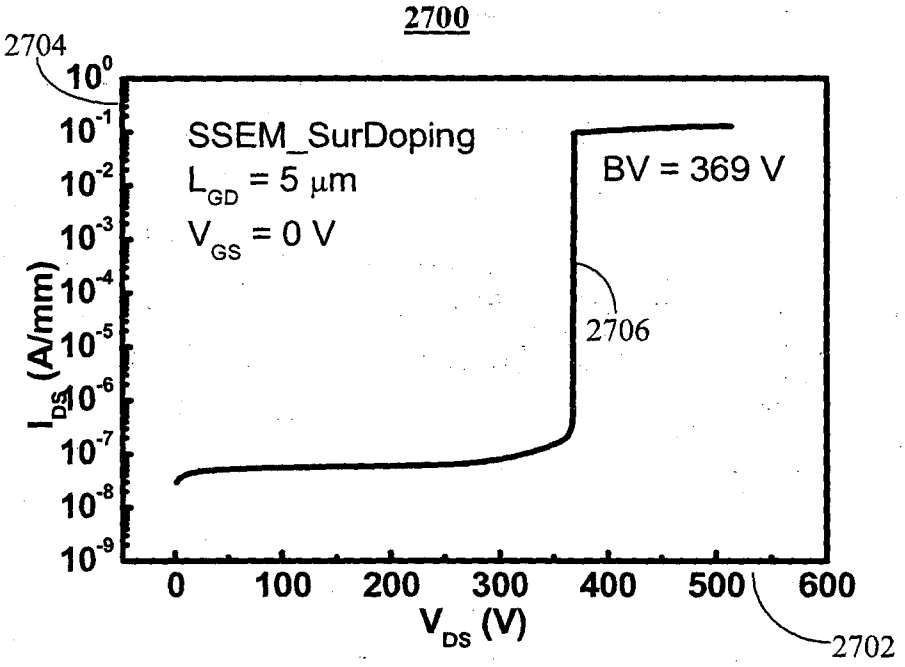

2700
2704
SSEM_SurDoping
L_{GD} = 5 μm
V_{GS} = 0 V
BV = 369 V
2706
I_{DS} (A/mm)
V_{DS} (V)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0
100
200
300
400
500
600
2702

FIG. 27

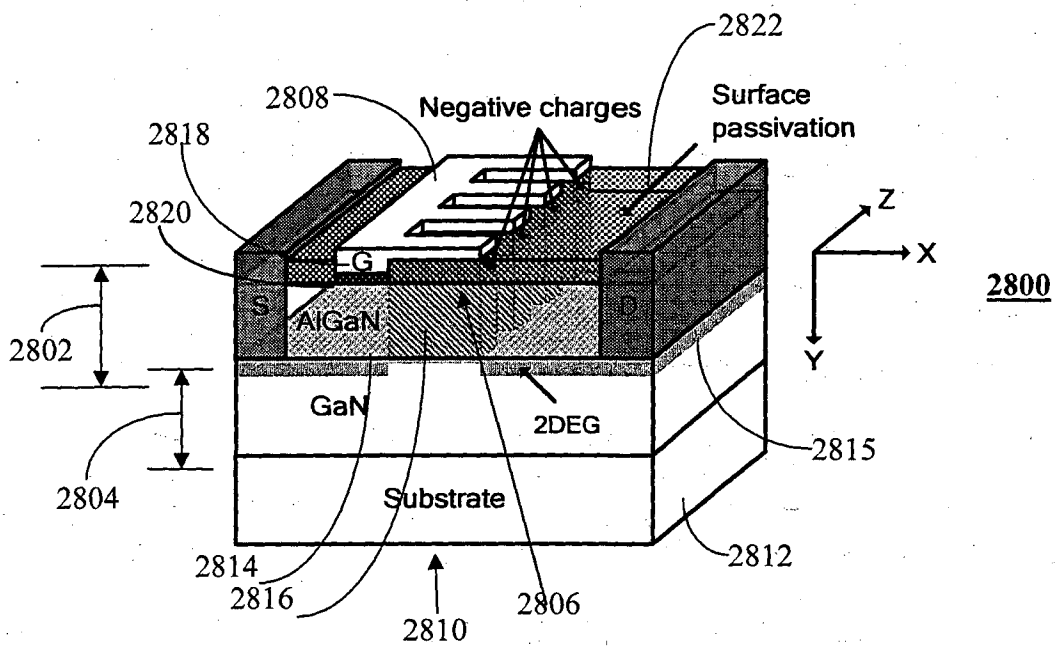


FIG. 28A

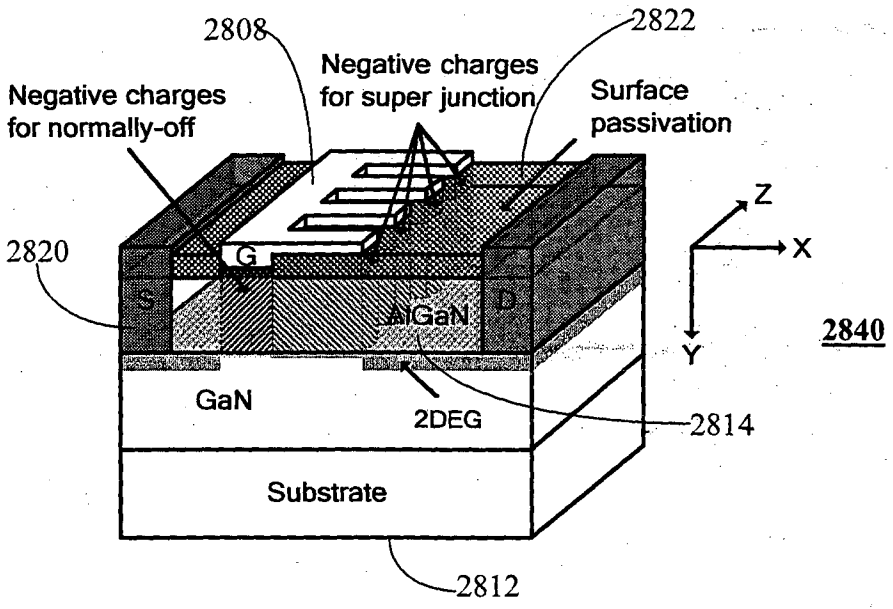


FIG. 28B

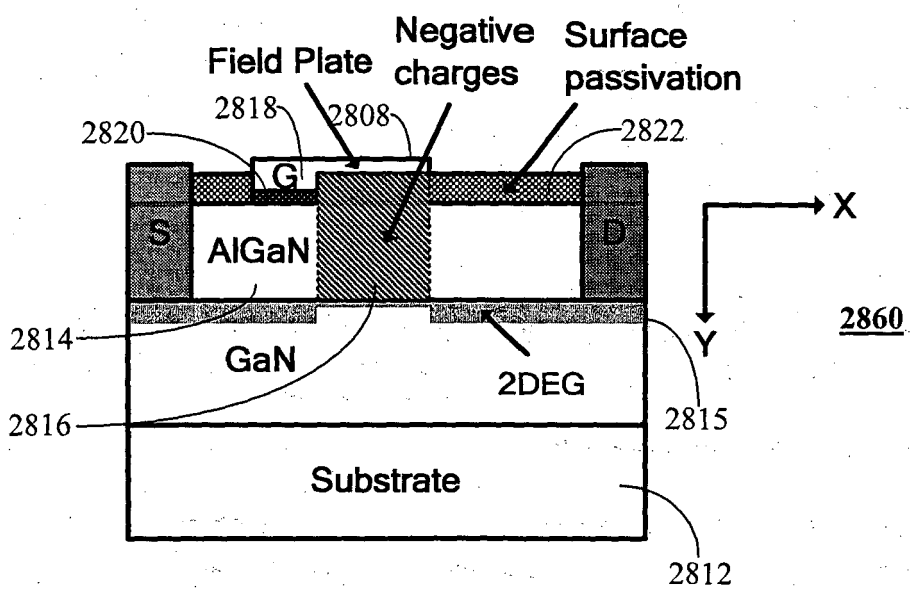


FIG. 28C

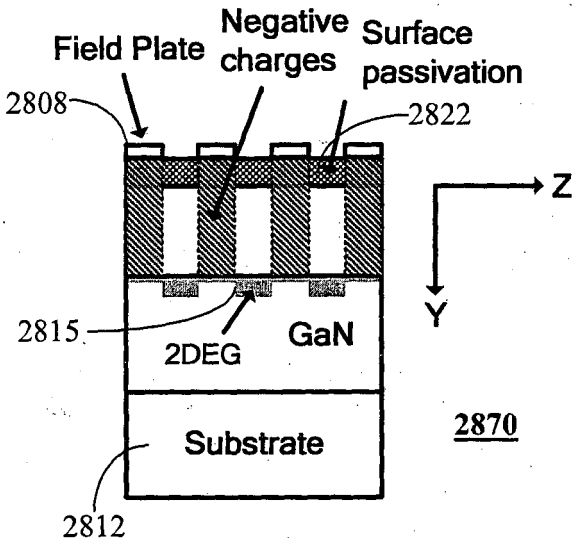


FIG. 28D

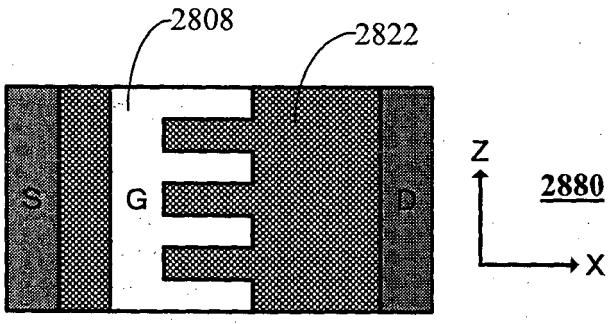
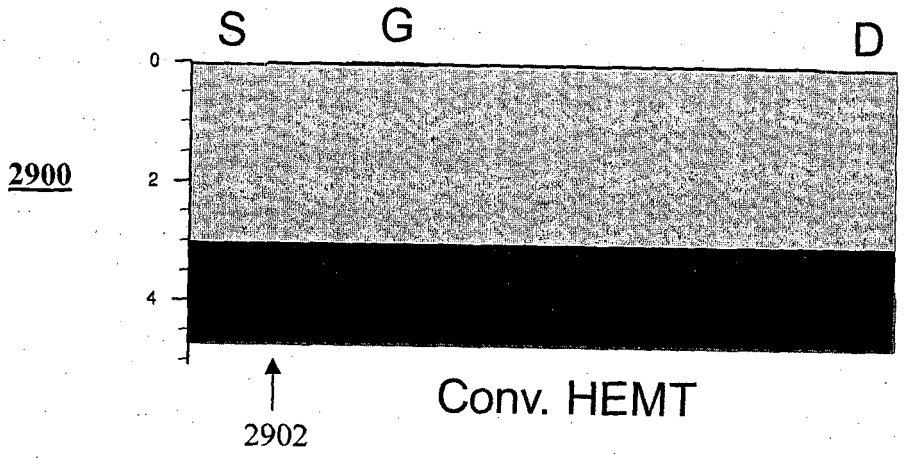


FIG. 28E



PRIOR ART

FIG. 29A

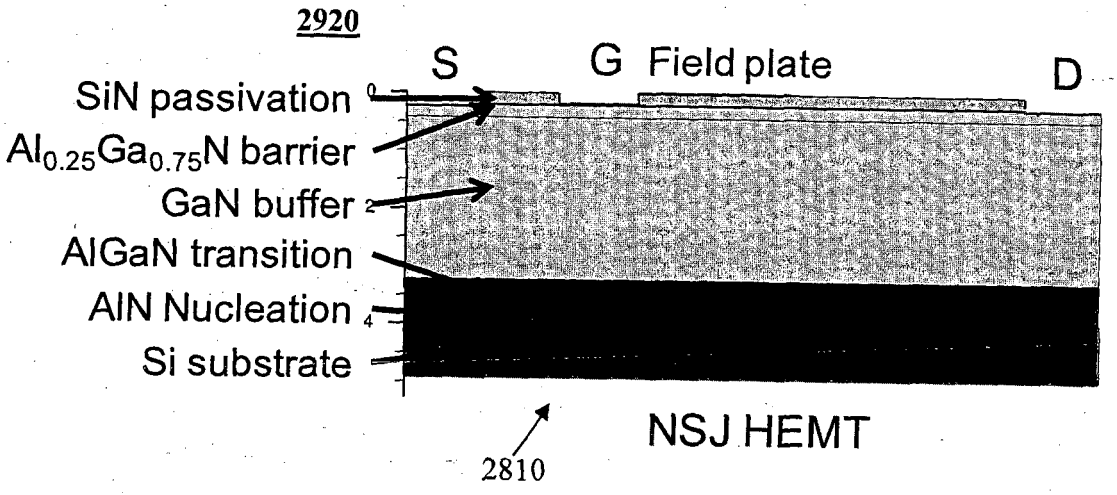


FIG. 29B

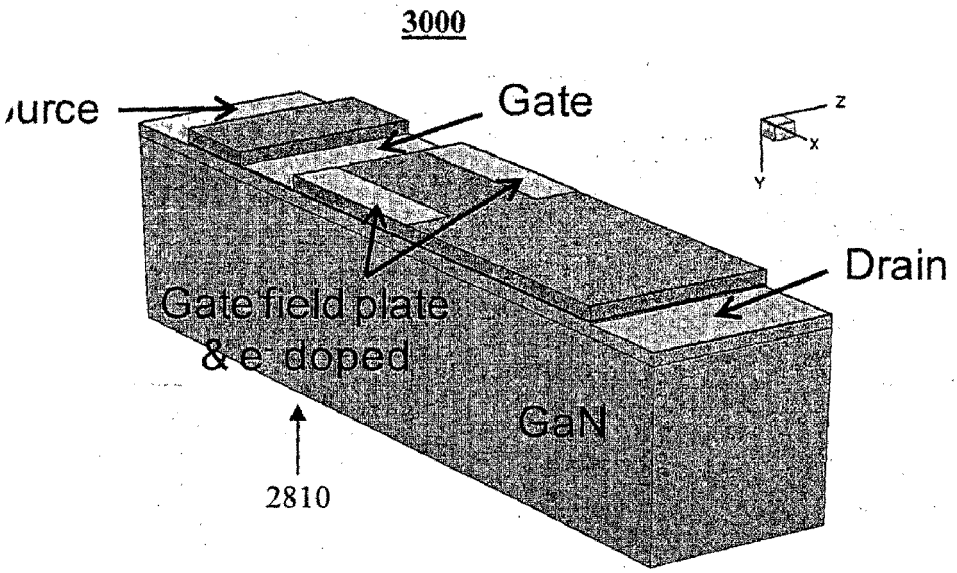

3000
ɹurce
Gate
Drain
Gate field plate
& e doped
GaN
2810
z
x
y

FIG. 30

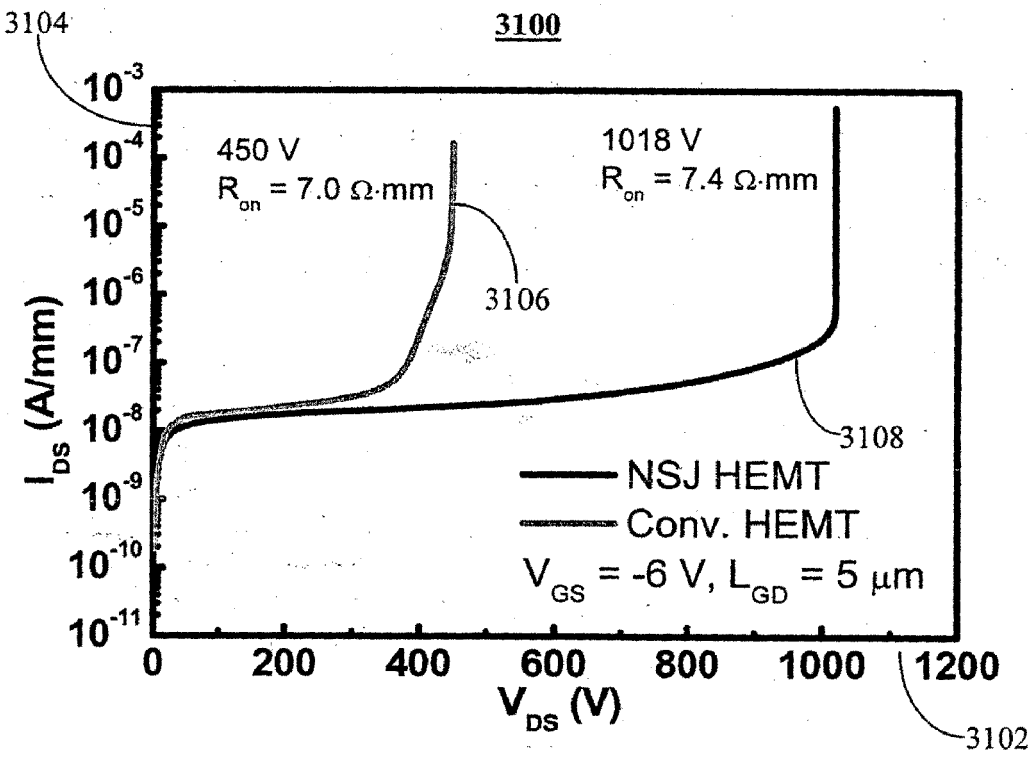

3100
3104
450 V
R_{on} = 7.0 Ω·mm
1018 V
R_{on} = 7.4 Ω·mm
3106
3108
NSJ HEMT
Conv. HEMT
V_{GS} = -6 V, L_{GD} = 5 μm
I_{DS} (A/mm)
V_{DS} (V)
3102

FIG. 31

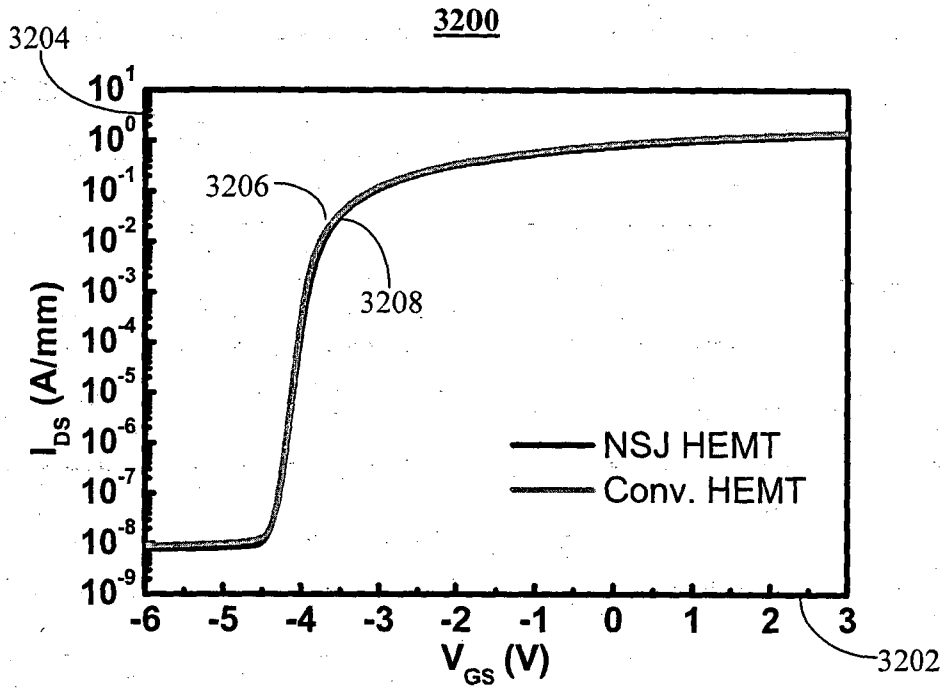

3200
3204
3206
3208
3202
NSJ HEMT
Conv. HEMT
I_{DS} (A/mm)
V_{GS} (V)

FIG. 32

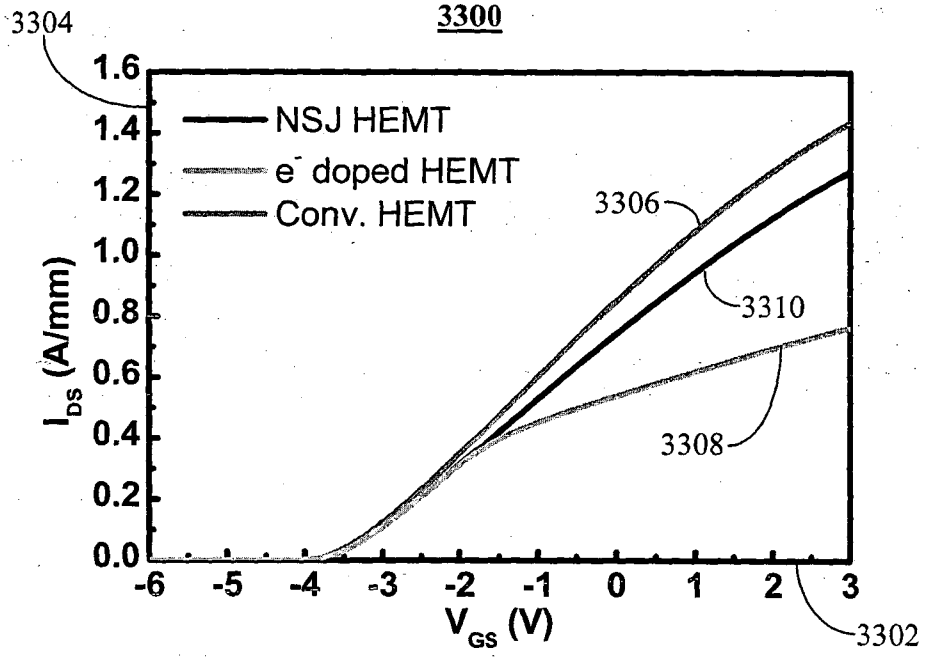
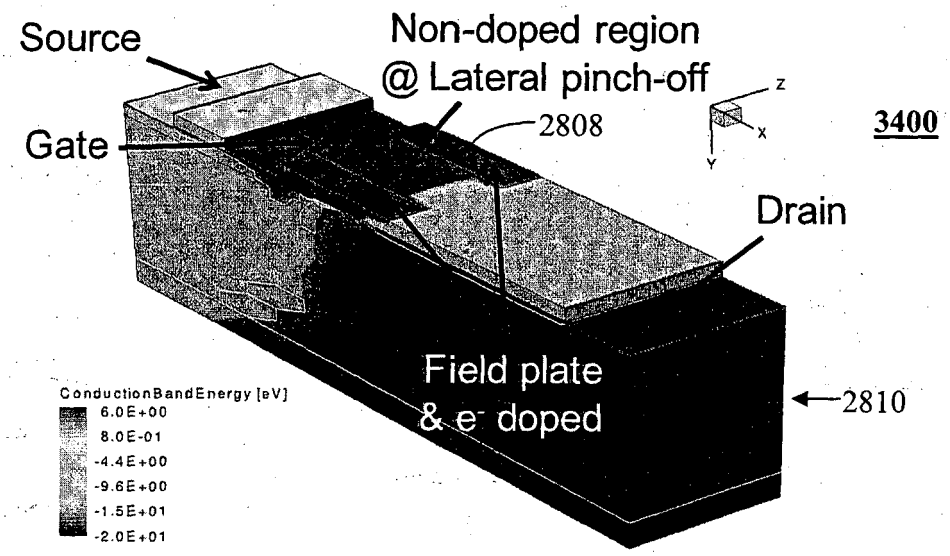

3300
3304
3306
3310
3308
3302
NSJ HEMT
e⁻ doped HEMT
Conv. HEMT
I_{DS} (A/mm)
V_{GS} (V)

FIG. 33



V_{GS} = -6 V, V_{DS} = 20 V

FIG. 34

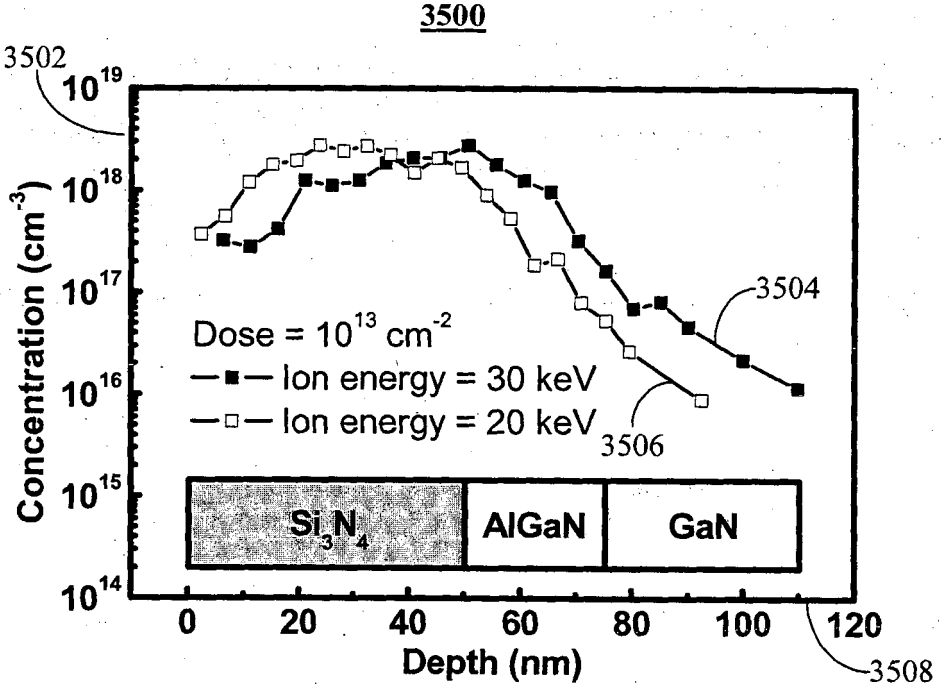


FIG. 35

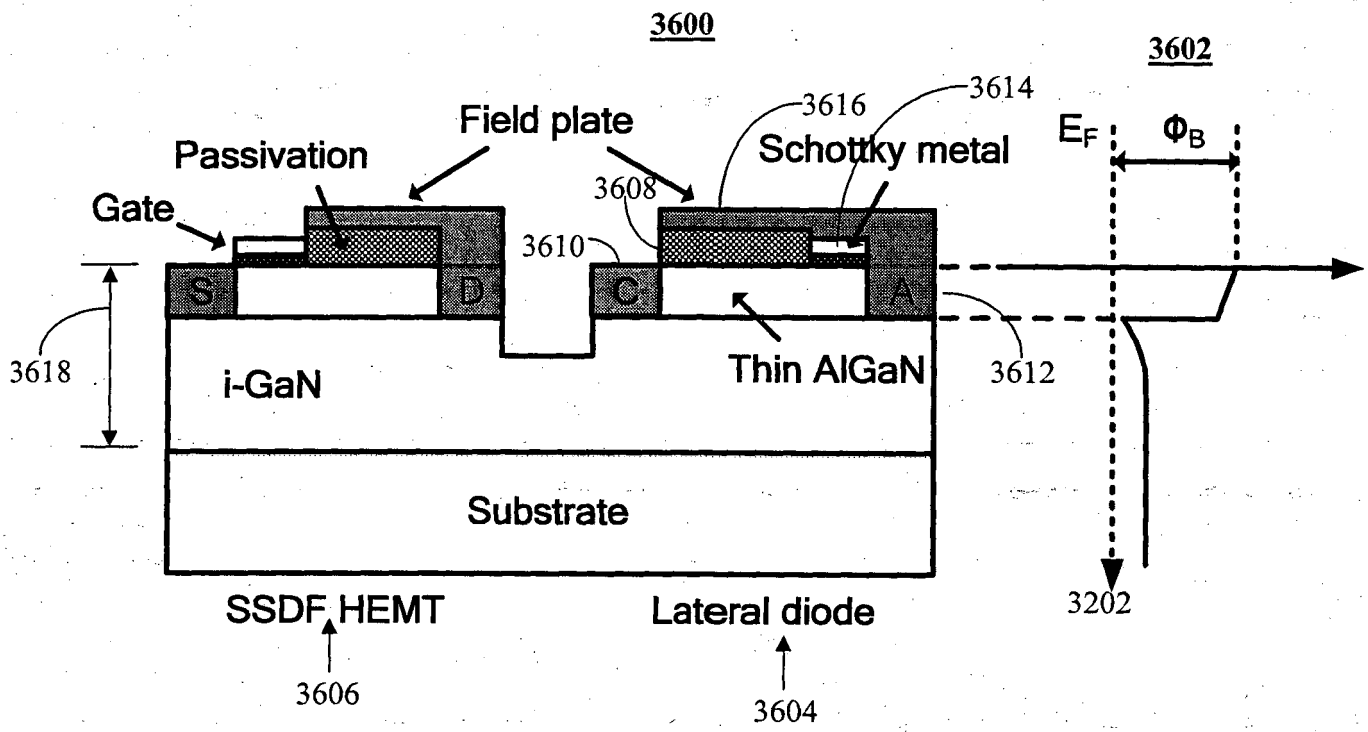

3600
3602
Field plate
3616
3614
Passivation
Schottky metal
E_F
Φ_B
Gate
3608
3610
S
D
C
A
3618
i-GaN
Thin AlGaN
3612
Substrate
SSDF HEMT
Lateral diode
3202
3606
3604

FIG. 36

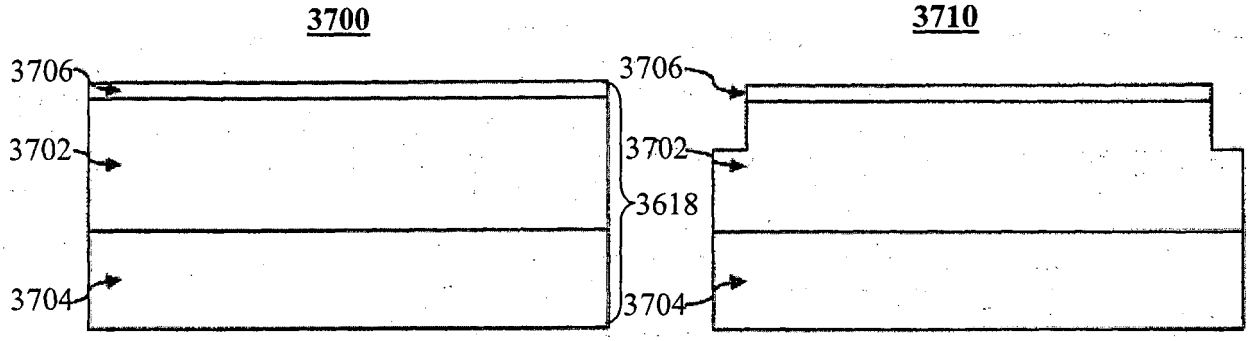


FIG. 37A FIG. 37B

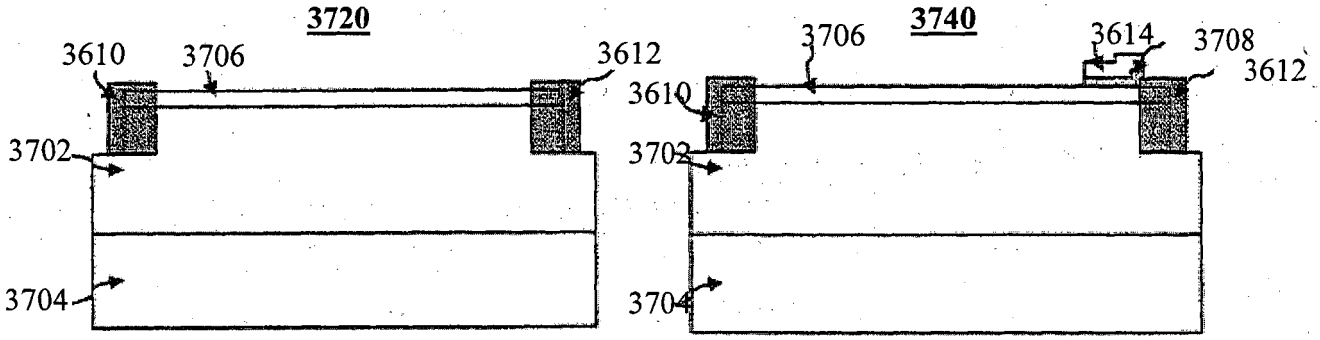


FIG. 37C FIG. 37D

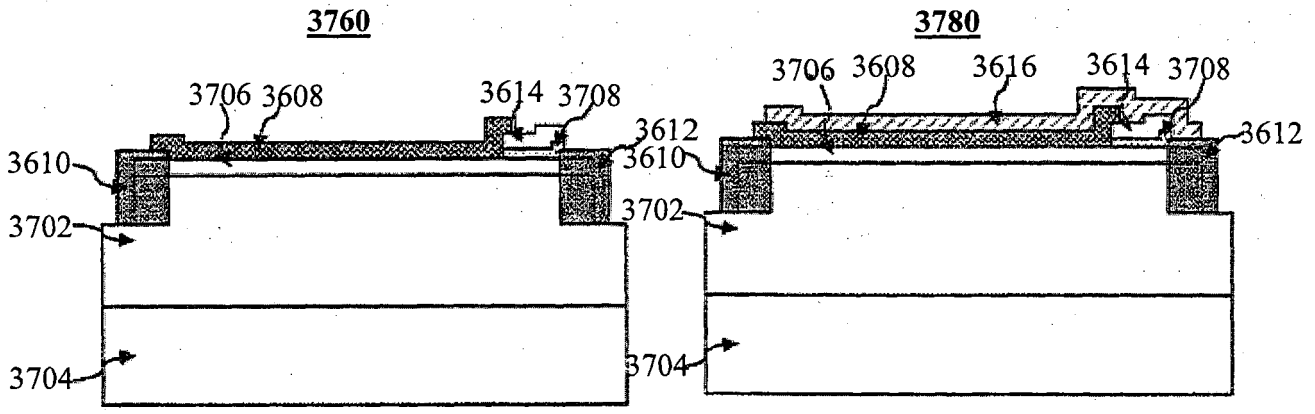


FIG. 37E FIG. 37F

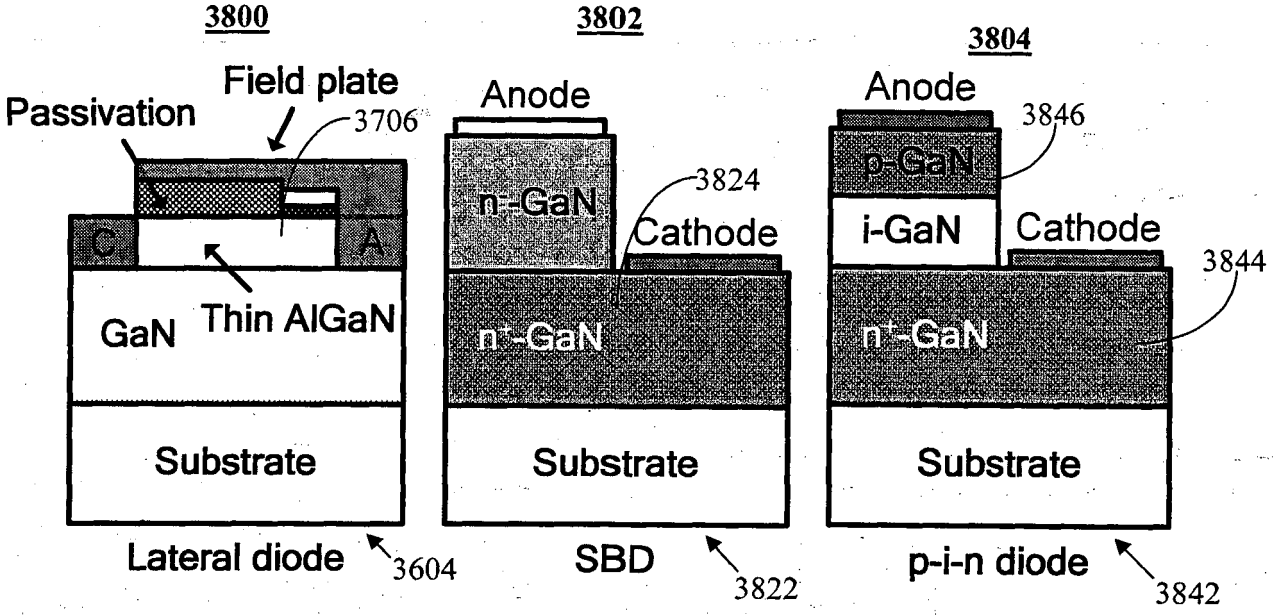


FIG. 38A FIG. 38B FIG. 38C

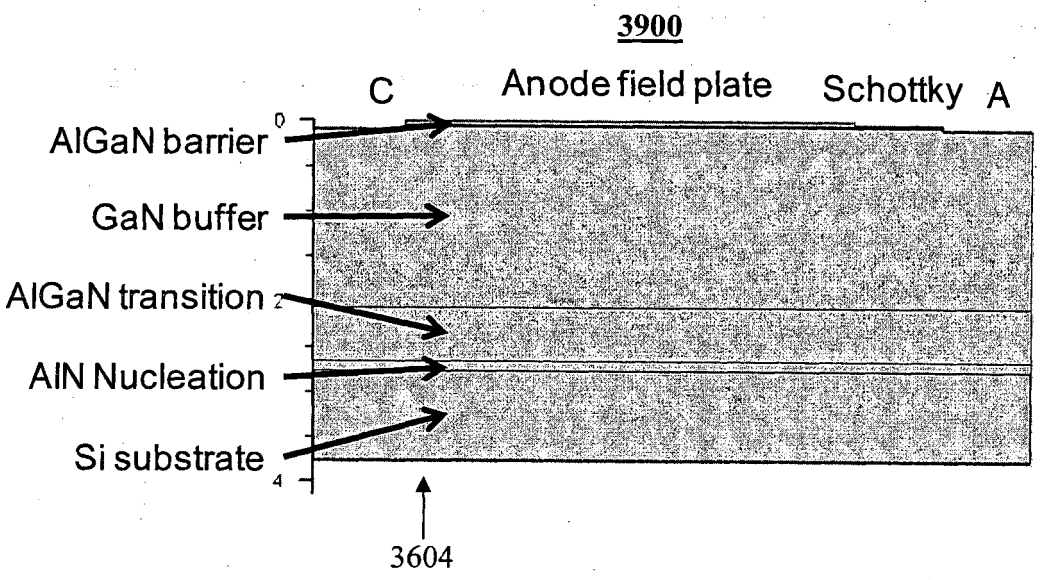


FIG. 39

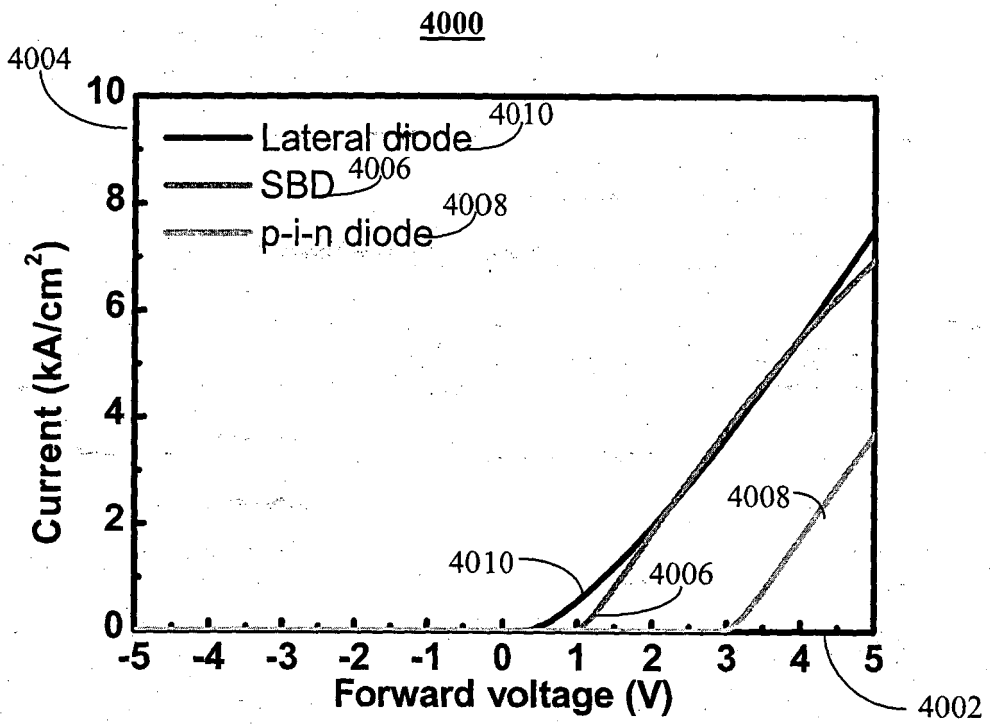

4000
4004
10
8
6
4
2
0
Current (kA/cm^2)
Lateral diode
SBD
p-i-n diode
4010
4006
4008
4008
4010
4006
-5 -4 -3 -2 -1 0 1 2 3 4 5
Forward voltage (V)
4002

FIG. 40

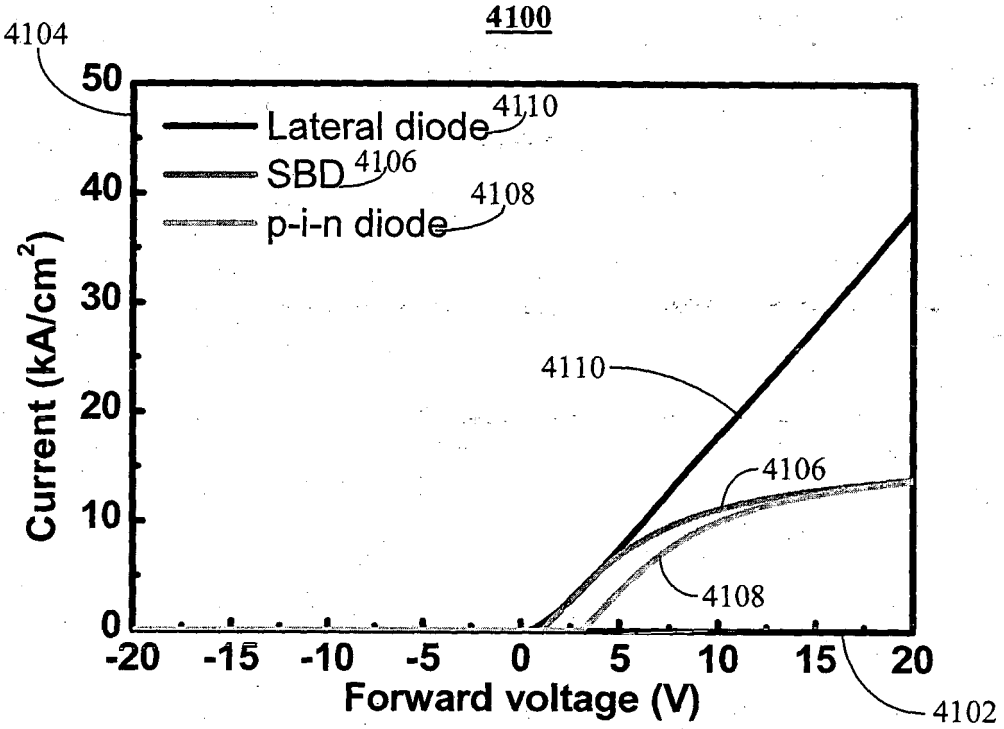

4100
4104
50
40
30
20
10
0
Current (kA/cm^2)
Lateral diode
SBD
p-i-n diode
4110
4106
4108
4110
4106
4108
-20 -15 -10 -5 0 5 10 15 20
Forward voltage (V)
4102

FIG. 41

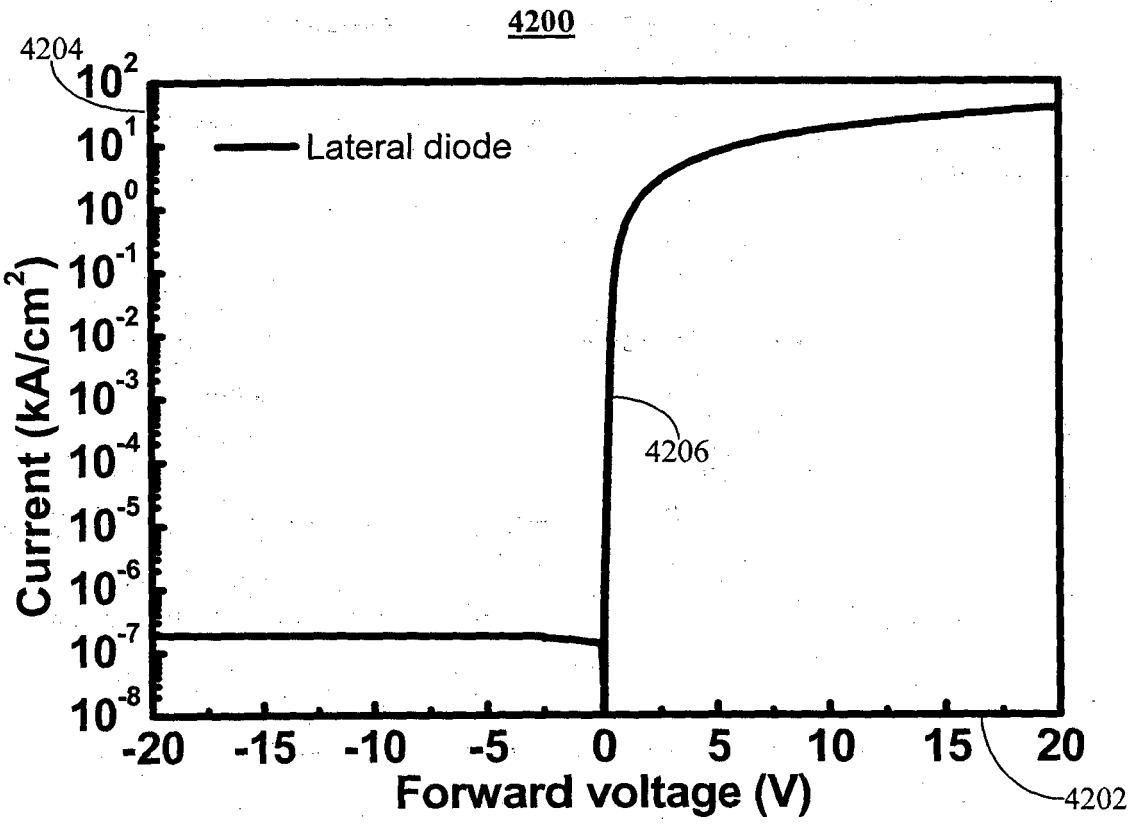

4200
4204
Lateral diode
4206
Current (kA/cm^2)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
-20 -15 -10 -5 0 5 10 15 20
Forward voltage (V)
4202

FIG. 42

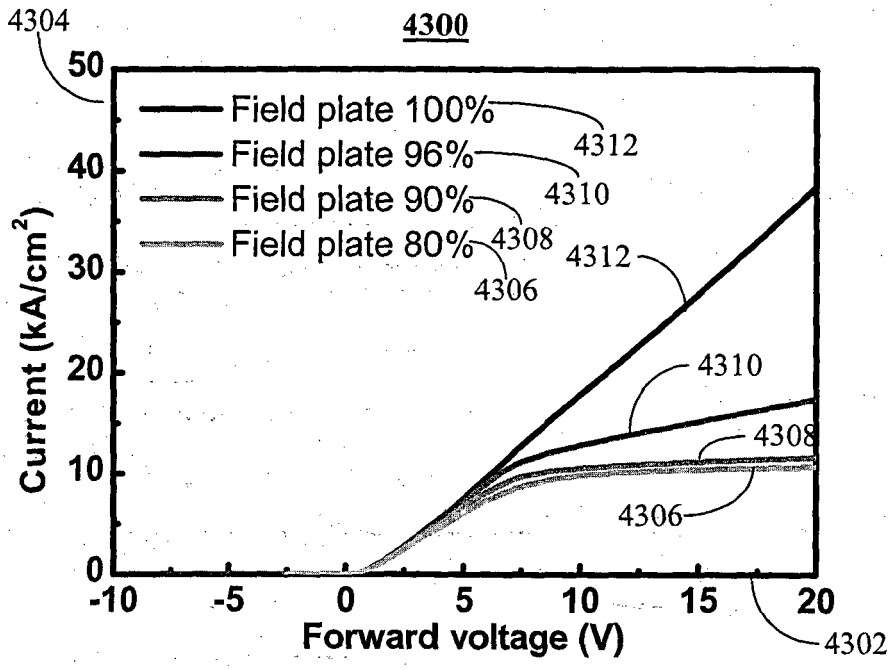


FIG. 43A

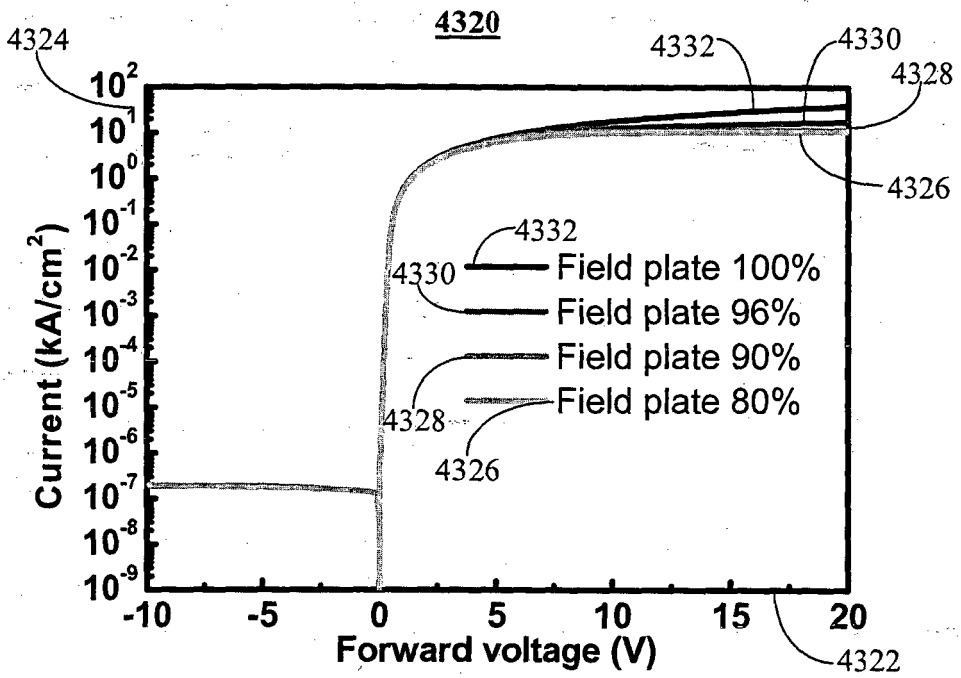


FIG. 43B

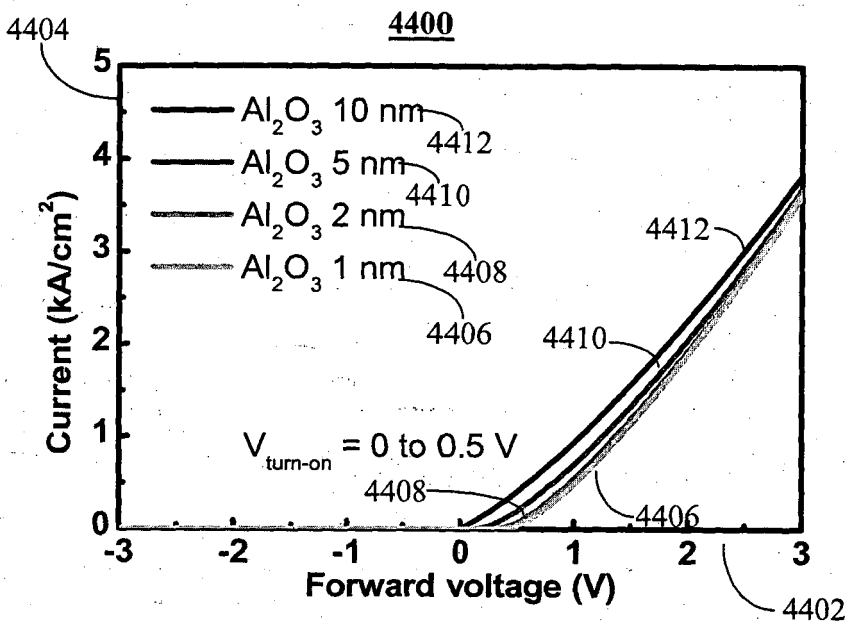


FIG. 44A

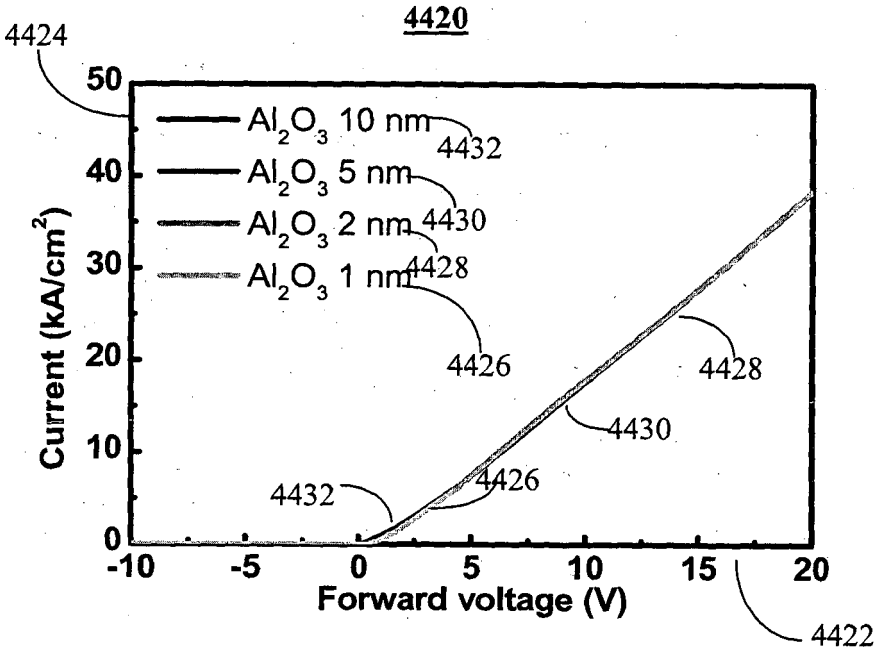


FIG. 44B

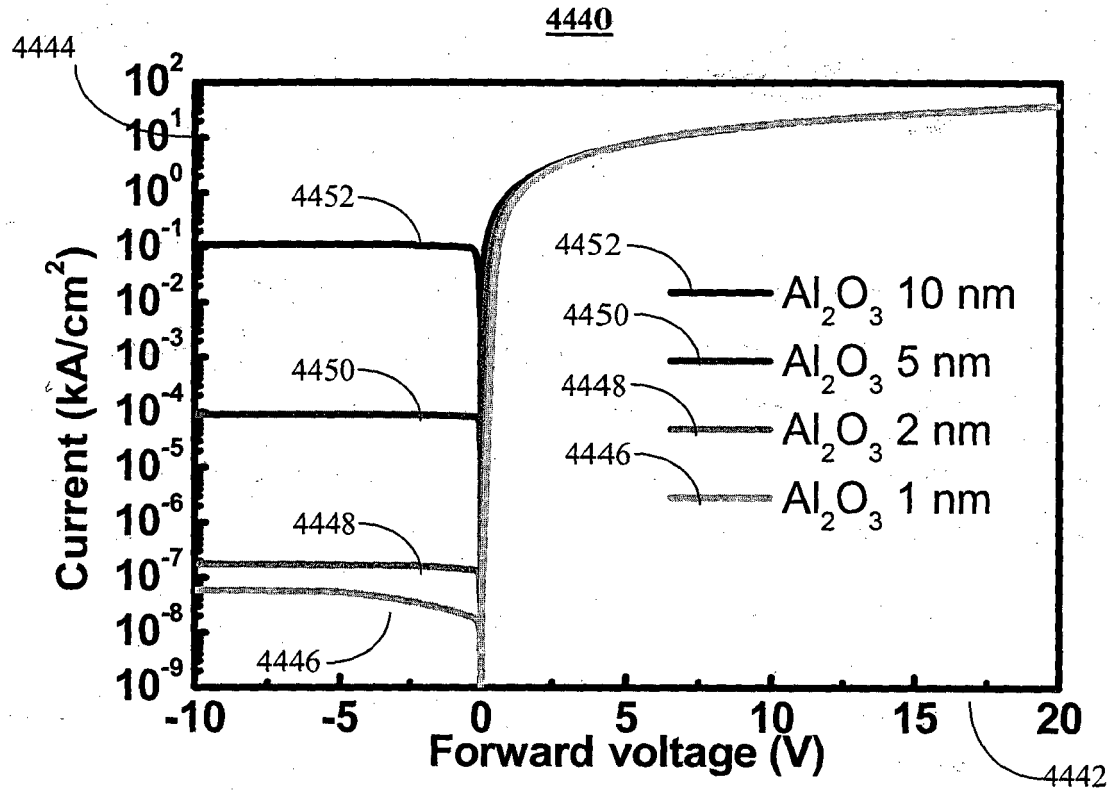
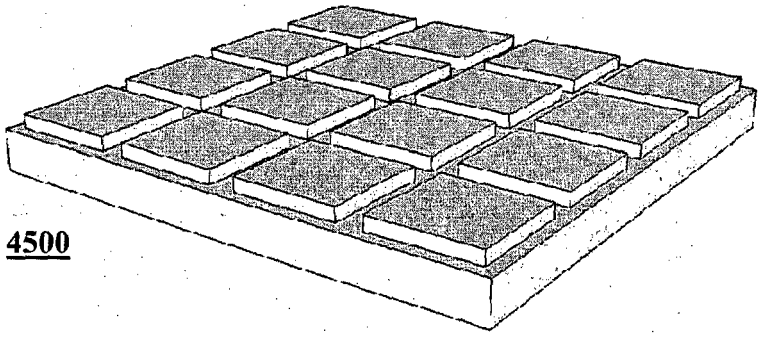

4440
4444
4452
4450
4448
4446
4452
4450
4448
4446
Al_2O_3 10 nm
Al_2O_3 5 nm
Al_2O_3 2 nm
Al_2O_3 1 nm
Current (kA/cm^2)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
-10
-5
0
5
10
15
20
Forward voltage (V)
4442

FIG. 44C



PRIOR ART

FIG. 45A

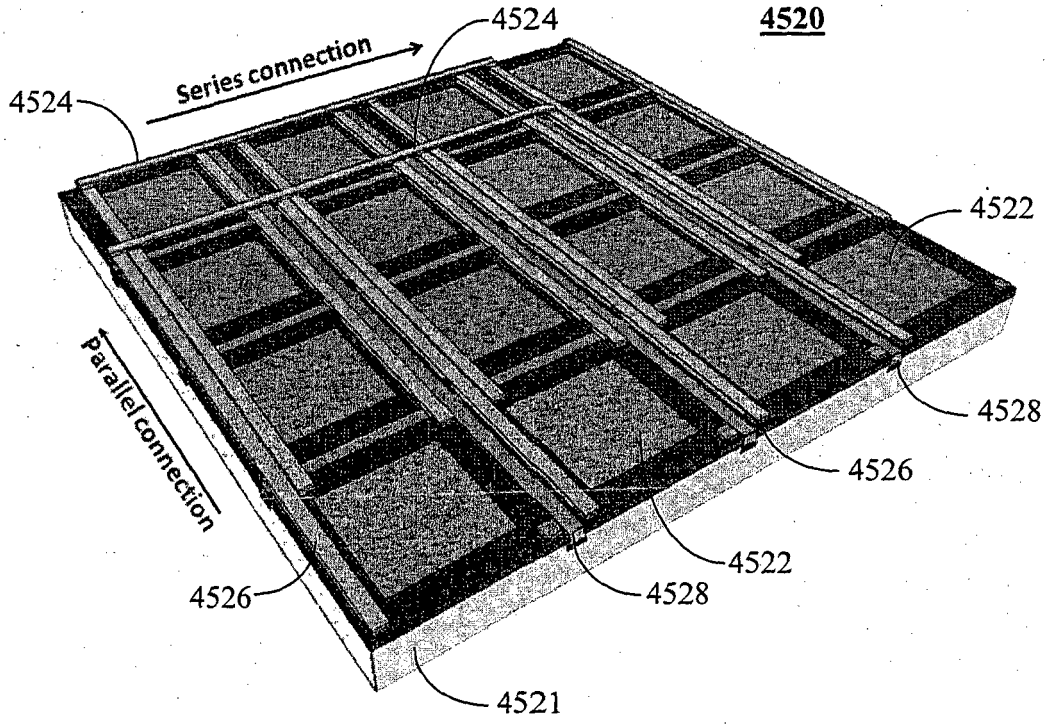
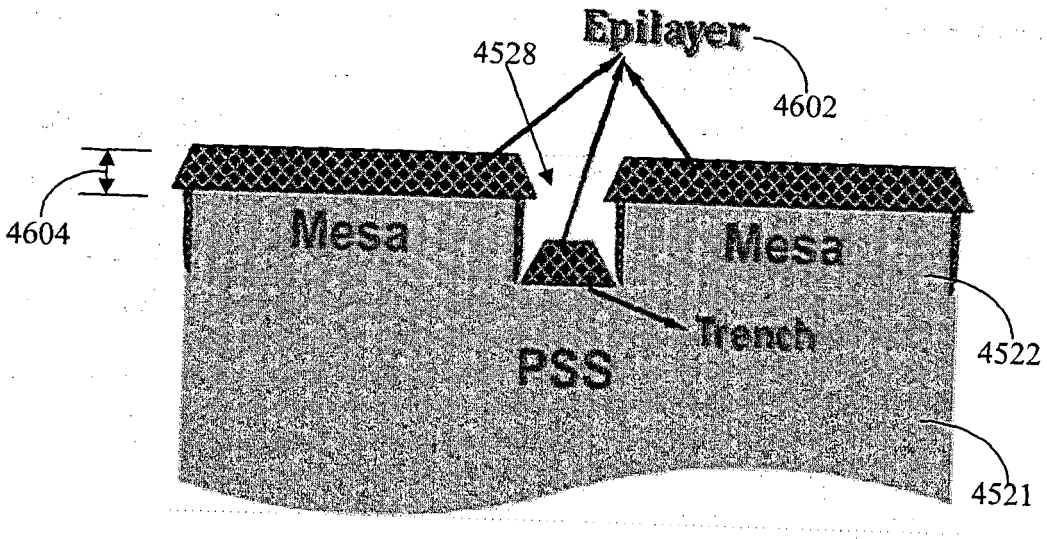
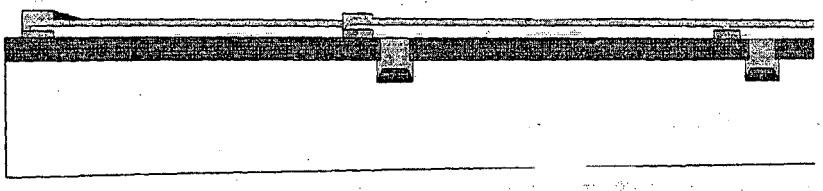


FIG. 45B



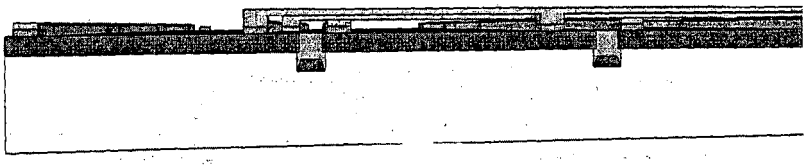
4600

FIG. 46



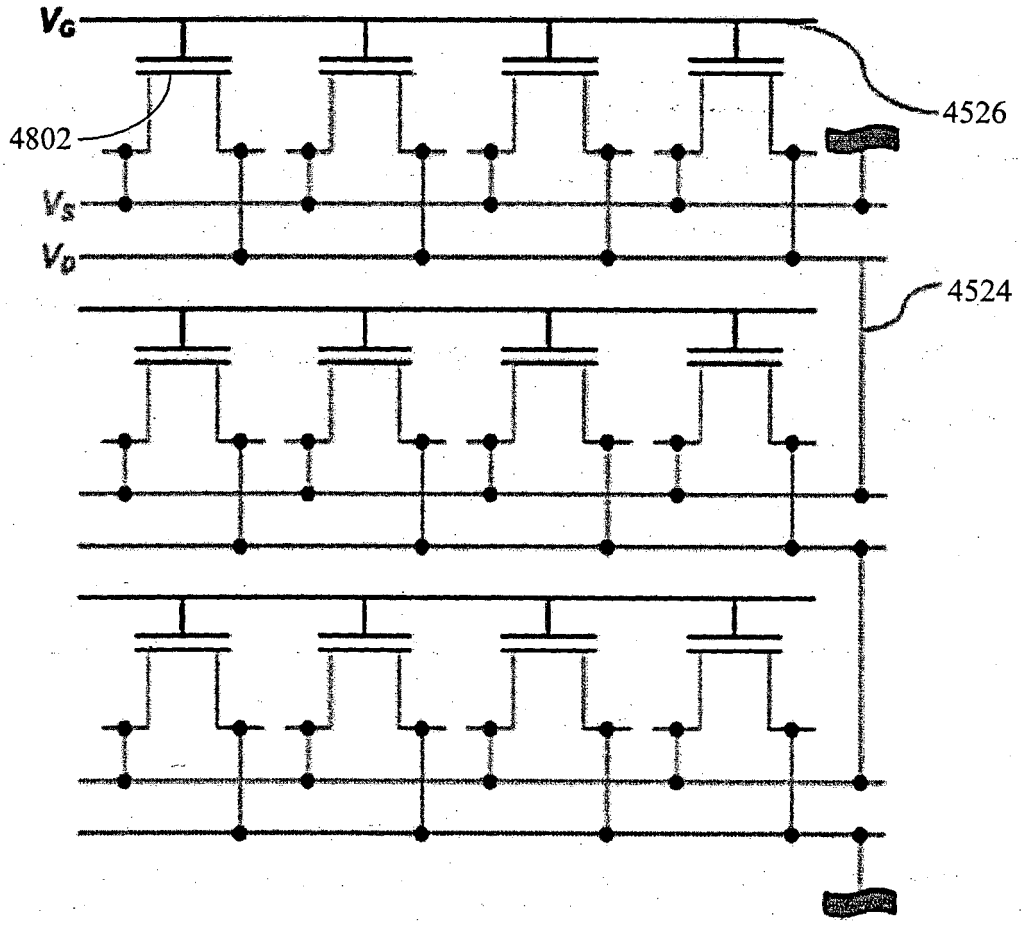
4700

FIG. 47A



4702

FIG. 47B



4800

FIG. 48

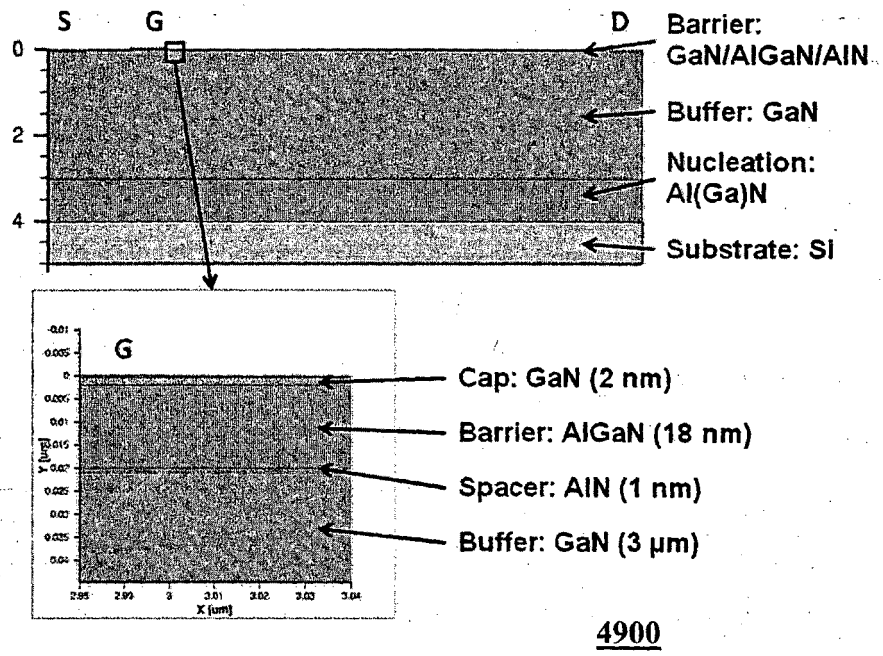

S
G
D
0
2
4
Barrier: GaN/AlGaN/AlN
Buffer: GaN
Nucleation: Al(Ga)N
Substrate: SI
G
Cap: GaN (2 nm)
Barrier: AlGaN (18 nm)
Spacer: AlN (1 nm)
Buffer: GaN (3 µm)
4900

FIG. 49

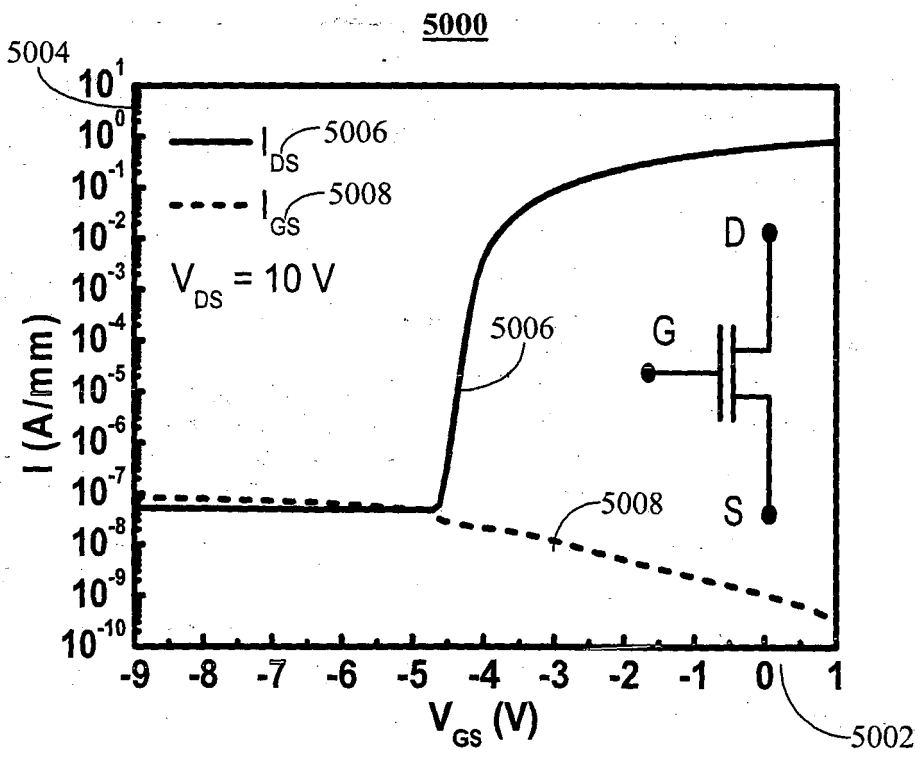

5000
5004
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
I (A/mm)
I_{DS} 5006
I_{GS} 5008
V_{DS} = 10 V
5006
5008
D
G
S
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1
V_{GS} (V)
5002

FIG. 50

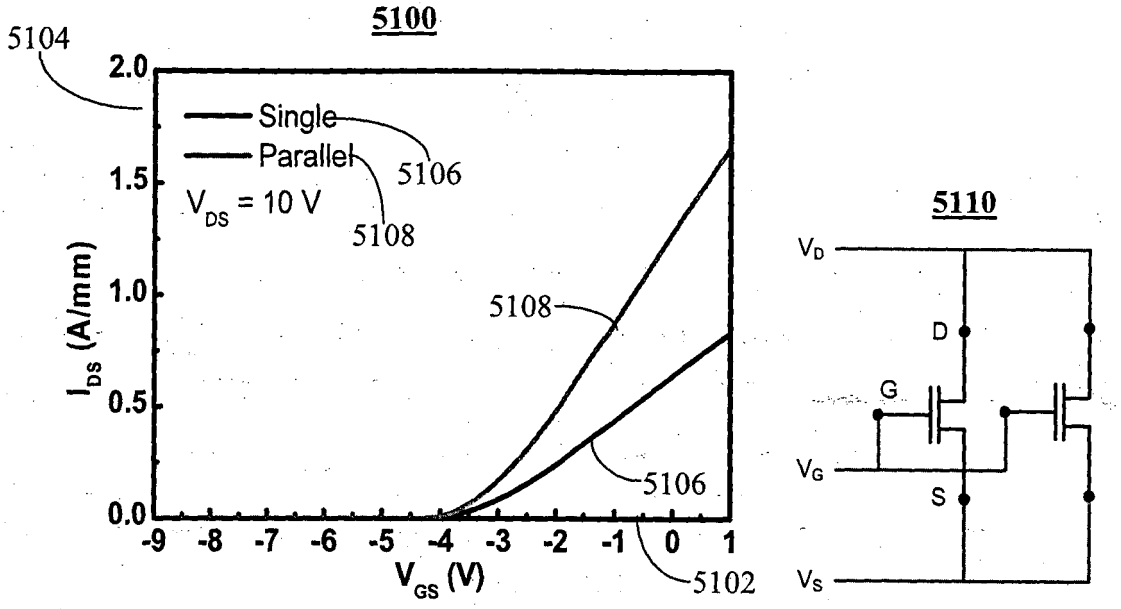

5100
5104
2.0
1.5
1.0
0.5
0.0
Single
Parallel
V_{DS} = 10 V
5106
5108
5108
5106
I_{DS} (A/mm)
-9 -8 -7 -6 -5 -4 -3 -2 -1 0 1
V_{GS} (V)
5102
5110
V_D
D
G
V_G
S
V_S

FIG. 51

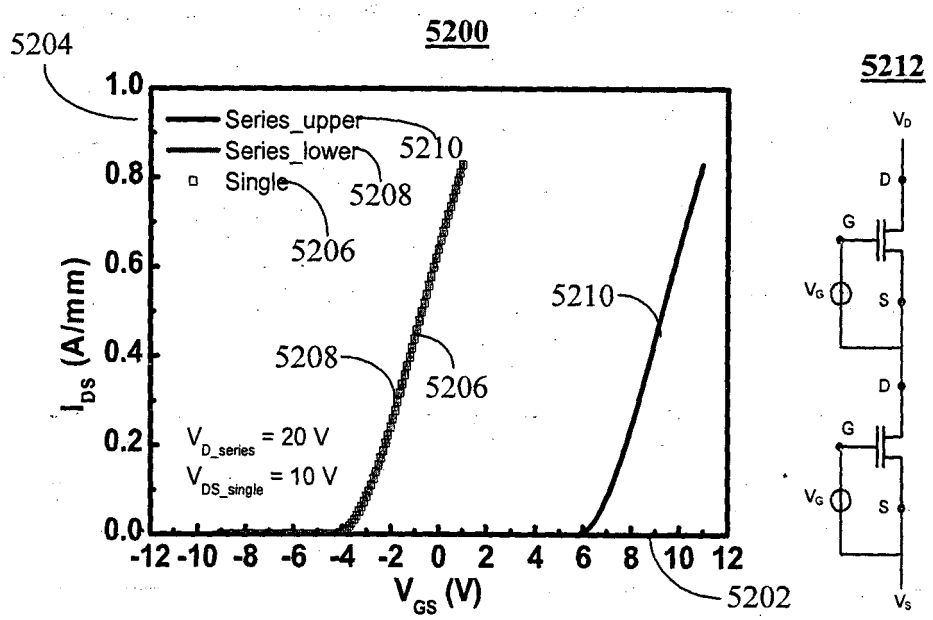

5200
5204
1.0
0.8
0.6
0.4
0.2
0.0
Series_upper
Series_lower
Single
5210
5208
5206
5210
5208
5206
V_{D_series} = 20 V
V_{DS_single} = 10 V
I_{DS} (A/mm)
-12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12
V_{GS} (V)
5202
5212
V_D
D
G
V_G
S
D
G
V_G
S
V_S

FIG. 52