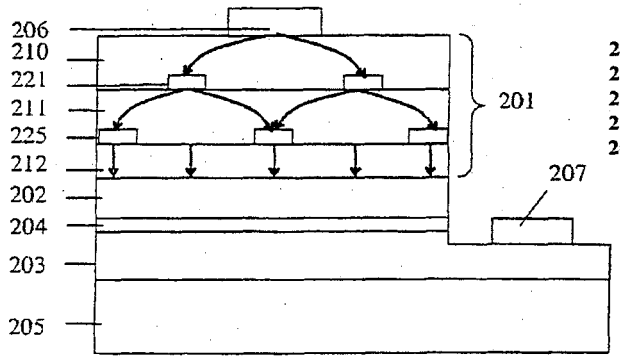


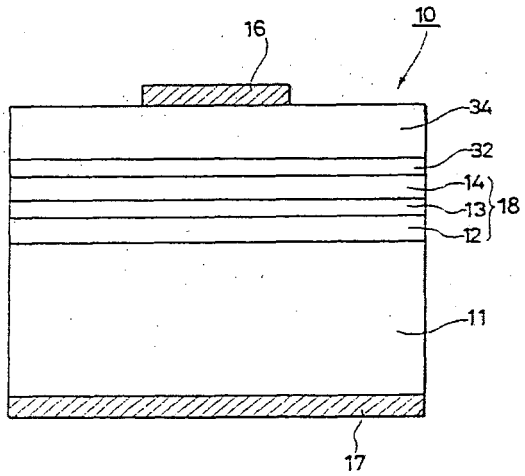

1. Transparent window layer
3. p-contact layer
4. Heavily doped layers as current spreading layer
5.p-doped cladding region
6.Active region
7.n-doped cladding region
8.n-doped contact layer
9.p-contact
10. n-contact

FIGURE 1 (Prior Art: US 7,026,653 B2 )




202.p-type semiconductor material
203.n-type semiconductor material
204. Active region
205. Substrate (e.g. sapphire)
201.Transparent current spreading layer
*210, 211 and 212. ITO*
*221 and 225.metallic pads for current spreading*

FIGURE 2 (Prior Art: US 7,834,373 B2)




10.Light emitting device
11. n-type GaAs
12.n-type $(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ cladding layer
13.$(Al_yGa_{1-y})_{0.51}In_{0.49}P$ ($0<y<0.7$) as active region
14.p-type $(Al_{0.7}Ga_{0.3})_{0.51}In_{0.49}P$ cladding layer
32.Undoped $Al_{0.7}Ga_{0.3}As$ as current spreading layer
34.p-type $Al_{0.7}Ga_{0.3}As$
16.p-electrode
17.n-electrode

FIGURE 3 (Prior Art: 5,600,158)

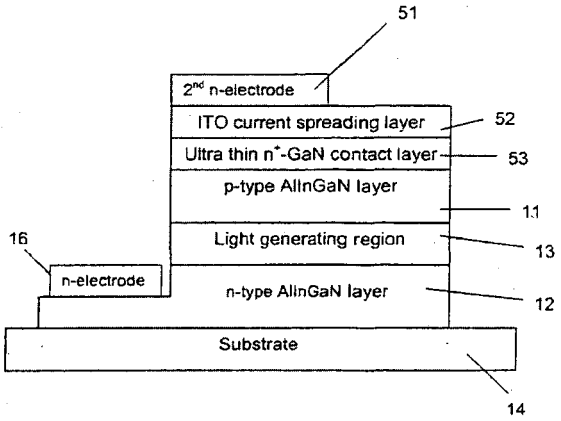



**FIGURE 4**

**(Prior Art: US 2005/0173724 A1)**

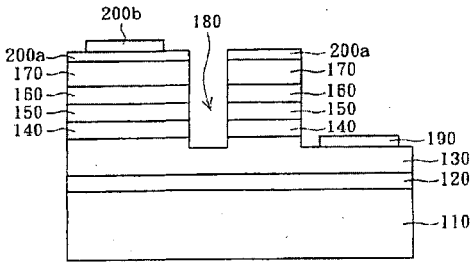



**FIGURE 5A**

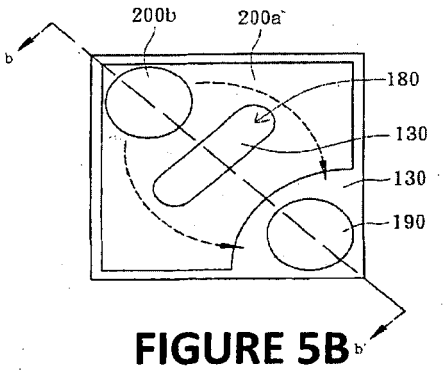
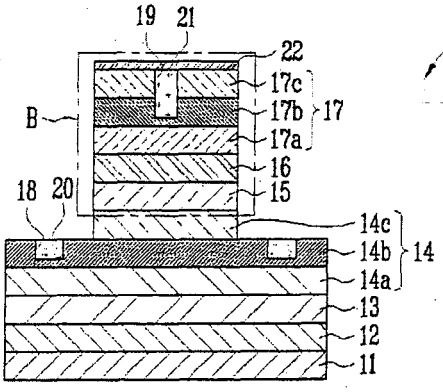



**FIGURE 5B**

**110. Substrate (e.g. sapphire)**
**120.Buffer layer (e.g. GaN, AlN)**
**130.First-polarity (AlxGa1-x)yIn1-yN**
**140.First-polarity (AlxGa1-x)yIn1-yN cladding layer**
**150.Active layer of AlxGa1-x)yIn1-yN**
**160.Second-polarity AlxGa1-x)yIn1-yN cladding layer**
**170.Highly doped contact layer for second polarity made of AlxGa1-x)yIn1-yN**
**200a.transparent electrode of second polarity**
**200b. Metal electrode pad of second polarity**
**180. Trench for current spreading**

**(Prior Art: US 6,781,147 B2)**




11: Substrate
12: Buffer layer
13: GaN support layer
14: n-type electrode layer
14a: n-GaN layer
14b: n-type current spreading layer (AlGaN/GaN)
14c: $n^+$-GaN
15: Active layer
16: p-type cladding layer
17: p-type electrode layer
17a: p-GaN layer
17b: p-type current spreading layer (AlGaN/GaN)
17c: p-type barrier layer ($p^+$-GaN)
18 and 19: Trench
20 and 21: Metal contact layer
22: Transparent electrode layer
30: Light emitting diode

FIGURE 6

(Prior Art: US 7,998,771 B2)

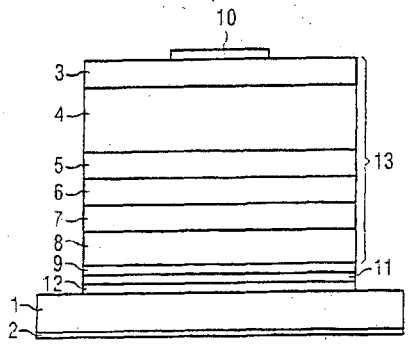



FIGURE 7A

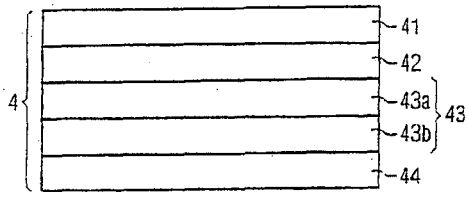



FIGURE 7B

1:Device carrier
2:Electrode
3:n-GaN layer
4:Current spreading layer
41:n-GaN
42:undoped GaN
43a:undoped AlGaN
43b:n-AlGaN
44:n-GaN
5:n-GaN
6:n-GaN
7:Acvtive region
8:p-GaN
9:p-electrode
10:n-electrode
11:TiWN
12:Connecting layer

(Prior Art: US 2011/0193057 A1)

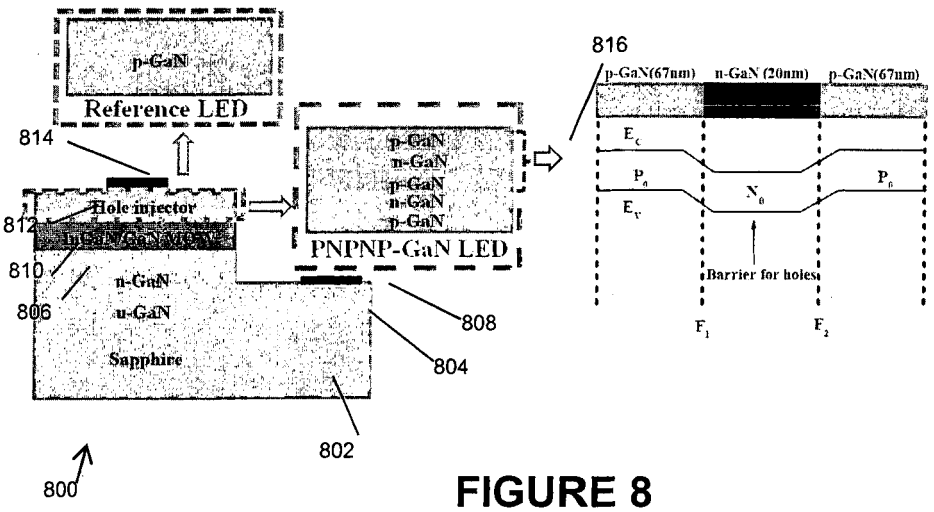



FIGURE 8

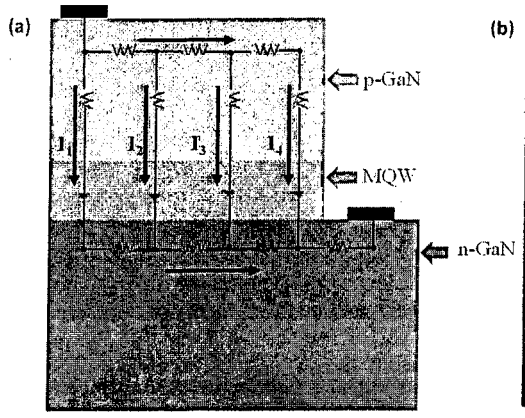



FIGURE 9A

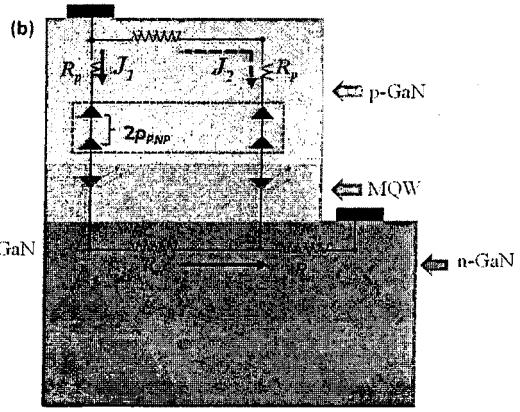



FIGURE 9B

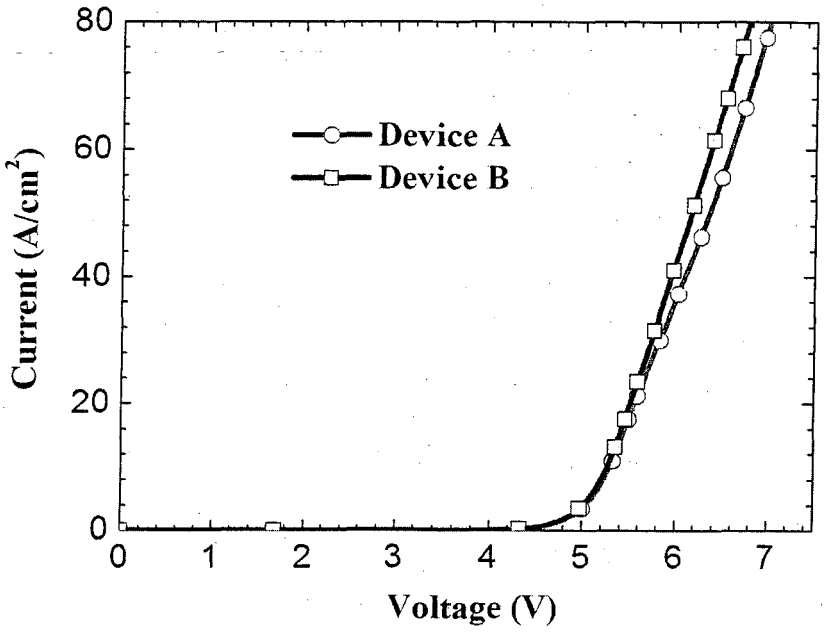



FIGURE 10A

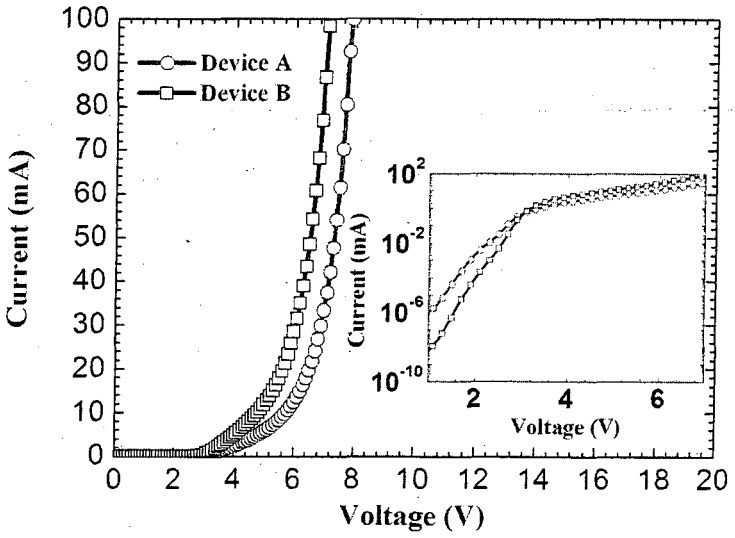
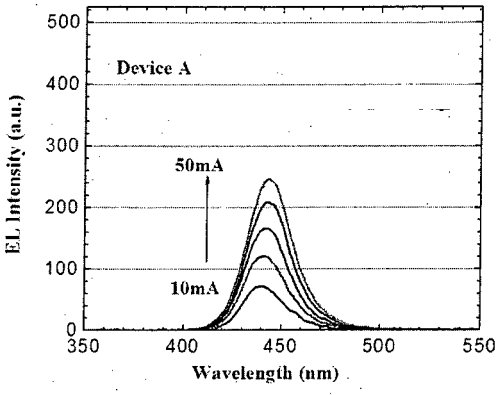



Figure 10B



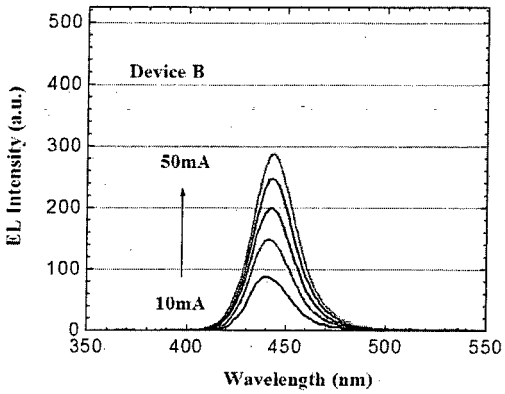




FIGURE 11A

FIGURE 11B

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

| Current (mA) | Current density (A/cm$^2$) |
|---|---|
| 10 | 8.16 |
| 20 | 16.33 |
| 30 | 24.49 |
| 40 | 32.65 |
| 50 | 40.82 |

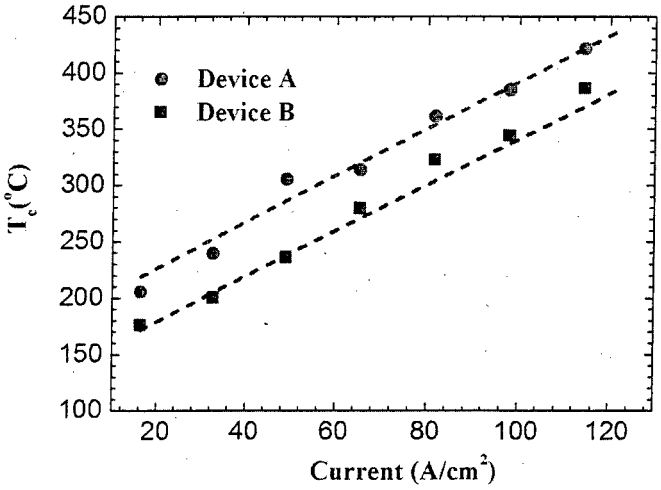
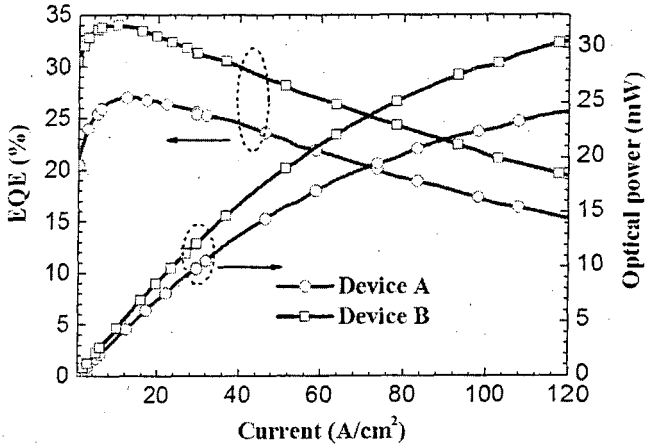



FIGURE 12

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

$T_c$: carrier temperature

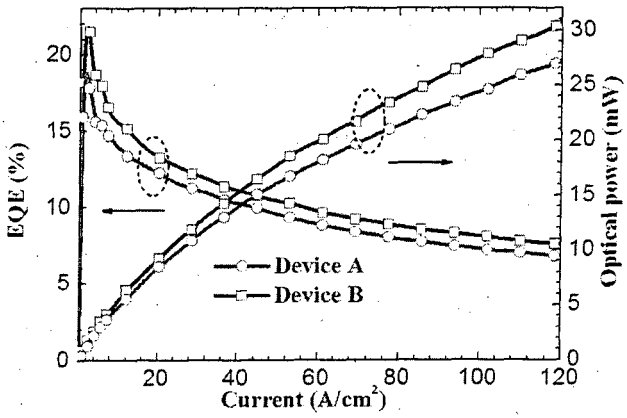



| Current density (A/cm²) | Simulated power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 5.22 | 6.50 | 24.52 |
| 60 | 16.27 | 20.00 | 22.93 |
| 120 | 21.43 | 26.80 | 25.06 |

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

FIGURE 13




| Current density (A/cm²) | Experimental power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 8.49 | 9.23 | 8.72 |
| 60 | 18.21 | 20.07 | 10.21 |
| 120 | 26.97 | 30.35 | 12.53 |

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

FIGURE 14

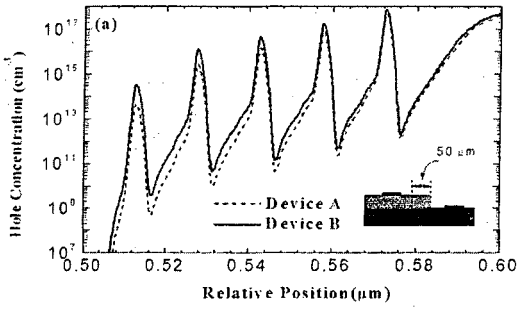



FIGURE 15A

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

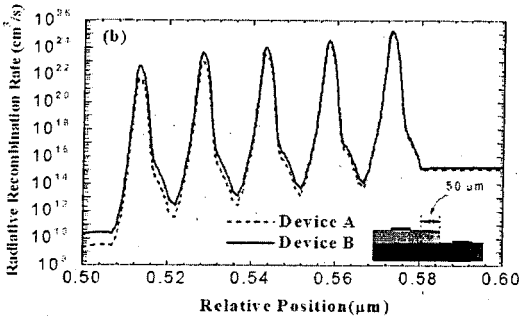



FIGURE 15B

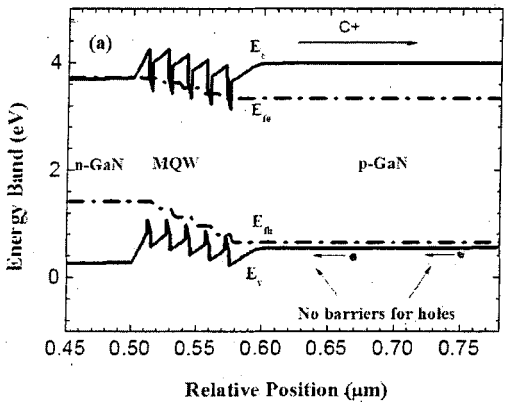



FIGURE 16A

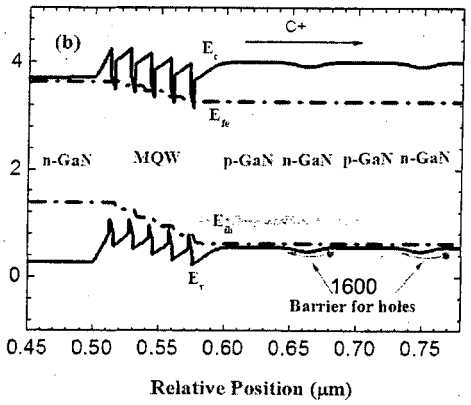



FIGURE 16B

Device A: reference LED w/o transparent current spreading layer

Device B: PNP-LED w/o transparent current spreading layer

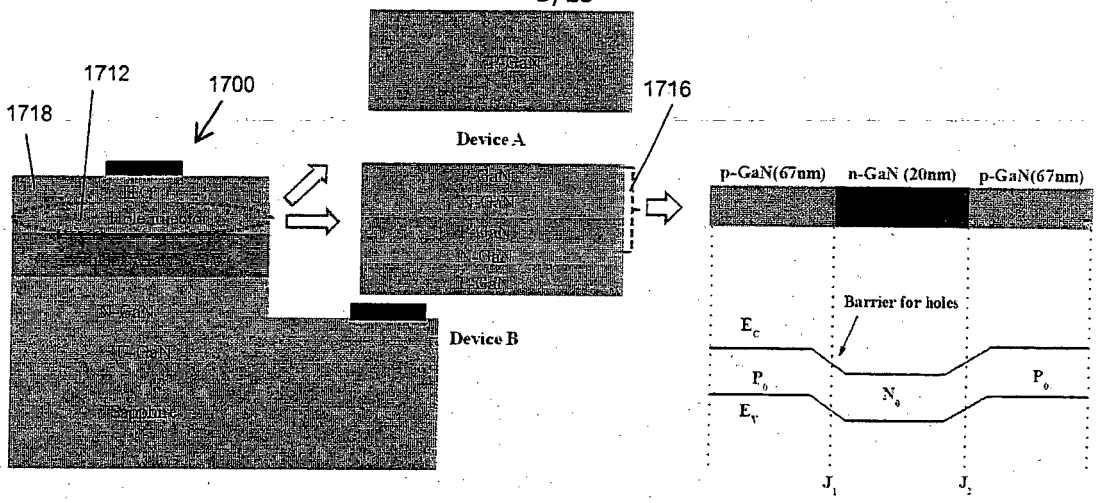



FIGURE 17

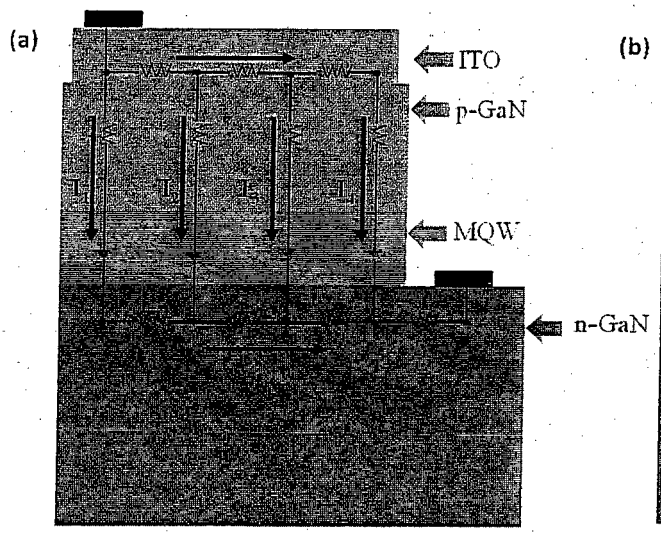



FIGURE 18A

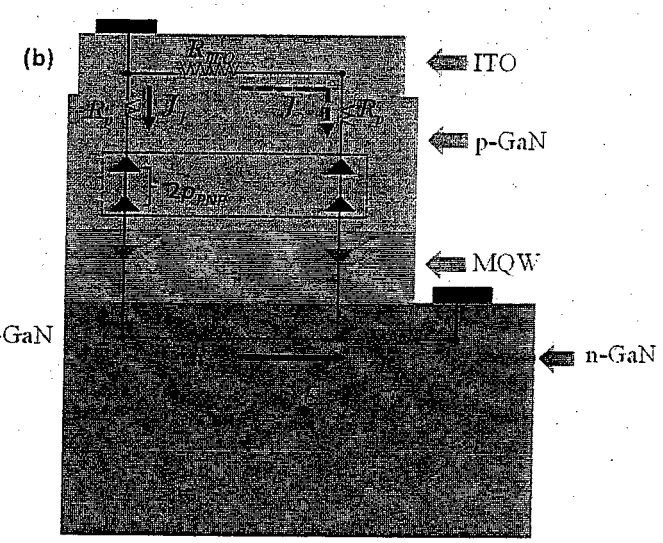



FIGURE 18B

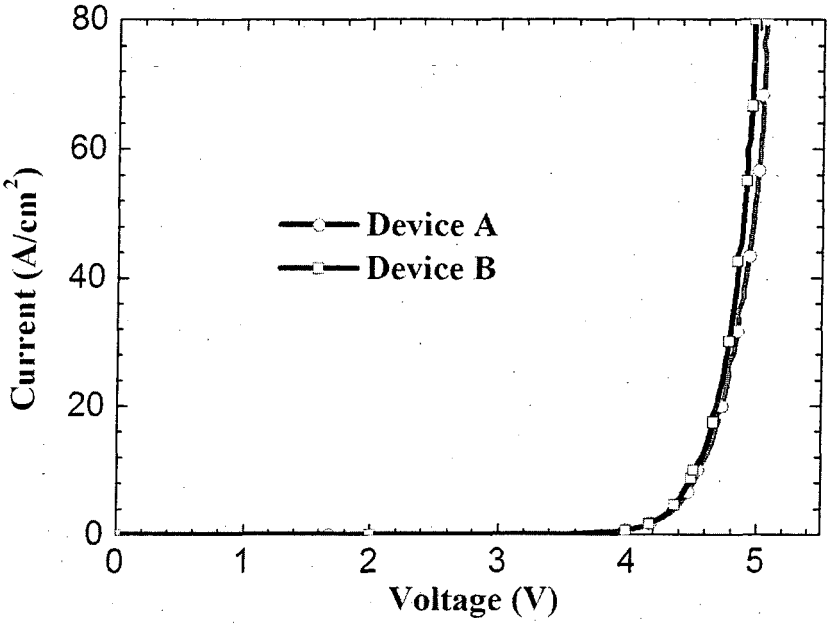



Figure 19A

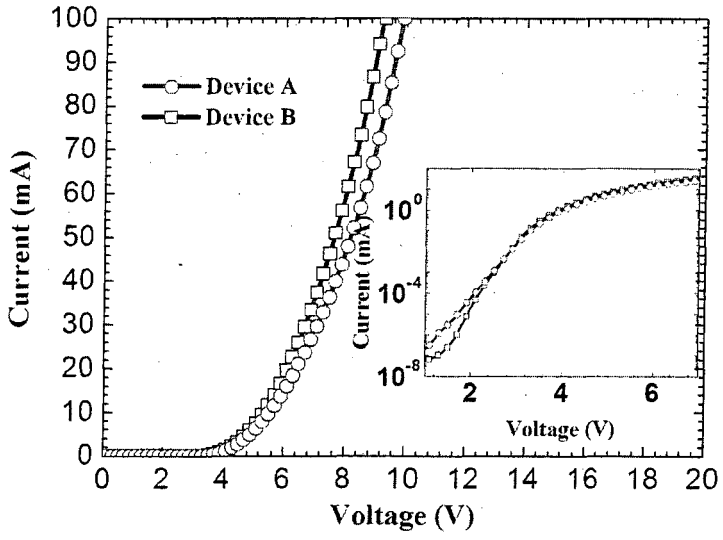



Figure 19B

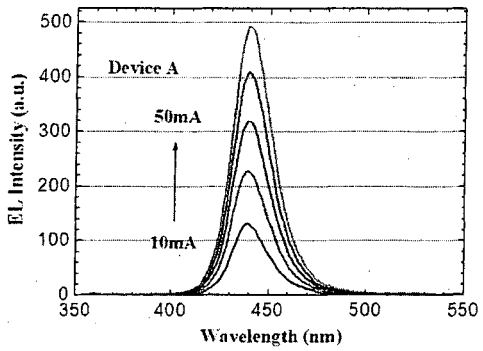



FIGURE 20A

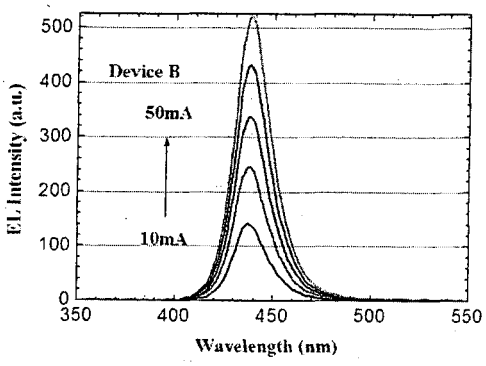



FIGURE 20B

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

| Current (mA) | Current density (A/cm²) |
|---|---|
| 10 | 8.16 |
| 20 | 16.33 |
| 30 | 24.49 |
| 40 | 32.65 |
| 50 | 40.82 |

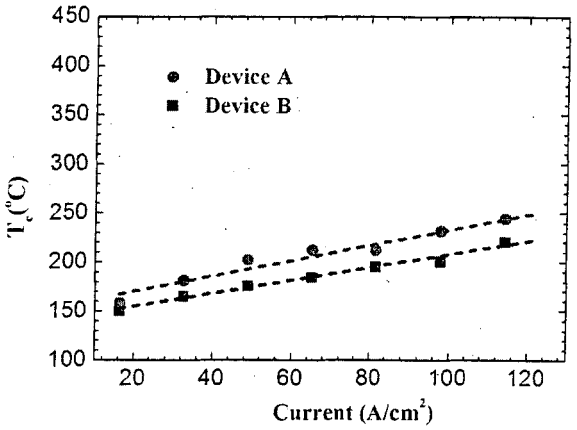



FIGURE 21

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

$T_c$: carrier temperature

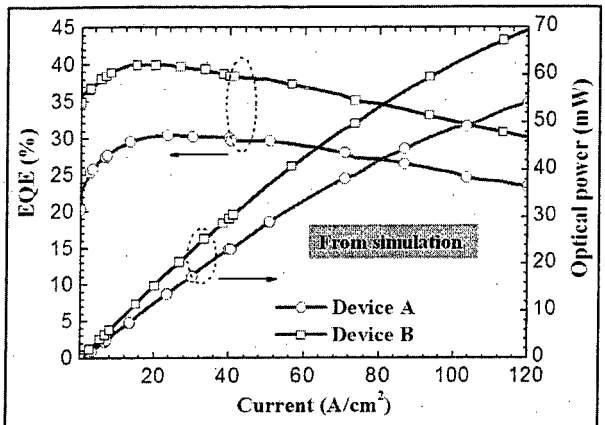



FIGURE 22

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

| Current density (A/cm²) | Simulated power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 11.67 | 15.38 | 31.80 |
| 60 | 33.46 | 42.78 | 27.85 |
| 120 | 54.23 | 69.60 | 28.34 |

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as as current spreading layer

| Current density (A/cm²) | Simulated power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 5.22 | 15.38 | 194.63 |
| 60 | 16.27 | 42.78 | 162.94 |
| 120 | 21.43 | 69.60 | 224.78 |

Device A: reference LED w/o ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

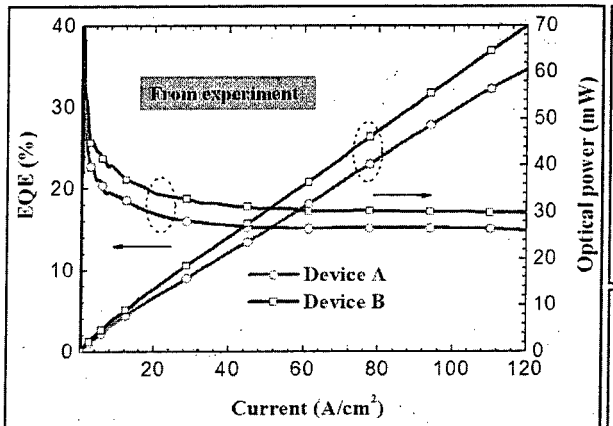



FIGURE 23

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

| Current density (A/cm²) | Experimental power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 11.87 | 13.70 | 15.42 |
| 60 | 31.71 | 36.36 | 14.66 |
| 120 | 60.68 | 70.27 | 15.80 |

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as as current spreading layer

| Current density (A/cm²) | Experimental power (mW) | | Increment (%) |
|---|---|---|---|
| | Device A | Device B | |
| 20 | 8.49 | 13.70 | 61.14 |
| 60 | 18.21 | 36.36 | 99.67 |
| 120 | 26.97 | 70.27 | 160.55 |

Device A: reference LED w/o ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

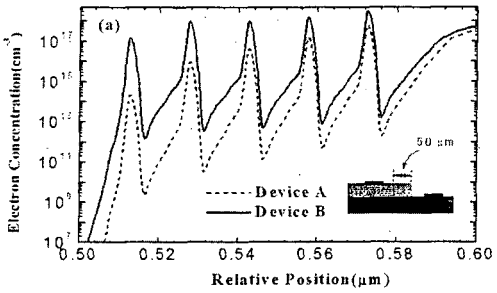



FIGURE 24A

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer

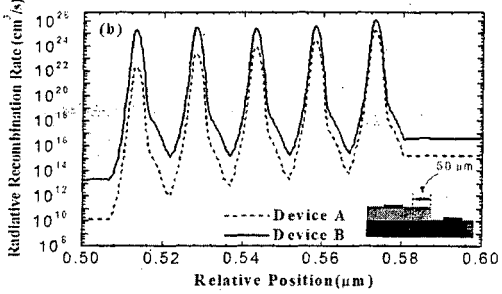



FIGURE 24B

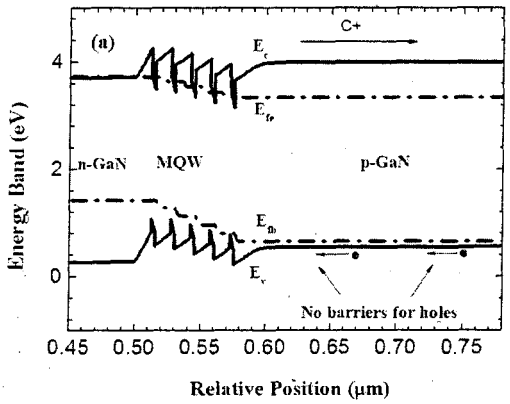



FIGURE 25A

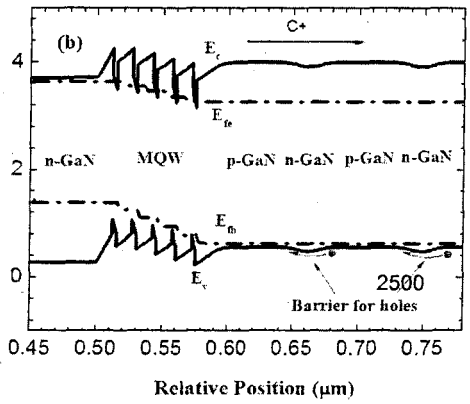



FIGURE 25B

Device A: reference LED with ITO as current spreading layer

Device B: PNP-LED with ITO as current spreading layer