High efficiency multijunction VCSEL arrays for 3D sensing

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VCSELs in 3D sensing

- 3D optical sensors are becoming widespread in consumer, industrial, and automotive applications

- Several approaches depending on required range and resolution:
  - Structured light (short distance)
  - Time of flight (medium distance)
  - LiDAR (long distance)

VCSEL based sensors:

**Benefits:**
- Beam quality (small spot, low divergence)
- Narrow spectral width
- Wavelength stability
- Fast rise time

**Challenges:**
- Power scaling
- Conversion efficiency (compared to edge emitters)
940nm VCSEL development at Vixar

940nm wavelength preferred for 3D sensors
- Low interference from ambient light
- Outside visible wavelength range
- Compatible with CMOS cameras

Rapid improvements in 940nm VCSEL performance
- Slope efficiency improvement from 0.85 W/A → 1.1 W/A
- 42% → 53% power conversion last year

Recent introduction of multijunction VCSELs
- Slope efficiency: >3 W/A
- Power conversion: >60%
Multijunction VCSEL design

**Motivation:**
- Increase gain volume by periodically stacking active regions in cavity
- Carrier regeneration in tunnel junctions → increased slope efficiency
- Re-optimize gain & loss in cavity for net efficiency improvement
- Trade off voltage and current for driver compatibility (faster rise time)

**Challenges:**
- Requires low resistance & low absorption tunnel junction
- Precise layer tuning to align QWs and TJ with standing wave

**Design Features:**
- Top emitting VCSEL with backside cathode
- Oxide aperture confinement
- p- and n-type AlGaAs DBRs
- Strained InGaAs MQWs
- Low resistance n+/p+ tunnel junction

Compatible with high volume fabrication:
- n-type GaAs substrates
- MOCVD grown epi
- 6-inch wafer processing

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Single, double, triple junction 940nm comparison

- Single 10um aperture VCSEL characterization
  - Continuous wave, room temp operation
  - Slope efficiency and voltage scale with junctions
    - 2.1 W/A $\rightarrow$ 160% DQE
    - 3.15 W/A $\rightarrow$ 240% DQE
  - Higher power & higher efficiency achieved
    - 60% PCE for triple junction VCSEL

Peak performance comparison:

<table>
<thead>
<tr>
<th>Design</th>
<th>PCE (%)</th>
<th>Power (mW)</th>
<th>Voltage (V)</th>
<th>Slope Eff. (mW/mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
<td>52%</td>
<td>5.0</td>
<td>1.9</td>
<td>1.1</td>
</tr>
<tr>
<td>Double</td>
<td>59%</td>
<td>10</td>
<td>3.3</td>
<td>2.10</td>
</tr>
<tr>
<td>Triple</td>
<td>60%</td>
<td>17</td>
<td>4.6</td>
<td>3.15</td>
</tr>
</tbody>
</table>
VCSEL array performance (single, double, & triple junction)

**Power**

- Single Junction
- Double Junction
- Triple Junction

**Voltage**

- Single Junction
- Double Junction
- Triple Junction

**Efficiency**

- Single Junction
- Double Junction
- Triple Junction

Fabricated VCSEL array die for high power
- 0.9 x 0.9 mm chip footprint
- 361 apertures (10um diameter)

LIV Comparison
- Operating condition: 100\(\mu\)s pulse width, 1% duty cycle, T=20\(^\circ\)C
- Peak efficiency of 53.3% at 2.5W & 5W (double and triple junction)
- Peak slope efficiency: 2.1 W/A & 3.0 W/A
- > 10W power at I=4A
High efficiency multijunction VCSEL arrays for 3D sensing

Short pulsed operation

High power pulsing experiments conducted with GaN-FET based driver

Triple Junction VCSEL array driven with 3.6ns pulses, 0.1% duty cycle
  • Peak pulse power of 147W recorded for 64 A peak current
  • No rollover observed (power limited by driver)

Equivalent irradiance: 281W/mm²
  • Emission area: 0.77 x 0.68 mm²
Conclusion

Demonstrated high power, high efficiency multijunction VCSELs at 940nm

- Measured slope efficiency: 2.1 W/A & 3.16 W/A (double & triple junction)
- Differential quantum efficiency: 160% & 240%
- 60% power conversion efficiency achieved
  - Highest reported for a multijunction VCSEL

Demonstrated high power VCSEL arrays in small footprint (0.9 x 0.9 mm)

- 9W output power with >50% efficiency & only 3.5A required
- >100W peak power achievable with short pulsed operation (peak irradiance 281W/mm²)

Multijunction VCSELs are promising devices for time-of-flight and LiDAR applications
Thank you