**Machine Learning Analysis of $2 \times 1$ VCSEL Array Coherence and Imaginary Coupling Coefficient**

**Pawel Strzebonski**, William North, Nusrat Jahan, Kent D. Choquette

Electrical and Computer Engineering Department
University of Illinois, Urbana, Illinois 61801 USA
strzebo2@illinois.edu

May 11, 2021

---

**Introduction**

- $2 \times 1$ arrays of optically coupled photonic crystal VCSELS
- When arrays are tuned to optical coherence:
  - Higher optical power [1]
  - Electrically-controlled beam-steering [1]
  - Lower intensity noise [1]
  - Higher modulation bandwidth [2]
- We explore machine learning for the analysis of optical coupling and coherence in VCSEL arrays

---

**Challenges**

- Coherently-coupled operation (and reaping benefits thereof) require tuning of driving currents
- Array design requires ability to characterize coherence and coupling behavior
- Many possible methods of analyzing coherence [3]
- Need to develop automated measurement and analysis methods for array

---

**Naive Approach**

- Want to calculate coherent optical power enhancement
- Need to know what the uncoupled array power would be
- “Naive” approach is to estimate this as sum of individual element powers:
  
  \[ P_{\text{total,uncoupled}}(i, j) \approx P_i(i) + P_j(j) \]

  For driving currents \( i, j \) and element optical powers \( P_i, P_j \)

---

**Issues**

- We calculate coherent power enhancement using naive estimate of uncoupled power
- Results show no enhancement nearly everywhere (even on the coherent ridge)
- Naive approach does not incorporate thermal cross-talk affecting element power even in uncoupled regime [5]

---

**Machine Learning (ML) Approach**

- Use artificial neural network (ANN) to infer the optical array power from the driving currents
- Train to minimize mean-square-error between measured and inferred power
- Coherent datapoints in training (measurement) dataset will induce error
- Use a two-pass approach:
  1. Train ANN on full measurement dataset
  2. Identify likely coherent datapoints (measurements with much more power than ANN inter)
  3. Train ANN on reduced dataset (excluding likely coherent datapoints)

---

**Results**

<table>
<thead>
<tr>
<th>$i_1$ [mA]</th>
<th>$i_2$ [mA]</th>
<th>$P$ [mW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>8</td>
</tr>
</tbody>
</table>

**Naive estimate of uncoupled array power**

---

**Conclusions**

- Machine learning approach enables better estimate of coherent power enhancement than the “naive” approach
- A two-pass approach enables unsupervised learning while minimizing prediction error due to inclusion of coherent data
- Coherent power enhancement can help identify coherently coupled operation conditions and quantify coupling coefficient
- Open source code available online [6, 7]

---

**References**


---

**Goals**

- Optical power measurements can help characterize and tune to coherence
- Want to develop methods of analyzing large driving current–optical power datasets to derive coherence and coupling coefficient

---

**Optical Power and Coupling Coefficient**

- Coherent coupling leads to array optical supermodes
- Optical supermodes can better extract gain from the array, leading to enhanced optical power
- The degree of power enhancement, $\Delta P_{\text{total}}$, is related to the imaginary coupling coefficient $\kappa_i$:
  
  \[ \Delta P_{\text{total}} \propto \kappa_i \]

  for some constant $a$ [4]

---

**ML estimate of uncoupled array power**

---

**Open source code available online [6, 7]**

---

**Spectral Mode Analysis of Non-Hermitian Phased Microcavity Laser Arrays**

By William North

---

**2 $\times$ 1 photonic crystal VCSEL array**

---

**SEM Image**

---

**ML estimate of coherent array power enhancement**

---

**ML estimate of imaginary coupling coefficient**

---

**ML estimate of coherent power enhancement**

---

*See the related talks:*

- “Extraction of Coupling Coefficient for Coherent 2x1 VCSEL Array” by Nusrat Jahan
- “Spectral Mode Analysis of Non-Hermitian Phased Microcavity Laser Array” by William North