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Optimizing Emission in Nanorod Arrays through Quasi-Aperiodic Inverse Design

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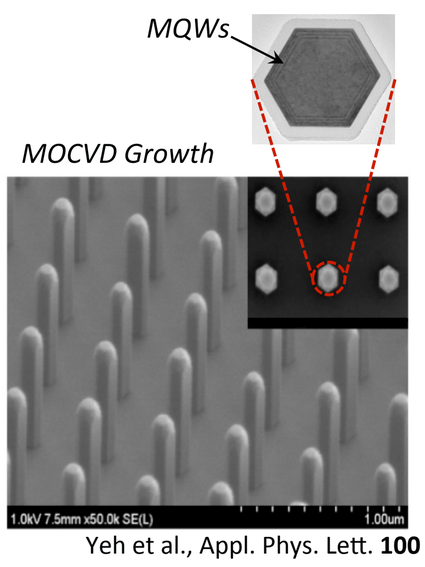
Motivation



Yeh et al., Appl. Phys. Lett. **100**

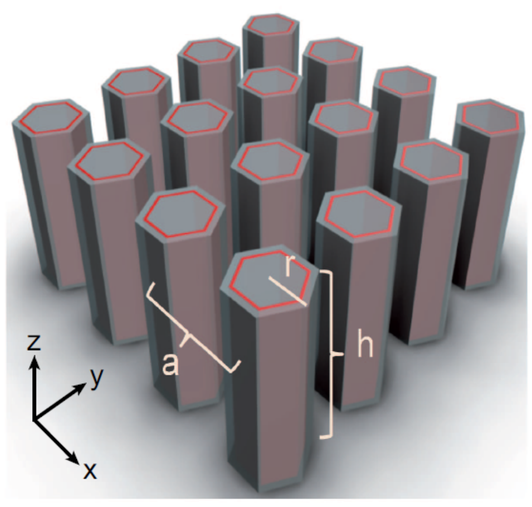
Nanostructuring to improve LED brightness

$In_xGa_{1-x}N/GaN$ core-shell nanorod arrays
- Wide wavelength tunability
- Enhanced active area (fixed chip size)
- Avoid piezoelectric fields

Periodic emitting structure affects
- Extraction efficiency
- Emission rate: local density of states

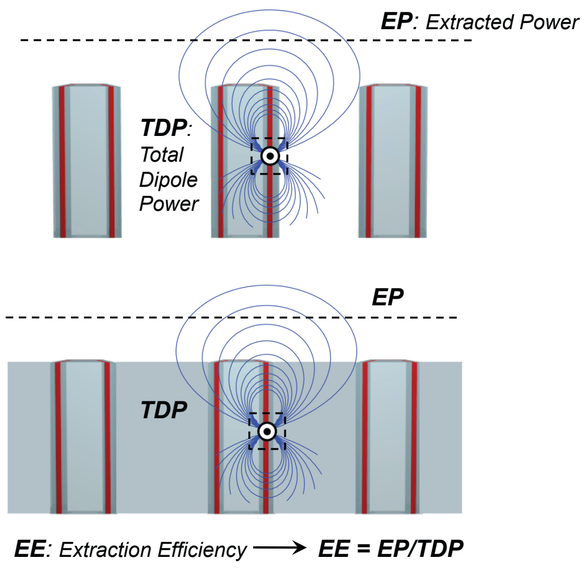
Periodic Array

Structure



r/a = 0.268, h/a = 0.14, n = 2.52

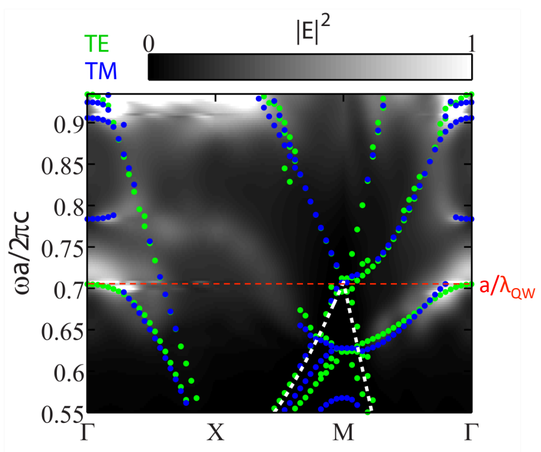
Forward Method



EE**: Extraction Efficiency* ⟶ ***EE = EP/TDP

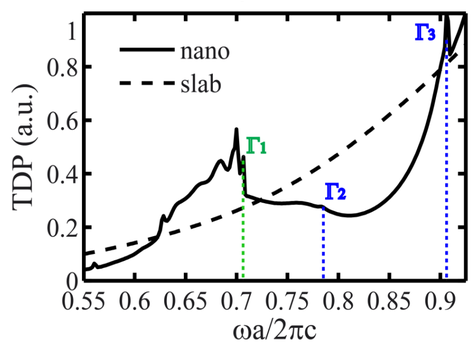
Emission Results

Far-field & Bandstructure



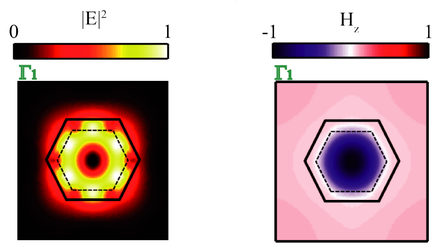
High emitted intensity near Γ-point modes

Total Dipole Power



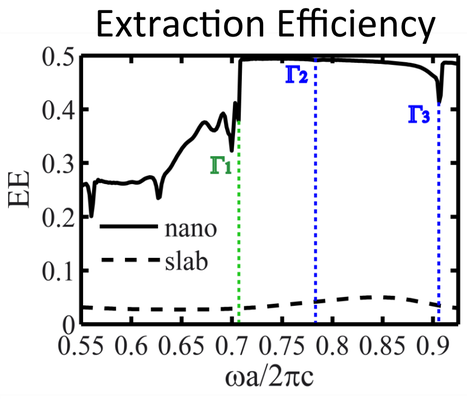
Γ_1 : Largest TDP enhancement

Mode-profile



High $|E|^2$ within QW — Uncoupled mode

Extraction Efficiency



Γ_1 : Dip in EE

Extracted Power Enhancement ≈ 25X

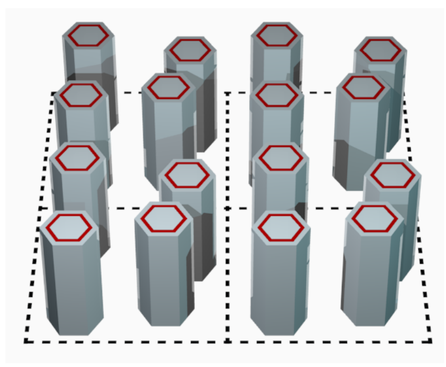
Anderson et al., Appl. Phys. A DOI 10.1007/s00339-014-8602-1

Support: This work was funded by the Center for Energy Nanoscience, an Energy Frontiers Research Center funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences, under Award No. DE-SC0001013.

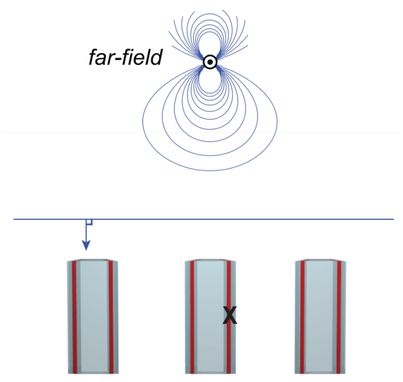
Quasi-Aperiodic Array

Controlling uncoupled resonances→ break mirror symmetries

Structure



Inverse Method



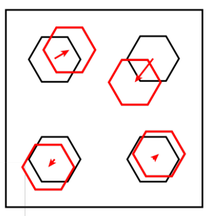
Forward vs. Inverse Methods:

Forward simulation
- Requires *N* simulations
- Large, finite-size lattice
- PML boundary conditions

Inverse simulation
- Requires one simulation
- Single unit cell
- Periodic boundary conditions

Random Walk Algorithm:

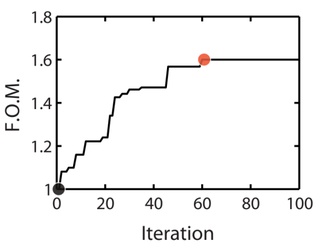
1. Randomly move rod



2. Calculate FOM

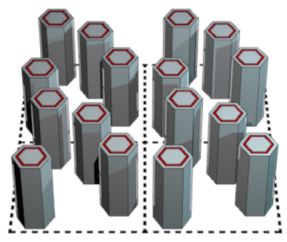
$$\text{F.O.M.} = \frac{\int_{\omega_0-\Delta}^{\omega_0+\Delta} |E|_{Ap}^2 \, d\omega}{\int_{\omega_0-\Delta}^{\omega_0+\Delta} |E|_{P}^2 \, d\omega}$$

3. Improvement?

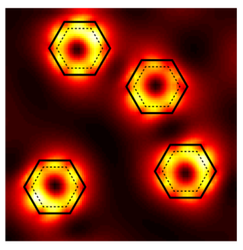


4. Iterate

Optimized geometry:

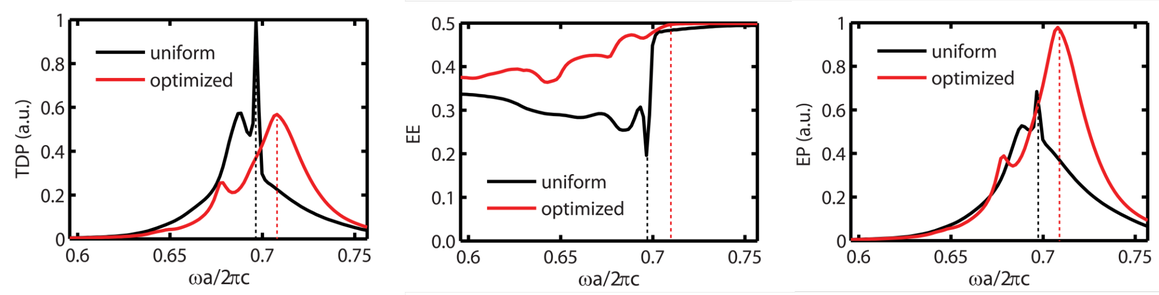


Breaks mirror symmetry



High $|E|^2$ within QW

Forward emission calculations:



Integrated Extracted Power Enhancement ≈ 1.5X

Conclusions

Periodic core-shell nanorod arrays enhance emission
- Γ-point mode with ideal $|E|^2$ profile
- Extracted power 25X larger than infilled slab

Quasi-aperiodic arrays can further enhance emission
- Broadens resonance, preserves integrated TDP
- Achieves perfect light extraction
- Extracted power 1.5X larger than periodic array