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Transverse properties of the electron beam emitted from a diamond nanotip

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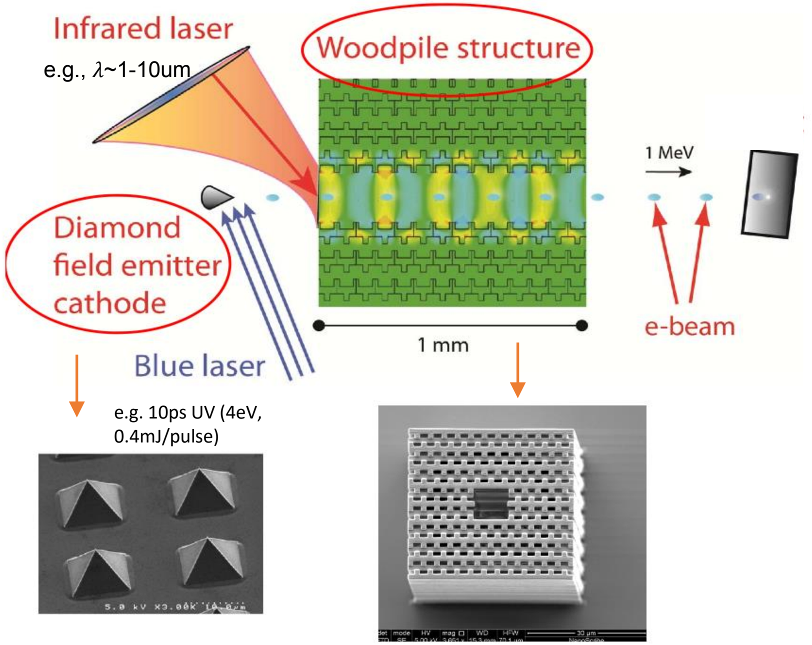
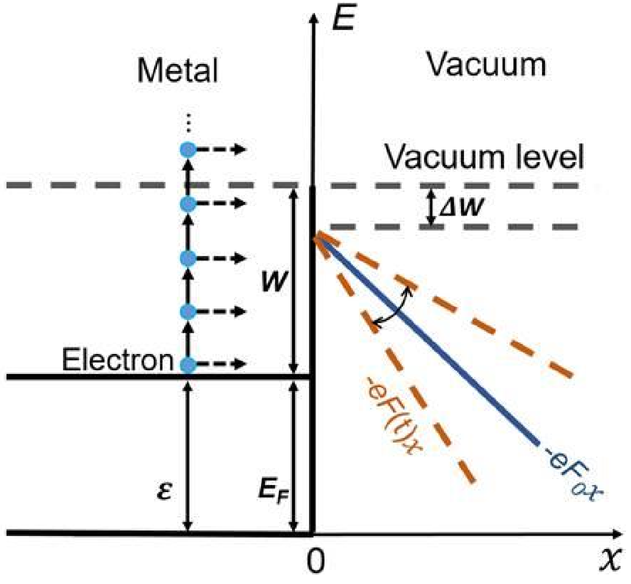
Motivation

- Advanced accelerators provide higher acceleration gradients but require compact electron sources. Diamond field emitter array (DFEA) cathode is an enabling technology for Dielectric Laser Accelerator (DLA).
- DFEA has µm size pyramids and nm size nanotips.
  - High current emission (> 15~20 µA/tip)
  - Emission from the nano-scale tips depends on quantum effects

Dielectric Laser Accelerator

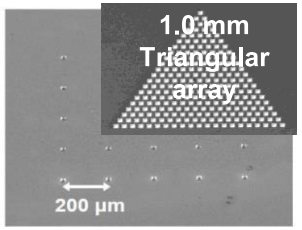


Photoemission

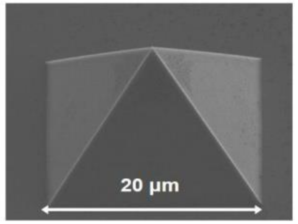


Y. Luo, et al, Phys. Rev. B 103, 085410 (2021)

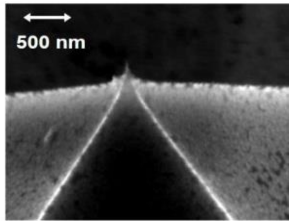
Diamond Field Emitter Array (DFEA) Cathodes



Pyramid emitter arrays on the diamond cathode

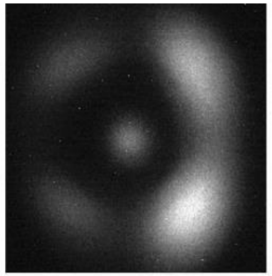


Diamond pyramid emitter

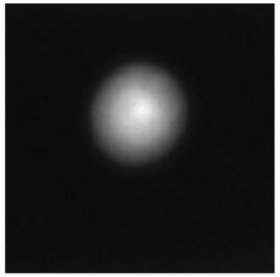


Nanotip on the top of the pyramid

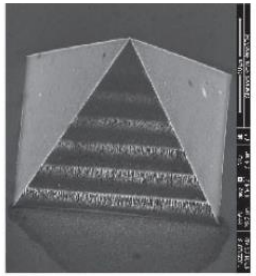
Observed Emission Pattern in Experiment



lower laser intensities



higher laser intensities



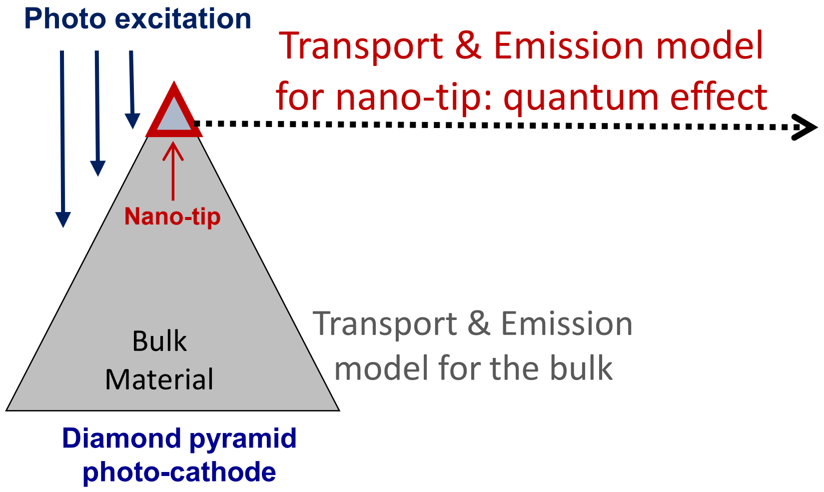
pyramid damaged by the laser light

Simakov et al, 10th Int. Particle Accelerator Conf. (2019)

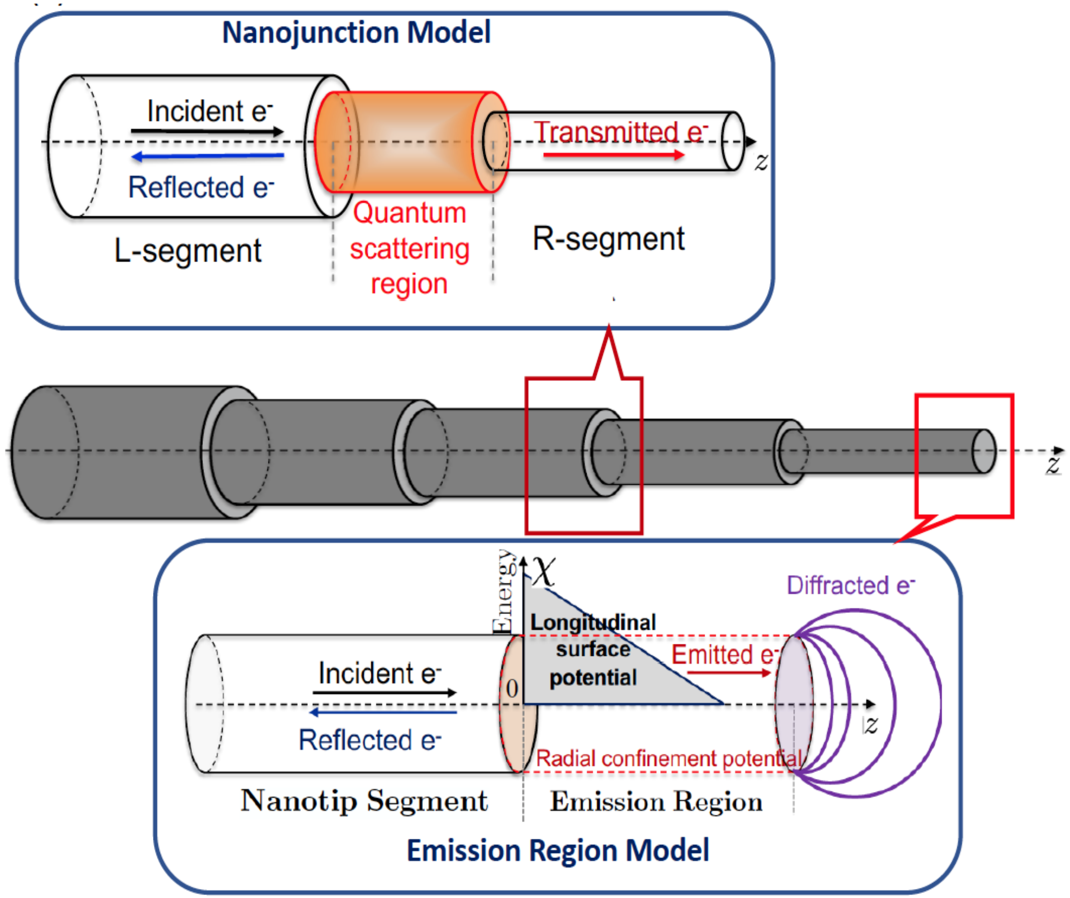
Modeling Emission from DFEA

Modeling diamond pyramid under photo excitation

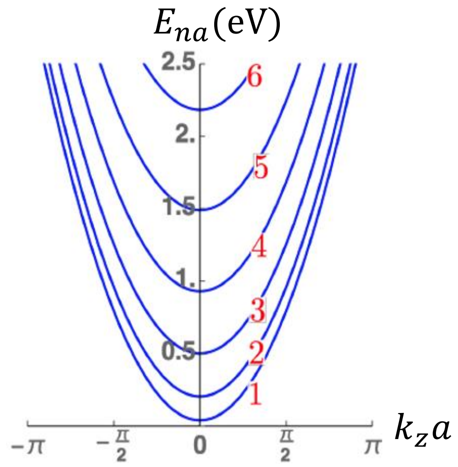
Piryatinski et al., J. Appl. Phys. 125, 214301 (2019)
Huang et al., J. Appl. Phys. 125, 164501 (2019)



Modeling nanotip as a sequence of co-axial cylindrical nanowire segments



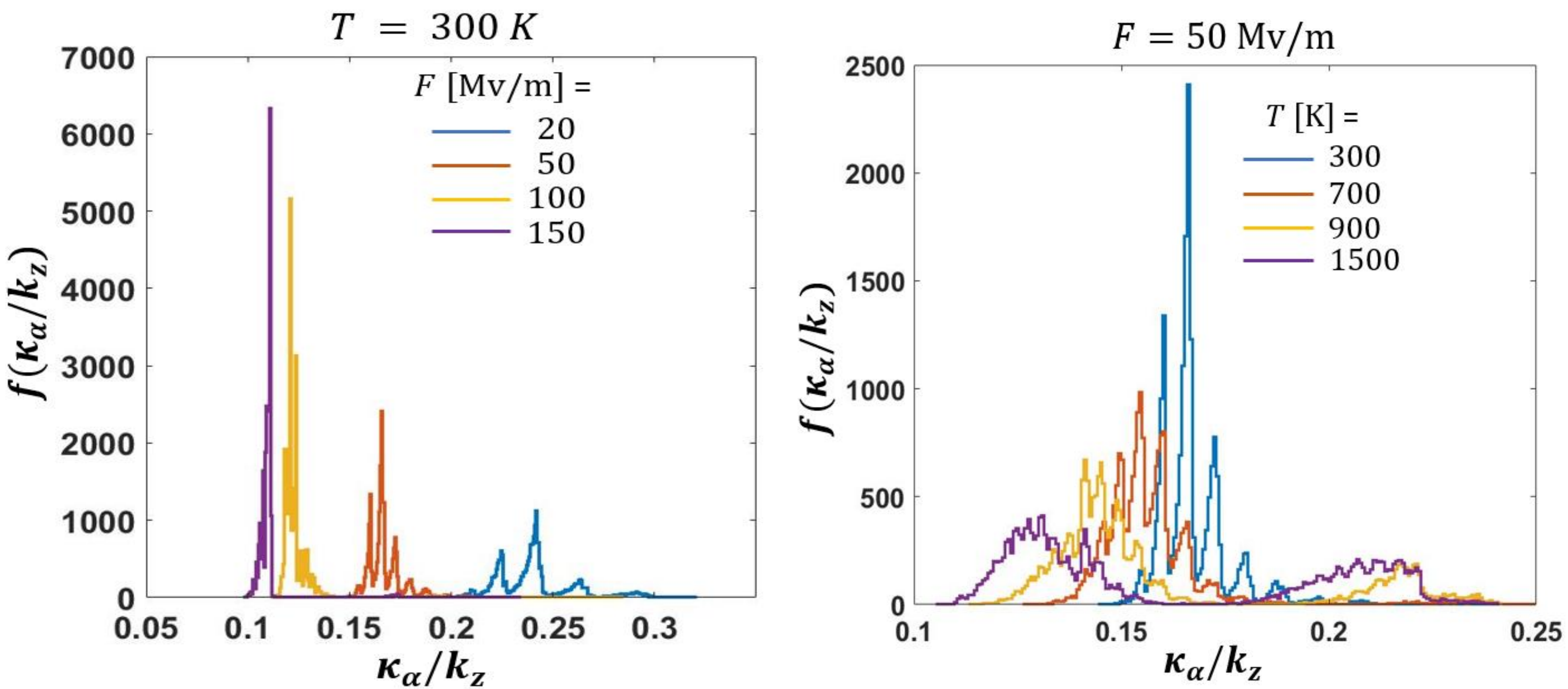
Conduction band quantization



- quantum numbers in the radial direction $\alpha = \{n, a\}$ denote the subbands
- k_z = longitudinal momentum
- κ_α = radial momentum
- Divergence ratio = $\frac{\kappa_\alpha}{k_z}$ is investigated.
- Goal: To study the transverse beam properties, to achieve better coherence.

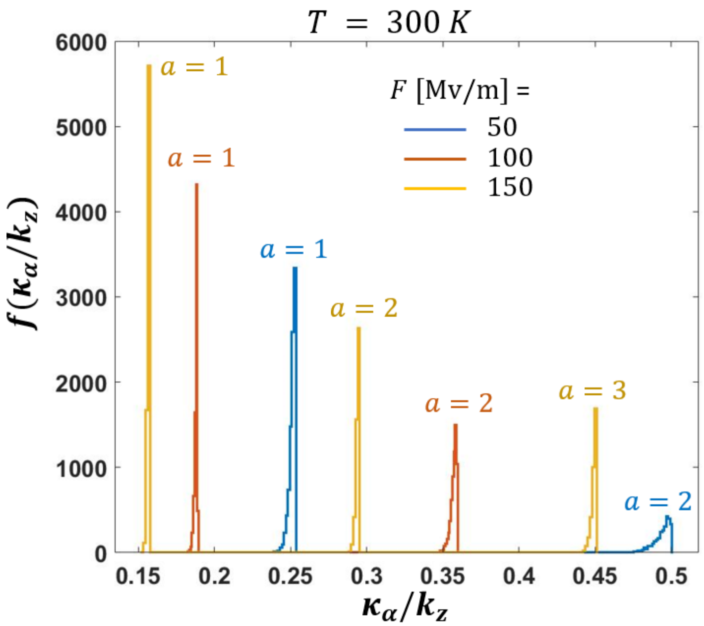
Monte Carlo Transport + Scattering + Tunneling model with band quantization

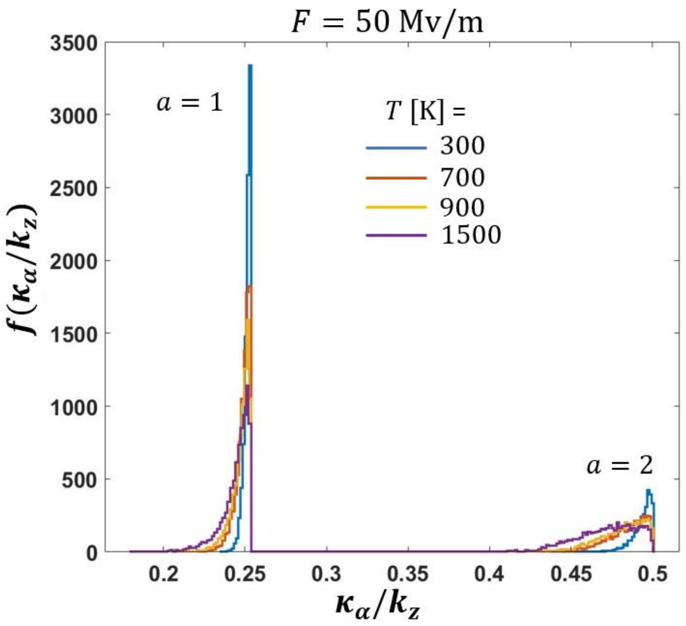
Divergence Ratio – with Phonon Scattering



- $\frac{\kappa_\alpha}{k_z}$ decreases when external field F increases. The spread of the histograms also decreases. High brightness coherent beam.
- $\frac{\kappa_\alpha}{k_z}$ decreases when temperature T increases. However, the spread increases because more electrons move to higher quantum state n.

Divergence Ratio – without Phonon Scattering





- Little energy loss without phonon scattering, electrons move to higher subbands (higher a) when the applied field F is increased.
- Since the initial electron distribution (Maxwellian) depends on temperature, the spread of $f(\kappa_\alpha / k_z)$ varies a little with temperature too.

Summary

- Monte Carlo + tunneling model including the quantum effects at the nanotip gives new emission characteristics → enables high brightness compact electron sources.
- Divergence of the emitted beam depends on applied field, temperature, and initial quantum states.
- In future, this work can be extended to include bulk transport and arbitrary number of nanowire segments.

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