Ultra-Low Emittance Electron Gun Project for FEL Application

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Low Emittance Gun project: motivations

• LINAC-driven FEL: normalized rms emittance at the undulator has a negligible effect on the gain if:

\[ \varepsilon_n << \frac{\beta \gamma \lambda_s}{L_G \frac{2\pi}{}} \]

• Reduction of beam energy requires small normalized emittance

• Reduction of size and cost of the accelerator facility: “short” LINAC, short gain length, relaxed peak current.
LEG approach

• LEG concept based on generation of electron bunches from Field Emission Array (FEA), followed by a fast acceleration in diode mode (electric gradient in the range 0.5-1GV/m, pulsed operation).

• Normalized transverse emittance ultimately limited by its initial value at the cathode:

\[ \varepsilon_n = \frac{r_c}{2} \sqrt{\frac{E_{\text{kin},r}}{m_0 c^2}} \]

• Overall cathode size:
  Can be reduced because of very high current density per tip (300 - 1000 kA/cm²).

• Radial kinetic energy governed by the electric field around the tips:
  More control on topology of electric field lines in the tips vicinity can be achieved by integrating a focusing grid layer.

• Emittance blow-up due to space-charge effects:
  Reduced by using high-gradient acceleration.
FEAs - diamond tips

- Commercial gated FEAs used as X-ray tube sources
- About 3,000 pyramidal diamond tips (1 µm basis / 1 µm high) deposited on silicon wafer
- Extracting Mo grid (gate layer) separated from silicon wafer by 1 µm-thick SiO₂ layer

FEAs - Mo tips

- About 50,000 conical Mo tips on a 1 mm diameter disk area
- Mo gate layer
- Si wafer

ZrC single tip

Single tip in ZrC grown on a truncated Zr tip
Peak currents

- DC operation: field-emitted current decreases monotonically with time (progressive contamination of the tips)
  Field emission also subject to rapid and important fluctuations
- Pulsed regime (50-Hz rep. rate, 100-ns gate voltage): very stable emission, no decrease of emitted current observed

I-V curves in DC and pulsed regime for a diamond-tip FEA

- ZrC single tip: 2 mA peak current has been obtained (pulse length: 100 µs)
Beam dynamics simulations

- Estimation of projected and slice emittance of e-beam generated by pulsed DC-gun with a field-emission cathode performed with MAFIA (PIC module) for different cathode-anode geometries and peak currents
- Electron bunches assumed to have a longitudinal Gaussian distribution - rms bunch length of 8.3 ps

- Current below 100 mA: projected emittances less than 0.1 mm mrad in all four cases - decrease as average gradient gets lower
- Above 5 A, advantage in operating at large gradient - increase of projected emittance less pronounced as gradient gets higher
- Slice emittances smaller than 0.07 mm mrad achievable for peak currents smaller than 5 A in all four cases

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