Ultra-Low Emittance Electron Gun Project for FEL Application

Jean-Yves Raguin, on behalf of the LEG project team
Paul Scherrer Institut

Low Emittance Gun project: motivations

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

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

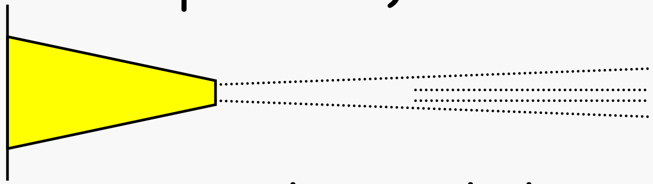
• Reduction of beam energy requires small normalized emittance

↓

• 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).



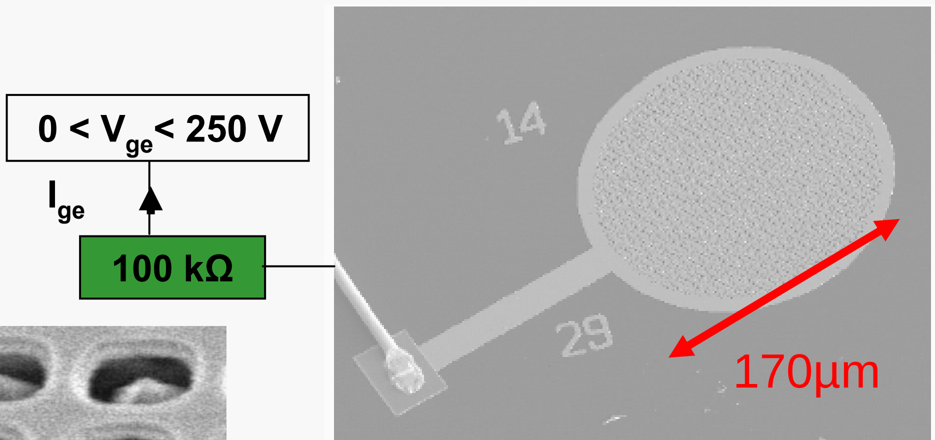
- Normalized transverse emittance ultimately limited by its initial value at the cathode:

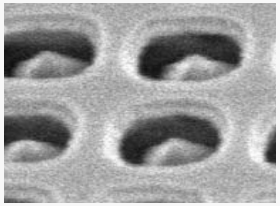
$$\varepsilon_n = \frac{r_c}{2}\sqrt{\frac{E_{kin,r}}{m_0 c^2}}$$

  - Overall cathode size:
    Can be reduced because of very high current density per tip (300 - 1000 kA/cm^2).
  - 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

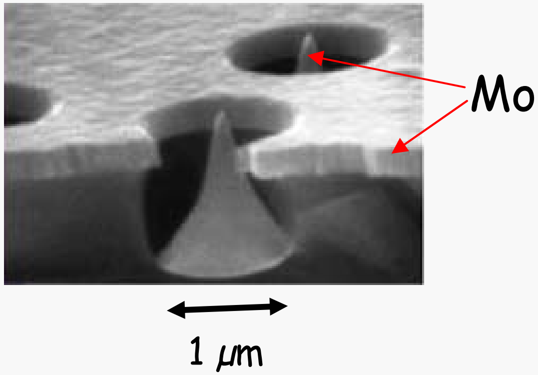
- Commercial gated FEAs used as X-ray tube sources
- About 3,000 pyramidal **diamond** tips (1 µm basis / 1 µm high) deposited on silicon wafer
- Extracting **Mo** grid (gate layer) separated from silicon wafer by 1 µm-thick **SiO_2** layer





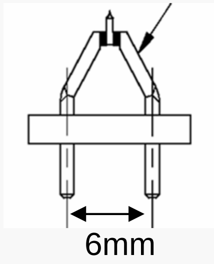
FEAs - Mo tips

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



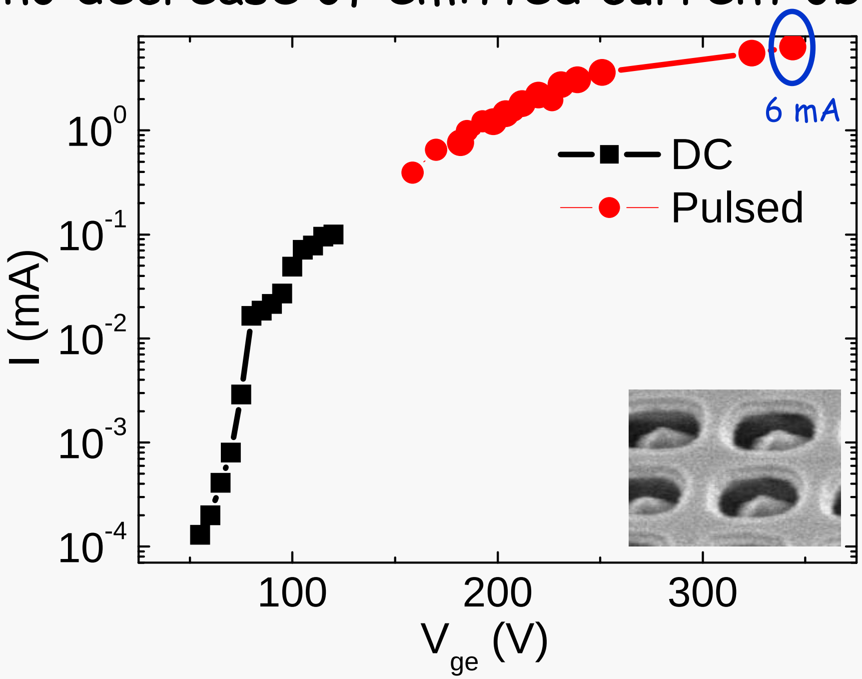
ZrC single tip

Single tip in **ZiC** grown on a truncated **Zr** tip

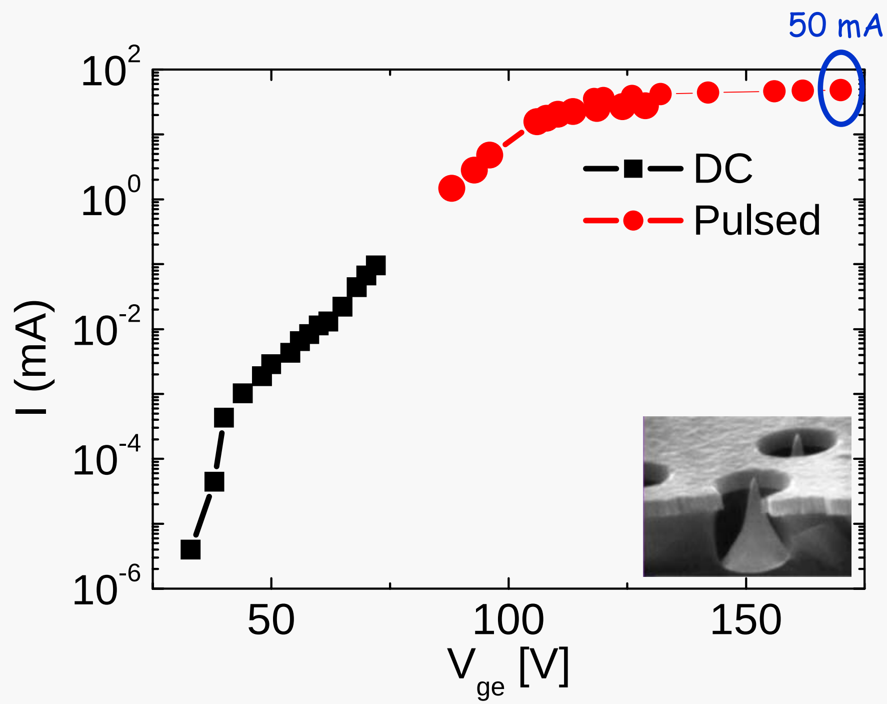


Peak currents

- 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



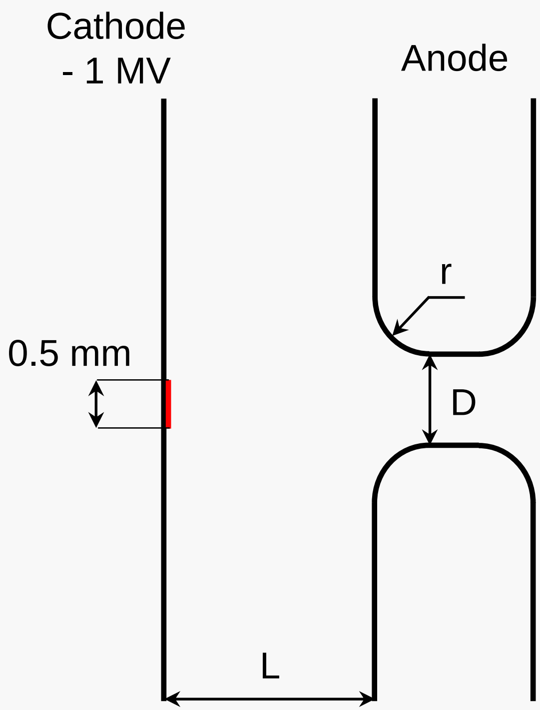
I-V curves in DC and pulsed regime for a diamond-tip FEA



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

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

Beam dynamics simulations



D (mm)	4	2	1.5	1
r (mm)	0.5	0.75	0.19	0.12
E_{avg} (MV/m)	100	200	500	1000

- 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