MOTIVATIONS FOR AND LIMITATIONS OF THE LOW EMITTANCE GUN

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The design of an electron gun capable of producing beam emittance one or two orders of magnitude lower than current technology would reduce considerably the cost and size of a free electron laser at 0.1 nm. Among the different possible electron sources, the field emitter array is a promising technology which benefits from the recent progress in nanotechnologies and vacuum microelectronics.

MOTIVATION FOR HIGH BRIGHTNESS ELECTRON SOURCES

In the synchrotron radiation community there is a strong request for high brightness, coherent light pulses. To satisfy the extreme dynamical resolution needed for example in the biological science, x-ray radiations from 1 down to 0.1 nm wave length, with pulses shorter than 100 fs are needed.

A Free Electron Laser (FEL), driven by a linear single pass accelerator (linac), is today the most promising mechanism able to produce such radiation. In the FEL physics the electron beam emittance plays a major role in the laser saturation process. For an ideal electron-photon matching, the electron beam normalized emittance must satisfy the diffraction limit:

$$\varepsilon < \frac{\beta}{L_G}\frac{\lambda\gamma}{4\pi}$$

Where λ is the radiated wave length, γ the relativistic factor, β the beta function, L_G the gain length and the ε normalized emittance. This relation shows that the energy of the electron beam can be decreased, together with the linac length, provided that the emittance is sufficiently small. The electron source, with its initial emittance and current, becomes thus the first master piece of the driving accelerator.

Emittances of the order of 1 10^{-6}m.rad, and sufficient charge to drive an FEL, are presently achieved using RF photo cathode guns. The linac energy for such a beam is in the 15-20 GeV range, for a peak current at the undulator between 2 and 5 kA. A substantial improvement (small linac, short gain length and relaxed peak current) would be achieved with emittances below 1 10^{-7}m.rad.

In Fig. 1, we present two FEL gain length optimisation curves, versus the undulator period. The radiated wave length has been fixed at 0.1 nm, and the undulator peak field at 1.06 T. The Linac energy is given by the resonance FEL condition:

$$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

Where λ_υ is the undulator period, $K=0.934\ B[T]\ \lambda_\upsilon$ [cm] is the undulator deflecting parameter, and B the undulator peak magnetic field.

The FEL parameters considered for this comparison have been fixed according to Table 1.

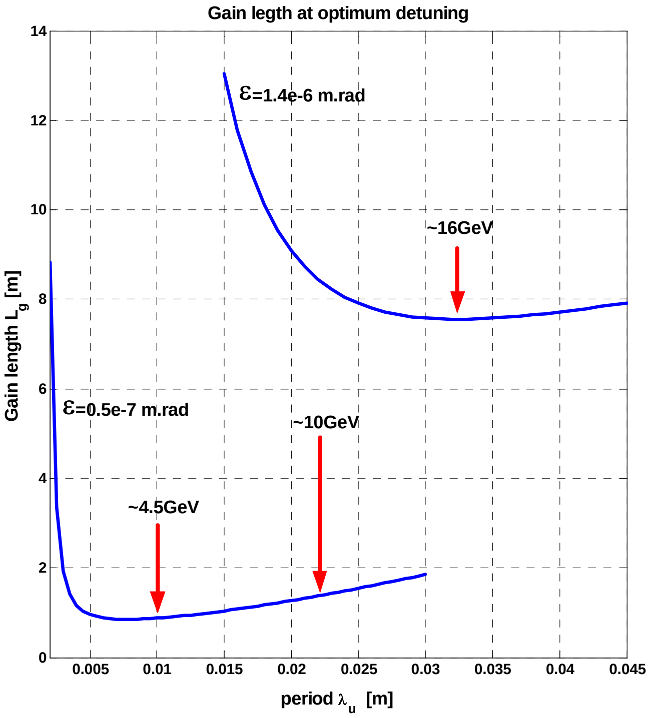

Fig. 1: FEL gain length versus undulator period for two different electron beam emittances.

Normalized emittance [m.rad]	1.4 10-6	0.5 10-7
Peak current [A]	5000	500
Absolute energy spread [KeV]	2500	500
Peak magnetic field [T]	1.06	1.06
Betatron function [m]	28.3	2
Undulator type	Planar	Planar
Radiated wave length [nm]	0.1	0.1

Table 1: FEL parameters

As shown in Fig. 1 the FEL gain length, and therefore the saturation length L_{sat} (L_{sat}~$22L_G$), can be considerably reduced by improving the electron beam properties. The size of the linac can as well be decreased, allowing an appreciable cost reduction of the accelerator facility.

LOW EMITTANCE CATHODE

The electron beam emittance is ultimately limited by the emittance value at the cathode level, where the electrons are emitted. The normalised transverse emittance can be expressed as follows:

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

where r_c is the cathode radius and $E_{r,kin}$ the mean transverse kinetic energy of electrons just after emission. To lower the cathode emittance one can either reduce the size of the emitting area (r_c) or reduce the mean transverse energy of emitted electrons. Main processes for extracting electrons from solid cathodes are photoemission, thermionic emission, field emission or a combination of these three mechanisms.

For thermionic cathodes the mean transverse energy (kinetic energy) is related to the cathode's temperature $E_{r,kin}$=3/2kT (~0.2 eV for a BaO_2 cathode at 1500 K). The typical current density in thermionic cathodes does not exceed 10^2 A/cm^2. This leads to a transverse emittance in the range of 10^{-6} m.rad if we assume a 50 A current requirement for the gun.

In the photoemission process the mean energy is defined by the difference between photon energy and the cathode work function: $E_{r,kin}$~hv-Φ (~0.4eV for a Cu cathode illuminated by a 262 nm laser light). The current density of photoelectrons can be as high as 10^4 - 10^5 A/cm^2. So that for the same current requirement of 50 A, the ultimate emittance at the cathode level would be as low as 10^{-7} m.rad.

In field emitter arrays (FEA), the electrons are emitted at the apex of conical or pyramidal tips (Fig. 2). The emitting surface does not exceed a few square nanometers per tip for a current as high as 1 mA. This leads to very high local current densities. On the other hand the electron beamlets emitted from each tip have a large angular distribution (~20° for a conical tip) due to the finite radius of curvature of the apex (10-100 nm). In order to shape the trajectories of electrons and reach low emittance values a focusing grid will be deposited one micrometer above the extracting layer (not represented on Fig. 2). A typical diameter aperture in the focusing layer is in the range of one micrometer. The challenge is then to obtain good emission homogeneity by diverse conditioning techniques.

In consequence, FEAs might be a promising and very innovative technology for the generation of a low emittance beam. However many unknowns are still present in the final cathode performance and beam dynamics.

CONCLUSIONS

Ultra low emittance guns are extremely important to efficiently drive the new generation of compact x-ray radiation facilities. Cold emission from nano tip array cathodes seems to be a promising technology to achieve emittances below 1 10^{-7} m.rad.

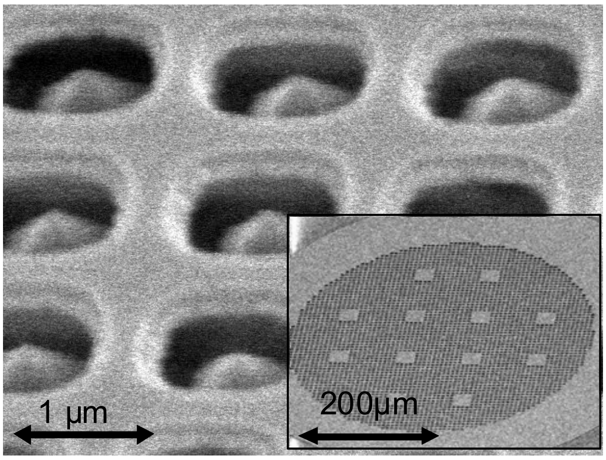

Fig. 2: SEM pictures of a field emitter array. Pyramidal tips are in a conductive diamond material (XDI Inc.).

REFERENCES

[1] W. Zhu, *Vacuum Microelectronics*, John Wiley & Sons, New York (2001).