PRELIMINARY RESULTS AND STATUS ON THE LOW EMITTANCE GUN PROJECT

R. Ganter, A. Candel, M. Dehler, J. Gobrecht, C. Gough, S. Leemann, K. Li, M. Paraliev, M. Pedrozzi , J.-Y. Raguin, L. Rivkin, V. Schlott, R. Schelldorfer, L. Schulz, A. Streun, A. Wrulich, S. Zelenika

The development of a new electron gun with the lowest possible emittance would help reducing the total length and cost of a free electron laser. Recent progresses in vacuum nanoelectronics make field emitter arrays (FEAs) an attractive technology to explore for high brightness sources. Indeed, several thousands of microscopic tips can be deposited on a 1 mm diameter area. Electrons are then extracted by a first grid layer close to tip apex and focused by a second grid layer one micrometer above the tip apex. The big challenge with FEA, is to achieve good emission homogeneity, we hope to achieve this with diverse conditioning techniques. However if we can achieve a low emittance with FEAs another challenge will be to preserve the emittance during the beam acceleration.

INTRODUCTION

To lower the emittance of an electron source it is necessary to reduce both the dimension of the source (emitting area) and to minimize the velocity component transverse to the acceleration axis. In accelerator devices, most of the electron sources are based on photoemission or thermionic processes and very few on field emission. However the achievable current density is much higher with field emission (10^8 A.cm^{-2} in comparison to 10^2 A.cm^{-2} for thermionic emission and 10^5 A.cm^{-2} for photoemission)[1,2] . In addition, the recent progress in microelectronics and nanotechnologies made now possible the fabrication of field emitter tips covered by an extracting grid layer and a focusing second layer, the whole being less than a few micrometers thick. This focusing layer, almost integrated to the source, should help to control the transverse velocity components of field emitted electrons. Of course such high current densities imply important space charge effects within the extracted beam. To limit the transverse spreading of the field emitted beam one can combine high electric gradient acceleration (hundreds of MV / m) and space charge compensation techniques with magnetic components. The goal of this low emittance gun project is to produce a beam with a low normalised emittance (between 10^{-8} and 10^{-7} m.rad) at relativistic electron energies where the emittance is frozen. In order to investigate the use of field emission cathodes in a new low emittance gun the construction of different test stands has been initiated this year.

PERFORMANCE AND LIMITATIONS OF FIELD EMITTER TIPS

In preliminary tests, field emitters arrays (FEAs) available on the market have been tested at PSI. These cathodes are made of electrically conductive microtips in the micrometer size range (Fig. 1) separated from a conductive gate layer by a one micrometer thick dielectric layer. By applying voltages between the gate layer and the tips (V_{ge}) field emission current can be extracted from the tips (see Fig 2). The field emitted current follow the classical Fowler Nordheim law[3]:

$$J = \frac{A}{\Phi}.(\beta.V)^2.\exp\left(\frac{-B.\Phi^{3/2}}{\beta.V}\right)$$

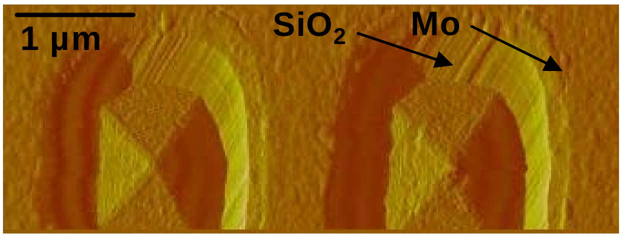

Fig. 1: Top view (Atomic force microscope) of field emitters tips from XDI Inc. Two pyramidal tips (height 1 µm) of conductive diamond material**.** Tips are separated by SiO_2 dielectric material (1 µm thick). SiO_2 is covered by a conductive Mo layer: the gate layer.

where A, B are constant values, V represents the applied voltage between tips and gate, Φ is the work function in eV and β is the enhancement factor of the electric field due to geometrical effect. The three important parameters for field emission current are the field enhancement factor β, the work function Φ and the emitting area.

To achieve field emission of electrons from a surface, the electric field must reach several hundreds of MV / m. In fact the electric field at the tip surface where electrons are emitted is even higher due to local geometrical enhancement. This enhancement comes from the conical shape of the tip but also from nanostructures even atomic structures present on the surface of the microtips. Fig. 1 clearly shows surface irregularities on the surface of the diamond tips. Most of the current will flow through one of these surface defects (presumably the sharper). Unfortunately these small geometrical differences can lead to emission non uniformity. In fact, before any surface treatment, only a few percent of the total number of tips contribute significantly to the emitted current[3]. The challenge here is to improve the emission homogeneity by various conditioning methods. In addition to these local protrusions which enhance the surface electric field, the local work function is also important for field emission intensity. For this reason, materials with low work function are preferred. On the other hand the local work function on the tip surface is highly sensitive to the presence of contaminants (oxygen or hydrogen atoms are always present on a surface). During emission, tips are heated and this leads, for non perfectly cleaned surface, to migration of adsorbed contaminants on the surface.

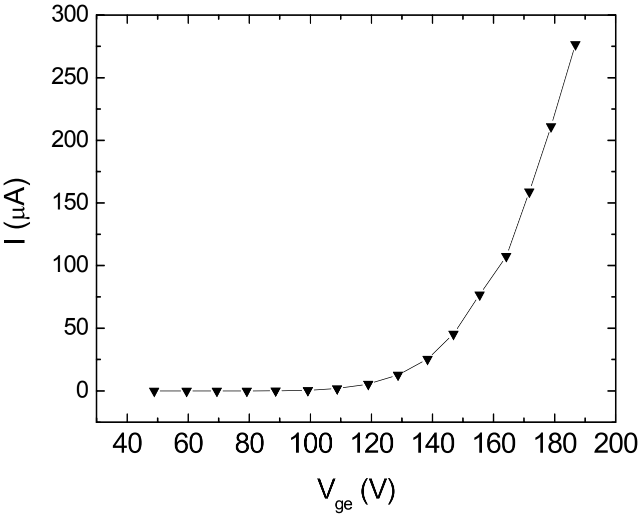

Fig. 2: Current voltage characteristic from a FEA with 2700 diamond tips made by XDI Inc (V_{ge} represents the voltage between gate layer and tips).

This appears as a change in the surface work function and thus in a strong variation of the field emitted current. Fig. 3 represents such an instantaneous variation of the current due to contaminants on the surface[4].

Another aspect of FEAs concerns the possibility of applying short voltage pulses between the gate and the tip. By applying such short pulses (ns range), larger current (several mA / tip) can be extracted before that tips temperature reach too high levels (thermal instabilities). In the same time such intense pulse treatments should enhance surface homogeneity by dulling the sharpest protrusions and desorbing surface contaminants[5]. In order to overcome these problems of homogeneity and cleanness of FEAs, a Scanning Anode Field Emission Microscope (SAFEM) is currently under construction at PSI. This SAFEM will enable the study of local emission (one single tip) and the test of local conditioning methods.

EMITTANCE PRESERVATION IN THE LOW EMITTANCE GUN

One other challenge in this low emittance gun is the preservation of the good emittance produced at the cathode level from space charge effects. Different approaches are under investigation in order to limit the emittance growth during this acceleration phase. At first, it is planned to test the effects of a focusing grid deposited one micrometer above the tips. This layer will help focusing the extracted beam and reduce the emittance growth immediately after the cathode tips. Then the basic idea is to accelerate the electrons with a very high electric field (several hundreds of MV / m) in order to reach the relativistic regime after the shortest possible distance. When high electric field is applied between two massive metallic pieces unwanted field emission is generated from all the surface defects of the cathode support[6]. In order to find the appropriate polishing and cleaning process to limit dark current a specific test stand has been build at PSI (Fig. 4). This test stand enables us to measure dark current and electric field strength (maximum applied electric field before arc regime) from surfaces of several cm^2 (Fig. 4). To start with an enhanced emittance at the cathode level is one important point but to limit the emittance deterioration during acceleration is equally important. Improvements in both aspects: electron generation and emittance preservation would be benefical for the gun.

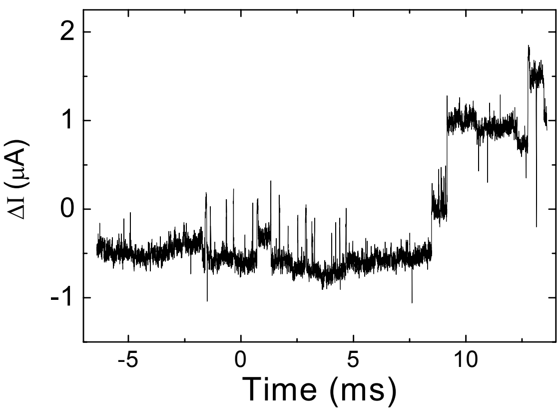

Fig. 3: Fluctuations of the field emitted current versus time due to local work function variations. The DC component of the field emitted current has been removed.

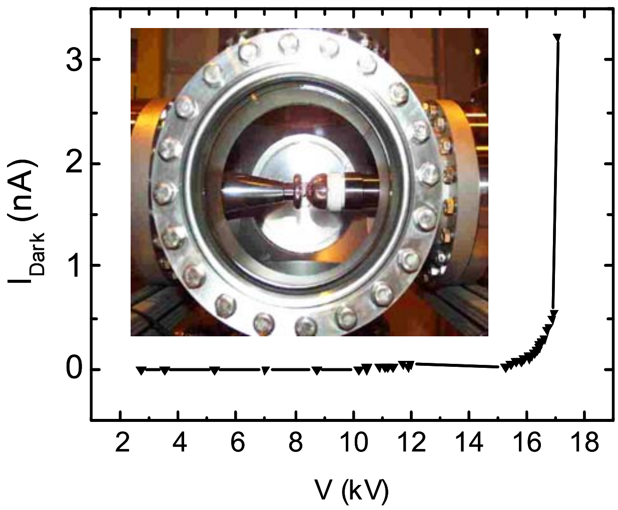

Fig. 4: Dark current between two massive cupper polished electrodes (picture). The gap is between 0.5 and 1 mm. The characteristic follow the Fowler Nordheim law.

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