

HIGH BRIGHTNESS ELECTRON BEAMS FROM A MULTI-FILAMENTARY NIOBIUM-TIN PHOTOCATHODE

F. Ardana-Lamas*, C. Vicario, F. Le Pimpec, A. Anghel and C. P. Hauri*,
 SwissFEL, Paul Scherrer Institut, 5232 Villigen-PSI, Switzerland

*also at Ecole Polytechnique Federale de Lausanne, 1015 Lausanne, Switzerland

Abstract

High-brightness electron sources are of fundamental interest for particle accelerators and modern free electron lasers. Inspired by the micro-structure of field emitter arrays [1,2] we report on a new type of metallic photo-cathode consisting of thousands of Nb₃Sn micro-columns. With this metallic photocathode we could demonstrate quantum efficiencies up to 0.5% under stable operation [3,4]. Preliminary emittance measurements on a 50 keV table-top electron gun are presented.

INTRODUCTION

SwissFEL is aiming for a low-emittance electron linear accelerator with a photo-electron gun based on a conventional, flat copper cathode. Since modern electron accelerators have shown capable to provide low emittance beams up to GeV energy, the generation of a low-emittance electron beam at the gun is essential. In principle, well polished technical metallic photocathodes are well suited since they provide fastest response time upon laser excitation and lowest electron beam emittance. They are furthermore less sensitive to vacuum conditions than the semiconductor (SC) type cathodes. Unfortunately, metallic cathodes suffer from a lower quantum efficiency (QE) than SC type electron emitters, which is a drawback for high charge extraction since larger laser spot size and higher laser energy need to be applied to reach an equivalent charge without risking ablation damage on the cathode. An enlargement of the electron-emitting surface on the cathode goes naturally along with an increase in electron beam emittance ($\epsilon \propto \sigma_{\text{laser}}$). The aim of our investigation was to find a metallic photocathode which withstands higher laser fluence and providing larger quantum efficiencies while keeping the advantages of metal photocathodes.

Here we report on the electron emission of a metallic-composite, multi-filamentary wire as potential candidate for a brilliant electron source. The micro-structured wire (Fig. 1) contains about 14'000 metallic filaments, each of them with a 2-5 μm diameter, grouped in bundles and embedded in a bronze matrix. A pure copper jacket and a tantalum ring keep the filament bundles together. The wire has been etched and reacted. The reacted wires contain the low- T_c superconductor Nb₃Sn while the non-reacted filaments are of pure Nb. Both the non-reacted and reacted wires have been investigated as electron emitters [3,4]. Although there is no structural difference between the

two, the reacted ones are interesting in view of their superconducting properties at 4.2 K. In this paper the cathode is operated only at room temperature.

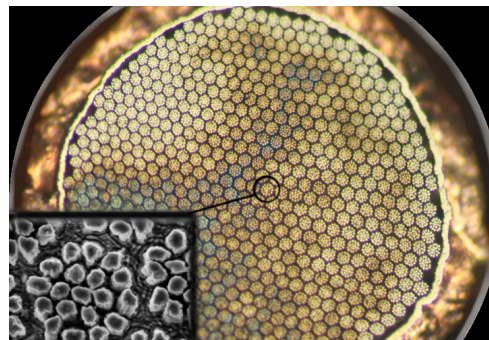


Figure 1: Multi-filament cathode (overall diameter 0.8 mm) with bundles of niobium filaments. The Nb filaments are arranged in bundles, one of which is shown in the close-up view (SEM picture). The cathode wire has a total of 14326 filaments, grouped in 754 bundles of 19 filaments each, (picture from [3]).

EXPERIMENTAL SETUP

The wire cathode has been implemented in a table-top 50 keV high-voltage pulser, as shown in Fig. 2. The high-voltage pulses have a rise/fall time of 1ns and a time jitter of approximately 200 ps from pulse to pulse. The applied electric field at the cathode tip is up to 15 MV/m.

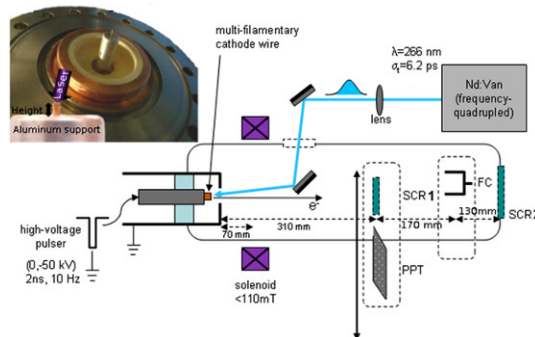


Figure 2: Experimental setup with the Nd:Van laser used to drive the electron emission process on the multifilament wire, located in the pulser. The electron beam properties are measured by a pepperpot (PPT), two YAG screens (SCR1,SCR2) and a Faraday cup (FC). The 2 ns, 50 kV pulser is used to accelerate the electron bunch from the cathode towards the anode at 10 Hz repetition rate, (picture from [4]).

A Nd:Van laser is synchronized to the HV pulser and delivers Gaussian like 15 ps long pulses with a pulse energy of up to 5 μJ . For electron emission the frequency-quadrupled output is used ($\lambda=266\text{ nm}$).

The electron bunch produced by the focused laser beam on the wire are accelerated by the 50 kV pulses and were characterized in charge, beam profile and emittance by a Faraday cup (FC), two yttrium aluminium garnet (YAG) screens (SCR1, SCR2) and a pepperpot (PPT). A moveable focusing solenoid located near the cathode can produce up to 110 mT and allows to control the expanding electron beam.

RESULTS

Electron emission has been explored in dependence of the laser intensity. A typical measurement is shown in Fig. 3 and unravels two different, stable emission regimes. At low laser intensity (fluence $\leq 10\text{ mJ/cm}^2$) a QE of the order of 10^{-5} has been measured, which is typical for metal cathodes. At higher intensities (fluence $\geq 50\text{ mJ/cm}^2$) a high-charge emission regime is observed with QE of 10^{-3} . In the transition region, the charge emission is very unstable, resulting in fluctuations of up to 100%. In the first regime, the maximum extracted charge was less than 30 pC while in the second regime, a charge up to 4000 pC could be achieved.

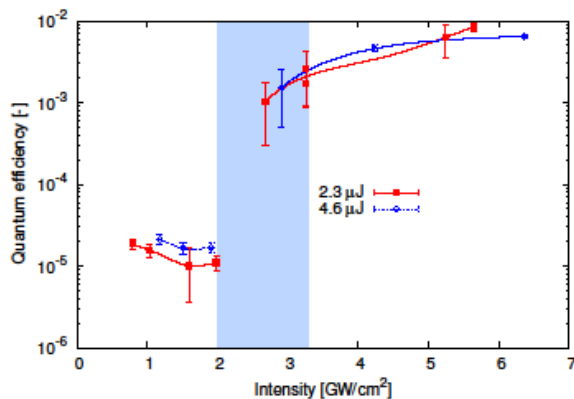


Figure 3: Quantum efficiency as function of the laser intensity on the filamentary cathode (from [4]).

In principle, the high-charge/high QE regime could be attributed to the explosive electron emission (EEE) regime. Despite the large charge extraction for up to hundred hours we could not observe any damage on the filamentary cathode at laser intensities of 10 GW/cm^2 . This indicates that the emission process in this high intensity regime differs from conventional EEE and is linked to the micro-structured emission surface. We speculate that the effect of enhanced quantum efficiency is a combination of field enhancement due to the filament geometry and the surface roughness, which can lead to an enhanced photoelectric effect due to plasmon resonance.

ISBN 978-3-95450-126-7

Due to the high space charge forces the initially circular beam profile becomes deteriorated and results in a doughnut shaped charge profile (Fig. 4).

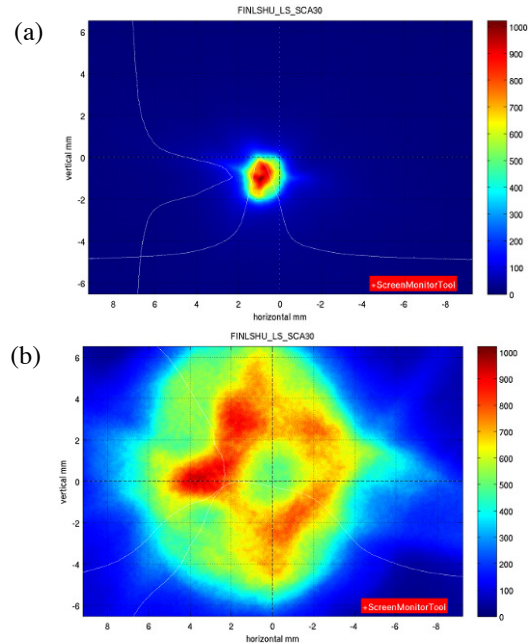


Figure 4: Electron beam profile in the low charge regime (a) and high-charge regime (b), respectively (from [4]).

It is obvious that space charge forces expand the electron beam transversely (Fig 4) and also longitudinally during the beam propagation from the source towards the diagnostics. In principle, the longitudinal expansion could be suppressed by using a higher acceleration gradient, such as in a conventional RF gun. There 80-100 MV/m could be achieved. Our limitation to accelerate the electrons to $\leq 50\text{ kV}$ results in a break up of the beam transversely and longitudinally.

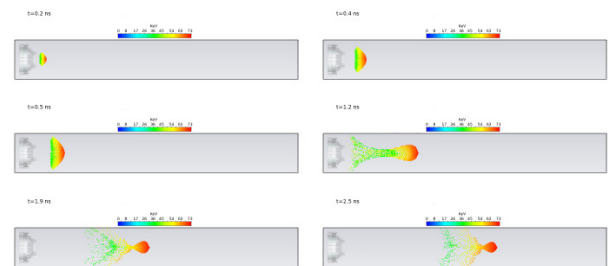


Figure 5: Particle in cell simulation for a 4 nC electron beam and a pulser voltage of 50 kV. (from [4])

Shown in Fig. 5 are particle in cell (PIC) simulations illustrating the beam expansion due to space charge forces acting on the 4 nC electron bunch. Our simulations indicate the formation of an on-axis bullet at high kinetic energy, which is followed by two

heavily space-charge dominated satellite bunches at lower energy. Some of the charge is not detected by the Faraday cup due to impact with the surrounding vacuum tube. In order to fight space charge forces we anticipate to implement this new cathode in the RF gun at the SwissFEL test injector facility in near future [5].

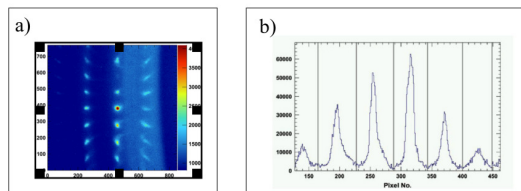


Figure 6: (a) pepperpot measurements on the YAG screen (SCR2) and corresponding cross section (b) used for emittance calculation with xanaroot [6] (from [3]).

Preliminary measurements on emittance were performed with the pepperpot (PPT) located 316 mm after the cathode. The PPT is made of a stainless steel foil with a 20x20 hole array of 50 μm diameter. We recorded PPT images for both the low-charge and high-charge regime. We observed that the beam is bigger than the pepperpot as consequence of the limited steering optics the large space-charge repulsion due to the high charge.

Under those conditions a normalized emittance of ≤ 1 mm.mrad is calculated for a charge of 2500 pC. The emittance at the cathode is expected to be lower due to the small electron emission area defined by the laser spot (50 μm FWHM). In the presented scheme, however, the low beam accelerating voltage of 50 kV is not enough to freeze the beam emittance. Therefore the cathode will be tested in an RF gun in near future.

ACKNOWLEDGMENT

We thank F. Roth for preparing the filamentary samples and are grateful to R. Ganter, M. Divall and P. Bruzzone for vaulable discussion and support. This work was supported by SNF grant no. PP00P2-1128493.

CONCLUSION

In conclusion, we reported on a new type of metallic photocathode consisting of $\approx 13'000$ individual Nb filaments as bright electron emitter. This type of cathode combines, for the first time, the advantage of the metal cathodes, such as fast response, low emittance, ultrashort electron bunches, with the advantage associated to semiconductor-based cathodes (high QE). A large charge extraction up to 4 nC is achieved by laser-assisted emission at an accelerating voltage of 50 keV. The electron emission in the high-charge regime is about 2 order of

magnitudes higher than what is typically provided by conventional polished, flat metal cathodes. Most strikingly the emission area is small which potentially leads to an ultralow electron beam emittance, provided that space charge blow up is hindered by fast acceleration.

REFERENCES

- [1] K. Okano, K. Hoshina, M. Iida, S. Koizumi, T. Inuzuka, "Fabrication of a dimond field emitter array," *Appl. Phys. Lett.* 64, 2742 (1994)
- [2] R. Ganter et al, "Nanosecond field emitted current pulses from Zr needles and field emitter arrays," *J. Vac. Sci. Technol. B* 24(2):974 (2006)
- [3] A. Anghel, F. Ardana-Lamas, F. Le Pimpec and C.P. Hauri, "Large charge extraction from metallic multifilamentary Nb₃Sn photocathode," *Phys. Rev. Lett.* 108, 194801 (2012)
- [4] F. Ardana-Lamas, F. Le Pimpec, A. Anghel and C.P. Hauri, "Towards high brightness electron beams from multifilamentary Nb₃Sn wire photocathode," *Phys. Rev. ST-AB*
- [5] T. Schietinger, M. Aiba, S. Bettoni, B. Beutner, M.C. Divall, K. Doshekenov, Y.C. Doshekenov, Y.C. Du, M. Guetg, C.P. Hauri, R. Ischebeck, F. Le Pimpec, N. Milas, G. Orlandi, M. Pedrozzi, P. Peier, E. Prat, S. Reiche, B. Smit, A. Trisorio, C. Vicario, "Progress report on the SwissFEL injector test facility," *Proceedings of the IPAC2012, New Orleans, Louisiana, USA* (2012)
- [6] T. Schietinger, "Xanaroot: An emittance measurement tool based on ROOT," <http://amas.web.psi.ch>