Conference Programme
Useful Information
Book of Abstracts

1 – 2 March 2011,
INFN of Lecce, Italy
Workpackage 3 of the IRUVX-PP project welcomes you to our EuroFEL Workshop on Photocathodes for RF Guns.

This workshop is focused on the following topics:
- Photoemission theory (derivation of QE and thermal emittance, cathode engineering)
- Photocathode growth and preparation (metal and semiconducting thin films and metal bulk surface treatments)
- Photoelectrons characterisations (quantum efficiency, thermal emittance, dark current)
- Photocathode lifetime (observations of pollution, RF conditioning influence, UV laser interaction with residual gas, etc.)
- Experience on photocathodes
- Cathode cleaning techniques (laser cleaning, annealing, ozone gas, etc.)
- Advanced photoelectron sources (carbon nanotubes, spinndt field emitter, ultracold electron sources)
- New material for photocathodes: high QE, cathodes for IR or green laser light, and for SC guns

Chairs
Antonella Lorusso, INFN
Giuseppe Penco, ELETTRA
Siegfried Schreiber, DESY

Programme Committee
Massimo Ferrario, INFN, Italy
Thorsten Kamps, HZB, Germany
Mikhail Krasilnikov, DESY, Germany
Antonella Lorusso, INFN, Italy
Keith Middleman, STFC, UK
Boris Millitsyn, STFC, UK
Robert Nietubyć, IPJ, Poland
Marco Pedrozzi, PSI, Switzerland
Giuseppe Penco, ELETTRA, Italy
Alessio Perrone, INFN, Italy
Siegfried Schreiber, DESY, Germany
Mauro Trovo, ELETTRA, Italy
Carlo Vicario, PSI, Switzerland
Sverker Werin, MAXLAB, Sweden

Local organisation
M. L. De Giorgi
Antonella Lorusso

About EuroFEL
EuroFEL is part of the ESFRI Roadmap 2008. The preparatory phase of EuroFEL (IRUVX-PP) prepares the establishment of the EuroFEL Consortium, which is a distributed Free Electron Laser facility that is going to link complementary national FEL facilities into a unique European Research Infrastructure. IRUVX-PP is funded by the European Commission under FP7.
Workshop on Photocathodes for RF guns
1 – 2 March 2011, INFN of Lecce, Italy

General Information

Venue  This workshop is organized in collaboration with INFN of Lecce and the Department of Physics of the University of Salento. It will take place at the Department of Physics/Department of Mathematics Campus Ecotekne Via per Arnesano 73100 Lecce, Italy

Sessions  The sessions on 1 March 2011 will be held in “Aula Benvenuti” in the Department of Mathematics (close to the Department of Physics). The working groups on 2 March 2011 will meet in “Aula Benvenuti” (Department of Mathematics) and “Aula Anni” (Department of Physics).

Meals  Coffee breaks and lunches will be served at the Department of Physics.

The conference dinner will take place at the Restaurant “Libertini” (Via Libertini, 23 / Lecce, Italy) Further details about the conference dinner will be communicated by the chairs.
Some details about Lecce

Lecce is the city in Puglia which more than any other, has entirely preserved its historical and cultural identity. As the natural main town of the Salento area, nearly halfway between the Ionic coast and that of the Adriatic, it dominates a great deal of lowlands marked only occasionally by small hills, a frontier land of sorts set on the far most eastern point of the peninsula. The landscape is characterized by an immense expanse of red earth and bare stony ground. One of the symbols of the city is the church, “Chiesa di Santa Croce” (1549), an object of recent restoration and to be found in the immediate vicinity of “Piazza S’ Oronzo”, at the centre and part of the beating heart of the city.

Lecce has also been defined as the “small Florence of the south” for its Baroque atmosphere and its beautiful monuments. The Lecce Baroque is a type of sculpture and architecture which, beginning in the 16th century, spread all throughout the province. It exploited the malleability of the Lecce stone, a calcareous stone which, compact and homogeneously honey-coloured, is used in decorating roads, balconies, buildings and churches. Even today, the shops still feature local artisans who, with plane and chisel, bring sculptures and other treasured objects to life.
Public transport

Tickets can be purchased directly on the bus (1.50 €).

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NOTE: Il VENERDI' il servizio termina alle ore 14.20 a Porta Napoli. Il servizio è sospeso in concomitanza delle festività natalizie e pasquali.
Public transport

Tickets can be purchased directly on the bus (1.50 €).
### Programme

**Tuesday, 1 March**

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<tr>
<th>Time</th>
<th>Duration</th>
<th>Speaker</th>
<th>Title</th>
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<tr>
<td>09:00</td>
<td>0’10</td>
<td>G. Mancarella (Director of INFN) A. Blanco (Director of Department of Physics) G. Penco (ELETTRA)</td>
<td>Welcome</td>
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<tr>
<td>09:10</td>
<td>0’30</td>
<td>F. Hannon</td>
<td>A Summary of the 2010 Photocathode Physics for Photoinjector Workshop</td>
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<tr>
<td>09:40</td>
<td>0’30</td>
<td>L. Cultrera</td>
<td>Overview of photocathodes for high brightness beams</td>
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<tr>
<td>10:10</td>
<td>0’30</td>
<td>G. Gatti</td>
<td>Cu photocathode operating experience</td>
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<tr>
<td>10:40</td>
<td>0’20</td>
<td>all</td>
<td>Coffee break</td>
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<tr>
<td>11:00</td>
<td>0’30</td>
<td>M. Trovo’</td>
<td>Cu cathode experience at FERMI and ozone cleaning</td>
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<tr>
<td>11:30</td>
<td>0’30</td>
<td>S. Tsujino</td>
<td>Nano field emitter arrays at PSI: progress and challenge for high-brightness cathode applications</td>
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<tr>
<td>12:00</td>
<td>0’30</td>
<td>D. Sertore</td>
<td>High quantum efficiency Cs$_2$Te photocathodes at INFN Milano - LASA</td>
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<tr>
<td>12:30</td>
<td>0’30</td>
<td>S. Lederer</td>
<td>Operation of Cs$_2$Te photocathodes at FLASH and PITZ, DESY preparation system</td>
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<td>13:00</td>
<td>1’30</td>
<td>all</td>
<td>Lunch</td>
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<tr>
<td>14:30</td>
<td>0’30</td>
<td>D. Dowell</td>
<td>Photocathode properties and requirements for photoinjector</td>
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<tr>
<td>15:00</td>
<td>0’30</td>
<td>X. Wang</td>
<td>Efficient low thermal-emittance metal cathode: A reality or pipe dream?</td>
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<td>15:30</td>
<td>0’30</td>
<td>A. Lorusso</td>
<td>Thin film metallic-photocathodes grown by pulsed laser ablation</td>
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<td>16:00</td>
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<td>16:30</td>
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<td>R. Nietubyć</td>
<td>Pb/Nb thin film photocathodes</td>
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<td>17:00</td>
<td>0’30</td>
<td>S. Schubert</td>
<td>Cathode preparation for high average current ERL accelerator</td>
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<td>19:30</td>
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<td>Conference dinner</td>
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Workshop on Photocathodes for RF guns
1–2 March 2011, INFN of Lecce, Italy

Wednesday, 2 March

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<tr>
<td>09:00</td>
<td>0’30</td>
<td>B. Militsyn</td>
<td>The perspective of use GaAs (III-IV) type photocathodes in the SRF guns</td>
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<tr>
<td>09:30</td>
<td>0’30</td>
<td>F. Le Pimpec</td>
<td>Photocathode experience and developments at PSI</td>
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| 10:00  | 1’30     | Split in two working groups (WG1/WG2) (coffee will be served) | WG1 cathode issues (M. Ferrario)
|        |          |                  | WG2 Cathodes for SC machines (T. Kamps)                              |
| 11:30  | 0’30     | all              | Visit to laboratories                                               |
| 12:00  | 0’30     | all              | WG1 and WG2 reports                                                 |
| 12:30  | 0’30     | all              | Final discussion and closure                                         |
| 13:00  |          | all              | Lunch                                                               |
### List of participants

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<th>Name</th>
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<td>Alexander, Igor</td>
<td>Universität Mainz</td>
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<td>Aulenbacher, Kurt</td>
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<td>Le Pimpec, Frederic</td>
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<td>Monaco, Laura</td>
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<td>Moody, Nathan</td>
<td>Los Alamos National Laboratory</td>
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<td>Nietubyć, Robert</td>
<td>Andrzej Soltan Institute for Nuclear Studies</td>
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<td>Perulli, Andrea</td>
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<td>Sertore, Daniele</td>
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Spezzani, Carlo  ELETTRA
Teichert, Jochen  HZDR
Trovo`, Mauro  ELETTRA
Tsujino, Soichiro  Paul Scherrer Institut
Tyukin, Valery  Universität Mainz
WANG, Xijie  BNL
Abstracts
A Summary of the 2010 Photocathode Physics for Photoinjectors Workshop

Ivan Bazarov, David Dowell, Fay Hannon, Katherine Harkay, Carlos Hernandez Garcia, Howard Padmore, Triveni Rao, John Smedley

1 Cornell University, Ithaca, NY 14850
2 SLAC National Accelerator Laboratory, Menlo Park, CA 94025
3 Thomas Jefferson National Accelerator Facility, Newport News, VA 23606
4 Argonne National Laboratory, Argonne, IL 60439
5 Lawrence Berkeley National Laboratory, Berkeley, CA 94720
6 Brookhaven National Laboratory, Upton, NY 11973

This contribution contains a summary and some highlights from the Photocathode Physics for Photoinjectors (P3) Workshop [1]. This workshop, held at Brookhaven National Laboratory in October of 2010, was aimed at bringing the photocathode community together to discuss and explore the current state of the art in accelerator photocathodes, from both a theoretical and a materials science perspective. All types of photocathode materials were discussed, including metals, NEA and PEA semiconductors, and ‘designer’ photocathodes with bespoke properties.

Topics of the workshop included:

- Current status of photocathodes for accelerator applications
- Current fabrication methods
- Applications of modern materials science to the growth and analysis of cathodes
- Photoemission spectroscopy as a diagnostic of cathode performance
- Utilization of modern user facilities
- Photoemission theory
- Novel ideas in cathode development
- Discussion forum on future collaboration for cathode growth, analysis and testing

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References

OVERVIEW OF PHOTOCATHODES FOR HIGH BRIGHTNESS BEAMS

L. Cultrera*

1 Cornell Laboratory for Accelerator-based Sciences and Education, Dryden Rd, 14850 Ithaca, NY

In last years a considerable interest has grown towards the realization of light sources as FEL and ERL that promise to deliver unprecedented high quality photon beams with shorter and shorter wavelengths in X-ray regions. The achievement of such emission properties is strongly related to the brightness of the electron bunches used as active medium and the brightness of the electron beam itself is limited by the performance of the electron source used. An overview of the recent progress on electron sources for high brightness beam is presented.

Figure 1: A not exaustive list of photocatode materials used as advanced electron sources.

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We report our experience about the employment of bulk copper photocathodes within the Sparc photoinjector activities. The use of such a photoemitter is widespread and many aspects have been understood and reported in literature. Nevertheless, the history of each cathode is peculiar, bringing new details to evidence, especially when probing new operating conditions [1][2]. Copper has been the choice for Sparc, because of its prompt time response [3] and its ruggedness. In fact, since the beginning of Sparc photoinjector activity, photocathodes have been used for long times (more than one year each), before getting to such detrimental performances, to lead to a replacement. We review and analyze some of the issues experienced using a copper photocathode in different operating conditions.

* Giancarlo.Gatti@lnf.infn.it

References

Cu cathode experience at FERMI and ozone cleaning

M. Trovò*, M. Coreno², M. Veronese¹, L. Rumiz¹ and C. Spezzani³

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²CNR-INFM TASC National Laboratory, Trieste, I-34012 Italy

The FERMI Photoinjector has been in operation since August 2009 [1]. The e-beam has been generated during the entire six machine runs of commissioning. Last December the first coherent emission from the undulator chain has been produced in seeded mode with an external laser at 260 nanometers.

After the first electron beam extraction, a quantum efficiency (Q.E.) drop has been observed after several weeks of continue operation, probably due to the deposition of residual gas on the Cu surface induced by the interaction with the UV driven laser or by the e-beam itself. The initial Q.E. value of $3 \times 10^{-5}$ decreased down to $2 \times 10^{-6}$. Moreover, the Q.E. drop is localized in the cathode center where the UV laser is more often driven (see Figure 1.a). Facing this common problem of emission efficiency [2, 3, 4], it has been decided to attempt a cleaning procedure of the copper cathode based on Ozone, a technique commonly used on other materials [5]. During the shut-down between November ’09 and February ’10 the cleaning procedure was performed for the first time, consisting in venting the RF gun with Ozone gas for few hours and baking it out for 2 days. The subsequent beam extraction occurred with a good efficiency again and the Q.E. went back to more than $3 \times 10^{-5}$. Figure 1 shows the comparison between the Q.E. map of October ’09 and that one of February ’10.

Figure 1: Q.E. map before (a) and after (b) the Ozone gas treatment.

The ozone cleaning treatment has been applied more times with success and historical data will be presented.

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References

Nano field emitter arrays at Paul Scherrer Institut: progress and challenges for high brightness cathode applications


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2Laboratory for Condense Matter, Paul Scherrer Institut, CH-5232 Villigen-PSI, Switzerland
3Department of Large Research Facilities, Paul Scherrer Institut, CH-5232 Villigen-PSI, Switzerland
4Physik Institut, Universität Zürich, Winterthurerstrasse 190, CH-8057, Zürich, Switzerland
5Laboratory for Electronics/Metrology/Reliability, EMPA, Überlandstrasse 29, CH-8600 Dübendorf, Switzerland
6Institute of Applied Physics, University of Bern, Siderstrasse 5, CH-3012 Bern, Switzerland
7SwissFEL Paul Scherrer Institut, CH-5232 Villigen-PSI, Switzerland

Paul Scherrer Institute has been undertaking the development of a novel field emission cathode comprising an array of metallic nano-tips, or a field-emitter array cathode, as a high current and high brightness cathode, in particular as a potential upgrade option for the SwissFEL X-ray free-electron laser.[1,2] Here we present 1) nanosecond pulsed field emission in the combined diode-RF cavity accelerator SwissFEL test facility,[3] 2) 5 pC electron bunch generation by ultrafast near infrared laser-induced field emission,[4,5] and 3) a factor 10 collimation of the field emission beam by an on-chip collimation gate electrode,[6,7] using the PSI field emitter array cathode.

Figure 1: (a) Schematic of FEA integration in the SwissFEL diode gun accelerator. (b) Scanning electron microscope image of a part of 5 µm-pitch single-gate FEA with $10^5$ emitter tips. The inset shows a single-tip near the apex. (c) Scintillator screen image of focused field emission beam from the FEA shown in (b) accelerated to 200 keV in 30 MV/m acceleration gradient.

* Electronic mail: soichiro.tsujino@psi.ch

References

[5] A. Mustonen et al., in 8th IVESC, Nanjing, China (2010);
High Quantum Efficiency Cs$_2$Te Photocathodes at INFN Milano - LASA

D. Sertore

INFN Milano - LASA, Via Fratelli Cervi 201, 20090 Segrate (MI), Italy

High Quantum Efficiency (QE) photocathodes are nowadays routinely used in RF Guns as laser stimulated electron sources. INFN Milano-LASA is involved in the field of high QE photoemissive film since the 1980’s. We begun studying multialkaly antimonied compounds and then moved to more robust multialkaly telluride like Cs$_2$Te. During these years, we have investigated different aspects related to photoemissive films and, at the same time, we have provided photocathodes used as electron sources in RF Guns in different facilities.

The R&D activities have been focused on understanding the photoemissive and optical properties of the photoemissive films. We apply surface science techniques (AES, XPS) to understand the photocathode growing process, we extensively analyse QE measurements (from deep UV to visible light) to determine the photoemissive threshold and, we apply angle resolved reflectivity measurements to have information about the optical properties of the films. Moreover, given the importance of the thermal emittance in high brightness electron sources, we have measured the angular resolved energy spread of the emitted electrons using a Time-Of-Flight (TOF) spectrometer. With this technique, we estimated, for the first time, the divergence of the beam at the source in absence of any accelerating field.

Another important research item has been the characterization of the photocathodes photoemissive properties for their operation in the RF guns. For this purpose, measurements of spatial QE uniformity over the cathode area (QE maps), of the film robustness (poisoning with different gases), of the reproducibility of the photoemissive properties (multivariate analysis, etc.) have been done. Moreover, the request of more reliable cathodes performances has stimulated further improvements to our production system, with the implementation of new diagnostics, that have given good results, in terms of reproducibility of the film characteristic and have improved the understanding of the formation of the film during its deposition. A controlled poisoning of the photoemissive film has allowed a production of uniform QE films with higher work function opening the possibility, in the near future, to control the electron beam divergence.

Concerning the cathode production for RF Guns, in 1994 we designed and assembled the first system for cathode production directly attached to a gun at the FNAL A0 Experiment. Since 1998, we routinely provide photocathodes for FLASH at Hamburg (DESY) and PITZ at Zeuthen (DESY). The photoemissive films are deposited in Milano and shipped, under UHV condition, to the different Labs. Up to now, we deliver more than one hundred cathodes to the two laboratories. In particular, the cathodes at FLASH operate 24/24h 7days per week reaching an operative lifetime of more than 100 days without significative degradation of extracted charge. Given the successful results obtained with the DESY systems, two new preparation systems will be commissioned in the next months at DESY and FNAL, where a transfer system that moves cathode into the RF Gun will be commissioned too.
Caesium telluride photocathodes are used as laser driven electron sources at the Free-Electron-Laser Hamburg (FLASH), the Photo-Injector Test facility Zeuthen (PITZ) and will be used at the European XFEL.

In terms of cathode usage, FLASH is mainly operated under moderate and constant conditions. The maximum accelerating gradient at the cathode is in the order of 45 MV/m and the RF pulse length between 300 and 900 µs. In contrary PITZ, as test facility for the European XFEL, is dedicated to operate the RF-gun at 60 MV/m with pulse lengths up to 700 µs.

One concern of the operation of photocathodes in user facilities is the degradation of quantum efficiency during operation. After improving vacuum conditions and removing contaminants, the cathode lifetime increased from a couple of weeks to several months (figure 1). Since summer 2008, at FLASH no cathode was exchanged because of a too low QE.

In this contribution, requirements on photocathodes for FLASH, PITZ, and the European XFEL will be presented. The contribution will be concentrate on measurements during operation at FLASH and PITZ, namely QE measurements for different operational conditions as well as QE-maps. In addition, measurements on darkcurrent will be discussed, another crucial aspect of operating RF-guns with long RF-pulses.

Finally we present first commissioning results of the new photocathode preparation system at DESY and show present and future tools for off-line cathode analysis.

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Figure 1: Quantum efficiency vs. days of operation at FLASH for Cs$_2$Te cathodes #77.2 and #13.4.
Abstract
This talk reviews the requirements and current status of cathodes for accelerator applications. Accelerator cathodes require long operational lifetimes while producing electron beams with a very low emittance. The thermal or intrinsic emittance is derived and the relations used to compare the various cathode materials. The emission properties of commonly used metal and semi-conductor photocathodes are summarized. The ultimate beam brightness relating the intrinsic emittance and the space charge limit is discussed as well as the technical issues of cathode uniformity, lifetime and contamination.
Efficient Low Thermal-Emittance Metal Cathode: a Reality or a Pipe Dream?

X.J. Wang

NSLS, Brookhaven National Laboratory, Upton, NY 11973, USA.

A robust photocathode with high quantum efficiency and low thermal emittance is one of the critical enabling technologies for future linac based light sources. Both semiconductors and metals have been employed as photocathodes in RF guns. Semi-conductor cathodes have the advantage of higher quantum efficiency (QE~10^{-2}) but with the burden of being more sensitive to their environment. The metal cathodes are more robust but they have a lower QE ~10^{-5}. Metal cathodes (Copper & Magnesium) have been employed at the BNL over 20 years, both positive and negative experiences in operating a metal cathode will be discussed in this talk. Currently, Mg cathode is used in all three BNL operating RF guns (ATF, LEAF & SDL). After many years struggling, we have successfully developed a reliable operational procedure for the Mg cathode [1-2].

Both the quantum efficiency (QE) and the thermal emittance of a Mg cathode are experimentally investigated at the NSLS SDL. The measured QE ~ 0.2% is the highest reported for a metal cathode. We observed no change in the Mg cathode thermal emittance as the QE varies from 0.015 to 0.15%. Furthermore, the upper limit of the thermal emittance – 0.5 mm-mrad per mm of the rms laser size, is about 50% lower than the theoretical prediction. Our experimental results are consistent with the surface photoemission, and are the first experimental demonstration of the feasibility of simultaneously having a high QE and a low thermal emittance for a robust metal photocathode.

References

Thin-film-metallic-photocathodes grown by pulsed laser ablation

A. Lorusso*1, L. Cultrera2, F. Gontad1, A. Perrone1

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In this paper we review the current status of metallic photocathodes based on thin films prepared by pulsed laser deposition (PLD), a very efficient technique for producing adherent and uniform thin films [1], exploring ways to improve the performance of these devices. Photocathodes based on Mg and Y thin films have been characterized by different diagnostics techniques and tested in a photodiode cell to deduce their photoelectron properties. The quantum efficiency (QE) of our photocathodes was systematically improved by laser cleaning treatments reaching the corresponding bulk values [2]. The level and the vacuum quality have an unquestionable influence on both, the QE value and lifetime, achievable on metallic-film-based cathodes. Time-resolved-mass-spectrometric investigations definitively suggest that the deposition of high purity metallic thin films should be carried out after a deep and careful laser cleaning of the target surface and in ultra-high-vacuum systems. This laser cleaning is highly recommended not only to remove the first contaminated layers but also to improve the quality of the vacuum, by reducing the partial pressure of contaminant chemical species as H2 and O2 molecules. The rule of the metallic photocathode adsorbed gases on the emission performance will be also reported and discussed.

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Pb/Nb thin film photocathodes

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Superconducting thin film lead photo-cathodes became recently a prospective approach in constructing an electron source dedicated for long pulse and high repetition rate operating accelerators. We report our achievements in thin film lead deposition onto a back wall of electron injector cavity. An UHV cathodic arc deposition method has been chosen because of the high kinetic energies of ions transported in arc plasma channel which facilitates the growth of uniform dense film and reduces defects formation. Lead has been chosen as the second, besides niobium, metallic superconductor, which shows however more than ten times higher quantum efficiency. Regular investigation of thin film Pb photocathodes started after successful proof-of-principle experiment in 2006, which had demonstrated the QE equal to 5.5⋅10⁻³ for the Pb film deposited without micro-droplets filtering and cleaned with VUV laser pulses. The lack of filtering resulted however in high population of micro-droplets having the size in the range of several micrometers. Such a rough surface precluded the reasonable application it disturbs the electron emission. The knee-shaped filter was used for filtering which removed the droplets, however in cost of deposition rate. Low rate resulted in low thickness. That hampers efficient surface cleaning with strong laser pulses, because they melted the film. Since that time the efforts were dedicated to establish optimal repeatable procedure of deposition and laser cleaning. A dedicated deposition system was constructed and a number of trial processes have been performed where polycrystalline and single-crystalline niobium plugs were coated. Next the surface characterization followed by cleaning procedure and quantum efficiency measurements using UV wavelength range of initiating laser were applied for deposited layers. Those experiments revealed an optimal procedure for an arc operation as well as for a laser cleaning of the Pb surface. In such conditions the value of QE equal to 0.0033 was found. In the following step, Pb films were deposited onto back wall of Tesla-like resonant cavities of electron injector. The process has been performed 5 times successfully. After typical BCP and HPWR treatment the cavities underwent cold RF test. For the best case a resonant quality higher than 3⋅10⁹ sustained up to the electric field gradient of 39 MV/m.

![Figure 1: Two achievements: reproducible QE for Pb and thin film deposited onto back wall of Tesla cavity.](image)

References

Cathode Preparation for high average current ERL accelerator

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A number of different types of photocathodes are considered as electron source for high brightness and high average current ERL accelerators [1]. Currently, metal, NEA GaAs and monoalkalitellurides, namely Cs$_2$Te, are most notably used.

The use of metal cathodes is mainly historically driven. The long lasting study and use makes them a well-understood material, whose preparation and handling are relatively easy to manage. One of their advantages is the prompt response time, what makes them very attractive towards applications, which depend on short electron bunches and a temporal profile. Disadvantageous is the low quantum efficiency, in order to overcome the typically high work function high photon energies are required.

Looking for materials which exhibit a higher quantum efficiency monoalkali- and multialkali – cathodes are brought into focus. Currently, the Cs$_2$Te system is applicable in FELs, e.g. DESY, and SRF electron injectors, e.g. HZDR. Cathode preparation requires UHV up to $10^{-10}$ mbar and is well reproducible. Cathodes produced under these conditions show a Q.E. up to 13% at 254 nm [2]. Unfortunately, due to its high work function of 3.5 eV [3] a UV laser system is required to operate these cathodes. Another promising system is CsK$_2$Sb, prepared under UHV conditions with a base pressure around $10^{-11}$ mbar , it shows a Q.E. above 10 % at 532 nm. The responds time is believed to be prompt, as the material is used in fast streak cameras.

Thin films of NEA GaAs on GaAsP are primarily used within polarized electron sources, by increasing the GaAs film thickness and therefore the quantum efficiency, it becomes also a candidate for an high average current ERL application. The GaAs cathode can as well be operated at 532 nm with a Q.E. usually around 10% [1]. These cathodes are even more sensitive towards contamination than (multi-) alkalicathodes and need to be handled at $p = 10^{-12}$ mbar UHV.

The use of superconducting RF electron injectors inspires the research on superconducting photoemissive materials. The electron injector usually consists of Niob, but Nb itself shows a poor Q.E. of $\sim 2 \times 10^{-5}$ [4], therefore the use of Pb, being superconductive and having a Q.E. of a magnitude larger than Nb is proposed and tested [5][6].

The presentation will focus on the cathode preparation and each systems advantages and disadvantages towards its use in ERL accelerators.

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The perspective of use GaAs (III-IV) type photocathodes in the SRF guns

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The development of linear colliders (LC) has restored interest in the development of polarized electron sources (PES). The current requirements for an LC PES are significantly beyond the state-of-the-art which has developed over more than 30 years. An LC should deliver an average current of up to 15 mA to the interaction point (IP) in 5 MHz trains with train duration of 0.5 ms at a repetition frequency of 5 Hz. The basic PES exploits the III-V family of superlattice photocathodes to deliver beams with a polarization of >90%, with a quantum yield of 1% in the DC mode [1]. However, the operation of this photocathode material requires extreme-high vacuum conditions (XHV) which must be maintained, even under application of the accelerating voltage. In practical terms, only two types of gun can provide these conditions – DC guns and SRF guns. The design of DC guns is well established and is considered by many groups as the basis for a LC. In contrast, the design of SRF guns is at an early stage, though development work is underway at BNL [2] and HZDR [3]. At ASTeC, we are considering the possibility of designing a polarized SRF gun, based on high-average current GaAs photocathodes technology designed for ERLs [4].

Operation in the SRF gun environment at 1.8 K imposes additional requirements on photocathodes. Of these, the most critical is time response which should not exceed 10% of the gun RF period, this being 77 ps for 1.3 GHz. The active layer thickness in highly-polarized superlattices does not exceed 100 nm, so it is possible that their response time will not exceed this value. Another critical photocathode parameter is thermal emittance. Experiments comparing the thermal energy of GaAs at room and liquid nitrogen temperatures have shown that thermal emittance is essentially defined by the level of electron affinity, with a poor dependence on temperature. It is critical that once moved into the gun, photocathodes should not introduce additional loss mechanisms in the SRF cavity. In addition, they must not pollute superconductive surfaces with caesium used for photocathode activation.

In order to emit polarized electrons, the photocathode surface is activated to a negative electron affinity (NEA) state in a dedicated photocathode preparation facility (PPF). In DC guns, the PPF is permanently connected to the gun chamber, and photocathodes are transferred into and out of the gun with a manipulator through a gate valve. Once activated, the NEA surface is extremely sensitive to oxygen-containing species such as O₂, H₂O, CO₂ etc., so XHV conditions should be maintained at all times during photocathode transportation. This implies that the gun should be cooled to cryogenic temperatures before photocathode load. The photocathode should also be cooled to the temperature of liquid nitrogen (or lower) before load into the gun, thus posing some extremely challenging demands in the design of the photocathode receptacle. For the (S)RF guns operational at the moment, photocathodes are prepared in PPFs which are not connected to the gun, so photocathodes are transferred in a transport vessel. In this article we consider both possible design approaches for photocathode preparation and load with and without use of transport vessel.

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PSI is aiming to construct an X-ray Free Electron laser at 1 Å, which should operate before the end of the decade [1]. The core of the machine is an RF photogun, which should accelerate a 200 pC electron bunch produced by a metal cathode. The electrons are generated by a Ti:Sapphire laser frequency tripled to 266 nm. A 250 MeV injector with an RF photogun using a Cu photocathode has been built to prove the SwissFEL concept. We will present the thermal emittance and quantum efficiency (QE) of the injector cathode obtained during its operation and compare them with results obtained from a combined diode-RF gun [2-3]. In parallel with the injector operation, a program on cathode testing is ongoing. Its aim is to investigate potential metal cathodes with higher QE like Mg or Al-Li alloy and low thermal emittance. We will show the QE dependence vs. laser wavelength for non-mirror Al and Mg (figure 1) and mirror-finish Cu samples using ps UV laser pulse and the effect of cleaning of an 8mm diameter laser beam (ν = 200 kHz; λ=355 nm, P=120 mW) on Mg samples (figure 1).

Figure 1: Wavelength dependency of the quantum efficiency for a polished but non-mirror like Mg cathode irradiated by a 1 ps, 1 kHz, Ti-sapphire laser

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