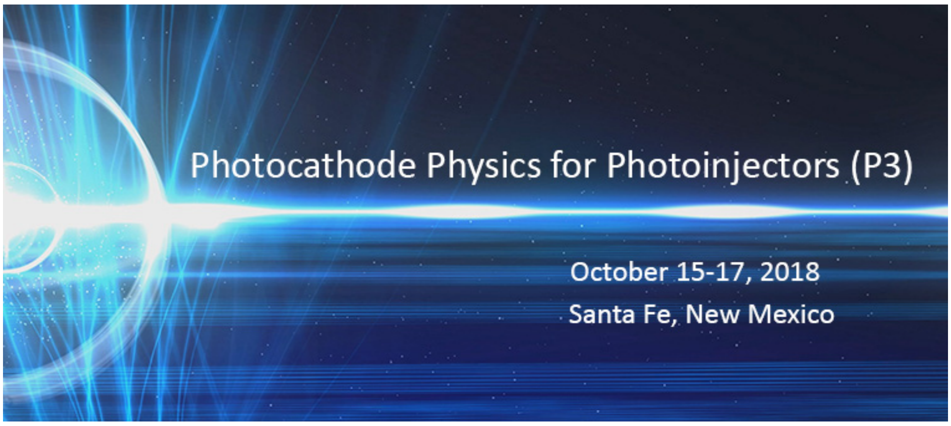
Photocathode Physics for Photoinjectors 2018

Monday, October 15, 2018 - Wednesday, October 17, 2018

Hilton-Buffalo Thunder



Book of Abstracts

Contents

Session 1 / 2

Overview of Photocathode Physics

Session 2 / 4

Review of requirements and challenges for UED/UEM

Ultrafast electron scattering (UES), including diffraction, imaging, and energy-loss spectroscopy, are emerging new techniques for visualizing dynamics of matter at atomic levels. These rapidly advancing new developments have generated scientific outcomes with broad and profound impacts in quantum material, solar energy conversion, chemical reaction, high energy density physics, and biology, among many other research fields. The capabilities of UES instruments are ultimately determined by the brightness of electron beams as well as how precisely we can shape the beams in spatial, angular, temporal, and energy domains. The photoemission process, which dictates how electron beams are generated in six-dimensional phase space at the very beginning, plays a critical role in defining the subsequent evolution and necessary manipulation of beams and hence the overall machine performances. In this talk, I will try to discuss the requirements of the photocathodes by making the connection to the required electron beam parameters for UES applications. Challenges and new R&D opportunities of photocathodes toward future UES instruments will also be discussed.

Session 2 / 5

Spatio-temporal quantum limits for UED/UEM from MTE

Photocathode physics plays a critical role in the formation of space and time resolution in time resolved stroboscopic electron scattering experiments like electron diffraction, microscopy, and spectroscopy. As effective photoemission temperatures approach single meV values, it is feasible to consider sources for <= 1 electron per pulse which approach the uncertainty principle emittance limit, having comparable or better transverse emittance and energy spread as compared to cold field emission tip sources. In this talk, I will give straightforward examples of how such sources might be realized experimentally, as well as simulations of electron scattering application examples where the current state of the art in low photoemission effective temperature can yield unprecedented temporal resolution in electron diffraction and microscopy.

Session 2 / 6

< 10 meV MTE from Cu

The brightness of electron beams is limited by the smallest possible mean transverse energy (MTE) of electrons emitted from the photocathode. In this talk, I will show the various factors that limit MTE and show how by minimizing each of these factors we obtained a record low MTE of 6 meV from the (100) surface of Cu. I will also describe the instrumentation developed to measure such a small MTE. Finally, I will talk about the various ongoing efforts within the Center for Bright Beams to obtain such small MTE along with large charge densities to increase the brightness of electron beams by two orders of magnitude.

Session 2 / 7

Laser-triggered nano-emitters for femtosecond pulse generation from flat surfaces

One way of increasing the electron beam brightness in radiofrequency electron guns is by shrinking the photoemission area. Unfortunately, sharp tips are not good candidates to be used in high field RF environments due to field emission and stability issues.
We use Surface Plasmon Polariton wave interference to produce sub-micrometer emission areas. Radially symmetric nano-structured patterns are used to absorb laser light, launch SPPs on the surface of a plasmonic material and concentrate the intensity into sub-wavelength areas, where the large enhancement factor favors electron emission by multi-photon absorption. We have fabricated several sources with electron-beam lithography and focused-ion beam milling. We also spatially mapped the plasmonic resonance modes in these sources with Cathodoluminescence Spectro-microscopy, observing the resonant mode we designed for an 800 nm laser source and studying the influence of fabrication. We will discuss the source design, simulation and measurement of the plasmonic resonance, and current progress on testing their photoemission.

Session 2 / 10

Engineered Nanodiamond Photocathodes

n-type ultra-nano-crystalline diamond (n-UNCD, a synthetic polycrystalline, a mix of sp3 and sp2 phases, diamond
with semimetallic electron conductivity) has emerged as a negative electron a±nity (NEA) photocathode platform
that can be engineered toward a speci¯c targeted application. This presentation summarizes our experimental results
related to (i) quantum e±ciency (QE); (ii) ruggedness/lifetime; (iii) emittance/mean transverse energy (MTE); (iv)
time response of n-UNCD photocathode structures.
NEA can be induced on UNCD via surface treatment in hydrogen. Such NEA is stable against air exposure for
extended time. The combination of air resistant NEA and n-doping is the key to engineer low work function. Nitrogen-
doped UNCD, (N)UNCD, processed in H2 plasma demonstrated QE »0.1% at 254 nm and enhanced photoelectric
response at wavelengths up to 400 nm. Recently, it was experimentally established that submicron (N)UNCD pho-
tocathodes feature optical interference. This e®ect suggests strong optical density enhancement on the photocathode
surface and minimized delay in photoelectron emission (potentially prompt response time) and points out a °exible
path to engineer optical response window of the photocathode to further enhance QE.
Lastly, we measured MTE of a (N)UNCD cathode that was found to be .250 meV with weak dependence on the
photon energy. We will outline a concept that link together our experimental results with the graphitic patch model
according to which electrons in UNCD are emitted from sp2 graphitic grain boundaries, implying that the e®ective
mass of emitted electrons is ¼1/18 of the free electron mass and explaining weak MTE dependence on the excess
energy of the primary photons. This fact together with nanometer surface roughness could pave a way to a small
intrinsic emittance.

Session 2 / 11

Workshop Discussion

Session 3 / 12

Requirements and Challenges of Photocathodes for Free Electron Laser Applications

Photocathodes are the source of electrons for nearly all modern accelerators. They are widely used due to their flexibility to meet a broad variety of beam requirements and are particularly important for machines relying on high-brightness beams. In this presentation, we will investigate the requirements and challenges for photocathodes used in linac-driven free electron lasers. The cathode requirements for an FEL can cover a wide-range, depending on the desired average/peak power and the laser wavelength. To meet the requirements, photocathodes have to be selected that generate beams with the emittance, bunch charge, and temporal response to match into the undulators appropriately, and at the same time maintain long operational lifetime. We will discuss the important beam properties and requirements for FELs, how various photocathode are used to meet these needs, and take a look at future directions.

Session 7 / 13

Photocathodes for Swiss FEL

After successful tests of Cs2Te photocathodes at the SwissFEL Test Injector Facility (SITF) in 2014, decision was made to use these types of semiconductor photocathodes for SwissFEL operation, rather than copper. Since SwissFEL first beam in winter 2016, only two photocathodes were used. Quantum efficiency (QE) degradation of 40 % has been observed after 6 months of operation or after 15 mC of charge extraction in a 5.0e-10 mbar pressure environment and with 100 MV/m peak electric field. Bunch slice emittance is similar to what it was for copper cathodes. The slower response time of Cs2Te also helps to smooth out the noise ripple of the illuminating laser profile. However, it is still not clear how much it affects the microbunching instabilities at Swiss FEL. Even if Cs2Te is compatible with Swiss FEL operation, a new deposition chamber has been assembled to produce Cs3Sb coatings, capable of emitting electron bunches under illumination with green laser light. Indeed laser shaping (longitudinally and transversally) is easier in the visible wavelength range providing potential improvements in the electron beam quality. The lifetime in the lab of first samples were however still much too short.

Session 3 / 14

In Pursuit of the Narrow Cone; Prospects for 2-photon and n-type Photoemission from Al(x)Ga(1-x)N

Although low effective mass semiconductors offer the promise of photocathodes with subthermal mean transverse energy (MTE), the effect has never been observed in practice. One proposed explanation for this is that the cesium coating used on many photocathodes, while decreasing their work function, increases the MTE of the photoemitted electrons. In this talk, we discuss the ongoing effort at Cornell to observe cesium-free photoemission from AlGaN, a low effective mass semiconductor,

through two novel techniques. In the first, n-type doping is used to populate the conduction band with electrons that may be emitted with an appropriately energetic photon. Similarly, in the second technique an initial pump pulse of photons is used to excite electrons from the valence band to the conduction band where they may be emitted using a probe pulse at a later time.

Session 6 / 15

Measurements of physical and chemical roughness of alkali-antimonides

Alkali antimonide photocathodes have attractive properties, such as low-emittance and high quantum efficiency, which makes them excellent candidates for high-brightness electron sources. Less attractively, these materials are highly reactive and require ultra-high vacuum conditions to prevent irreversible oxidation, which precludes ex-situ characterization. Such limitations have stymied a complete understanding of the effects of chemical and morphological heterogeneity on performance. In this talk, I will discuss recent research in the Center for Bright Beams, a NSF-funded Science and Technology Center (STC), on the growth, transfer, and surface characterization of highly reactive cesium antimonide photocathodes in vacuo. The chemical heterogeneity of the photocathodes was studied using x-ray photoemission spectroscopy (XPS), which showed that the near-surface composition is a mixture of stoichiometric cesium antimonide and metallic antimony with a cesium-rich surface layer. Scanning tunneling microscopy (STM) shows rough surfaces with atomic height steps in some domains. On-going efforts to measure spatially-resolved quantum efficiency using a coaxial STM tip will be discussed.

Session 3 / 16

Increase of intrinsic emittance induced by multiphoton photoemission from copper cathodes illuminated by femtosecond laser pulses

Electron sources driven by femtosecond laser have important applications in many aspects, and the research about the intrinsic emittance is becoming more and more crucial. The intrinsic emittance of polycrystalline copper cathode, which was illuminated by femtosecond pulses (FWHM of the pulse duration was about 100 fs) with photon energies above and below the work function, was measured with an extremely low bunch charge (single-electron pulses) based on free expansion method. A minimum emittance was obtained at the photon energy very close to the effective work function of the cathode. When the photon energy decreased below the effective work function, emittance increased rather than decreased or flattened out to a constant. By investigating the dependence of photocurrent density on the incident laser intensity, we found the emission excited by pulsed photons with sub-work-function energies contained two-photon photoemission. In addition, the portion of two-photon photoemission current increased with the reduction of photon energy. We attributed the increase of emittance to the effect of two-photon photoemission. This work shows that conventional method of reducing the photon energy of excited light source to approach the room temperature limit of the intrinsic emittance may be infeasible for femtosecond laser. There would be an optimized photon energy value near the work function to obtain the lowest emittance for pulsed laser pumped photocathode.

Session 3 / 17

Workshop Discussion

Session 4 / 19

Recent R&D Endeavor on Polarized Photocathodes at JLab

Many physics experiments at Jlab require high current polarized electron beams and we have been actively engaged in research and development that are intended to improve the existing photocathode performance as well as exploring new photocathodes with the goal to improve the operation capability and the quality of accelerator facilities. Since last P3 workshop, some interesting studies have been carried out at JLab and I will present an update on the activities and share our experience in my talk. While I will be focused on new topics such as nano-structured photocathodes, electrons with orbital angular momentum from a GaAs photocathode, etc., I will also briefly report on recent work on DBR photocathodes, SSL GaAsSb/AlGaAs photocathodes and high current test with conventional GaAs/GaAsP photocathodes.

Session 4 / 20

Operation of Jefferson Lab Polarized Electron Sources

This contribution describes Jefferson Lab polarized electron sources where the world record of high current polarized electron beam was delivered. Polarized GaAs Superlattice photoguns with long lifetime represents a significant challenge for proposed facilities that must operate in excess of tens of mA of polarized average current. Damage due to ion bombardment is the dominant mechanism that reduces photocathode yield. Highlights of R&D to improve the performance of polarized electron sources and prolong the lifetime of strained-superlattice GaAs are presented.

Session 4 / 21

Experimental evaluation and Monte Carlo simulation of the thin GaAs photocathodes

The quantum efficiency (QE) spectral response of five thin GaAs photocathodes with different active layer thickness and dopant density was experimentally evaluated, and to better appreciate the experimental results, a Monte Carlo model was developed to simulate electron transport and emission. The simulation accurately predicts expected behavior, namely QE is enhanced for thicker GaAs photocathodes and for higher dopant concentrations. More significantly, the simulation predicts that electrons excited to the conduction band of the GaAs can be reflected by the AlGaAs barrier layer and contribute to enhanced QE. The simulation also predicts that electrons in conduction band suffer more scattering for thicker GaAs photocathodes and for higher dopant concentration, leading to longer response time. This Monte Carlo model may improve our understanding of the performance of more complicated GaAs-based structures composed of many thin layers.

Session 4 / 23

Next generation robust polarization photocathodes

Session 4 / 24

Semiconductor photocathode in a transmission electron microscope

We have demonstrated that the SPTEM can provide both TEM images and diffraction patterns. The TEM images were obtained at a spatial resolution of 1 nm with a 30-kV acceleration voltage. The apparatus has an electron beam energy width below 114-meV in the TEM without any monochrometors. The energy width indicates that the temporal coherence is approximately 34 fs. The brightness is measured by taking a spot size and a convergent angle on an image plane. The measured brightness is approximately 4 × 107 A cm−2 sr−1 at 30-keV beam energy with a polarization of 82% and a drive-laser power of 800 kW/cm2 on the photocathode. The brightness for 200-kV beam energy is estimated to be 3 × 108 A cm−2 sr−1, which is converted using a Lorentz factor. The order of the brightness is sufficient for an interference experiment. Therefore, we could demonstrate interference fringes of a spin-polarized electron beam using a newly installed biprism. The resulting electron beam exhibits a long coherence length owing to its low initial emittance of 2.6 nm rad, which can generate interference fringes representative of a first-order correlation using an electron biprism. These results indicate that the SPTEM can provide enough coherence in both the lateral and longitudinal directions even if the semiconductor photocathode is used for an electron emitter.

Session 4 / 25

Spin polarized low energy electron microscopy: 3D vector-magnetometry and workfunction mapping

Using spin-polarized electron beams in a low energy electron microscope provides opportunities to measure microscopic spin structures of domain walls and related spin textures, as SPLEEM permits imaging the vector orientation of the magnetization with high spatial- and angular resolution. This talk outlines key principles of relevant magnetic properties and opportunities in photocathode and electron source design. LEEM also provides interesting ways to image electronic properties such as workfunction with high spatial and energy resolution, which is useful for cathode research relevant to the P3 community.

Session 4 / 27

Workshop Discussion

Session 5 / 28

Review of requirements and challenges

Session 5 / 29

Synthesis and x-ray characterization of Cesium Telluride photocathodes

Cesium telluride (CsTe) photocathodes has been the first hand choice for electron sources by worldwide accelerators, due to its high quantum yield, stable performance at complicated operation environment and long lifetime. In this work we compared the results of in situ x-ray characterization of the traditional sequential and co-evaporation growth of CsTe photocathodes. We were able to achieve ~2nm surface roughness, high crystallinity and a quantum efficacy of 18 % at 266 nm wavelength.

Session 5 / 30

Cathode thermal decomposition

Session 5 / 31

Manufacturing and Packaging of Reliable Bialkali Photocathodes via Sputtering

The future upgrade at Relativistic Heavy Ion Collider (RHIC) calls for the implementation of electron cooling strategies, where ultra-cold electron beams will be generated by photoinjectors. To meet this requirement, the photocathode in the injector is required to deliver a high average current of 50 mA. Bialkali cathodes can deliver the required current, however owing to their short lifetime, they have to be replaced daily. Hence, there is a need for manufacturing process where photocathodes can be produced reliable and supplied in sufficient quantity to cater to the RHIC needs.
This challenge is being addressed by adopting two key strategies- first, by sputter deposition, a new method to grow bialkali cathodes using a pre-fabricated bulk target; and second, by in vacuo sealing and unsealing of the cathodes that lends to a "packaged" cathode-in-a-cartridge. Recent results demonstrate the growth of more than 20 photocathodes from a pre-fabricated K2CsSb sputter targets measuring 2" in diameter and these cathodes exhibit a reproducible QE of ~20% at 220 nm and ~3% at 530 nm. The cathode sealing and unsealing techniques have been demonstrated
The sputter-growth permit facile, reliable and economic production of cathodes, which can be stockpiled for the frequent use at RHIC operation.

Session 5 / 32

Workshop Discussion

Session 6 / 33

Review of requirements and challenges for holistic cathode design

Session 12: Novel Research and Applications (and concluding discussion) / 34

Femtosecond electron beam emission from ultra-high field laser illumination of nano-blade structures

Session 6 / 35

Ultra thin-film coatings and Novel approaches toward Superconducting Photocathodes

We examine the potential of thin surface coatings to increase the QE of Nb while minimizing any additional RF losses. It is found that ultra-thin layers of Cs2Te on Nb, as low as 1.5 nm, still exhibit QE~6%. A phenomenological model of the Nb/Cs2Te bilayer is in good agreement with the measured thickness dependence. We also explore metal overlayers to exploit the superconducting proximity effect. Uniform Mg layers of 10nm increase the QE of Nb by a factor of 10. The addition of 4.0 nm islands leads to a QE enhancement of up to 400 which we attribute to plasmonic effects. There will also be a short discussion on studies of the non-ideal nature of interfaces of MgO/Ag/MgO multilayer structures.

Session 6 / 36

Interference Photocathodes for Enhanced Quantum Efficiency

Interference enhanced, etalon photocathodes are promising due to the potential to enhance quantum efficiency without increasing emittance. This is likely so long as emittance is dominated by the excess energy (ħω-φeff) rather than being thermalization dependent, since the etalon effect does not directly change the band structure of the material. Enhancement occurs both by increasing absorption and by increasing the relative fraction of energy absorbed near the surface. Reflective metal substrates are predicted to have QE enhancement up to 6-fold in comparison to semitransparent substrates such as Si. The enhancement increases for thinner cathodes and energies near threshold. An analytical model, as well as recent experimental results with Cs3Sb on Ag and Si substrates will be shown. Ongoing efforts to more fully model effects such as surface roughness and substrate thickness will also be presented.

Session 6 / 37

Towards photocathodes with elongated lifetimes and high quantum efficiency by passivating with two dimensional materials

Photocathodes are important electron sources for X-ray free electron laser (XFEL) and X-ray energy recovery linacs (XERL), which generate brilliant, ultrafast, and coherent X-rays for exploration of matter with ultrahigh resolutions in both space and time. Quantum efficiency (QE) and operational lifetimes are two of the key figures of merit of photocathodes performance. Whereas alkali-based semiconducting photocathodes display high QE in the visible light spectrum, their lifetimes are shorter than their metallic counterparts due to the sensitivity of alkali-based surfaces to the residual gases in the vacuum chamber. Herein, a novel approach is proposed to protect alkali-based photocathodes with two dimensional (2D) materials. It is found that a monolayer of BN can maintain the QE of semiconducting photocathodes in addition to protecting the surfaces. On the other hand, a monolayer of graphene or molybdenum disulfide (MoS2) suppresses the QE. Analyses of the electronic structure reveal that the induced dipole moments at the interfaces of photocathodes and 2D materials play central roles in affecting the work function of the coated photocathodes, thus their QE.

Session 3 / 38

Ultra-thin two-dimensional crystalline nanoporous coatings as cathode protection layers

Operational lifetime of cathodes for high brightness electron sources are often limited by three factors – ion bombardment of the cathode, chemical contamination and thermal decomposition. The recent development of 0.5 nm thick crystalline two-dimensional nanoporous silica and aluminosilicate structures has the potential of reducing these detrimental effects and thus significantly increase the cathode lifetime during operation. This talk will describe these new materials and the opportunities they offer as ultra-thin protection layers.

Session 6 / 39

Workshop Discussion

Session 7 / 40

Space-charge dominated photoemission in the photocathode RF gun at PITZ

The Photo Injector Test facility at DESY in Zeuthen (PITZ) was built to develop and optimize high brightness electron sources for short wavelength, SC linac driven free electron lasers like FLASH and the European XFEL. High quantum-efficiency Cs2Te photocathodes are driven by a UV laser to produce up to 5 nC charge per single electron bunch in the PITZ gun. Experimental characterization of the Cs2Te photocathodes and the photoemission processes in the gun taking into accounts multiple machine parameters delivers a standard working point in the space-charge dominated regime. Operating the facility at the obtained working point renders an optimized transverse normalized emittance of a 1 nC electron bunch at the injector exit for the European XFEL. The talk will give an overview about the PITZ facility and the experimental and numerical studies of space-charge dominated photoemission using Cs2Te photocathodes. In addition, an experimental observation of microseconds-order spiky intra electron bunch train photoemission from a fresh Cs2Te photocathode at FLASH will be shown and corresponding analysis at PITZ will be presented.

Session 7 / 41

A new photocathode R&D program at the Argonne Wakefield Accelerator facility: photocathode fabrication chamber and higher-power testing with a 1.3 GHz NCRF injector test stand

A New Photocathode R&D program at the Argonne Wakefield Accelerator facility: photocathode fabrication chamber and high-power testing with a 1.3 GHz NCRF injector test stand abstract -> A new program is under development at the Argonne Wakefield Accelerator (AWA) facility to fabricate and test photocathodes. The goal is to provide high quality beams for the in-house structure-based wakefield acceleration program as well as to serve the advanced photocathode community. The AWA houses three independent 1.3 GHz NCRF photocathode guns: the 1.5 cell drive gun, with a cesium telluride cathode, for generating drive bunches with 0.001 − 100 nC single bunch and 600 nC bunch train; the 1.5 cell witness gun, with a magnesium cathode, for generating the low emittance and low charge main beam; and a 0.5 cell high-gradient gun on an injector test stand that is dedicated to cathode studies. The AWA is developing start-to-end photocathode research capabilities, including fabrication of cesium telluride and other semiconductor cathodes using two deposition chambers, in-situ cathode characterization of quantum efficiency and thermal emittance, and ex-situ cathode inspection taking the advantage of the various surface analysis resources inside Argonne. The photocathode R&D program at AWA is flexible and open to collaborators worldwide. Highlights of the nascent photocathode research program at the AWA, plans for future studies and collaborative efforts will be reported on.

Session 7 / 42

The LBNL setup for high brightness electron beams characterization and photocathode testing

We will describe the LBNL experimental setup for high brightness beams production and measurements. The system includes an high repetition rate radiofrequency electron gun (the APEX gun), with 2 beamlines used for Ultrafast Electron Diffraction experiments, beam shaping and characterization.
We are also developing a 30 kV testbed for testing novel photo-emitters, before the high voltage-high energy test on APEX.

Session 3 / 43

Photocathode research at the UCLA Pegasus Laboratory

The Pegasus photoinjector laboratory has a variety of activities related to photocathode technology. In the upcoming months we plan to test the performances of advanced photocathode materials such as alkali antimonide cathodes in the high gradient radiofrequency photoinjector using a recently developed ultrahigh vacuum load-lock chamber. I will also present an update on a different project where a low energy electron beamline in combination with a tunable UV laser source is used to characterize metal cathodes and their response to short pulse excitation.

Session 7 / 46

The photocathode studies for normal conducting RF gun in Tsinghua University

In this talk, we will introduce our recent works in our lab on photocathode physics, including the normal conducting RF gun development, the surface roughness effects, the improved model of photoemission of semiconductors, the two photo-injector beam lines in our lab and their capabilities for the possible experiments.

Session 8 / 48

Bialkali Photocathode performance for electron cooling application operated in DC and SRF guns

Session 8 / 49

Cornell DC cryogun

Many recent efforts to improve the intrinsic emittance of photocathodes have centered on lowering the excess energy of the emitted electrons by using photon energies at or below threshold. However, this comes at the significant expense of quantum efficiency. Thus, for short pulse applications, nonlinear photoemission is a concern, due to the commensurate increase in excess energy in higher order photon processes. Alkali antimonides are an interesting choice to lessen nonlinear effects due to their intrinsically high quantum efficiency. However, they have remained untested under sub-picosecond laser pulses. In this talk, I will present measurements of the non-linearity of photoemission as a function of photon energy from a sodium potassium antimonide photocathode using a ~200 fs laser pulse. These measurements could shine some light on the optimal photon energies to use for minimum intrinsic emittance for ultra-fast electron beams.

Session 8 / 50

Overcoming challenges related to the operation of photocathodes in SRF photoinjectors

The HZB accelerator project bERLinPro (berlin Energy Recovery Linac Prototype) is continuously developing and is aiming for first operation in 2019. The goal of bERLinPro is to demonstrate a superconducting ERL with high current and low emittance. Within this highly complex R&D project a key component has been developed in-house: the photocathode, which is the electron source, and fundamentally defines the beam properties. Cesium-potassium-antimonide (Cs-K-Sb) has been chosen for the photocathode material, because of its high quantum efficiency (QE) in the visible wavelength regime. For the operation of bERLinPro, a dedicated UHV-infrastructure was built to grow and optimize Cs-K-Sb photocathodes, to transport them to the accelerator and finally to exchange the photocathode in the SRF photoinjector. In my talk I will present the method developed for high QE Cs-K-Sb photocathodes growth as well as studies relating to their operation in the SRF-photoinjector.

Session 8 / 51

Jlab magnetized gun

Bunched-beam electron cooling is a key feature of all proposed designs of the future electron-ion collider, and a requirement for achieving the specified collision luminosity. For the Jefferson Lab

Electron Ion Collider (JLEIC), fast cooling of ion beams will be accomplished via so-called 'magnetized cooling' implemented using a recirculator ring that employs an energy recovery linac. In this presentation, we describe the production of magnetized electron beam using a compact 300 kV DC high voltage photogun with an inverted insulator geometry and alkali-antimonide photocathodes. Beam magnetization was assessed using a modest diagnostic beamline that includes YAG view screens for measuring the rotation angle of the electron beamlet passing through a narrow upstream slit. Magnetization characterization including drift emittance were measured for various gun bias voltages and laser spot sizes at the photocathode using 532 nm lasers with DC and RF time structure. With magnetized beam, photocathode lifetime at currents up to 28 mA CW was measured and high bunch charge up to 0.7 nC was demonstrated.

Session 8 / 52

The photocathode research for DC-SRF Photoinjector at Peking University

Session 9 / 54

Review of requirements and challenges

Session 9 / 56

Timing of photoemission and the dielectric response of metallic surfaces

Progress in attosecond science in the past decade has enabled the study of ultrafast electronic processes with unprecedented temporal resolution [1]. We extended an interferometric two-photon technique named RABBITT [2] based on attosecond XUV pump pulses and a phase-matched IR probe
field from gas phase to solid surfaces to study the dynamics of the photoelectric effect [3].
Experiments on the noble metal surfaces Ag(111) and Au(111) revealed a strong energy
dependence of the delays for photoemission from the d-valence band [3]. The origin of photoemission
delays in solid surfaces has been the subject of numerous theoretical investigations and initial vs. final
state effects have been discussed heavily. Our experiments were sensitive for final state effects only and will be discussed in terms of final state band structure and electron propagation.
Interpretation of the observed delays requires a precise model of the probe field distribution at the surface. The RABBITT technique was used in a similar experiment to sample the IR field distribution on a Cu(111) surface [4]. Finally, I will show how such techniques can be used to study the effective field of low-frequency THz pulses at metal surfaces and nanostructures [5].

Session 9 / 57

Perspectives on Alkali Antimonide Semiconductors from Density-Functional Theory

In calculating materials properties, a density-functional theory (DFT) has come to represent many functional theories, as well as many-body concepts that go beyond ground-state and density-dependent properties. The average practitioner should be aware of the complexion of DFT. We will outline the modern usage of DFT and its applicability to Alkali Antimonides; specifically, the density of states, index of refraction, reflectivity and other relevant parameters for photoemission models are calculated. As usual, no DFT works very well without interface with experimenters, so we summarize what we have learned about these materials from the existing literature and ask what needs to be determined through experiment.

Session 9 / 58

Band Structure Interpretation of Mo(100) and W(100) Spectral Emission Properties

Measurements of the spectral dependence of the mean transverse energy (MTE) from single crystal Mo(100) and W(100) photocathodes display a non-uniform increase with excess photoemission energy. The observed behavior is attributed to the bulk electronic band structure of the emitting states in the Γ-H direction of these body-centered cubic (bcc) metal crystals; specifically, the influence of the well-known 'lens' in the band structure about the (100) emission direction. Differences in the emission characteristics of the two photocathode materials are explained by the atomic number increase from Mo to W which requires relativistic effects to be included in the DFT-based electronic structure calculations for Tungsten.
The spectral MTE values for both the Mo(100) and W(100) photocathodes were extracted from an extended analytical Gaussian beam propagation simulation of the employed solenoid scan technique that uses a 3.0-5.3eV (235-410nm) laser-based, tunable UV radiation source. The experimental data are compared to simulations of one-step photoemission using an exact quantum solution to transmission through and over a triangular barrier evaluated by R.G. Forbes and H.B. Deane [Proc. R. Soc. A 467, 2927 (2011)]. This analytical solution has been extended into the transverse dimension, using conservation of transverse momentum in electron emission, to include parabolic electronic bands with cylindrical symmetry; that is, with a longitudinal effective mass mz differing from the transverse effective mass mT isotropic in the plane of the crystal emission face. In addition to including the local density of the emitting states (multiplied by the appropriate Fermi-Dirac population distribution) in the photoemission simulation, the vacuum density of states are also now included; that is, the density of the recipient states for the emitted electron. In agreement with this emission analysis, the measured spectral dependence of the quantum efficiency (QE) for both single-crystal metal photocathodes does not follow the Fowler-DuBridge quadratic dependence with excess photoemission energy – an effect directly related to the influence of both the local density of states of the emitting electronic bands and the vacuum density of states.

Session 9 / 59

Emission models and beam dynamics for diamond emitters in a compact source of high brightness beams

Many applications, such as compact accelerators and electron microscopy, demand high brightness electron beams with small source size and ultra-low-emittance. Diamond emitters manufactured from the semiconductor process can be employed as such a compact beam source. The micron-scale pyramid structure of the emitter allows enhancement of the external field compared to that at the substrate, leading to emission with small beam size. We investigate the dependence of the field enhancement on the shape of the emitter and the resulting emission characteristic. The beam dynamics are simulated with the LSP PIC code for extraction of the macroscopic observables, such as the beam size and divergence. To account for the semiconductor

charge transport in the bulk material and the tunnelling through the surface, a first principle semi-classical
Monte-Carlo (MC) emission model is developed for the diamond pyramid. A nano-scale
tip that may be present on the pyramid resulting from its fabrication process can further enhance external fields and beam emission, as well as introduces electronic structure size quantization affecting the transport and tunnelling processes within the tip. These phenomena are accounted for in our newly developed nanowire emission model.

Session 10 / 63

Simulating Quantum Efficiency of Polarized Photocathodes

Abstract

Obtaining high efficiency of polarized electron sources is a priority task, especially for the upcoming Electron-Ion Collider to be able to reach the luminosity needed to reach its physics goals [1].
In this presentation, we review several proposed methods and related simulations aimed at enhancing quantum efficiency (QE) of polarized GaAs photocathodes. Among recent significant developments is a Monte Carlo solution to the Boltzmann transport equation that also includes spin de-polarization mechanisms and was able to describe measured anti-correlation between QE and spin polarization [2]. Another path toward high-efficiency polarized photocathodes was predicted through COMSOL Multiphysics simulations that included an important property of piezoelectric fields in GaAs, namely, suppression of electron-hole recombination at the photocathode surface [3]. The piezoelectric fields were due to generation of surface acoustic waves in the photocathode, leading to predicted enhancement of QE, while simultaneously extending spin lifetimes through reduced electron-hole interaction.
In a further development, we consider nanostructured GaAs photocathodes for enhanced QE and ion damage tolerance. Recent results show Mie resonant arrays of nanopillars improve optical absorptivity of GaAs, but emission can occur simultaneously from nanopillar faces or walls with mixed effects on QE, lifetime, polarization, and mean transverse energy. We anticipate application of the above Monte Carlo solution to the 3D structure of a nanopillar array to probe emission effects.

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Session 10 / 64

Recent development on the modeling of laser induced electron emission

Laser induced electron emission is important to the development of novel plasma and vacuum devices [1, 2],
compact electromagnetic radiation sources and accelerators, and time-resolved electron microscope. The rapid

development in nanotechnology and ultrafast laser optics has brought great opportunities to control electron
emission at ultrashort spatiotemporal scales and offers unprecedented scientific advances. This talk summarizes
recent development on the modeling of ultrafast electron emission, due to the arbitrary combination of a DC electric
field and a laser field [3]. Our exact solution is valid for general laser frequency and metal properties (work function
and Fermi level). Various emission mechanisms, including multiphoton absorption or emission, optical or dc field
emission, single-photon induced over-barrier emission, and various combinations of them, are all included in a
single formulation. Most recently, the theory has been extended to electron emission due to two-color laser fields,
where the effects of laser intensities, relative phase delay, and harmonic numbers are studied. Also highlighted are
recent modeling works on electron emission in vacuum geometric diodes [4] and field emission from carbon
nanotube (CNT) fibers in a finite cathode-anode gap [5]. Comparison with recent experiments will be discussed.

Session 10 / 65

Modeling quantum yield, emittance and surface roughness effects from metallic photocathodes

The thermal limit of the intrinsic emittance of photocathodes represents an important property to measure experimentally and to understand theoretically. Detailed measurements of intrinsic emittance have become possible in momentatron experiments. Moreover, recent developments in material design have allowed growing photoemissive layers with controlled surface roughness. Although analytical formulations of the effects of roughness have been developed, a full theoretical model and experimental verification are lacking. We aim to bridge this gap by developing realistic models for different materials in the three-dimensional VSim particle-in-cell code. We have recently implemented modeling of electron photo-excitation, transport, and emission from photoemissive layers grown on a substrate. We report results from simulations with these models on electron emission from antimony and gold. We consider effects due to surface roughness, density of states, photoemissive layer thickness, and how they affect the spectral response of quantum yield and intrinsic emittance.

Session 10 / 67

The Modeling of Delayed Photo-Emission Processes in PIC Codes

The high quantum efficiency of modern cesiated Semiconductor photocathodes is a consequence of the
deeper penetration depth of the drive laser, a smaller (or absent) surface barrier, and - critically - the tendency of the dominant scattering mechanism during electron transport to the surface to be less effective at draining the initial energy of the photoexcited electron. As a consequence, a time delay exists between when groups of electrons are photoexcited and when they are emitted. The present work develops a theoretical model that divides the photoexcited electrons into an unscattered (”Shell”) and scattered (”Sphere”) groups and evaluates the delayed emission characteristics for each. The

emission algorithms are incorporated into Particle tracking codes (Particle-in-Cell and meshless codes)
that are able to characterize the consequences of delayed emission on current oscillations, emittance growth, space charge effects, and off-peak emission. These effects are increasingly important when the
pulse width of the drive laser is very short and the active cathode region very small, as for x-ray Free Electron Lasers. Lastly, complications to the emission model due to surface roughness effects, and emission delays due to electrons with a few to many scattering interactions, are generalizations of the
methodologies under development for which the interaction with space charge forces is particularly acute and consequential, but for which any prediction of effects must be obtained through simulation.
The development of a predictive time-dependent photoemission model incorporating non-prompt emission effects and submicron geometric effects, the development of an emission library for use by third party codes, and its insertion into an advanced beam optics codes such as the MICHELLE code is
presented.

Session 10 / 68

Predictive QE Models for PIC Codes Using DFT, TMA, Delay Models, and Optical Models

High brightness photo-generated electron bunches for next generation and x-ray FEL's and light sources rely on particle-in-cell codes used for their modeling and design. The codes in turn require predictive and accurate models of photocathode yield, emittance, emission promptness and beam characteristics based on accurate material and environmental parameters, but in a but in a manner that does not computationally burden beam optics codes. In the present talk, three levels of theory and modeling are described ranging from existing models using simple and/or empirical input to models under development relying on advanced materials physics techniques.

1. Basic[1]: how a simple Fowler-DuBridge 1D photoemission model results from the same theory giving rise to thermal and field emission models and how a Moments-based distribution function approach gives yield and emittance using empirical optical and material parameters in a no-scattering approximation.
2. Modifications[2,3,4]: how transmission probabilities for triangular barriers are included; how scattering effects and delayed emission effects modify the emitted bunch and result in emission tails governed by the number of scattering events and the energy loss associated with them; and how a Lorentz-Drude model for metals allows optical constants such as reflectivity and penetration depth to be found for arbitrary wavelengths.
3. Augmentations[5,6]: How Density Functional Theory simulations are incorporated for the prediction of density of states, hyperbolic dispersion relations, and optical constants; how optical parameters from DFT results provide input to Lorentz-Drude (metal) and Adachi (semiconductor) models; how Airy function Transfer Matrix Approaches are used to treat resonant and reflectionless barrier and well structures and heterostructures; how Point Charge Models are used to describe surface roughness and shielding effects for random and periodic array surfaces.

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Session 11 / 70

The accelerator on a chip with a special focus on source requirements

Dielectrics at optical frequencies withstand fields up to two orders of magnitude larger than metal cavities of conventional particle accelerators at microwave frequencies. Making use of the advances in nanofabrication and ultrafast lasers, extremely compact accelerating structures can be fabricated on chip including waveguides for laser power delivery. Acceleration [1-3], deflection [3] and focusing [4] of electrons have been experimentally shown and pave the way for an all-optical particle accelerator on a chip. The evanescent character of the accelerating mode requires nanometer sized electron beams and low divergence is needed to accelerate over long distances. Confirmed by simulations, an emittance of 100 pm rad is needed to accelerate more than 50% of the electrons from 83 keV to 1 MeV in 5 mm distance [5]. To achieve sufficiently high field strengths on the order of 1 GV/m without damaging the structures, sub-picosecond laser pulses are typically used. The electron bunch duration needs to be even shorter than the laser pulses to capture the whole charge. To meet these challenging specifications without sacrificing most of the bunch charge, we explore different photocathodes like silicon, tungsten, diamond and LaB6 nanotips and various coatings on the search for a compact electron source with high brightness. As space charge effects eventually limit the bunch charge of every electron source, we also investigate emitter arrays to increase the average current achievable with a dielectric laser accelerator.
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Session 11 / 71

Generation of attosecond electron pulses by inelastic ponderomotive scattering at an optical traveling wave

Author: Martin Kozak[1]

Co-authors: Norbert Schönenberger [2]; Peter Hommelhoff [2]; Timo Eckstein [2]

[1] *Charles University*

[2] *Friedrich-Alexander-Universität Erlangen-Nürnberg*

In this contribution we report on experimental demonstration of generation and detection of attosecond electron pulses. It is reached via inelastic ponderomotive scattering of electrons at an optical

traveling wave formed by two laser pulses at different frequencies. This scheme represents an analogy to the classical Kapitza-Dirac effect [1], in which the electron beam diffracts/reflects at an optical standing wave. In our geometry, the longitudinal component of electron momentum is modulated at difference frequency of the two driving laser fields. We demonstrate a large modulation of the kinetic energy of subrelativistic electrons with initial kinetic energy of 29 keV, achieving a peak acceleration gradient of G=2.2 GV/m (energy gain/travelled distance) [2]. An introduced time-correlated modulation of longitudinal momentum of the electrons leads to a ballistic compression and formation of attosecond electron pulses. The sub-cycle temporal structure of the electron pulse train was characterized via energy streaking using a second phase-controlled travelling wave [3]. Measured spectrograms (spectra as a function of the time delay between the two interactions) and their comparison with numerical calculations allow monitoring the evolution of the electrons' longitudinal phase space distribution.

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Session 11 / 72

Mapping optical properties of semiconductor heterostructures on the nanometer scale

Carefully designed and fabricated semiconductor heterostructures are key to tunable and optimal optoelectronic devices, often enabling ways to overcome the performance bottlenecks defined by imperfections and defects native to the semiconductor crystals. Visualizing structure, corelated with function at the relevant length, time and energy scales remain a key challenge, but also are an enabling tool. Whether used for energy harvesting, light emission or photoemission applications, the identification of the performance limiting defects often requires a combined use of many techniques. Traditionally electron microscopy is used to resolve morphology and structure with atomic resolution, while optical properties are measured with diffraction limited resolution typically defined by the wavelength of the excitation source. Electronic properties, on the other hand, are deduced from device performance characteristics typically on a micron scale. The disparity in resolution length scales between the different methods makes correlating structure with function a key challenge. In my talk I will describe recent developments in efforts to link defect morphology, structure and related changes in electronic properties to macroscopic figures of merit used to quantify device performance. In my talk I will focus on our efforts at the Molecular Foundry to develop a methodology that combines optical, electron and scanning probe spectro-microscopic methods. I'll focus on study of optical properties of light emitting materials aimed at measuring optical properties of buried interfaces with time resolved two photon photoluminescence , as well as the premise of defeating the diffraction limit by use of cathodoluminescence.

Session 11 / 73

Workshop Discussion

Session 6 / 74

Towards adaptive, automated growth of photocathodes

Author: Vitaly Pavlenko[1]

[1] *Los Alamos National Laboratory*

We report on our recent advancements in development of a fully automated growth procedure for alkali antimonide photocathodes. Our goal is to create a capability that allows fabrication of uniform fully stoichiometric alkali antimonide films of any given thickness at sufficiently low substrate temperatures, where the compounds are stable. We show that co-evaporation procedure at low substrate temperatures requires delivery of reactants to the growth surface in precise proportions; otherwise, non-stoichiometric material is produced. For the purposes of process control, we introduce a thickness-independent parameter that reflects photocathode's quality (quality parameter) and can be used to monitor the growth process and provide feedback for flux control algorithms. We demonstrate a technique that allows quasi-continuous acquisition of spectral response characteristics during the growth, which renders the quality parameter. We provide experimental data that indicates feasibility of on-the-fly flux adjustments that are needed to quickly achieve and then maintain the optimum stoichiometry of the film during the growth cycle. We discuss the choice of the flux control algorithms with the emphasis on adaptive control and simultaneous optimization of multiple parameters.

Session 12: Novel Research and Applications (and concluding discussion) / 75

Observations of the femtosecond laser-induced emission from the diamond field emitter tips

We present the results of experimental observation of emission from single diamond field emitter tips when
triggered by an ultra-short laser pulse. Diamond field emitter array (DFEA) cathodes were originally proposed
for applications that require large current densities. DFEAs represent periodic arrays of diamond pyramids with
micron-size dimensions and tips with diameters of the order of tens of nanometers. DFEAs are known to
produce significant currents in field emission regime under direct current (DC) fields and in radio-frequency
(rf) guns. It has been proposed that single diamond tip emitters can be employed for production of small tightly
focused electron beams for dielectric laser accelerators (DLAs) that accelerate particles using the energy of light
produced by infrared lasers. To generate short electron bunches required by DLAs diamond pyramids could
be triggered with a laser. We have recently observed emission produced by a single diamond pyramid when
triggered by a laser at different wavelengths: 256 nm, 512 nm, 1024 nm, and 2020 nm. We have conducted
studies with the goal to understand mechanism of the emission. We clearly observed the change in emission
mechanism when the wavelength changed from 256 nm to 512 nm. We believe that while the emission at 256
nm is a clear photoemission, the emission at longer wavelengths is likely the field emission caused by intense
electric fields of the laser.

Session 12: Novel Research and Applications (and concluding discussion) / 76

Closing the loop between photocathode growth, characterization and emittance measurements: a cryogenic transverse energy meter

Recent research on photocathode materials has focused on the achievement of very low intrinsic emittance. Future research goals require the setting up of a measurement apparatus capable of measuring very low mean transverse energy values, as low as 1 meV. Furthermore, cooling the photocathode to cryogenic temperature is also a way to reduce the intrinsic emittance and to control and study the scattering mechanisms affecting the photoemission process.
At Cornell University we chose to use voltage and solenoid scans to characterize the intrinsic emittance of innovative photocathode materials. We plan to test innovative materials and heterostructures specifically designed to achieve low intrinsic emittance. The instrument needs to be compatible with universal sample holders allowing UHV transfer of sample from the growth system (molecular beam epitaxy or other, in situ ARPES) to surface science characterization chamber (scanning probe microscopy and x-ray photoemission spectroscopy) to the transverse energy meter. The use of a standard sample holder will allow flexibility to access even more growth and UHV analysis instruments. Cooling to temperatures below 10 K is achieved by a low vibration closed cycle cryocooler. All sources of error in the measurement process need to be evaluated in order to ensure that the mean transverse energy of the photoelectrons can be measured with the required accuracy.

Session 12: Novel Research and Applications (and concluding discussion) / 77

Workshop Discussion

Session 1 / 78

Welcome and Overview

The P3 organizing committee is pleased to announce that Los Alamos National Lab will be hosting the next Photocathode Physics for Photoinjectors (P3) Workshop, October 15th-17th 2018. This year's workshop will be the fifth workshop of the extremely successful series that began in 2010 at Brookhaven National Laboratory.

Photocathode research remains a vibrant and critical field for future accelerators. The last few years have seen significant progress in a number of exciting areas such as realization of new photocathode devices, better understanding of physics and material properties related to photoemission, as well as delivering bright, high charge beams from photoinjectors.

This 3-day workshop hosted by Los Alamos National Laboratory will explore the current state of the art in accelerator photocathodes, from both a theoretical and a materials science perspective. We aim to establish directions for future research and identify opportunities for collaboration within the community.

Session 3 / 80

Effects of Chemical and Physical Roughness on MTE

The performance of x-ray light sources, such as free electron lasers, ultrafast electron diffraction systems and ultrafast electron microscopy, is limited by the brightness of the electron beam. Given the improvements in photocathode design and synthesis, the source surface roughness has become a key limiting factor on the intrinsic emittance, specifically the mean transverse energy (MTE), of the electron beam. Here we discuss how measurements of the source's spatially dependent height and surface potential variations can be used to compute the electron beam MTE. Our simulations show the importance of modeling the effects surface physical and chemical roughness simultaneously.

Session 10 / 81

Ab initio many-body calculations of the mean transverse energy for proposed high-brightness photocathode materials

The state of the art in creating next-generation high-brightness electron beams requires that electrons emerge with mean transverse energy (MTE) of ~10 meV or lower. Identification of new, promising materials requires predictive understanding of the physics underlying photoemission. This talk will present our first-principles ab initio solid-state calculations of MTE for a variety of proposed photocathode materials. Within the approximation that the vast majority of photoelectrons come from transitions among the bulk electronic states of the material, our calculations accurately reproduce the experimentally measured MTE as a function of photon energy for emission from PbTe(111), producing results that are significantly more accurate than previous theories [arXiv:1704.00194v1 [physics.acc-ph] (2017)] that underestimate these measured MTEs by a factor of 10–20. Using our new approach, we further find that the MTE from single-crystal Cs3Sb(001) is around 1–10 meV near the emission threshold, without any limitation being placed by the thermal ~ kB T energy scale.

Session 2 / 82

Brightness of nonequilibrium femtosecond photoemission in metallic photocathodes near threshold

Operating photoemission electrons sources with photon energy near the work function has been shown to minimize the intrinsic emittance, but at the cost of several orders of magnitude lowered quantum efficiency. Thus, modern femtosecond photocathode electron sources would require very high intensity laser pulses to extract significant charge, which results in dynamic changes to the electronic distribution of the material during photoemission, giving rise to multiphoton photoemission and electron heating. In this work, we track the occupation function of electrons in time under high intensity laser illumination based on a Boltzmann equation to predict its dynamic effects on the quantum efficiency, mean transverse energy, and emission brightness of metal photocathodes. We find the multiphoton photoemission is significant under high intensity laser illumination resulting in an order of magnitude decrease in achievable brightness.

Session 2 / 83

Computational Screening for New Photocathode Materials

The majority of materials used as photocathodes for accelerators have been discovered through empirical methods. This process is often trial and error, without significant input from computational materials science. We have developed an approach that is heavily informed by computational resources such as density functional theory (DFT), materials databases, and high-throughput techniques to identify potential photocathode materials. We begin by searching the Materials Project database for both synthesized and theoretical compounds. Starting from about 69,000 materials, we apply a set of initial screening criteria: 1) no radioactive elements in the composition, 2) a hull distance ≤50 meV/atom, 3) a bandgap between 0 and 4 eV. This preliminary screening narrows the number of potential materials 38,000. Next, we identify for which of those materials the database contains a calculated electronic band structure (77% of the database) and then determine the curvature of the conduction band minimum and valence band maximum. We select the materials with a curvature corresponding to an effective mass of 0.2 me or less. For the resulting 517 materials, we recalculate the bandstructure with a higher k-point density to obtain more accurate effective masses. Finally, we estimate the MTE of the materials we investigate. First, we look at the possible optical excitation between bands at each k-point in the band structure to better identify the momentum distribution. Following, we look at which electrons are capable of escaping the possible surfaces of the material as opposed to being reflected internally to determine which electrons contribute to the mean transverse energy (MTE). After narrowing our search further with these criteria, we will generate slabs of these materials to identify the work function, electron affinity, and surface states of the potential photocathodes and determine their effect on the emission of electrons. Also, we match the resulting candidate photocathodes to our database of experimental substrates to identify substrates that provide the best crystallographic match, maximizing the chances for successful growth.

Session 7 / 86

XFEL Facilities at Shanghi

In the past decade, X-ray free electron lasers (XFEL) has seen a rapid development in China. The center of the activities is at Shanghai, led by Shanghai Institute of Applied physics (SINAP) of the Chinese Academy of Sciences (CAS). The starting point was a test facility, where state-of-the-art experiments of FEL physics have been conducted. Since then, SINAP has led the effort of successfully building an VUV and a soft X-ray FEL based on room temperature linacs. Recently, an ambitious high-repetition ray hard X-ray FEL project, Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE), is under way. This paper will present materials on these activities, with an emphasis on the on-going project SHINE.

Session 4 / 87

Spin filters based photocathode

Session 8 / 88

Robust Cs2Te and Mg photocathodes in SRF gun at ELBE center successful for CW IR FEL and THz radiation

Quality of photocathodes is one of the critical issues for the stability and reliability of the light source facility. In 2014, SRF gun-I with Cs2Te provided stable electron beams successfully for IR FEL at HZDR [1]. Cs2Te worked in SRF gun for more than one year without degradation. Currently, Mg photocathodes with QE up to 0.5% are applied in SRF Gun II, which is able to generate e- beam with bunch charges up to 200 pC in CW mode with sub-ps bunch length for the high power THz radiation facility for the ELBE users [2].

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Poster Session and Networking Reception, Rooms: Vista A and B / 89

Free-standing bialkali photocathodes using atomically thin substrates

Poster Session and Networking Reception, Rooms: Vista A and B / 90

One-step photoemission simulation: Exact triangular barrier solution with bulk and vacuum electronic states

Poster Session and Networking Reception, Rooms: Vista A and B / 91

First-principles many-body study of the electronic and optical properties of CsK2Sb, a semiconducting material for ultra-bright electron sources

Poster Session and Networking Reception, Rooms: Vista A and B / 92

Eliminating the space charge limit with meta-materials

Poster Session and Networking Reception, Rooms: Vista A and B / 93

Holistic Cathode Design

Poster Session and Networking Reception, Rooms: Vista A and B / 94

Validity of DFT approaches for the prediction of photocathode performance

Poster Session and Networking Reception, Rooms: Vista A and B / 95

Characterization, modeling and simulation of photoemission-based electron sources

Poster Session and Networking Reception, Rooms: Vista A and B / 96

Study of Mean Transverse Energy (MTE) of (N)UNCD with Tunable Laser Source

Poster Session and Networking Reception, Rooms: Vista A and B / 97

Synthesis and characterization of Plasmonic and multilayer structures for uses in Photocathode technologies

Poster Session and Networking Reception, Rooms: Vista A and B / 98

Diamond-tip Cathodes

Poster Session and Networking Reception, Rooms: Vista A and B / 99

Status of DLA experiments and ACHIP

Poster Session and Networking Reception, Rooms: Vista A and B / 100

The possible utility of nanoscale science and related structural mechanisms in optimizing photoemission emittance and quantum efficiency

Poster Session and Networking Reception, Rooms: Vista A and B / 101

High Brightness Beam Generation by Ultrafast Field Emission Gating

Poster Session and Networking Reception, Rooms: Vista A and B / 102

Alkali-based Photocathode Degradation