Materials for Bright Beams Workshop 2025

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Cornell University

Book of Abstracts

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High power RF testing of high-temperature superconductors

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Superconducting materials such as niobium have been extremely useful for accelerator technology but require low temperature operation ~2 K. The development of high temperature superconductors (HTS) is promising due to their operating temperatures being closer to that of liquid nitrogen ~77 K. This work aims to determine the high-power RF performance of these materials at X-band (11.424 GHz). We have tested several types of rare earth barium copper oxide (REBCO) materials, such as films deposited by electron-beam physical vapor deposition, coated conductors soldered to a copper substrate, and solid pucks formed from powder. RF testing was done via a hemispherical TE mode cavity that maximizes the magnetic field and minimizes the electric field on a 2-inch sample region. We will report on surface resistance vs temperature measurements at low and high power,as well as RF testing of a pulse compression cavity lined with REBCO coated conductors.

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Development of a Plasma-Enhanced Chemical Vapor Deposition System for High-Performance SRF Cavities and Thin Film Studies

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Next-generation, thin-film surfaces employing Nb3Sn, NbN, NbTiN, or other compound superconductors are essential for reaching enhanced RF performance levels in SRF cavities. However, optimized, advanced deposition processes are required to enable high-quality films of such materials on large and complex-shaped cavities. For this purpose, Cornell University developed and commissioned a plasma-enhanced chemical vapor deposition (CVD) system that facilitates coating on complicated geometries with a high deposition rate. This system is based on a high-temperature tube furnace with a high-vacuum, gas, and precursor delivery system, and uses plasma to significantly reduce the required processing temperature and promote precursor decomposition. Here we present the commissioned system with all the control aspects and safety considerations addressed and the materials we are interested in growing.

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Molecular beam epitaxial growth of sodium antimonide photocathodes

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The Center for Bright Beams (CBB) at Cornell University has been developing techniques to grow single-crystal photocathodes for electron sources using molecular beam epitaxy (MBE). As a result, the first single-crystal Cs3Sb photocathode was produced, which has shown high quantum efficiency and is expected to have a low mean transverse energy (MTE). Now, other alkali materials are being explored. In this work, we report the epitaxial growth of Na-Sb photocathodes at the PHOtocathode Epitaxy Beam Experiments (PHOEBE) laboratory at Cornell University.The photocathodes were characterized through quantum efficiency (QE) measurements and reflection high-energy electron diffraction (RHEED) patterns collected during growth. The RHEED streaky pattern shows angle dependence, confirming their single-crystal structure. Notably, these Na-Sb photocathodes exhibited a QE exceeding 1% at 400 nm, which is much higher than previous reports on this compound. The possible reasons for this discrepancy are discussed.

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Measurements of Stability Diagrams in the IOTA Ring at Fermilab

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Nonlinear focusing elements enhance the stability of particle beams in high-energy colliders via Landau Damping, a phenomenon that acts through the tune spread these elements introduce. This experiment at Fermilab's Integrable Optics Test Accelerator (IOTA) aims to investigate the influence of nonlinear focusing elements on transverse beam stability by employing a novel method to directly measure the strength of Landau Damping. This method employs an active transverse feedback system as a controlled source of impedance to induce a coherent beam instability. The beam's resulting growth rate can then be used to directly measure the stability diagram, a threshold which maps the system's stability conditions. A proof-of-principle experiment of this measurement method was first explored at the LHC, where the experiment at IOTA aims to map out the entirety of the stability diagram and to obtain the beam distribution function from the stability diagram, a procedure never done before that would enable one to obtain the beam distribution tails. Here we present the experiment's methods and the initial results of stability diagram data analysis, simulations, and plans for further investigation.

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Synthesis of ordered Na-K-Sb photocathodes with oxygen-enhanced quantum efficiency

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Alkali antimonide photocathodes are recognized for their efficacy as photoemissive materials in electron sources. This study investigates the fabrication of ordered films of sodium potassium antimonide via Molecular-Beam Epitaxy (MBE) and the impact of oxygen on their performance at the PHOtocathode Epitaxy Beam Experiments (PHOEBE) laboratory within the Center for Bright Beams (CBB) at Cornell University. We utilized a co-deposition technique to reduce the Mean Transverse Energy (MTE) while maintaining high quantum efficiency (QE). The synthesized photocathodes were characterized in terms of their QE and crystal structure. QE measurements were taken across the 400- to 700-nm wavelength range to determine their utility in the visible light spectrum. Reflection high-energy electron diffraction (RHEED) patterns confirmed the successful growth of ordered crystal structures for the first time on both Si(111, 100) and STO. The oxygen background was also measured before sample growth and was found to correspond to an increase in photocathode QE in samples using Si substrates. An excess of oxygen still proved to decrease photocathode photoemissivity. Conversely, STO substrates showed QE loss with increased oxygen background, likely due to the contributions of the oxygen within the substrate to the photocathode composition. Additionally, not all oxidations proved detrimental to the photocathodes' photoemissivity. A sample grown on STO, under the same conditions as the sample grown on Si, was able to recover the lost QE. The conditions that lead to this increased resistance are being further investigated.

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Status of the CYBORG beamline at UCLA: First Room Temperature Photoelectrons, soon available at 80 K!

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The intrinsic emittance obtained from radio-frequency (RF) photoinjectors is notably reduced by increasing the launch field at the cathode. Moreover, cryogenic RF guns offer the possibility of producing stronger fields, due to the higher bulk conductivity and lower breakdown rate, while reducing the mean transverse energy (MTE) of near-threshold photo electrons. Such devices thus constitute an ideal tool for driving low emittance electron applications like ultra fast electron diffraction (UED) and free electron lasers (FELs). The CYBORG beamline at UCLA is a stepping stone facility meant to investigate the production of very low MTE photoelectrons in cryogenic RF guns. Here we report

on the status of the beamline operation. In particular, we recently produced the first photoelectrons from the C-band RF gun at room temperature and are currently working on the diagnostics that will allow a thorough characterization of such beams. We also discuss some of the technical challenges that we encountered in the process and the ones that we are still addressing.

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Identifying the connections between grain growth and flux expulsion in low RRR niobium SRF cavities

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The SRF community has shown that high temperature annealing can improve the flux expulsion of niobium cavities during cooldown. The required temperature will vary between cavities and different batches of material, typically around 800 C and up to 1000 C. However, for niobium with a low residual resistance ratio (RRR), even 1000 C is not enough to improve its poor flux expulsion. The purpose of this study is to observe the grain growth behavior of low RRR niobium coupons subjected to high temperature annealing to identify the mechanism for improving flux expulsion. We observe that low RRR material experiences less grain growth than high RRR when annealed at the same temperature. We search for the limitations to grain growth in low RRR material and develop a diagnostic based on grain structure to determine the appropriate recipe for good flux expulsion. The results of this study have the potential to unlock a new understanding on SRF materials and enable the next generation of high Q/high gradient surface treatments.

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Investigating Dirac semimetal cadmium arsenide as a potential low-MTE photocathode

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We report on the quantum efficiency (QE) and mean transverse energy (MTE) of photoemitted electrons from cadmium arsenide ($\mathrm{Cd_3As_2}$), a three-dimensional Dirac semimetal (3D DSM) of interest for photocathode applications due to its unique electronic band structure, characterized by a 3D linear dispersion relation at the Fermi energy. Samples were synthesized at the National Renewable Energy Laboratory (NREL) and transferred under ultra-high vacuum to Arizona State University (ASU) for measurement using a photoemission electron microscope (PEEM). The maximum QE was measured to be $3.37 \cdot 10^{-4}$ at 230 nm, and the minimum MTE was 55.8 meV at 250 nm. These findings represent the first reported QE and MTE measurements of $\mathrm{Cd_3As_2}$ and are an important step in evaluating the viability of 3D DSMs as low-MTE photocathodes. Such photocathodes, constrained

to lower MTEs by the electronic band structure, may prove effective in advancing beam brightness in next-generation instruments and techniques.