Small Business Innovation Research/ Small Business Technology Transfer (SBIR/SBTT) Exchange

2023 Principal Investigators' Meeting

August 15-17, 2023

DoubleTree by Hilton Washington D.C. North/Gaithersburg and via Zoom

Office of Nuclear Physics

U.S. DEPARTMENT OF ENERGY | Office of Science

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Abstracts

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Tuesday, August 15 *(Day 1)*

Data Management Solutions for Next-Generation Nuclear Physics

Jeffrey Maggio, SkuTek Instrumentation, NY

Grant Title: Data Management for High Speed, Distributed Data Acquisition

NP SBIR/STTR Topic: Instrumentation

Science is progressively becoming more data driven. Modern physics instrumentation can produce tens of gigabytes of data per second and the DOE is investing in "exascale" computing platforms and 100 Gbps networks to facilitate this next-generation of high data-volume science. New systems are required to utilize these modern tools and provide for data collection and transfer between experimental facilities and High Performance Computing (HPC) centers. SkuTek is developing commercial tools for every stage of this data management pipeline: 10 Gbps streaming digitizers for data collection, collection computers capable of 100 Gbps stream reception, and data transfer computers optimized for use on 100 Gbps scientific networks such as ESNet. These tools build on our 10+ years of experience developing high-performance digitizers and our history of close collaboration with the DOE and individual researchers.

High-Voltage Short-Pulse Generator for Driving Stripline Kickers

James Prager, Eagle Harbor Technologies, Inc., Seattle, WA

Grant Title: High Voltage Pulse Generator for High-Energy Beam Kickers

NP SBIR/STTR Topic: Accelerator

Brookhaven National Laboratory (BNL) requires a short-pulse stripline kicker for the 150 MeV energy recovery LINAC for the Electron Ion Collider. The kicker power system must deliver ±50 kV pulses with pulse widths of less than 38 ns into a 50 Ω load and with low jitter while being highly reliable and robust to potential faults. To address this need, Eagle Harbor Technologies is developing a 50 kV inductive adder that can meet the challenging pulse requirements of BNL. In the Phase I, EHT designed a single inductive adder stage to demonstrate the pulse characteristics including fast rise and fall times, low jitter, and flat-top stability while operating at the full current, 1 kA. In Phase II, EHT is developing the full-scale inductive adder system. EHT will present company information and capabilities, development status and output waveforms, and potential future work to drive down the system cost.

Ultrafast Radiation Hard Gallium Oxide Scintillators

Amlan Datta, CapeSym, Inc., Natick, MA

Grant Title: High Performance Scintillator for Nuclear Physics Research

NP SBIR/STTR Topic: Instrumentation

Under this Phase II program, we are advancing the development of doped gallium oxide (β-Ga_2O_3) scintillators designed for crystal calorimetry in nuclear physics research. These non-hygroscopic and high-density scintillators are extremely radiation hard and robust, with light yields as high as 20 times that of the current state-of-the-art lead tungstate scintillators with ultrafast decay times of around 2 ns. The high-temperature crystals are grown using crucible-free optical float zone technique. We have obtained the highest light yields of 6476 ± 712 photons per MeV and decay times as fast as 0.68 nanoseconds. Additionally, we obtained an excellent energy resolution of 7% for 662 keV gamma rays using β-Ga2O3:Ce crystals. Interestingly, the gamma radiation resistance of β-Ga2O3 crystals was better than that of the leading radiation-hard lead tungstate (PbWO4) crystals. Even after exposure to 2Mrad radiation within a few hours, the scintillation performance remained consistent. This evidence suggests that these β-Ga2O3 scintillators, being cost-effective, high-density, non-hygroscopic, and ultrafast, have the potential to become alternatives in applications demanding extremely high radiation resistance.

Scalable Micron-Sized Flexible Interconnects Enabled by Dielectric-Metal 3D Printing Technology for the Packaging of Large and Segmented Nuclear Physics Detectors

Reza Abbaspour, DUJUD LLC, Atlanta, GA

Grant Title: Scalable Micron-Sized Flexible Interconnects Enabled by Dielectric-Metal 3D Printing Technology for the Packaging of Large and Segmented Nuclear Physics Detectors

NP SBIR/STTR Topic: Electronics

Particle accelerators in operation worldwide contain a substantial number of high precision detectors requiring high performance metrics. Accordingly, ever growing research programs aim to develop more sensitive detectors which will eventually impact other applications in a wide range of areas and industries, from medical diagnostics, automotive, semiconductor manufacturing to particle detector technologies for screening at borders and national security. However, any newly developed detector is extremely challenging (if not impossible) to be integrated with existing infrastructure due to lack of upgradability in large scale electronics found in particle accelerators. Currently, this issue has become more pronounced since the semiconductor industry continuously rolls out denser and smaller transistor nodes every 2 years. This alone limits the performance of said particle accelerators to older generation of electronics.

To address the shortcomings, we are developing a new class of heterogeneously integrated microelectronic systems enabled by DUJUD's proprietary micron-scale 3D flexible interconnects (3FIs) technology. The 3FI technology aims to circumvent permanent wire bonds, tape bonding, and flip-chip bonding in pixel detectors module circuits and therefore facilitates frequent upgrades of these particle detector modules by applying the latest electronic chips to the detectors front-end modules. Moreover, multi-chip modules (MCM) seen in particle detectors which consists of multiple electronic chips will be upgradable at silicon chip level using 3FIs. This Phase II project presents a unique challenge and opportunity to develop a solution that not only eliminates permanents interconnects and hence enabling upgradability but also it reduces high inductive and capacitive parasitics imposed by long wirebonds—hence resulting in lower background noise. This will bring critical improvements for next generation of particle accelerators that demand higher accuracy of particle detection.

Inexpensive Low Noise Fast Switching DC High Voltage Power Supplies

Larry Sadwick, INNOSYS, INC., Salt Lake City, UT

Grant Title: Inexpensive Low Noise Fast Switching DC High Voltage Power Supply

NP SBIR/STTR Topic: Accelerator

There are needs for inexpensive, highly efficient, very low noise power supplies for magnetrons used in scientific experiments and explorations at USA national facilities and labs as well as other domestic and global applications and uses.

For example, there is significant need at DOE facilities for a flexible, extremely efficient, modular, low noise family of magnetron power supplies and related electronics that are scalable in output power. These power supplies offer substantial cost reduction and efficiency boost as inexpensive, adaptable, ultra-efficient, compact form factor power supplies for the scientific community as well as numerous commercial, industrial and military applications.

There is also a need for upgrades to the power supplies and related electronics for high power magnetron systems. This will also significantly increase the up-time, flexibility, innovation and reliability of the magnetron systems while reducing down time and maintenance costs. To address this need, we are investigating and implementing low noise, fast switching, highly efficient power supplies to replace existing power supplies with these state of the art switching power supplies with additional capabilities, features and functions. These switching power supply replacements must be flexible, intelligent and robust enough to meet current and expected future performance standards at National Labs and elsewhere.

Magnetrons tend to wander in frequency, can be noisy and have power level fluctuations and performance non-optimization issues unless locked or synchronized. Synchronization typically requires sophisticated approaches which, if done properly, result in high performance, low cost and highly efficient operation.

Power consumption and energy use in large national labs and facilities and other such facilities can be extremely high. Properly designed power supplies are needed to more fully take advantage of the capabilities of the magnetrons while dramatically reducing the power consumption, increasing the useable up time and significantly reducing maintenance costs and risks. These power supplies also include a number of safety features, functions, safeguards and protections.

To address and meet these needs, we are researching, designing and implementing very low noise switching power supplies that cover the range of 1000s of watts to many hundreds of watts and include filament/heater and additional optional power supplies. The design approach for this DOE SBIR is highly scalable. The filament heater supply can be included/incorporated as part of the overall power supply. The filament heater supply 'waveform' can be programmable to have a soft start ramp up (either linear or step, digital or analog, etc.). These improvements and enhancements advance the performance, flexibility and use of magnetrons including in fundamental, practical and commercial, industrial and defense applications.

High-Density Glass with Tuned Scintillation/Cherenkov Response to Improve Hadron Energy Resolution in Nuclear Physics Experiments

Ian Pegg, Scintilex, LLC, Alexandria, VA

Grant Title: High-Density Glass with Tuned Scintillation/Cherenkov Response to Improve Hadron Energy Resolution in Nuclear Physics Experiments

NP SBIR/STTR Topic: Instrumentation

PI: Tanja Horn, Topic Number and Subtopic Letter: 38.d

Achieving high-quality science at nuclear physics facilities requires the measurement of particle energy with excellent calorimeter energy resolution. Particles that produce electromagnetic showers can be detected with high precision. However, there is a need to improve the energy resolution of hadron calorimetry. This Phase I/II STTR project addresses this need through the development of high-density scintillating glass for calorimeters based on dual readout, one of the most promising methods to achieve better performance for hadronic calorimeters, which consists of the simultaneous measurement of signals produced by Scintillation light (S) and Cherenkov light (C) in the same detector. This method is particularly effective in homogenous calorimeters. Phase I established the fabrication techniques for lab-scale production of high-density scintillating glass (CSGlass) with favorable C/S signal ratio, reproducible optical properties, and dimensions up to ~10 radiation lengths. Measurements with R&D prototypes along with simulations have shown that CSGlass produces measurable Cherenkov and Scintillation light of sufficient intensity that can be separated for physics. The glass samples have excellent optical properties and radiation resistance (no damage up to 1000 Gy electromagnetic and 1015 n/cm2 hadron irradiation, the highest doses tested to date). The present samples have densities up to 5.4 g/cm3, X0=2.2-2.8 cm, and a Moliere radius of 2-3 cm. The feasibility for scaling up the size was demonstrated with the production of 2 x 2 x 40 cm3 blocks. Other CSGlass benefits include reduced time and complexity of manufacturing, resulting in significant cost reduction compared to crystals, and increased flexibility in shape and size for the final detector. Phase II work has demonstrated that signals from CSGlass blocks coupled to state-of-the-art light sensors can be separated into Scintillation and Cherenkov components that are measured simultaneously and separated by various methods including wavelength filtering, timing, and/or by waveform. ML/AI algorithms have been developed and trained for discrimination by waveform. Simulations have been developed to aid materials optimization and to assess projected performance at GeV scale. Production capability for larger numbers of uniform CSGlass block and in different shapes is being developed. Prototypes detectors are being developed to permit more detailed studies of the performance of CSGlass using particle beams. The Phase II program is aligned to make CSGlass blocks available to meet the needs of key nuclear physics experiments, e.g., the large-volume calorimeters for the Electron-Ion Collider (EIC), JLab, or future LHC upgrades, that require high performance scintillator material in large quantities on specific schedules.

Polymer-blend Organic Glass Scintillators for next generation neutron detectors at FRIB

Urmila Shirwadkar, Radiation Monitoring Devices, Inc., MA

Grant Title: Organic Glass Scintillators for Nuclear Physics Experiments

NP SBIR/STTR Topic: Instrumentation

Urmila Shirwadkar[1], Edgar V. van Loef[1], Tawan Jamdee[1], Nathaniel Kaneshige[1], Lakshmi S. Pandian[1], Chuncheng Ji[1], Jarek Glodo[1], Patrick L. Feng[2], Annabelle Belin[2], Ryan Witzke[2], Remco G. T. Zegers[3], Jorge Pereira[3], and Cavan Maher[3]

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[3]Michigan State University, East Lansing, MI 48824, USA

In a collaborative effort, Radiation Monitoring Devices (RMD), Sandia National Laboratory (SNL), and Michigan State University (MSU) are developing polymer-blend Organic Glass Scintillators (OGS) that can be scaled up to large sizes and offer effective fast neutron detection and pulse shape discrimination. Although, pure OGS is highly suitable for this application, it is still brittle for large size and high aspect ratio detectors that must be self-supporting. SNL has shown improvements in strength by adding as little at 3 wt. % of a polymer to OGS. In another variant of the polymer-blend OGS, we are imparting tin compound to the composition for enabling gamma-ray spectroscopy. Experiments were conducted at MSU using polymer-blend OGS, tin-OGS, and compared the results currently used plastic scintillators for neutron detection. Their initial results are promising which show low energy thresholds for PSD with polymer OGS, fast decay, excellent timing properties, and scalability. In the phase-II we have further optimized the composition by concentration studies of the polymer. Recently investigated new tin compounds will be explored in the polymer-blend OGS. In this talk, investigations and scaleup of these novel polymer-blend OGS will be presented.

Compact, low-cost higher order mode absorbers formed by cold spray of metal matrix composites

Paul Carriere, Radiabeam Technologies, LLC., CA

Grant Title: Low-cost higher order mode absorbers formed by cold spray of metal matrix composites

NP SBIR/STTR Topic: Accelerator

RadiaBeam proposes cold spray the inside diameter of a water-cooled vacuum assembly with a lossy metal/ceramic powder blend which will be used for beam line absorbers (BLA). BLAs are critical components of current and proposed accelerator machines because of the ability to provide HOM dampening decoupled from the Nb cavity fabrication process, i.e. no additional forming, electron beam welding, tuning of antenna pick-ups, etc. Our proposed approach is well-suited for large (>12" diameter) BLA assemblies such as those required for the high current electron storage ring (eSR) upgrade of the Electron-Ion Collider (EIC) at Brookhaven National Lab (BNL). Current fabrication approaches rely on shrink-fitting of the lossy RF load into a water-cooled metallic sleeve, necessitating extreme tolerances and costly manufacturing. Our approach alleviates this costly machining operation.

In Phase II, our focus is on optimizing the powder and spray parameters associated with RF absorbers. Ensuring that our approach is compatible with the 12” inside diameter, room temperature BLAs required for the x17 single-cell 591MHz cavities needed for the eSR of EIC. At a fundamental level; these high power, room temperature BLAs have a round form factor which interfaces between the cryomodule and storage ring. This round form combined with recent upgrades to high power testing at RadiaBeam has motivated a revision to our materials testing plan, which previously focused on flat plates. Specifically, we propose to measure the vacuum and high power RF characteristics under cyclic RF loading, ideally bringing the parts to failure via cracking. Cracking of lossy ceramics near the SRF cavity is a significant concern for any superconducting device because of the risk of particulate contamination.

Development of Ultra Low Radioactivity Cables and Circuitry

Harshad Uka, Q-FLEX INC, Santa Ana, CA

Grant Title: Development of Ultra Low Radioactivity Cables and Circuitry
NP SBIR/STTR Topic: Instrumentation

Flexible printed cables and circuitry based on copper-polyimide materials are widely used in experiments looking for rare events due to their unique electrical and mechanical characteristics. However, copper-polyimide flexible cables contain a significant source of radioactive background. Q-Flex is developing a new radiopure fabrication process used to produce new ultra-low radioactivity cables and circuitry. The development of these fully-functioning flexible cables and circuitry would not only reduce the total backgrounds of rare event physics experiments, such as those searching for dark matter, but could also allow for the deployment of additional sensors, and will be helpful for other low-background applications such as neutrinoless double beta decay and quantum computing as well.

QFlex has proprietary process that allows fabrication of long cables up to 15 ft. These long cables with Ultra Low Background Radiation, the monitoring instruments can be placed far away from the sensors.

Qflex Inc has developed necessary cleaning process parameters and the cleaning process units are set up.

A New Medium Field Superconducting Magnet for the EIC

Ramesh Gupta, Particle Beam Lasers, Inc., CA

Grant Title: A New Medium Field Superconducting Magnet for the EIC
NP SBIR/STTR Topic: Accelerator

Will introduce a novel optimum integral design, particularly suitable for short superconducting magnets. Will provide the latest status and test results. Will also explore the possibility of collaborating others for Phase IIA to develop magnets based on this technology for Eledctron Ion Collier (EIC) and other applications.

Large area diamond detector for position and energy determination
Valeriy Konovalov, Applied Diamond, Inc., DE
Grant Title: Fast, Large-Area Detector for Position and Energy Determination
NP SBIR/STTR Topic: Instrumentation

Diamond radiation detectors have an excellent radiation tolerance and have been found to withstand irradiation doses many times exceeding the common Si detectors. Large size detector grade polycrystalline diamond (PCD) material is currently available, providing a fast response and position determination, but PCD detectors are not suitable for energy determination, e.g. product identification. Single crystal diamond (SCD) detectors provide an energy resolution close to Si detectors, but the size of today's commercially available detector-grade SCD material is limited to about 4.5 mm, which is smaller than the beam size. Applied Diamond Inc. proposed to make the large area SCD mosaic material suitable for fabrication of radiation detectors used for energy and position determination and having a fast time response. Providing beam position measurement quality similar to large PCD detectors (while providing more sensitivity), they will also allow the spectroscopic measurements for heavy ion identification in environments where high beam intensity and good detector spectral resolution will be needed.

Two types of large size mosaic SCD detectors have been developed. The first type represents an array of individual SCD plates bonded together by foreign material. As the first prototype, a 9×9 mm SCD detector was made from four individual 4.5×4.5 mm plates having the identical thickness of 52 ± 1 μm. The width of a "dead zone" between the individual plates was reduced to 100 μm, which completely satisfies the current needs of several customers. The prototype was successfully tested and the spectra from a combined alpha source demonstrated an excellent 0.5% spectral resolution, identical across the whole detector area.

The second type of mosaic SCD material, which is currently under development, represents "all diamond" material when individual SCD plates are bonded together by overgrown CVD diamond. This is much more challenging technological process which includes three important tasks: CVD process development for effective CVD bonding of diamond plates avoiding growth defects and cracks, and for the growth of detector grade SCD material. Also, it includes the development and construction of a new CVD reactor suitable for the growth of detector-grade SCD.

High Output Pulsed Power Source
Alexander Smirnov, Radiabeam Technologies, LLC., CA
Grant Title: High Output Pulsed Power Source
NP SBIR/STTR Topic: Accelerator

Brookhaven National Laboratory has recently been selected as the site for the Electron-Ion Collider (EIC). The EIC will consist of two intersecting accelerators, one producing an intense beam of electrons, the other a high-energy beam of protons or heavier atomic nuclei, which are steered into head-on collisions. One of the sections of the EIC beamline will require a hadron injection kicker system. The injection kicker system for EIC will be required to support single bunch transfers with a bunching frequency of 24.6 MHz. As a result, this kicker system must provide rise, flat-top and fall times which cumulatively add to no more than 40.7 ns. The entire system will consist of 20 kicker units. The requirements on the driving pulse for EIC injection kickers are challenging from both perspectives: high amplitude of 50 kV (corresponding to current amplitude of 1000 A into a 50 Ohm kicker input impedance), +/-5% tolerance of flatness and stability; rise and fall times that must be less than 10 ns each. RadiaBeam is developing such dual-channel pulse generator (pulser) based on Gallium Nitride technology (GaN); and the summary of our findings and progress is reported.

Electron Gun for Sheet Electron Probe for Beam Tomography

Vadim Dudnikov, **Mary Anne Clare Cummings**, **Galina Dudnikova**, **Rolland P. Johnson**,
Muons, Inc., Batavia, IL

Grant Title: Sheet Electron Probe for Beam Tomography

NP SBIR/STTR Topic: Accelerator

An electron beam probe has been successfully used for the determination of accelerated particle density distributions. However, the apparatus used for this diagnostic had a large size and complex design, which limit the broad use of this diagnostic for tomography of accelerated bunches. We propose a new approach to electron beam tomography: we will generate a pulsed sheet of electrons. As the ion beam bunches pass through the sheet, they cause distortions in the distribution of sheet electrons arriving at luminescent screen with CCD device on the other side of the beam that are interpreted to give a continuous measurement of the beam profile. The apparatus to generate the sheet beam is a strip cathode, which, compared to the scanning electron beam probe, is smaller, has simpler design and less expensive manufacturing, has better magnetic shielding, has higher sensitivity, higher resolution, has better accuracy of measurement and better time resolution. With this device it is possible to develop almost ideal tomography diagnostics of bunches in linear accelerators and in circular accelerators and storage rings. Design of electron gun for sheet electron probe production for ion beam tomography will be discussed.

Novel Cryogenic Breaks & Bushings

Christopher Rey, Energy to Power Solutions (e2P), FL

Grant Title: Novel Cryogenic High Voltage Breaks

NP SBIR/STTR Topic: Accelerator

The US Department of Energy (DOE) is actively seeking to develop new and improved Cryogenic High Voltage Breaks (CHVBs) that are used to electrically isolate cryogenic devices and equipment (e.g., accelerator magnets, fusion energy magnets, electrical power equipment, etc.) operating at High Voltages (HV) from nearby grounded components and structures (see Fig. 1). The CHVBs needed for DOE's particle accelerators and fusion energy machines have many stringent technical requirements including: HV puncture withstand, HV flashover creep strength, support of high mechanical stresses, withstand high internal gas pressures at cryogenic temperatures (77 K to 1.9K), survive repeated thermal cycling while maintaining low gaseous helium (GHe) leak rates < 10-9 std-cc/s, non-magnetic metal to flange connection, and they must sustain radiation doses in the range of 1 to 50 MGy via high-energy particle bombardment. e2P has chosen two avenues to investigate: a) low cost high yield fabrication for high volume throughput and b) a thermally insulating CHVB variant with high pressure LN2 on its interior and atmosphere on its exterior. We report progress towards both and efforts towards commercialization of this product.

An ASIC with a Low Power Multichannel ADC for Energy and Timing Measurements

Anton Karnitski, Pacific Microchip Corporation, Culver City, CA

Grant Title: An ASIC with a low power multichannel ADC for energy and timing measurements

NP SBIR/STTR Topic: Electronics

Pacific Microchip Corp. previously developed an ASIC with a low-power multichannel ADC for energy and timing measurements. It includes 32 independent 12-bit 200MS/s ADCs with an integrated digital backend for event detection and recording. Within the Phase IIB project, we fabricated a second-generation ASIC with improved performance and fixed discovered issues.

Radiation Hardened Opto-atomic Magnetometer

Jae Choi, Hedgefog Research Inc., CA

Grant Title: Radiation Hardened Opto-atomic Magnetometer

NP SBIR/STTR Topic: Instrumentation

The Office of Nuclear Physics of the Department of Energy (DOE) is supporting the development of a new radiation-resistant magnetic field probe that can be adopted in high-radiation environments of high-power target facilities and accelerators. Among these facilities, rare isotope beam (RIB) facilities allow studies of exotic nuclei with a proton-to-neutron ratio drastically different from the stable isotopes. In RIB facilities, production, and manipulation of the reaction products, including ionization, purification, acceleration, and transport, need to be optimized individually to achieve the maximum production rate of target nuclei. Precise electromagnetic manipulation of reaction products, often in harsh ionizing radiation, is required to deliver intense rare-isotope beams with good ion optical quality and desired timing/energy characteristics. Therefore, radiation-hardened magnetic-field probing is one of the essential diagnostic tools needed in the routine operation of RIB facilities.

Addressing the DOE need, Hedgefog Research Inc. (HFR) is developing a Radiation Hardened Opto-atomic Magnetometer (RHOM) for applications in high-radiation environments (up to 10 MGy per year), offering high precision (Î”B/B < 4Ã—10-5, 0.2 T < B < 5 T), high sampling rate (> 1 Hz), and prolonged operating lifetime (> one year, projected). HFR is assembling a prototype system for delivery to DOE and testing in a relevant environment during the current performance period.

Wednesday, August 16 *(Day 2)*

HOM Absorber Design for eRHIC ERL Cavity (Now EIC)
Tom Schultheiss, TJS Technologies, NY
Grant Title: HOM Absorber Design for eRHIC ERL Cavity
NP SBIR/STTR Topic: Accelerator

The Office of Nuclear Physics long range plans include allocation of resources to develop technology for a polarized electron-ion collider. Early BNL effort of their Electron Ion Collider (EIC) included an Energy Recovery Linac design that would provide for significant upgrade in luminosity. One of the components that requires significant development is the high current ERL SRF cavity. To preserve the beam and its characteristics it requires higher order mode absorbers both in-line and cavity damped. This SBIR focuses on the design and development of an HOM absorber module to be used with a multi-cell cavity and in-line beampipe. In Phase 1 TJS Technologies provided analysis to show that it has the proper material and geometry to absorb the required HOMs at the expected power level. We then developed an HOM manufacturing plan, design, and cost. BNL also requested a beamline design using a similar core of tile and backer. In Phase II we manufactured a waveguide and a beamline prototype assembly. Both are at BNL and are planned to be tested when they have available funds and personnel. In Phase IIA TJS Technologies performed low power RF tests of the waveguide assembly. BNL has provided equipment, personnel and performed high power absorption tests of tile assemblies. A crab cavity HOM assembly is being fabricated. This absorber includes lighter weight tile/backer assemblies and a light weight housing. BNL will perform high power tests on the light weight tile/backer assemblies.

Radiation Hardened Infrared Focal Plane Arrays and Cameras
Yong Chang, Epir, Inc., IL
Grant Title: Radiation Hardened Infrared Focal Plane Arrays
NP SBIR/STTR Topic: Instrumentation

We will present our work on the design and fabrication of mid-wavelength-infrared (MWIR) HgCdTe-based focal plane arrays (FPAs) and on assembling the neutron radiation-tolerant infrared cameras to be used in nuclear reactors and the next-generation rare isotope beam facilities. The material system (HgCdTe) that we chose for FPA fabrication is relatively insensitive to radiation effects. Additionally, we optimized the device processes to mitigate expected changes in material properties under irradiation. High sensitivity HgCdTe FPAs can be tailored for response across the entire infrared spectrum and are commonly utilized at EPIR for the fabrication of infrared cameras. During this project, we demonstrated in collaboration with Fermilab, material, device, and camera stability under 109 neutrons/cm2/s irradiation flux, which is four orders of magnitude higher than the typical fluxes encountered in the isotope beam facilities. Under accumulated neutron doses of larger than 1.5×1013 neutrons/cm2, our FPAs also demonstrated imaging capabilities. We also demonstrated material and device-level stability under 100 krad(Si) and 63 MeV proton irradiation. We will present our current progress in material growth, device processing, and camera development. We optimized the design of the camera architecture and shielding so that the detectors and electronics are exposed only to a small fraction of the total neutron flux. Our designed camera is capable of operating at standard frame rates with a radiation tolerance for prolonged operation in the presence of neutron fluxes higher than 105 neutron/cm2/s and a total absorbed dose of ~ 1MRad/yr. In addition, MCNP simulations were also conducted to confirm that the camera will maintain full imaging functionality under a very strong radiation environment. The energy deposition calculations considered all relevant mechanisms involved in the interactions between the FPA and the high energy electron, photon, proton, and neutron particles. By properly designing the camera configuration and structure, we are capable of significantly reducing damage due to secondarily generated proton irradiations to ensure a long-time operation of the FPA and camera. Neutron irradiation tolerant MWIR lenses were also designed. Liquid nitrogen and Stirling cooled MWIR systems with lenses were fabricated and are ready for operation under neutron exposure conditions.

Low-cost and Efficient Cooling of on-Detector Electronics Using Conformal Thermoelectric Modules

Giri Joshi, **Steve Savoy**, **Rey Guzman**, **Zachary Smadi**, Nanohmics, Inc., Austin, TX

Grant Title: Low-cost and Efficient Cooling of on-Detector Electronics Using Conformal Thermoelectric Modules

NP SBIR/STTR Topic: Electronics

Thermoelectric coolers (TECs) are a well-established technology. Solid-state TECs have no moving parts and provide more consistent, uninterrupted, maintenance-free, and environmentally-friendly cooling when compared to traditional cooling systems such as vacuum-based refrigeration compressors. However, high costs and a slightly lower Coefficient of Performance (CoP < 1.0) relative to compression refrigeration have limited traditional TECs to niche applications such as automotive seat cooling, portable coolers, and biotech applications, though the ~$600MM total TEC market in 2020 which can exceed ~$1.3B by 2030 Furthermore, conventional methods used in TE cooler manufacturing do not provide a means for production of large-area, conformal TECs to break into mainstream refrigeration, air conditioning, medical and commercial markets that include niche areas such as on-detector spectrometer electronics cooling needed desired by Department of Energy facilities such as the Thomas Jefferson National Accelerator Facility (TJNAF) and Electron Ion Collider (EIC) of Brookhaven National Lab.

During Phase I&II programs, Nanohmics team developed an efficient, cost-effective and conformal TEC system capable of cooling and maintaining the EIC/RHIC/TJNAF on-detector electronics at a temperature below 20°C with COP~2.0. Team demonstrated a functional alpha-prototype – 12” × 12” using modular and conformal TEC units with the Bi_2Te_3-based alloys with ~$5/module manufacturing cost. The cooling power of ~0.75 W/cm2 (4 W/in.2) is measured at 20°C TEC hot side and $\Delta T = 10$ °C which is enough to cool the heat produced by on-detector electronics. The Phase II demonstrated alpha-prototype TEC cooling system will be manufactured in large scale (in the order of 50,000 devices) to address the cooling needs of detector cooling as well as the other commercial applications such as TEC cooled wearables with DuPont and therapeutic device with Zen Artho. The device efficiency and cooling power compared favorably to other competitive cooling systems such as vacuum compressors and Rankine coolers. Furthermore, price per TEC module of ~5 is demonstrated for 50,000 devices scale, a significant reduction in the costs of present commercial modules even of low-end TE modules. When considering all the stated advantages, the proposed technology becomes cost-competitive compared to all other alternatives and immediately impact both cooling/heating (such as aerospace and defense, electronics, automotive, and biomedical cooling) as well as waste heat recovery markets (such as automotive and industrial waste heat).

Fast Multi-Harmonic Kickers
Brock Roberts, Electrodynamic, NM
Grant Title: Fast Multi-Harmonic Kickers
NP SBIR/STTR Topic: Accelerator

Fast Multi Harmonic Kickers is a collaboration between Electrodynamic and Jefferson Lab. Jlab's SRF group designed and built a multi-harmonic transverse kicker cavity while Electrodynamic designed and constructed a multi harmonic RF driver for it. These came together at Jlab's injector test facility and were used to kick one bunch per eleven of an 6.5 Mev beam. The design of the RF Driver and progress toward driving longitudinal multi-harmonic cavities will be presented.

Large Volume Ring-Contact HPGe Detectors (RCD) for Low-Background Counting Arrays and Radiopurity-Assay
Ethan Hull, PHDS Co., Knoxville, TN
Grant Title: Large volume Ring-Contact HPGe Detectors (RCD) for low-background counting arrays and radiopurity-assay
NP SBIR/STTR Topic: Instrumentation

DOE Nuclear Physics missions include the ongoing search for rare processes including neutrinoless double-beta decay. Arrays of high-purity germanium detectors are being used to pursue this research. A new Ring Contact Detector (RCD) design is being investigated as a complement to the successful point contact and inverted point-contact detector designs. RCDs will provide the largest overall volume of depleted germanium per volt of applied bias voltage. The RCD detector design is being experimentally researched through novel germanium detector processing and high-purity germanium crystal growth.

High Performance Glass Scintillators for Nuclear Physics Experiments
Ian Pegg, Scintilex, LLC, Alexandria, VA
Grant Title: High Performance Glass Scintillators for Nuclear Physics Experiments
NP SBIR/STTR Topic: Instrumentation

PI: Tanja Horn, Topic Number and Subtopic Letter: 34.d

High performance scintillator materials are needed for particle identification and measurements of energy and momentum of electromagnetic particles in modern nuclear physics experiments. Achieving high-quality science at nuclear physics facilities requires the measurement of particle energy with excellent calorimeter energy resolution in the momentum range 0.1 – (10-20) GeV/c. Crystals such as lead tungstate ($PbWO_4$) have been used in precision calorimeters but their production is slow and expensive. This Phase I/II/IIA project addresses the need for alternative high performance scintillator materials by developing the basis to replace such crystals with scintillating glass that is simpler and faster to produce in large quantities while meeting the desired specifications. The reduced time and complexity of manufacturing results in significant cost reduction compared to crystals and increased flexibility in shape and size for the final detector. Phase I established the formulation and fabrication techniques for producing small batches of SciGlass blocks. During Phase II, considerable progress was made on improvement of glass properties and the manufacturing process for blocks of ~15 radiation lengths (X_0). Beam tests with a small detector prototype indicate, along with Geant4 simulations, that SciGlass has an energy resolution comparable to $PbWO_4$ for block sizes of a comparable number of radiation lengths. The glass samples have excellent radiation resistance (no damage up to 1000 Gy electromagnetic and 10^{15} n/cm^2 hadron irradiation, the highest doses tested to date), response time of 20-50 ns, and near-UV transmittance (78% at 440 nm). Sufficient 2 x 2 x 40 cm^3 SciGlass bars have now been produced to meet the objective of building and testing a larger 5x5 detector prototype. This objective is supported by characterization results, simulations, and community feedback, and additional information that has become available on the EIC detectors. In addition, the block size will be optimized relative to the Moliere radius and the objective of demonstrating the ability to produce bars of various shapes will be completed. The Phase IIA program is aligned to make SciGlass blocks available to meet the needs of key nuclear physics experiments, e.g., the large-volume calorimeters for the Electron-Ion Collider or JLab, that require high performance scintillator material in large quantities on specific schedules.

First report on the successful testing of the low loss conductive ceramic RF windows at the 100 kW CW power range

Ben Freemire, Euclid Techlabs, LLC, Beltsville, MD

<u>Grant Title: Low RF Loss DC Conductive Ceramic for High Power Input Coupler Windows for SRF Cavities</u>

NP SBIR/STTR Topic: Accelerator

A. Kanareykin[1*], B. Freemire[1], J. Guo[2], C. Jing, S. Kazakov[3], R. Rimmer[2], N. Solyak[3], V. Yakovlev[3].

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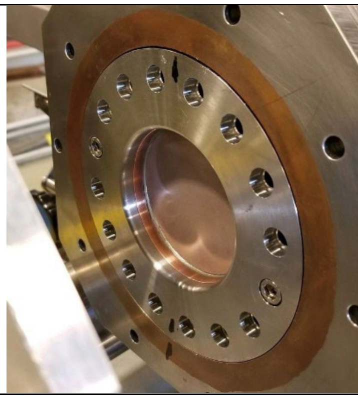
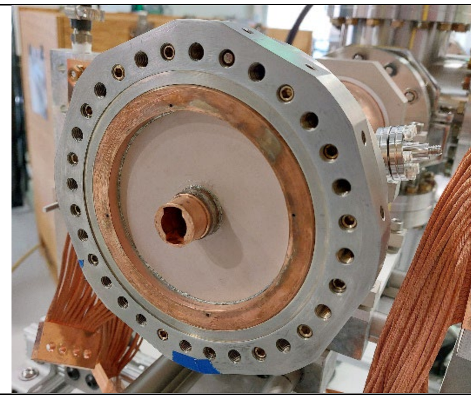
[2]Thomas Jefferson National Laboratory, Newport News, VA, USA
[3]Fermi National Accelerator Laboratory, Batavia, IL, USA.

Euclid Techlabs LLC, in collaboration with JLab and Fermilab, has developed a new ceramic material with a finite DC electrical conductivity combined with a low RF loss tangent for use in high power coupler windows. The goal of the project was to develop windows with a loss tangent not exceeding that of alumina but with significantly increased DC conductivity for effective electrical discharge. Several SRF coupler windows operating in the 650 MHz and 1.5 GHz frequency ranges were fabricated and successfully tested at high power. Euclid developed magnesium titanate ceramic elements with relative dielectric constant ε=15.2, a figure of merit, Q×f, in the range of 60,000–125,000 GHz, providing tan $\delta \sim 5.2\times10^{-6}$ - 2.1×10^{-5} at 650 MHz and 1.5 GHz correspondingly, and increased conductivity from 10^{-12} S/m to 10^{-9} S/m. This ability to tune the conductivity will allow a window to effectively discharge any deposited charge.

	
Waveguide 1.5 GHz window before testing at Jlab at 12 kW CW	Coaxial 650 MHz window for the 30-90 kW CW test at Fermilab

Two 1.5 GHz waveguide window assemblies were fabricated for Jlab using a tin-silver-titanium-magnesium active solder produced by S-Bond. Both were successfully tested at high power in vacuum up to 12 kW CW power, which was the limit of the klystron in travelling wave mode. The maximum temperature recorded on Window 1 was approximately 92°C, and on Window 2 was approximately 78°C. There was no evidence of multipacting or sparking during the high power test of the waveguide windows, or inspection afterward.

A 650 MHz coaxial window assembly was fabricated using the same active solder as the waveguide window assemblies. The conductive ceramic coupler assembly was tested at Fermilab in conjunction with a spare alumina window coupler assembly. Four field configurations were tested; a CW power of 30 kW was achieved with a stable window temperature for each. For three of the configurations, 50 kW CW was achieved, and up to 90 kW CW was reached for two configurations. The temperature of the conductive ceramic window as measured with an IR camera did not exceed 61°C for any configuration. Post high power test inspection revealed multipactor signature at the alumina window but there were no signs of electron activities at the conductive ceramic windows tested at Fermilab.

CMOS Integrated With Float Zone Pixel Sensor Update

Robert Patti, NHanced Semiconductors, Inc., IL

<u>Grant Title: CMOS Integrated With Float Zone Pixel Sensor</u>

NP SBIR/STTR Topic: Electronics

NHanced is developing a low mass 3D-Advance Hybrid Sensor (AHS) device that will achieve picosecond timing resolutions and micrometer scale spatial resolution. This revolutionary new technology can also provide angular resolution within a single layer detector. No other existing technology can do this. We propose to use our in-house 3D assembly technology (DBI®) to integrate the fast Read-Out IC (ROIC) tier to an ultra-low mass particle detector tier. Our 3D technology allows us to connect any type of detector to our ROIC in a Lego®-like fashion, creating a family of products that could serve a wide variety of applications relevant to NP (low material, low power sensor), HEP (sensor with angular resolution capabilities) or we could turn our product to an X-RAY or gamma ray imager (very thick, fully depleted silicon piece).

High-Quality Conformal Bellows Coatings Using Ultra-Fast HiPIMS with Precision Ion Energy Control

Thomas Houlahan, Starfire Industries LLC, Champaign, IL

Grant Title: High-Quality Conductive Bellows Coatings Using Conformal Ionized PVD To Replace Unreliable Electroplating Processes

NP SBIR/STTR Topic: Accelerator

W. M. Huber, C. M. Roberts, A. S. Morrice, I. F. Haehnlein, B. E. Jurczyk, R. A. Stubbers, T. J. Houlahan

In this work we demonstrate a replacement for traditional 'wet' chemical deposition processes using a vacuum, ionized physical vapor deposition (iPVD) process that results in a conformal metal film, capable of coating complex, convoluted parts that are common in modern particle accelerators (e.g., bellows, RF cavities). Results are presented for a process utilizing the combined deposition and etching that are achieved using ultra-fast high-power impulse magnetron sputtering (HiPIMS) coupled with precision control of the ion energy using a positive voltage reversal. This process results in a conformal film and has been used to coat both test coupons and full bellows assemblies. The resulting Cu films, which are 5-10 µm in thickness, exhibit excellent adhesion. Further, they have been shown to tolerate temperature extremes ranging from 77 K to a 400 C vacuum bakeout as well as extreme plastic deformation of the substrate without any buckling, cracking, or delamination. This technology has been used to coat bellows assemblies that are identical to those used in the LCLS-II. Present development efforts are largely focused on achieving a conformal deposition over the extreme aspect ratio presented by the CEBAF waveguide assemblies.

Boron Nitride Nanotube Vibration Damping for SRF Structures

Roy Whitney, BNNT, LLC, Newport News, VA

Grant Title: Boron Nitride Nanotube Vibration Damping for SRF Structures

NP SBIR/STTR Topic: Accelerator

Controlling microphonics that create length oscillations in the structures that accelerate particles in Superconducting Radio Frequency (SRF) accelerators requires costly RF power for both capital and operating expenses above what is otherwise required for accelerating the particles. Passive viscoelastic vibration damping at cryogenic temperatures of 2 Kelvin (K) provided by our boron nitride nanotubes (BNNTs) provide a cost-effective alternative to enhance management of the microphonics. Under our SBIR Phase IIA we have installed and successfully demonstrated BNNT vibration damping in a full Jefferson Lab CEBAF C100 cryomodule in the testing facility, and the cryomodule is now installed in the full CEBAF accelerator for testing late summer/early fall. Further, a SLAC LCLS-II cryomodule with BNNT vibration damping installed in two of its cavities will also be testing in the SLAC accelerator in the same time frame.

High Rate Picosecond Photo Detector or HRPPD Development - Final
Michael Foley, Incom Inc., MA
Grant Title: Large Area Multi-Anode MCP-PMT for High Rate Applications
NP SBIR/STTR Topic: Instrumentation

The development of the High Rate Picosecond Photon Detector (HRPPD) was initiated by Incom Inc. under DOE NP Phase I SBIR project (award DE-SC0020578) to fulfill specific requirements on photosensors to support the need for devices to detect, analyze, and track photons, charged particles, and neutral particles such as neutrons, neutrinos, and single atoms. We will discuss a novel device with various pixelated signal boards (as small as 2-3 mm pads). Other design features are that it can perform at high rates (200 kHz/cm2) in a 2-3 Tesla magnetic field with high gain, low intrinsic background, and high photocathode efficiency to support the high rates found in noisy radiation environments. as exemplified by the EIC collaboration, and other NP programs. Realization of these features in 20 cm x 20 cm form factor LAPPD™ currently being commercialized by Incom Inc. is rather challenging although LAPPD has already demonstrated picosecond timing, high gain, low noise and high Quantum Efficiency (QE).

In order to meet these needs, a new direct readout anode was demonstrated in Phase I to offer improved signal to noise compared to alternative approaches. Because of the complexity the technical development for this novel anode, it was decided to prototype it initially using a smaller 10 cm x 10 cm form before scaling up to full size (20 cm X 20 cm) LAPPD size.

We have demonstrated feasibility of directly coupled 3 mm x 3 mm anode readout; developed 10 cm x 10 cm ALD functionalized MCPs with 10-micron pores for better timing and magnetic field tolerance and tested a fully functional open face High Rate Picosecond Photo Detector (HRPPD) package. The first year this Phase II project has been to demonstrate fully functional sealed HRPPD suitable for pilot production, test and evaluate prototype HRPPD in practical beamline trials (BNL).

The main areas to be discussed:

Performing multiple HRPPD sealing trials (11 total) with a complete MCP stack. Multiple sealing trials were performed with complete detector package to find optimal sidewall geometry and metallization methodology in a dedicated Integration and Sealing Tank. These fully functioning detectors will have a standard bi-alkali photocathode, a pair of 10-micron pore ALD-GCA-MCPs, and a pixelated capacitively coupled readout. Directly coupled anode versions were also be fabricated. We continuously updating kit components drawings.

Development of a reliable production process for large area 10-micron pore MCPs. As mentioned above under Phase I project, 108 mm x 108 mm 10-micron ALD-GCA-MCPs have been produced. However, the production yield for these GCA-ALD-MCPs was rather low due to the need to refine the production of large format 10-micron pore. In this Phase II we will increase yields and quality of larger format 10-micron pore MCPs by improving GCA fusing process and optimizing ALD process.

Characterization of HRPPD/ Magnetic Field Tolerance. In order to characterize the HRPPD, a dedicated readout board was designed. Quantum Efficiency, gain, timing and spatial resolution, and the high-rate capability of HRPPD was measured in a dedicated setup. HRPPD performance at high magnetic fields (up to 1.5T) was be evaluated.

Commercialization. Capacitively couple LAPPDs and HRPPDs are being sold, rented and loaned for various programs worldwide. Directly coupled HRPPDs are the device of choice for the major EIC Program at BNL and TJNAF. Device design revisions are being finalized for the first round of qualifications tests slated for early 2024 on 5 custom devices. The PET community and other bioscience industries are also considering HRPPD.

Machine learning for anomaly detection at CEBAF and RHIC

Jonathan Edelen, RadiaSoft LLC, Boulder, CO

Grant Title: A Browser Based Toolkit for Improved Particle Accelerator Controls

NP SBIR/STTR Topic: Accelerator

Over the past several years machine learning has increased in popularity for accelerator applications. Here we have explored the use of inverse models for anomaly detection at the Continuous Electron Beam Accelerator Facility injector beamline at Jefferson Lab and for the transfer line from the AGS to RHIC at Brookhaven National Laboratory. For our work at JLab the model utilizes input readings from the machine to compute expected machine settings. These are compared with the control setpoints and errors are used to flag anomalies. Our work with BNL utilizes a similar approach however here deviations in the model prediction are used to identify anomalies implicitly. In this talk we present the machine learning methods used for both these applications and summarize our results.

A Real-Time, 2D-Profile, Scintillator-based Beam Monitor (SBM) for Nuclear Physics Research and Medical Ion Beams

Peter Friedman, Integrated Sensors, LLC, OH

Grant Title: High Performance Scintillator and Beam Monitoring System

NP SBIR/STTR Topic: Instrumentation

P. S. Friedman[1] (PI/PM), C. Ferretti[2], T. Ginter[3], D. S. Levin[2], D. Litzenberg[4], N. Ristow[2], M. Tecchio[2]

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We have developed a high-performance, Scintillator-based, Beam Monitor (SBM) that provides real-time beam analysis across a wide range of isotopes, ion energies, and intensities. It has attracted attention at facilities where fast beam imaging and tuning are at a premium, as well as single-particle imaging. It uses a low-noise machine-vision camera and thin scintillator targets that can be moved into/out of the beam without breaking vacuum. Two proprietary scintillators are used: 1) a semicrystalline polymer film tested over a thickness range of ~1 to 190 µm. It produces, per unit thickness, much stronger signals than common PVT based plastic scintillators, and can be transmissive for fast beams. 2) An opaque sheet of thickness 100-400 µm consisting of inorganic crystal grains in a polymer hybrid matrix. It generates an order of magnitude larger signal per unit thickness than a single crystal CsI(Tl) reference. Importantly it produces a sharp beam image, with minimal secondary reflections and little to no observable halo. Both scintillator types are non-hygroscopic and are highly radiation damage resistant with no observed signal loss with ~10 kGy total dose. The SBM was staged at the FRIB (Facility for Rare Isotope Beams, Michigan State University) using a 86Kr+26 reaccelerated 2.75 MeV/u ion beam, demonstrating real-time beam profiles and rate analysis spanning more than five orders-of-magnitude including visualization of single-ion signals with ~10 µm spatial resolution. This instrument is also a development platform for a transmissive and ultrafast 20 kHz real-time monitor (updated every 50 µs) intended for FLASH radiotherapy. The monitor was also staged in an 8 MeV electron beam at the Notre Dame Radiation Laboratory at FLASH compatible dose rates of ~2 Gy per 2 ns pulse at 30 Hz. This work is funded by both the DOE Office of Science, Office of Nuclear Physics, and the NIH National Cancer Institute, the latter under a three-year "Direct-to-Phase-II" SBIR.

Additively Manufactured Microchannel Plates with Fast Timing Readout and Software For Beam Diagnostics

Jerome Moore, Robot Nose Corporation, IL

<u>Grant Title: Additively Manufactured Z-Channel Detectors for Heavy Ion Accelerator Diagnostics</u>

NP SBIR/STTR Topic: Accelerator

The possibility of additive manufacturing at submicron scales suggests a new way of making microchannel plates (MCPs) that surpasses the 50-year-old technology of pulled capillary arrays, which is time consuming, labor and capital intensive and expensive. This new approach promises flexibility in the final shape over a wide scale, and the opportunity of using new materials.

Efforts to produce 3dMCPs using a commercial ultra high resolution printer will be presented. The team can routinely create cm diameter flat, complete, unbroken 3dMCPs with channels that are uninterrupted and completely open on the ends. The electroded plates can then be made functional by atomic layer deposition (ALD) with one of two methods. The resulting samples are quality controlled with optical or scanning electron microscopy, laser diffraction in the case of straight pores, and then electroded on both sides with <100 Ohm-cm Ni 625 superalloy.

The development of readout systems meant for use in accelerator environments will also be described. These systems consist of embedded computer systems with time-to-digital convertors and custom software with a novel architecture. These systems are in use currently on our MCP test stands. Our improved methods for characterization of the 3dMCPs includes a new in-house system built to measure gain over a wide dynamic range. It is now possible to check MCPs with low gain processed under different conditions, to understand how to improve these to the needed >103 level.

This phase II project (DE-SC0019535), which has a significant subcontract to Argonne National Laboratory is continuing on a no-cost extension. The ultimate goal of the project is to improve time resolution for MeV ion detection so that additively manufactured microchannel plates (3dMCPs) can be used as beam diagnostics in heavy ion accelerators such as ATLAS and FRIB.

Design and Fabrication of the HDSoC- High Density Digitizer System-on-Chip
Luca Macchiarulo, Nalu Scientific LLC, HI
Grant Title: Design and Fabrication of the HDSoC- High Density Digitizer System-on-Chip
NP SBIR/STTR Topic: Instrumentation

We present our work on the design, fabrication and testing of a waveform sampling ASIC (HDSoC), optimized for high density light detectors, such as Silicon Photomultiplier (SiPM) or MA-PMTs, suitable for large and high rate NP experiments such as the Relativistic Heavy Ion Collider and the future Electron Ion Collider. The first revision of HDSoC has 32 channels and operates at 1 GSa/s sampling; the second HDSoC revision (fabricated, packaged and ready for testing) increased this to 64 channels. The HDSoC is a System-on-Chip with built-in SiPM biasing, input TIA, internally controlled digitization via a digital core that allows independent operation of each of the channels permitting low latency and high data rate, as well as multiple acquisition modes. In this presentation we cover the initial design and testing of the 32 channel prototype, improvement of the design, fabrication of the full 64 channel revision of the chip.

Optimizing the Design of Cutting Edge Accelerators
Karl Smolenski, Xelera Research LLC, Ithaca, NY
Grant Title: Energy Recovery Linac Designs and Studies for Electron Cooling of Hadron Beams
NP SBIR/STTR Topic: Accelerator

In this unique SBIR project, Xelera Research leveraged its accelerator physics and mechanical design experience to perform an extensive advanced accelerator design study. Working with colleagues at BNL (Brookhaven National Lab) and JLab (Thomas Jefferson National Accelerator Facility), the Xelera team has produced an initial complete design for an Energy Recovery Linac (ERL) for strong hadron cooling (SHC) via the coherent electron cooling (CeC) process. Additionally, work is progressing in producing ERL design solutions for the combined SHC-CeC ERL and the Precooler ERL systems, with initial solutions for the shared injector, merger, and booster sections completed. This effort acts as a first example for our business as an accelerator design consulting firm.

Supercritical Fluid Separation and Purification of Rare Earth Elements, particularly Lanthanides including 177-Lu, to Lower Energy Consumption, Reduce Processing Time and Reduce Wastes
Laura Sinclair, CF Technologies, Inc., Hyde Park, MA
Grant Title: CF Tech's Technology for Purifying Radioisotopes
NP SBIR/STTR Topic: Isotopes

Purification of Lutetium 177 with Novel Chromatography Process

A novel chromatography process has been developed by CF Tech (Boston, MA, USA) for separation of lanthanides. The process was demonstrated in the production of no carrier added lutetium-177 (177Lu) for cancer treatment. 176Yb targets were irradiated in the MIT Nuclear Reactor generating 177Lu with activity levels up to 10.3 Ci/g target. The chromatography process recovered more than 90% of the 177Lu, meeting all measured radionuclidic and radiochemical purity standards (175Yb, 176Yb, Cu, Zn, Pb). The chromatographic process takes less than 5 hours, uses off-the-shelf chemicals and resins, and requires only a single column pass to achieve decontamination factors of 10^6 or greater. This breakthrough technology offers simplicity and speed, with potential for quickly purifying many other lanthanides and short lived radioisotopes. CF Tech's technology is available for licensing.

Digital Data Acquisition with High Resolution and Linearity

Wojtek Skulski, SkuTek Instrumentation, NY

Grant Title: Digital Data Acquisition with High Resolution and Linearity

NP SBIR/STTR Topic: Electronics

We are working on improving the integral nonlinearities (INL) of digitizers based on the pipelined ADC technology. This ADC architecture causes semi-periodic nonlinearities due to imperfect matching of the ADC stages forming a signal sampling pipeline. Nonlinearity is impacting resolution in high precision experiments. We will present the progress of this project.

Diaphanous diamond x-ray beam imaging system

James Christian, Joshua Tower, Evan Weststrate, Vivek Nagarkar, Radiation Monitoring Devices (RMD); **Erik Muller**, BNL; **Gianluigi DeGeronimo**, DG Circuits

Grant Title: Diaphanous diamond x-ray beam imaging

NP SBIR/STTR Topic: Instrumentation

Applications in harsh high-radiation environments, which limit the lifetime of devices fabricated with conventional semiconductor materials, include x-ray beam monitoring, spent fuel cask monitoring, heliophysics, and space weather. This effort developed thin, <200 um thick, diamond X-ray detectors grown by chemical vapor deposition for the transmission imaging of hard and soft X-ray beams to facilitate the use of dynamic focusing at advanced-light-source facilities. The program investigated the use of single-crystal and polycrystalline electronic grade diamond substrates (5 mm × 5 mm and larger) and developed an application-specific integrated circuit (ASIC) for the front-end readout electronics. The diamond sensor uses a crossed-strip electrode configuration to image the X-ray beam with a reduced number of readout channels compared to a pixelated configuration. This work summarizes the performance of diamond substrates from different vendors, compares single and polycrystalline diamond detectors, and shows images of the X-ray beam from the NSLS-II facility.

ML-enabled End-to-End Tracking Reconstruction and Trigger Detection

Yu Sun, Sunrise Technology, Inc, NY

Grant Title: High Performance FPGA-based Embedded System for Decision Making in Scientific Environments

NP SBIR/STTR Topic: Software

In 2023, the sPHENIX experiment commenced data collection at the BNL Relativistic Heavy Ion Collider. The high-rate detectors analyze high-energy heavy ions and produce vast amounts of unprocessed information that surpasses the available DAQ and data storage capability. To meet this challenge, we propose to develop a state-of-the-art AI-based trigger system to select events in real time. This will allow to effectively sample the full high-energy collision events delivered by the accelerators while maintaining the final data throughput for offline storage at a manageable level within the available DAQ bandwidth, storage, and computing capacity. This project designs real-time AI-based algorithms operating on high-rate data streams, allowing the identification of important rare physics events from abundant backgrounds in the sPHENIX's p+p and p+Au collisions. We collaborated on creating physics-aware high-speed Graph Neural Networks that can complete complex tasks such as identifying collision event hits, reconstructing tracks, and detecting triggers in real time. Successfully integrating this system would be the initial stage in implementing autonomous control loops for large-scale, multifaceted high-energy nuclear physics experiments using powerful online AI algorithms.

Final Configuration and Testing of a Device for the Purification of 211At, Global FIA, Inc., Fox Island, WA

Graham Marshall, Global FIA, Inc., Fox Island, WA

Grant Title: Automated Preparation Of 211At For Targeted Alpha Therapy Applications
NP SBIR/STTR Topic: Isotopes

Graham Marshall[1], Matthew O'Hara[2], Anne Farawila[2], David Holdych[1], Daniel Hunt[1], Dan Jones[1]

[1] Global FIA, Inc. 684 6th Ave Fox Island WA, 98333, [2] Pacific Northwest National Laboratory, 902 Battelle Blvd., Richland WA 99352

High-purity therapeutic isotope products are essential for high-yield protein radiolabeling for radiopharmaceutical use. This project has focused on the automation of the production of antibody labeled - 211At. This short half-life (7.2 hours) alpha-emitting radionuclide that has been identified as a candidate for targeted alpha therapy in the treatment of leukemia, lymphoma, and micro-metastatic disease. Existing manual methods of purification are tedious, time consuming and pose radiological dose risks to technicians.

The procedure to be automated comprises of several unit operations that encompass the extraction of the isotope from the cyclotron-irradiated target and its isolation from the bismuth target matrix, conversion to a compound and matrix suitable for bio-labeling with a disease-seeking antibody, and processing of the labeled isotope to make it suitable for clinical testing and ultimately, treatment.

To achieve this purification, Global FIA, with expert help from Pacific Northwest National Laboratory, developed hardware and a procedure to automate these unit operations in flow-based 211At handling modules. Recently, a test and demonstration of the entire purification sequence was carried out using the developed hardware at the University of Washington Molecular Radiotherapy Research Laboratory.

In this presentation, the system design will be described and a few preliminary results from the final test will be presented. Once the data have been fully processed, further results will be included in the final project report.

Picosecond Detector Readout System with 25GE Links

Radu Radulescu, Telluric Labs LLC, Red Bank, NJ

Grant Title: Picosecond Detector Readout System with 25GE Links
NP SBIR/STTR Topic: Software

The Picosecond Detector Readout system utilizes commercial 25GE IP networks to provide unparalleled scalability, performance, and flexibility, all while minimizing operational and capital expenditures (CAPEX). It represents a paradigm shift, demonstrating that numerical synchronization over packet networks is more accurate than the traditional method of distributing synchronization signals through a separate wire network.

The foundation of the system rests on three technological pillars: a 2 Gsps picosecond Ergodic TDC, the General Timing Synchronization methodology, and a distributed packet switch equipped with 25GE ports.

Timing synchronization equations are derived from packet travel times through bidirectional communication channels. Established protocols like Precision Timing Protocol (PTP) and White Rabbit employ a 4-step Request and Answer packet handshake to exchange remotely captured timestamps. In contrast, our GTS introduces an innovative approach that greatly surpasses PTP in both efficiency and precision. This is accomplished through higher precision ETDC, blanket timestamping of general traffic, the transfer of hundreds of timestamp and packet id pairs as regular IP packet payload, and the generation of polynomial synchronization functions over short time intervals

Additionally, the system eliminates the need for conventional switches by utilizing the internal FPGA switch, capitalizing on the multiple available 25GE ports inherent in most FPGA commercial cards. Unlike PTP, our technology doesn't interfere with the board oscillators, enabling seamless upgrades of existing readout systems based on FPGAs.

Cold Spray Technology Applications for SRF Cavity Thermal and Mechanical Stabilization

Roman Kostin, Euclid Techlabs, LLC, Solon, OH

Grant Title: Cold Spray Technology Applications for SRF Cavity Thermal and Mechanical Stabilization

NP SBIR/STTR Topic: Accelerator

A. Kanareykin[1*], G. Brock[2]. G. Ciovati[3], C. Jing[1], R. Kostin[1], R. Rimmer[3].

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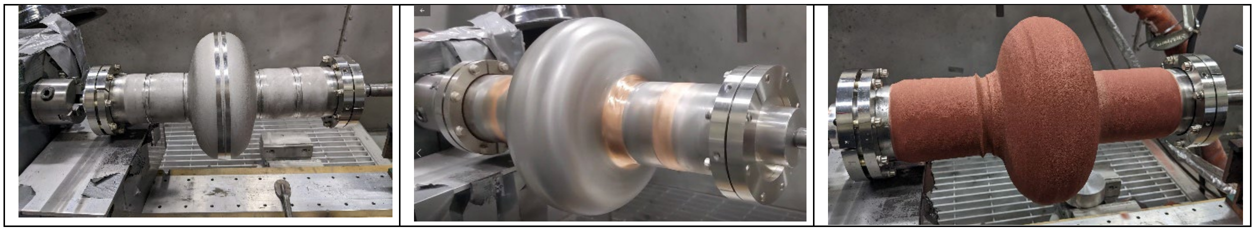
[2]CTC, Inc., Johnstown, PA 15904, USA
[3]Thomas Jefferson National Laboratory, Newport News, VA, USA

The overall objective for the proposed program is to apply the cold-spray technology for the improvement of SRF cavity parameters. In Phase II of the project, this new technology was used for SRF cavity fabrication to provide mechanical and thermal stability in its application for conduction-cooled industrial SRF-based accelerators. The main accomplishments of Phase II are: (1) the niobium sheets were cold sprayed with (a) copper (b) copper-tungsten powders in various spraying regimes, and microstructure analysis was carried out to define the best performance. Also, the thermal conductivities of the resulting bimetallic materials were measured. A single-cell 1.3-GHz pure Niobium cavity was uniformly cold sprayed with 8-mm-thick copper. The copper-coated 1.3-GHz cavity was high power tested at JLAB's VTS facility, and the test results were encouraging: the pressure sensitivity was reduced by a factor of 1.65 and the Lorentz Force Detuning (LFD) was reduced by a factor of ~2, which is consistent with SRF cavity parameter modeling.



From left to right: Nb cavity as received with grooves; Nb cavity with filled in grooves prepared for copper deposition; Nb cavity with 2 mm thick cold-sprayed copper layer.

Currently, we are finishing the optimization of the copper cold-spray deposition technology for an Nb_3Sn-coated SRF cavity. This requires improved thermal conductivity of the cold-sprayed copper layer, degassing the initial copper powder, optimization of the annealing regimes at up to 900 °C, precise control of the Nb_3Sn-coated cavity shape during the cold spray process, and multiple VTS tests of the copper-deposited Nb_3Sn cavities. Finally, the optimized parameters of the Nb_3Sn cavities will be demonstrated with the conduction-cooled cryomodule installed at Euclid's facility in Bolingbrook IL.

Reporting period 01/30/2023-07/30/2023. We have taken some important steps to address the outgassing issue by collaborating with Penn State University and utilizing their cold spray technology expertise. The degassing of the copper powder using the HIP (Hot Isostatic Pressing) process is a crucial step to reduce the presence of volatile substances and minimize outgassing during the cold spray deposition process. The degassed copper powder was sprayed on a single cell Nb cavity layer-by-layer monitoring the frequency shift of the cavity and the cavity shape deformations with the intent to investigate the cavity deformations by the deposition process. The frequency shift of the cavity was found to be linear relative to the deposition thickness and equaled to -956 [MHz /mm]. The data we obtained from the 3D scans and RF frequency measurements are being processed for understanding of the reason of the frequency change and deposition process optimization.

Our future plan is to complete the buildup of the cold-sprayed layer up to the previously measured 8 mm thickness and to conduct a cryogenic high-power test followed by high-temperature baking for stress relief. By doing so, we will be able to assess the performance and stability of the cold-sprayed layer under operational conditions. Also, we will be able to compare whether HIP process resolved the degassing issue. Given the positive results observed with the degassed copper powder and its potential to prevent cracking, annealing the cold-sprayed layer to restore the cavity frequency is a reasonable course of action. If successful, this approach will enable one to produce a stable and high-performing SRF cavities for intended applications.

Overall, it seems like we have a well-planned strategy in place to address the outgassing issue, optimize the cold spray deposition process, and achieve the desired cavity performance.

Publication and presentation:

1. H. Pokhre, G. Ciovati, P. Dhaka, J. Spradlin, C. Jing and A. Kanareykin. *Electrical and thermal properties of cold-sprayed bulk copper and copper-tungsten samples at cryogenic temperatures*. SRF 2021, SUPTEV010.

2. G. Ciovati. *Overview o-n Recent Development of Conduction Cooling Cavities*. SRF 2021. WEOTEV02.

3. R.Kostin. C. Jing, A. Kanareykin G. Ciovati, G. Brock. *Lorentz Force Detuning in SRF Cavity by Copper Cold Spraying.* NAPAC 2022, Albuquerque NM 2022, WEPA52, p. 749.

Low Cost, High-Density Digital Electronics for Nuclear Physics

Wojtek Skulski, SkuTek Instrumentation, NY

Grant Title: Low Cost, High-Density Digital Electronics for Nuclear Physics

NP SBIR/STTR Topic: Instrumentation

We developed a family of digital pulse processors for Nuclear Physics. The devices range from a low cost, 2-channel FemtoDAQ, all the way up to 40-channel DDC-40. The devices offer low noise, high speed digitization with 14 bits at 100 MSPS, suitable for both scintillators and high resolution semiconductor detectors. Digitizer setup, control, and monitoring is handled with embedded Linux single board computer (SBC) running embedded Linux for the ARM processor. We will review and summarize the progress achieved under this grant.

Long-Term Radiation Rugged Rotary Vacuum and Water Seals in Heavy-Ion Accelerators

Jennifer Lalli, NanoSonic, Inc., Pembroke, VA

Grant Title: Long-Term Radiation Rugged Rotary Vacuum and Water Seals in Heavy-Ion Accelerators

NP SBIR/STTR Topic: Accelerator

The Department of Energy's Office of Nuclear Physics has identified a need for materials that will survive high radiation environments to support next generation rare isotope beam facilities such as Michigan State University's (MSU) Facility for Rare Isotope Beams (FRIB). The goal of this Phase IIA program is to expand upon the results achieved in the Phase II program through down-selection of materials and higher dose irradiation studies to develop a long-lifetime, rotary vacuum and water seal that can survive 0.5 – 1.5 MGy/month for up to a year to minimize maintenance within this radioactive environment. Irradiation (total dose: 0.2 MGy, 2.0 MGy, and 20 MGy) has been conducted at Brookhaven's Linac Isotope Producer (BLIP). Current lip seals do not offer the combined mechanical and radiation survivability needed for multiple years of service. The approach for the new seals involves the extrusion of high-performance polymers compounded with radiation tolerant materials that offer combined low air and water permeability with extreme radiation durability. New seal housings have been tested during this program. Mechanical and thermomechanical testing of the new materials are being conducted pre- and post- irradiation alongside current commercial off-the-shelf (COTS) seal materials from Garlock. Currently, we are working towards a Technology Readiness Level of 7 via permeation, rotational abrasion, and sealing experiments post representative rare isotope high radiation environment exposure at MSU. Radiation durable rotary vacuum and water seals shall be manufactured for use with rare isotope beam facilities for the stable production of new and rare isotopes. These isotopes shall also benefit medical accelerators, advanced imaging needs within the medical community, and military and space applications.

Low Cost Data Acquisition Synchronization for Nuclear Physics Applications

Wojtek Skulski, SkuTek Instrumentation, NY

Grant Title: Low Cost Data Acquisition Synchronization for Nuclear Physics Applications

NP SBIR/STTR Topic: Software

We completed our work on interfacing SkuTek digitizers with the digital acquisition framework at Argonne National Laboratory. The project brings significant improvements of the digitizer architecture, readout speed, and online control. The digitizer provides 32 channels of low noise digitization with 14 bits at 100 MSPS, suitable for both scintillators and high resolution semiconductor detectors. The onboard FPGA is running real time signal processing firmware derived from Digital Gammasphere (DGS) firmware. The GRETA-compatible Trigger and Timing Control Link (GTCL / TTCL) is using fast point-to-point serial links compatible with Gamma Ray Tracking Array (GRETA). The event readout is performed over copper Ethernet at 1 Gbps, or optical fiber Ethernet at 10 Gbps. Digitizer setup, control, and monitoring is handled with embedded Linux single board computer (SBC) running embedded Linux for the ARM processor. We will present the progress of this project.

DWDM Photonics Integrated Circuit (PIC) featuring minimal detector footprint

Radu Radulescu, Telluric Labs, Red Bank, NJ

NP SBIR/STTR Topic: Software

The DWDM Photonic Integrated Circuit (PIC) developed by Telluric Labs converts the low voltage analog signals generated by the detector into optical signals. These optical signals are subsequently transmitted through a single-mode fiber to the Backend Electronics (BE), where they undergo conversion back into electrical signals. This process optimizes cost-effectiveness and enhances performance through the utilization of commercial-off-the-shelf (COTS) digitizers. Consequently, the need for custom, heat-emitting, and space-consuming digitizers (and/or coax cable drivers) on the Detector is completely eliminated. This streamlined approach simplifies both the cryogenic setup and mechanical structure, while simultaneously improving the Signal-to-Noise Ratio (SNR).

The PIC is designed for both digital and linear (analog) signal transmission. It is remotely illuminated by DWDM lasers external to the Detector. The PIC operates on the foundation of MicroRing Resonators (MRR), configurable as differential or single-ended modulators, functioning on a 200GHz ITU grid. This provides the flexibility to balance linear characteristics, stability, and noise immunity against achieving a higher channel count.

The PIC encompasses both modulation and demodulation capabilities. MRRs offer numerous advantages, including inherent wavelength filtering, heightened sensitivity, compact dimensions (~10um), tunability, low power consumption, and cost-effectiveness.

The PIC has exceptional performance in laser modulation, effectively managing signals well below 1V. Its 2x4mm size ensures efficient space utilization and energy conservation, particularly beneficial for cryogenic and low-noise experiments.

Our innovative differential Microring Modulator architecture ensures impeccable modulation linearity, enabling 16 C band channels per single-mode fiber.

MRRs present a multitude of benefits, including inherent wavelength multiplexing, gradual saturation, heightened sensitivity, small dimensions (~10um), tunability, low power consumption, radiation resilience, and cost-effective manufacturing through traditional Si foundries.

Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

Alexander Smirnov, RadiaBeam Systems, CA

Grant Title: Ultrafast High Voltage Kicker System Hardware for Ion Clearing Gaps

NP SBIR/STTR Topic: Accelerator

The ionization scattering of the electron beam with residual gas molecules causes ion trapping in the electron rings, both in the collider and electron cooling system. The trapped ions may cause emittance growth, tune shift, halo formation, and coherent coupled bunch instabilities. Therefore, the beam temporal structure needs gaps to clear the ions to prevent them from accumulating turn after turn. Typically, the gap in the bunch train has a length of a few percent of the ring circumference. RadiaBeam is developing the bunch deflecting system which consists of a kicker and pulse generator to provide with +/-1200 V peak voltage, 100 ns FWHM, <15ns rise/fall times and 1.4 MHz repetition rate.

Design and fabrication of the "AODS": All-in-One Digitizer System-on-Chip

Isar Mostafanezhad, Nalu Scientific, LLC, HI

Grant Title: Design and fabrication of the "AODS": All-in-One Digitizer System-on-chip

NP SBIR/STTR Topic: Electronics

Statement of the problem or situation that is being addressed throughout Phase II portion of your proposal: Nalu Scientific will develop the "AODS", a fast measurement tool to readout high speed signals generated by particles in particle and high energy physics experiments. Detection of individual charged particles and photons and estimation of their properties is the basis for a wide range of scientific and commercial applications from high-energy, nuclear and astro-physics to medical imaging and diagnosis and LIDAR. We are targeting the data acquisition market for medium to large scientific experiments in the energy or intensity frontiers. These complex experiments require hundreds to thousands of recording channels capable of fast data acquisition and signal processing. The AODS allows for timing resolutions on the order of 100s of picoseconds, which will translate to highly accurate estimates of charged particles and their tracks. Low cost, low power designs are especially attractive for experiments with thousands of recording channels.

General statement of how this problem is being addressed: We propose to design and make commercially available the "AODS": a low-cost, low-power and high density waveform sampling chip capable of analog signal conditioning, fast waveform sampling, and integrated readout with high dynamic range mode. The AODS device will also have calibration and monitoring circuitry in addition to a deep sampling buffer making it suitable for large Particle Physics and High Energy Physics experiments with potentially long trigger delays.

What was done in Phase I: We designed a full AODS chip satisfying the specifications, thus demonstrating the feasibility of the project. The chip will be available for testing at the beginning of phase II.

What is to be done in Phase II: We will test performance and advance the design for robustness. We will also fabricate several revisions of the prototype and incrementally add features until desired chip is created.

Commercial Applications and Other Benefits: This device can be used by scientists in high energy and nuclear physics experiments for fast analog data acquisition. It also has applications in high end general purpose instrumentations, medical/PET imaging, automotive and remote sensing (self-driving vehicles) with LIDAR. We anticipate the ability to sell the device as an OEM manufacturer, provide associated design services or license it to a larger device manufacturer due to the low cost and low power nature of the design which will give us a competitive edge.

Key Words: waveform sampling, digital signal processing, application specific integrated circuit, low cost, low power, lidar, picosecond

Summary for Members of Congress: Modern sensors with applications in measuring fundamental properties of matter require advanced electronics for fast processing of data. Our solution provides a low cost, low power, but high performance electronic processing microchip with applications in fundamental research as well as commercial applications in lidar and medical imaging.

An RF beam Sweeper for Purifying In-Flight Produced Rare Isotope Beams

Sergey Kutsaev, RadiaBeam Systems, Santa Monica, CA

Grant Title: An RF Beam Sweeper for Purifying In-Flight Produced Rare Isotope Beams

NP SBIR/STTR Topic: Accelerator

RadiaBeam is developing an RF beam sweeper for puri-fying in-flight produced rare isotope beams at the ATLAS facility of Argonne National Laboratory. The device will operate in two frequency regimes – 6 MHz and 12 MHz – each providing a 150 kV deflecting voltage, which dou-bles the capabilities of the existing ATLAS sweeper. We present the design of a high-voltage RF sweeper and discuss the electromagnetic, beam dynamics, and solid-state power source for this device.

A New Approach to Achieving High Granularity in Low-Gain Avalanche Detectors

Rafiqul Islam, Cactus Materials, Tempe, AZ

Grant Title: Low Gain Avalanche Detector (LGAD), solid-state, tunable, silicon diode pixilation production

NP SBIR/STTR Topic: Electronics

The Low Gain Avalanche Detector (LGAD), a new type of solid-state detector, has achieved a timing resolution of better than 20 psec., enabling the development of fast timing layers for the ATLAS and CMS detectors. The high speed of LGAD signals have also drawn the attention of the nuclear, low energy x-ray, and photon science communities. This company is fabricating the first-ever prototype of a proprietary new approach to the production of high-granularity LGADs that employs silicon diode pixilation, effectively removing the granularity limit suffered by current state-of-the-art LGAD sensors. The dynamic range of our LGAD is limited only by space-charge saturation of the bias field and is tunable by up to two orders of magnitude via the externally-applied bias voltage. We are seeking relationship with defense and commercial customers in particle detectors, photodetector space, and medical imaging applications.

Novel methods for in-situ high-density surface cleaning (scrubbing) of ultrahigh vacuum long (100m or longer) narrow tubes to reduce secondary electron yield and outgassing

Joe Poole, Ady Herschovitsch, Poole Ventura, Inc., Oxnard, CA & Brookhaven National Lab

Grant Title: Novel methods for in-situ high-density surface cleaning (scrubbing) of ultrahigh vacuum long (100m or longer) narrow tubes to reduce secondary electron yield and outgassing

NP SBIR/STTR Topic: Accelerator

A. Custer, M. Erickson, H. J. Poole

Electron clouds in existing accelerators limit machine performance through dynamical instabilities and associated vacuum pressure increases. Bare metal vacuum walls have shown to prevent electron cloud formation due to low SEY. Proper scrubbing of stainless steel, copper, or niobium vacuum walls can mitigate the problems of electron clouds and increase accelerator luminosity. Present scrubbing by ion beams and plasmas have resulted in unsatisfactory surface cleaning by not scrubbing all surfaces and poor debris pumping-out due to low-density plasma/gas generation in the molecular flow range. Novel plasma discharge cleaning techniques and tools were developed for in-situ scrubbing long, small diameter tubes by generating high-density unmagnetized plasmas, in the viscous flow range, to completely affect each exposed surface, with effective debris pump-out. One technique involves high plasma density magnetron mole, the other is based on 2.45 GHz microwave plasma injection that generates high-density plasma. High-density plasma scrubbing in the viscous gas flow range can reach all surfaces and pump out all debris. A magnetron discharge cleaning test stand, which is operational, is about to commence discharge cleaning samples for testing their properties, especially SEY. The microwave discharge cleaning test stand is ready for assembly.

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