Beams, magnets and modeling to advance the quest for fusion energy at Berkeley Lab

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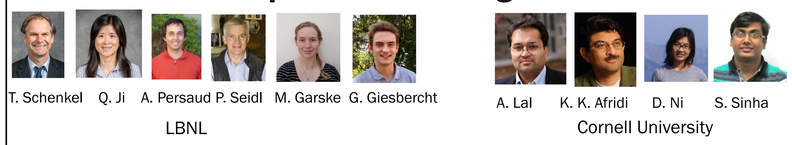
BERKELEY LAB · ATAP ACCELERATOR TECHNOLOGY & APPLIED PHYSICS DIVISION · U.S. DEPARTMENT OF ENERGY · arpa·e

1. Compact multi-beam ion accelerators for plasma heating



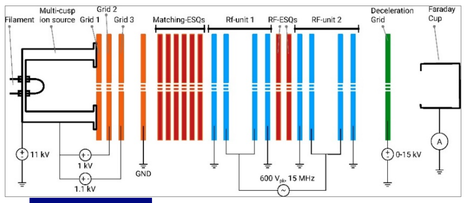
T. Schenkel Q. Ji A. Persaud P. Seidl M. Garske G. Giesbercht

LBNL

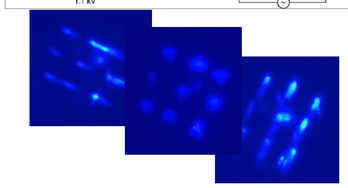
A. Lal K. K. Afridi D. Ni S. Sinha

Cornell University

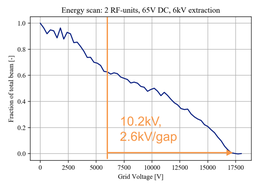
Ion beams are widely used in many applications, and they are attractive for fusion plasma heating.
We are developing compact, low cost multi-beam ion accelerators that can be scaled to high beam power.



Schematic with focusing and acceleration wafers.

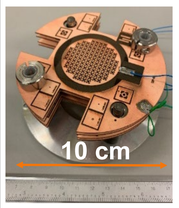


Images of ion beamlets for a series of electrostatic quadrupole (ESQ) settings demonstrating focusing.



Multi-beamlet Ar^+ ion current vs. retarding grid bias showing ion acceleration with 2.6 kV/gap.

We have demonstrated the concept of multi-beam ion accelerators made from stacks of low cost wafers.
The next step is scaling to high beam power.

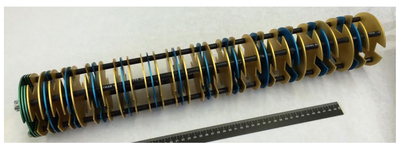


Multi-beamlet RF accelerator unit with 112 beamlet array (1 mm apertures, 3 mm spacing).

Compact RF power supply from Airity Tech, LLC, designed for 10 kV/gap at 13.56MHz

High power, multi-beam RF accelerators can advance plasma heating in MFE (neutral beam injectors), MTF (liner formation and compression and IFE/HIF

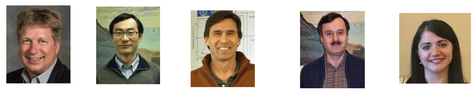
- Low cost components and fabrication based on MEMS technology



Scalability to high ion current (>1 Ampere) and high kinetic energy (>1 MeV) in a modular approach. Left: model if a 300 keV module.

- 10x higher system current density than single beam accelerators
- Mid term goal is 1 MeV in 1 m, higher gradients in progress
- Safe – no need to stand-off high voltages due to sequential acceleration, no x-ray hazard
- *US Patent 2019/0159331 A1, May 23, 2019.*
- *A. Persaud, et al. Rev. Sci. Instrum. 88, 063304 (2017)*
- *P. A. Seidl et al., Rev. Sci. Instrum. 89, 053302 (2018).*

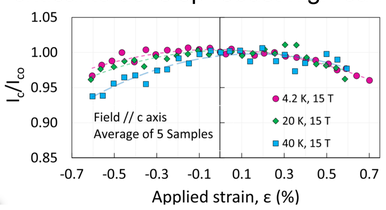
2. High Temperature Superconducting Magnets for Fusion Reactors

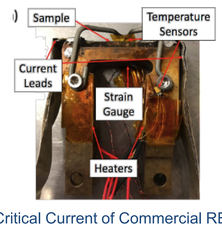


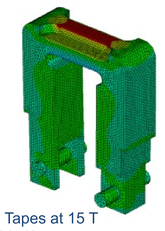
S. Prestemon X. Wang G. L. Sabbi M. Martchevskii F. Pierro

- We are working on the exploration, development, and application of HTS for Fusion
  - on conductor characterization and initial feedback to cabling
  - investigating novel diagnostics for quench detection/protection

The strain measurements on commercial REBCO tapes provide first data set critical to develop robust high-current fusion conductors

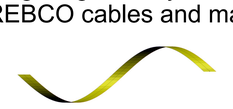




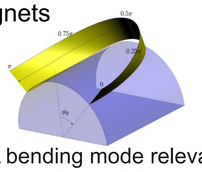


Ref. F. Pierro et al, "Measurements of the Strain Dependence of Critical Current of Commercial REBCO Tapes at 15 T between 4.2 and 40 K for High Field Magnets", IEEE Trans. Appl. Supercond. Vol. 29, No. 5, 8401305(2019)

Development of optimal cable and magnet geometry to manage strain in REBCO cables and magnets



A helical winding used in CORC® cable



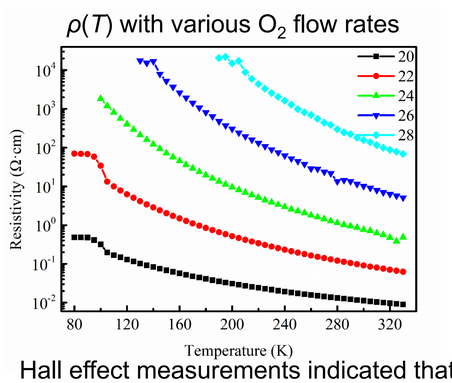
A bending mode relevant for stacked cable

Ref: X. Wang et al, "Strain Distribution in REBCO Coated Conductors Bent with the Constant-Perimeter Geometry", IEEE Trans. Appl. Supercond., 6604010, 2017.
https://doi.org/10.1109/TASC.2017.2766132

High-field REBCO magnet technology relevant for HTS fusion

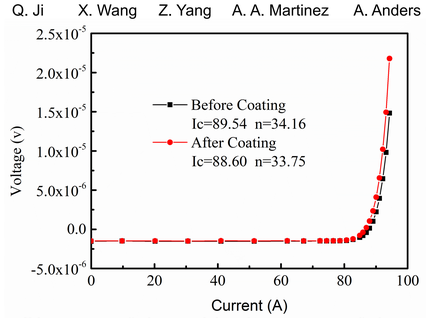
The world-class cabling facility and expertise at LBNL can contribute to the development of HTS fusion cables

We demonstrated VO_x coating on short REBCO tapes using cathodic arc plasma deposition as a first step to enhance protection capability for REBCO cables and magnets



Hall effect measurements indicated that the resistivity of the V_2O_3 films at room temperature was at least 3 orders of magnitude lower than at 77 K.

Q. Ji X. Wang Z. Yang A. A. Martinez A. Anders



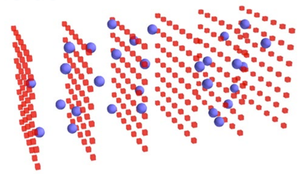
Change of the critical current of the REBCO tape before and after coating is negligible.

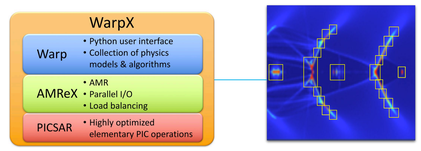
Ref: Z. Yang et al, "Cathodic arc deposition of VOx films and their application in quench protection of high-temperature superconducting magnets", in preparation.

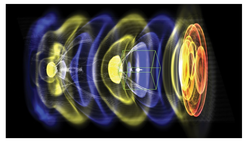
3. Collisional interaction modules in WarpX for Fusion Research

J. L. Vay R. Lehe M. Thevenet A. Huebl

- WarpX is a Particle-In-Cell code: *ab initio* simulations of interaction between plasma particles and electromagnetic fields







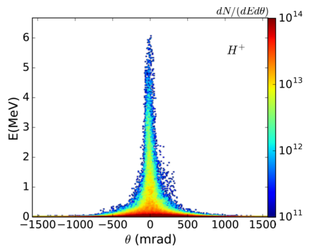
ECP EXASCALE COMPUTING PROJECT

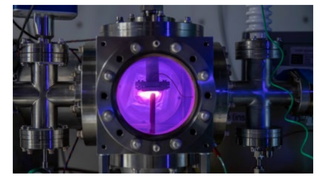
NNSA National Nuclear Security Administration · U.S. DEPARTMENT OF ENERGY · Office of Science

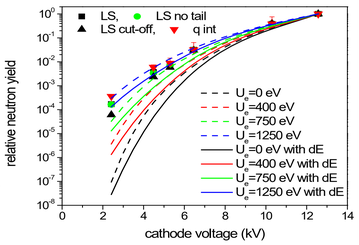
- WarpX is massively parallel, optimized on DOE supercomputers; supported by the DoE Exascale project
- Examples of fusion relevant applications:
  - Interaction between intense lasers, intense beams and dense targets for inertial fusion, fast ignition
  - Interpenetration of high-energy plasmas, Weibel instability, …
  - Kinetic effects in heating processes inside plasmas, heating by RF fields or neutral beams in tokamaks, laser heating, …
  - Some applications may require developing new modules in WarpX, esp. collisional interactions
- J.-L. Vay, et al, Nucl. Inst. Meth. A 909, 486-479 (2018)

4. Fundamental studies of fusion processes with high impact potential

Fusion rates are determined by tunneling through the Coulomb barrier. Can we discover new ways to enhance tunneling rates ? Electron screening in dense plasmas is a known-unknown, let's hack it !







Exploratory; opportunities to advance basic understanding and master new control vectors to enhance fusion rates. Theory, simulations and fusion experiments with ion pulses, lasers, plasmas, …

- J. H. Bin, et al., Rev. Sci. Instrum. 90, 053301 (2019)
- T. Schenkel, et al., https://arxiv.org/abs/1905.03400
- C. P. Berlinguette, et al., Nature 570, 45 (2019)
- **funded in part by GOOGLE LLC through a Crada with LBNL**

This work was supported by the Director, Office of Science, Offices of HEP and FES, and by ARPA-E, U.S. Department of Energy, under Contract No. DE-AC-0205CH11231 (LBNL).