EFRC: CENTER FOR EMERGENT SUPERCONDUCTIVITY (CES)

UPDATED: AUGUST 2016

AWARDS: $22.5M (August 2009 – July 2014); $14M (August 2014 – July 2018)
WEBSITES: http://science.energy.gov/bes/efrc/centers/CES/; http://www.bnl.gov/energy/ces
TEAM: **Brookhaven National Laboratory (Lead):** Peter D. Johnson (Director), John M. Tranquada, J.C. Seamus Davis, Ivan Bozovic, Cedomir Petrovic, Genda Gu, Qiang Li, Mark Dean, Jon Rameau; **Argonne National Laboratory**: Wai Kwok, Michael Norman, Duck Young Chung, Alexei Koshelev, Dean Miller, Ulrich Welp, Mercouri Kanatzidis; **University of Illinois:** Jim Eckstein, Peter Abbamonte, David Ceperley, Philip Phillips, Daniel Shoemaker, Jian-Min Zuo; **Rutgers University**: Gabriel Kotliar; **Florida State University**: Laura Greene; **Los Alamos National Laboratory**: Leonardo Civale

SCIENTIFIC MISSION AND APPROACH

The central mission of the CES is the development of an understanding of high Tc superconductivity (HTS) to enable the prediction and perfection of new HTS materials for use in energy technologies including generation, storage and transmission   Research in the CES is directed towards three key areas:

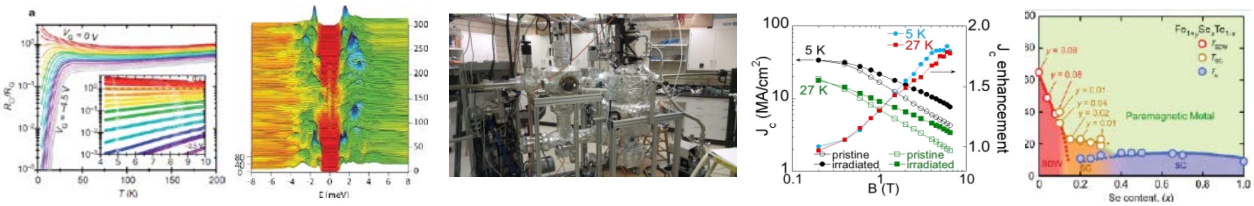
1) ***Materials***: Develop new synthesis routes and new theoretical approaches to create new classes of superconducting materials by design.

2) ***Mechanisms***: Develop a fundamental understanding of the mechanism of high-temperature superconductivity through a range of experimental and theoretical studies.

3) ***Vortices and Critical Currents***: Develop an understanding of the current carrying limiting processes of existing high-temperature superconductors that will lead to enhanced performance by design.

SELECTED SCIENTIFIC ACCOMPLISHMENTS

- Molecular Beam Epitaxy was used to invent a new field-effect technology that was applied to HTS to demonstrate that the condensation of pre-formed pairs above Tc drives the transition.
- The first atomic scale visualization of the electronic structure of the “parent” compound of the Fe-based HTS and identification of a nematic phase. These observations were followed up to demonstrate that the pseudogap of copper based HTS is also an electronic nematic.
- Many different Fe-based HTS samples were synthesized and distributed across CES, allowing detailed spectroscopic and transport/thermodynamic studies on the same samples. Systematically mapping out the phase diagrams enabled breakthroughs in HTS vortex-matter research.
- Demonstrated that the cuprate pseudogap phase contains a previously unknown electronic state – a density wave with a *d*-symmetry form factor. This exotic density wave state may prove to be the key to the existence of the pseudogap phase itself.
- The in-field current carrying capacity of commercial YBCO (HTS) wires was doubled with oxygen-ion irradiation in exposure times that are technologically viable.
- Investigations of vortex pinning at the atomic level in iron based superconductors using ion-irradiation found that the strongest vortex pinning occurs at the metallic-core columnar defects and secondary pinning at clusters of point-like defects.



CES research, from left: superconductor-insulator transition in cuprate thin films driven by field-effect technology; STM measured superconducting gaps in the vortex core region in an FeTeSe superconductor; Momentum resolved electron energy loss spectrometer; Magnetic field dependence of the critical current density J_c demonstrating the critical current enhancement due to ion-irradiation of commercial YBCO coated conductors; Phase diagram of the iron-based superconductor FeTeSe.

IMPACT

- The new *Critical-Current-by-Design* paradigm parallels the Materials Genome Initiative, and provides a rational approach to introducing tailored heterogeneity into commercial HTS superconductors to optimize their current carrying capacity for targeted applications.
- Members of the CES have now given close to 500 invited talks at national and international meetings. CES researchers were responsible for the organizations of the 10th International Conference on Materials and Mechanisms of Superconductivity held in Washington DC, 2012 (The Secretary of Energy was a Plenary Speaker at this event) and the 13th International Workshop on Vortex Matter in Superconductivity held in Chicago 2011.
- Crabtree, Johnson and Greene co-edited a Reports on Progress in Physics *Special Issue on the Fe-based Superconductors* and Johnson co-edited a book on *Iron-based Superconductivity* in the Springer Series in Materials Science. These efforts helped promote CES and HTS internationally.
- Doubling of the critical current by short ion-irradiation times has led to the development of a rapid reel-to-reel irradiation method on commercial HTS wires from **American Superconductor (AMSC)**. This method has launched a viable industrial procedure for enhancing the in-field current carrying capacity of existing post-production wires in a uniform fashion over long lengths. Moreover, the enhanced value of the current density is to the point where they can be used in superconducting rotating machinery. AMSC is one of the leading producers of high Tc superconducting cable in the USA. http://www.amsc.com/

PUBLICATIONS AND INTELLECTUAL PROPERTY

As of May 2016, CES had published 193 peer-reviewed publications cited over 4,300 times and filed 2 disclosures and 2 US patent applications. One disclosure application has been licensed. The following is a selection of impactful papers:

- Chuang, T. -M. *et al.* Nematic Electronic Structure in the "Parent" State of the Iron-Based Superconductor $Ca(Fe_{1-x}Co_x)_2As_2$, *Science* **327**, 181, doi: 10.1126/science.1181083, (2010). [**293 citations**]
- Lawler, M. J., *et al.* Intra-unit-cell electronic nematicity of the high-T-c copper-oxide pseudogap states, *Nature*, **466**, 347-351, doi: 10.1038/nature09169 (2010)**.** [**224 citations**]
- Bollinger, A. T. *et al.* Superconductor-insulator transition in $La_{2-x}Sr_xCuO_4$ at the pair quantum resistance, *Nature*, **472**, 458-460, doi: 10.1038/nature09998 (2011). [**184 Citations**]
- Leroux, M. *et al.* Rapid doubling of the critical current of $YBa_2Cu_3O_{7-\delta}$ coated conductors for viable high-speed industrial processing, *Applied Physics Letters* **107**, 192601, doi: 10.1063/1.4935335 (2015). [**5 Citations**]
- Sadovskyy I. A. *et al*. Towards superconducting critical current by design, *Adv. Mater*. **28**, 4593-4600, doi: 10.1002/adma.201600602 (2016). [**2 Citations**]
- Lv W. *et al.* Orbital ordering and unfrustrated (π, 0) magnetism from degenerate double exchange in the iron pnictides*, Phys. Rev. B* **82**, 045125, doi: 10.1103/PhysRevB.82.045125 (2010). [**135 Citations**]
- Huecker M. *et al.* Stripe order in superconducting $La_{2-x}Ba_xCuO_4$ (0.095 <= x <= 0.155), *Phys. Rev. B* **83**, 104506, doi: 10.1103/PhysRevB.83.104506 (2011). [**108 Citations**]