

RadiaBeam Technologies Products and Capabilities

Marcos Ruelas

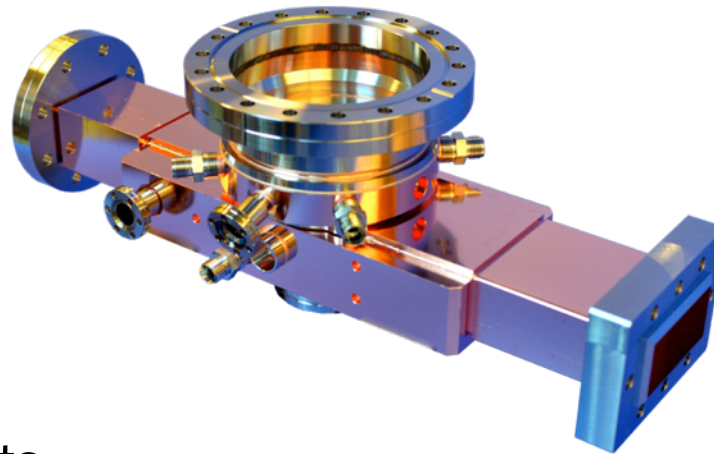
Who We Are



- Spun-off from the UCLA Particle Beam Physics Laboratory in 2004
- ~50 employees, including 9 PhD scientists and 22 engineers
- Strong accelerator physics and engineering backgrounds
- Worldwide sales, service, software, and consulting with a strong R&D program
- Offices in
 - Headquarters, Los Angeles
 - Sales, San Francisco bay area
 - European office, Italy
- *A One Stop Accelerator Shop*



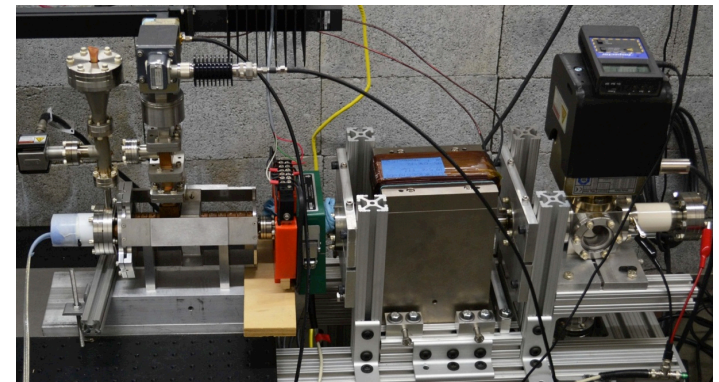
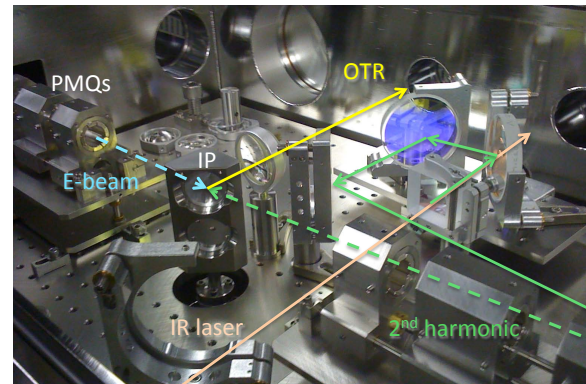
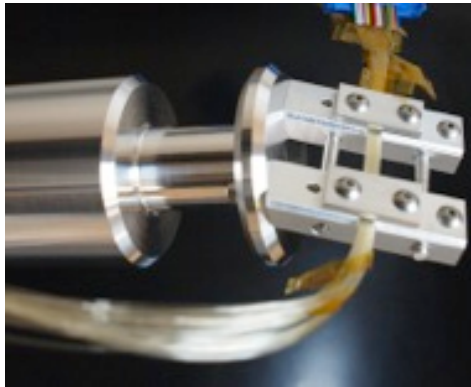
- Turnkey accelerators
 - Turnkey injectors
 - Transport lines
 - Industrial linacs
- Diagnostics
 - Beam profile monitors
 - Bunch length monitors
 - Charge, emittance, et cetera
- RF structures
 - RF photoinjectors
 - Bunchers
 - Linacs
 - Deflectors
- Magnet systems
 - Electromagnets
 - Permanent magnets
 - Systems (chicanes, final focus, spectrometers)



Customers

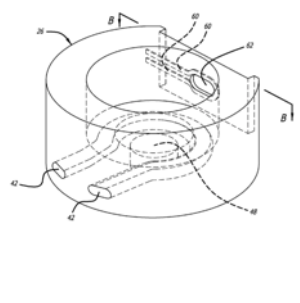


- Average research budget of \$5m per year supported primarily by US funding agencies
- Focus on novel acceleration schemes, compact sources, precision diagnostics, and **advanced fabrication techniques**
- Collaborate with leading international institutes and scientists



Additive manufactured Niobium

- Additive manufacturing techniques allow for higher average power and otherwise impossible designs
- Layers of atomized metal powder is selectively melted with an electron beam
- Allows for nearly monolithic, seamless, and thermally-stabilized SRF niobium structures of arbitrary shape at reduced cost
- First to develop the electron beam melting additive manufacturing process for copper and niobium
- Since 2006, \$3.5m investment in copper, niobium, and Ti-Nb joining with electron beam melting techniques



Fabricating Copper Components with Electron Beam Melting

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The ability to make components from copper and copper alloys via additive manufacturing is opening a range of novel applications.

Invest fabrication of fully dense metal structures using the electron beam melting (EBM) process developed by Andrew AB, Inc., Inc., has been demonstrated for a wide range of materials including Ti-6Al-4VTM, InconelTM, stainless steelTM, 316L steelTM, and nickel base alloysTM. A growing interest in additive manufacturing (AM) to build components from copper and copper alloysTM has led to a variety of applications including novel radio frequency (RF) components. A critical issue for high average power, high frequency applications is the design of a cavity for generating high brightness electron beams used in some of today's linear accelerators—in efficient cooling. Radiabeam Technologies is exploring the use of AM to fabricate complex, RF abutment structures with geometries optimized for thermal management. Specially optimized internal cooling channels can be fabricated without the constraints typically associated with traditional manufacturing methods.

However, several properties of pure copper present significant processing challenges for the metal AM. For one, pure copper has a relatively high thermal conductivity (~400 W/mK) at 300K, which, while ideal for thermal management applications, quickly conducts heat away from the melt area resulting in local thermal gradients. The use of laser cutting, deformation, and ultimately, heat and part failure. Additionally, copper's high ductility hinders pure build powder removal and accuracy. Surface also needs aggressive, reducing overall flexibility and spreading powder deposition. Because Cu is sensitive to oxidation, great care must be taken in handling and storage before, during and after fabrication.

Fabrication methods
Initial experiments focused on identifying viable processes for processing copper using EBM. An Arcam model S12 at North Carolina State University, and an Arcam model S12 at the University of Texas El Paso, Raleigh the available for this experiment. EBM hardware is a powder bed fusion process. A powder bed is built layer by layer, high temperature laser energy melting approximately 100µm thick layer on a 10-mm-thick bed of base

copper powder was the build substrate. Initially, the electron beam exits the scan plane surface at high power and high speed, melting the plane underneath to "EBM" EBM, that maintains thermal maintenance of a relatively high temperature throughout the build process, reducing thermal stresses caused by thermal gradients.

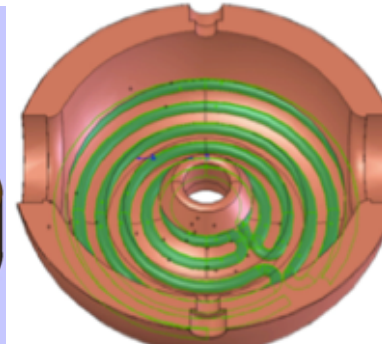
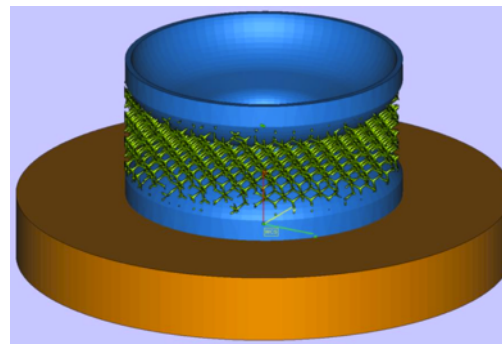
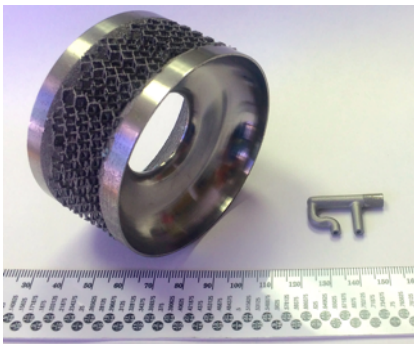
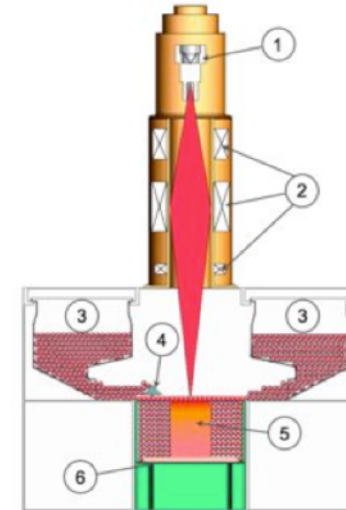
Processing each layer typically requires two separate parameter sets called zones, which consist of all the required process parameters, such as beam speed and power, and focus offset. The first zone is parameterized such that the power temperature and focus is high to melt the next step, melting which is divided into two sub-zones centered and leading. The center zone uses relatively low current and speed to trace the outline of each layer with a proprietary control step called melt lines, which uses the high low use rate capabilities in large between multiple locations on the contour, especially. This approach improves surface finish compared to single spot contouring while maintaining productivity. In the finishing zone, beam current and speed are increased and the focus is re-adjusted to melt the surface uniformly. With each layer the focus direction is rotated 90° and spacing between each layer is offset by 100 µm.

EBM process parameters
Preliminary efforts to parameterize development. EBM hardware is a powder bed fusion process. Powder from three materials was deposited. These high purity 99.99% Cu powders (A and B) were annealed in argon, while a 5000 ppm purity 99.99% Cu

US Patent 7,411,361: *Method and apparatus for radio frequency cavity;*
 Joint patent with JLab - pending: *Additive Manufacturing Method for SRF Components of Various Geometries*

EBM material development summary

- EBM AM advantages:
 - Cost/time savings
 - Excellent material properties
 - **Freedom in design**
- Need a larger investment in developing the process
- Further refinement of the apparatus and its operating parameters



- RadiaBeam's wealth of experience and efficient R&D program make it ideal for development of enabling technologies
- Additively manufactured niobium compliment and extend the capabilities of future colliders with proper attention
- We can serve as a supplier, integrator, and collaborator
- Our expert team is always available for discussion
- EBM AM Acknowledgements
 - R. Rimmer, J. Spradlin, P. Dhakal, J. Henry; Thomas Jefferson National Laboratory
 - C. Terrazas, S. Gaytan, J. Mireles, D. Espalin, F. Medina, R. Wicker, L. Murr; U. of Texas El Paso
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Thank you