CHANGING WHAT'S POSSIBLE

High Efficiency, Megawatt-class Gyrotrons for Instability Control of Burning Plasma Machines

GAMOW Kickoff Meeting
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U.S. DEPARTMENT OF ENERGY

Team – Industry, University and a National Lab

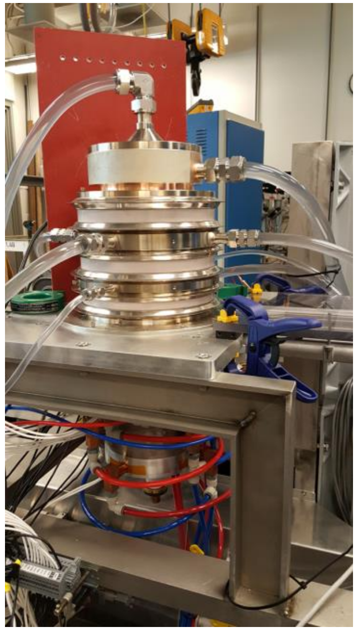
- Jagadishwar Sirigiri
  - PI
  - Top level system design, physics design and electrical design of gun, cavity and collector, experiments
- Tomoya Nakatsugawa
  - Project Management, engineering and experimental setup design
- Anshul Chandel – Mechanical modeling and optimization
- Mudit Pasagadagula – RF component design
- Dennis Gautreau, Walter Hrynyk, Ivan Mastovsky – Engineering team (combined 100 years of vacuum tube fabrication expertise)
- Bridge12 – US small-business – one of only five gyrotron tube manufacturers in the world

- MIT
  - Steve Wukitch
    - Co-PI
    - Additive Manufacturing design of gyrotron collector, experimental setup and experiments
  - Adam Seltzman
    - Optimization of AM design, modeling and testing of prototype parts
- ORNL
  - Muralidharan Govindarajan
    - Co-PI
    - Analyze properties of brazed and e-beam welded prototype joints
    - Thermal life-cycle testing of prototype test joints

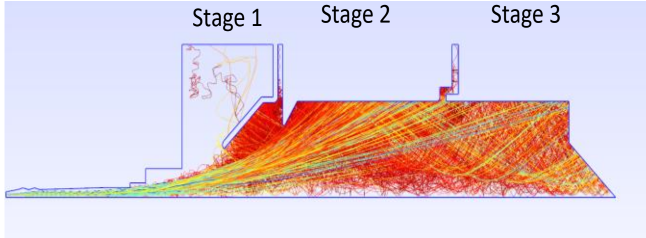
MOTIVATION AND GOALS

- 1 MW, 250 GHz Gyrotron with high (>65 %) efficiency will support ECRH and ECCD in a burning plasma machine
- High Frequency (>250 GHz) – key for compact commercial fusion reactors
- High Efficiency – key for reducing input power (drive up Q) and reduce recirculating power in the plant

- Additive Manufacturing – reduce manufacturing costs and time cycle
- Advanced Materials – GRCop-84 to reduce system size, cost and increase reliability and lifetime
- Advanced Physics – Multi-stage depressed collector for energy recovery



100 kW class gyrotron with multi-stage depressed collector



Spent beam trajectories in a multi-stage depressed collector

- Electron Cyclotron Resonance Heating (ECRH) – necessary for heating the fuel
  - Typical plant may required 40-80 MW of ECRH power
- Electron Cyclotron Current Drive (ECCD)
  - Control instabilities like NTM and extend confinement time
- ECRH assisted startup
  - Reduce DC power required for plasma startup
  - Important for high field machines

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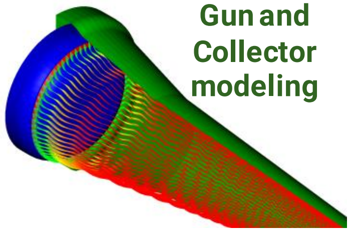
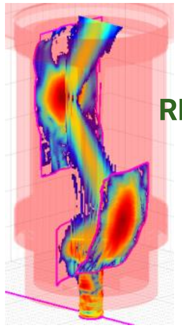
Tasks, Milestones, Risks and Outcomes

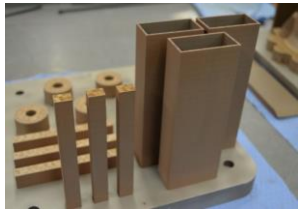
- Tasks
  - Physics and engineering design of 1 MW, 250 GHz gyrotron for CW operation
  - Collector design optimization for additive manufacturing (AM) using GRCop-84
  - Thermal lifecycle test of prototype joints for AM components
  - Fabrication
  - Testing at 1 ms pulse operation
- Milestones
  - Collector design that is manufacturable with SOA AM
  - Thermal analysis to demonstrate operation at 2 X power densities in the collector than SOA



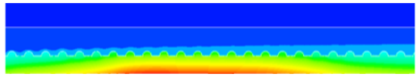
Gun and Collector modeling



RF Modeling



AM RF Parts



HyperVapotron cooling

- Risks
  - Physics – Mode competition in the gyrotron
  - Total Efficiency – >65 % is 15 % higher than SOA
  - Mechanical Fabrication – Integration of AM and conventionally fabricated components
- Outcomes
  - Verified physics and engineering design for a highly efficient and robust source for a ECRH and ECCD system
  - Essential technology for a commercial fusion plant
  - Assuming 80 MW ECRH for a plant the proposed system will save
    - 37 MW of prime power
    - ~10 MW of power for cooling

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T2M Plans

- Techno-economic metrics
  - Goal 2 $/W for 1 MW class gyrotron system for burning plasma machines
  - 10 year operating lifetime
  - For a typical ECRH system when compared to SOA reduce
    - 37 MW of prime power
    - ~10 MW of power for cooling
- Test and Deployment
  - SPARC and DEMO type high field tokamaks requiring >250 GHz ECRH
  - 350 GHz system for EC assisted startup on SPARC
  - Lower frequency systems for replacing currently deployed systems to increase ECRH power
- Commercialization plans
  - Commercial fusion plants
  - Investigating portable MW class millimeter wave gyrotrons for a different commercial application
    - Goal to develop a demonstrator in 2 years
    - Potential annual market for tens of units