Employing High Epsilon Dielectric Materials for Enhancing Cu Accelerator

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Agenda

Motivation

- Increasing the RF efficiency of normal conducting RF accelerator cavities.

Concept

- Utilize high ε dielectrics with low loss to increase cavity efficiency.

Simulations

- Preliminary published simulations and current work.

Ceramics

- Candidate ceramics have been ordered and will be characterized.

Known Issues

- Operational and Fabrication challenges.

01 Motivation

Normal Conducting – Standing Wave Accelerator Cavities are Ubiquitous

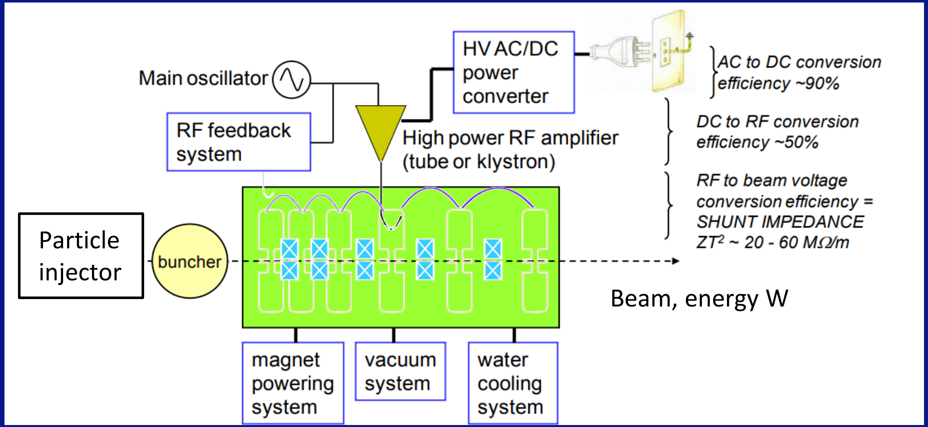
1. Discovery Science
2. Medical: Medical isotope production, Sterilization of devices/equipment
3. Industrial: E-beam material processing, E-beam irradiation, Food Irradiation/sterilization
4. Security: Cargo-screening

01 Motivation – Energy Conversion

- First conversion of the AC power from the grid into DC power takes place in a power converter. Pulsed power converters (modulators) have high efficiency, of the order of 90%.

- The following conversion of DC power into RF power takes place in a RF source: RF tube, klystron, transistor, etc. RF conversion efficiency depends on the specific device and on its class of operation. Typical RF efficiencies are in the range 50–60%.

- The last conversion of RF power into power given to the particle beam takes place in the gap of the accelerating cavity; its efficiency is proportional to the shunt impedance of the cavity and the beam current.



Large cost-drivers for accelerators are total accelerator length, and required RF power.

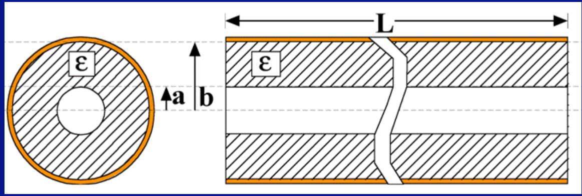
02 Concept

Alternatives to all-metal Structures:

Dielectric based structures have traditionally offered higher shunt impendences and therefore better efficiency.

Dielectric loaded accelerator concept:

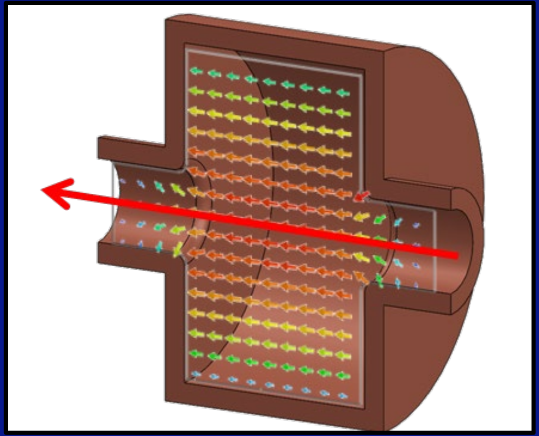
Accelerating field limited to ~ 5-10 MV/m



Dielectric-based structure limitations:

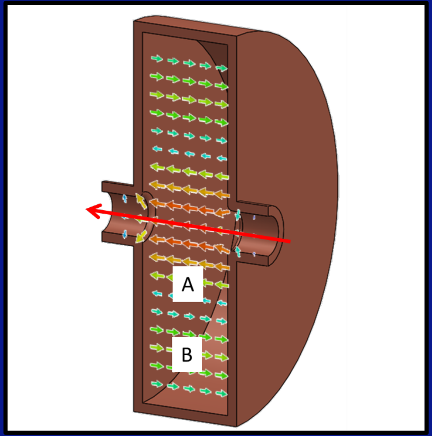
- Dielectrics’ high secondary electron emission yields
- low RF field breakdown limits in comparison to metallic surfaces
- dielectric charge-up from both field emission and beam “halo” particles striking and embedding in the dielectric

02 Concept – Dielectric sleeve placed in low-field region.



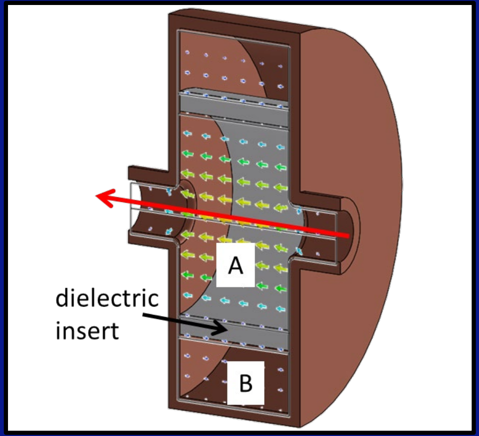
TM010 Mode

All three cavities are resonant at 5.7 GHz; the accelerating gap length is 2.6 cm.



TM020 Mode

The TM020 mode offers a high field region A, and a low field region B.

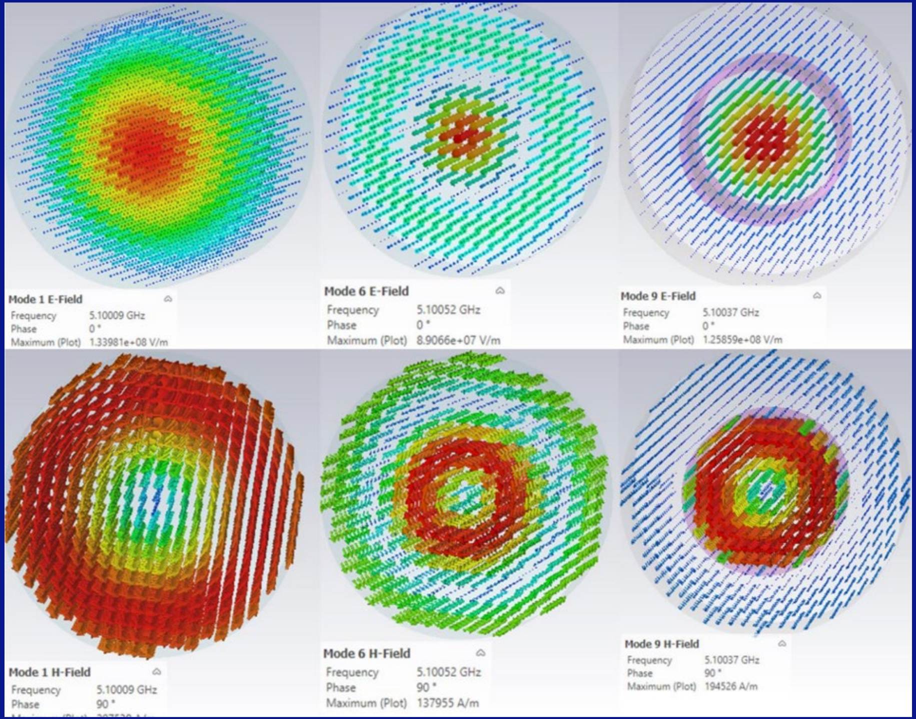


TM020 like mode

Dielectric sleeve places near the null in the TM020 mode – separates regions A and B.

03 Simulations

1. The Electric and Magnetic field of TM010 (left) , TM020 (center) and TM 020 (right) with dielectric sleeve inserted (ε=36).
2. Shunt Impedance of 2.69 MΩ, 1.75 MΩ, and 4.18 MΩ respectively.
3. This corresponds to almost 40% reduction in RF power required.
4. On axis E-field nearly identical.

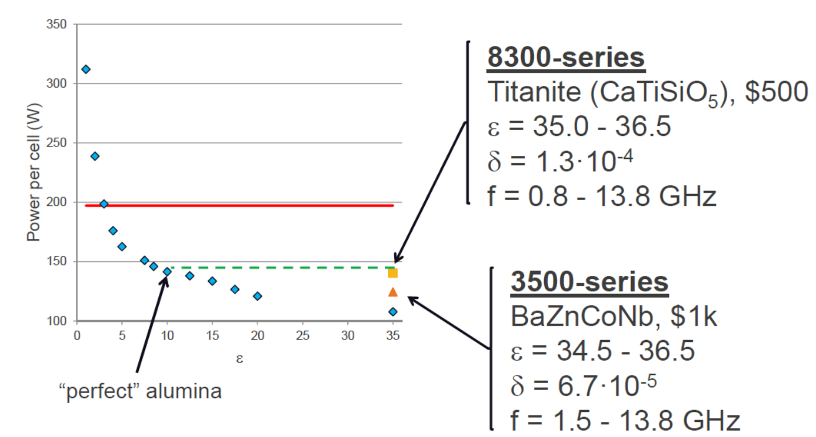


J. Upadhyay, J. W. Lewellen and K. Nichols, "Design of a Dielectric Loaded Normal Conducting Standing Wave Structure for Higher Shunt Impedance", (Submitted PRAB, August 2020)

04 Ceramics

High ε, low loss dielectrics recently developed for cell-towers are great potentials for this application:

- Traditional ceramics used in accelerators also being tested.
- Low-loss ferroelectric material being developed by Euclid Techlabs.
- Ceramics have been ordered from Skyworks – Trans Tech
    - Characterization of loss tangent,
    - Dielectric constant at operational frequencies
    - Vacuum suitability

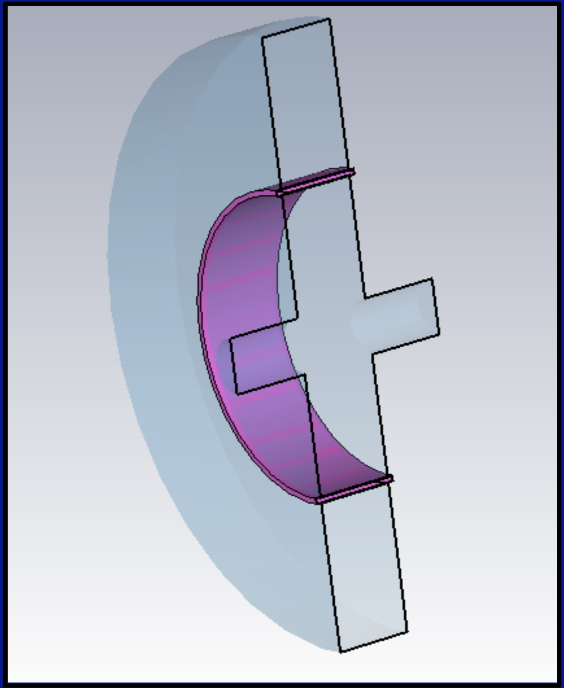


Predicted RF power to generate 1 MV/m on-axis fields in CEAS cavity, as a function of insert dielectric constant e. (Red line = conventional TM_{010}-mode cavity.)

Engineering Design of Test Cavity

Prediction Study:

1. A single copper cavity will be fabricated with a groove cut for inserting different ceramic materials.
2. The cavity will not be optimized for every ε tested but will provide us with predictive results.
3. The cavity is C-band with operation frequencies ranging from 5-6 GHz.



05 Known Issues

Fabrication

- Alignment/tolerances
- Ceramic vs. copper material properties (thermal expansion, brittleness, brazing)
- How to make multi-cell structures
- How to couple power cell-to-cell
- Joint design – metal/ceramic/vacuum interface (multipacting)

Operational

- Mode Competition
- Duty factor
- Thermal effects
- Multipacting
- Beam/structure interactions

Thank you for your attention!

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