ICRF Breakdown Studies
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Summary
- **ICRF voltage breakdown experiment has been designed and tested**
- Acting achieved with energy deposition between 11 and 30U
- Acting only occurs with applied DC magnetic field
- Resolution of arc location insufficient to quantify results: evaluation of complex fields and electrical contact will continue

Introduction
One of the challenges of ICRF operation in tokamak plasma is reliable operation at high voltage. On Alcator C-Mod, we observe arcing among ICRF antenna components at electric fields of 1.5 MV/m for E∥B. Breakdown is influenced by the antenna materials, neutral pressure, ionizing radiation, and the tokamak magnetic field. While copper is typically utilized due to its superior conductivity, it has a relatively low melting temperature (1083 K), low tensile strength, low breakdown field (270 MV/m), and strong material displacement after breakdown. The low melting temperature and tensile strength lead to a reduced voltage breakdown limit. The material displacement after breakdown is consistent with observations that the antenna voltage limits degrade with operation. Due to high tensile strength and melting temperature, refractory metals could improve voltage limits. A test stand has been designed and built to characterize ICRF relevant voltage breakdown. The vacuum test stand structure is a double-ridged, tapered waveguide which creates a peaked electric field of 7.5 MV/m at the electrode location. Effects of electrode material, surface structure, magnetic field, and neutral pressure are investigated.

ICRF Breakdown
The ICRF Breakdown Experiment is a tapered double-ridge waveguide which is used to study ICRF relevant voltage breakdown.
- **Compact design**
- High E-fields between ridges
- Source with matched load until breakdown event (no ringing)
- Provides robust method to benchmark LC-geometry and strip material against various refractory materials
- **Variable B-field and neutral pressure**
- Voltage current probe, optical diagnostics to analyze breakdown — quantify dark current, field emission data

Motivation
Evidence of arcing on Alcator C-Mod ICRF antennas. Alternate materials have the potential to increase voltage handling of ICRF antennas and striplines.
- Refractory metals: high tensile strength, high melting point materials may breakdown at higher surface fields
- E-field strong dependence on B-field orientation (ICRF operational limit = 1.0MV/m for E∥B and ~1.5MV/m for E⊥B) in Alcator C-Mod
- Antenna ground surface damage from arcing

Design
Double-ridge waveguide optimized and operated for Alcator C-mod ICRF frequency of 78 MHz. The ridges taper from end to center, creating a peaked electric field at the middle of the waveguide.
- Simulated and measured transmission and reflection coefficients are in good agreement.
- Excellent match at design frequency (78.14MHz).

Electrode Damage
Local melting and cratering observed on both types of electrodes. However, arcing is not always isolated to central test sample region. Possible causes:
- Possible multipactor condition present due to Be/Cu fingerstock electrical contact
- Complex interaction of DC / RF magnetic field

Arc Trains
Arc trains form in several locations, both on the central region of the copper ridges and on the aluminum waveguide side walls. These trains, different from the craters shown to the far right, only occurred for longer (0.5s) duration — highest pulse energy. Typical energy deposition was ~100 J. Arc trains have been observed to form as cathode spots move across electrode surface with monopolar F<sub>0</sub> ~ 1/2 F<sub>0</sub> of mono polar. This may explain the movement observed here. However, more simulation must be done.

Future work
- Eliminate Be/Cu fingerstock from central region
- Eliminate possible multipactor / glow discharge phenomena
- Concentrate magnetic flux density in similar region —e.g. iron core / smaller magnets
- Improve modeling to better understand magnetic fields, particle trajectories and cathode spot movement

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