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Load Impedance Dynamics in the RITS-6 Self-Magnetic–Pinch (SMP) Diode*

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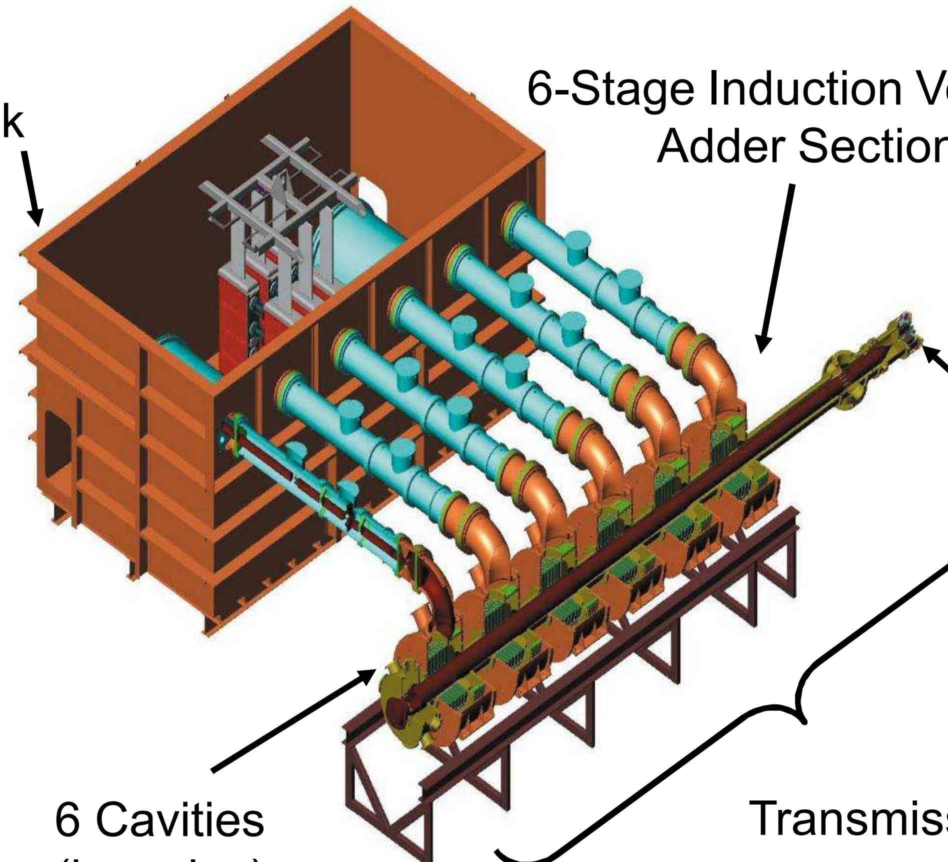
Outline

- RITS-6 Accelerator.
- SMP diode Configuration with typical current profiles.
- Study of different materials-based changes to ‘standard’ Reynold’s foil baseline design:
  - Al-coatings on Ta surface
  - Silver emulsion paint on cathode tip replaced by various materials
  - ‘Limited’ anode targets
  - ‘Large’ and ‘Small’ cathode radii lead to differing results
- Summary

SMP Diode Research Has Been Conducted on the RITS-6[1] Pulsed-Power Accelerator

Radiographic Integrated Test Stand (RITS-6)

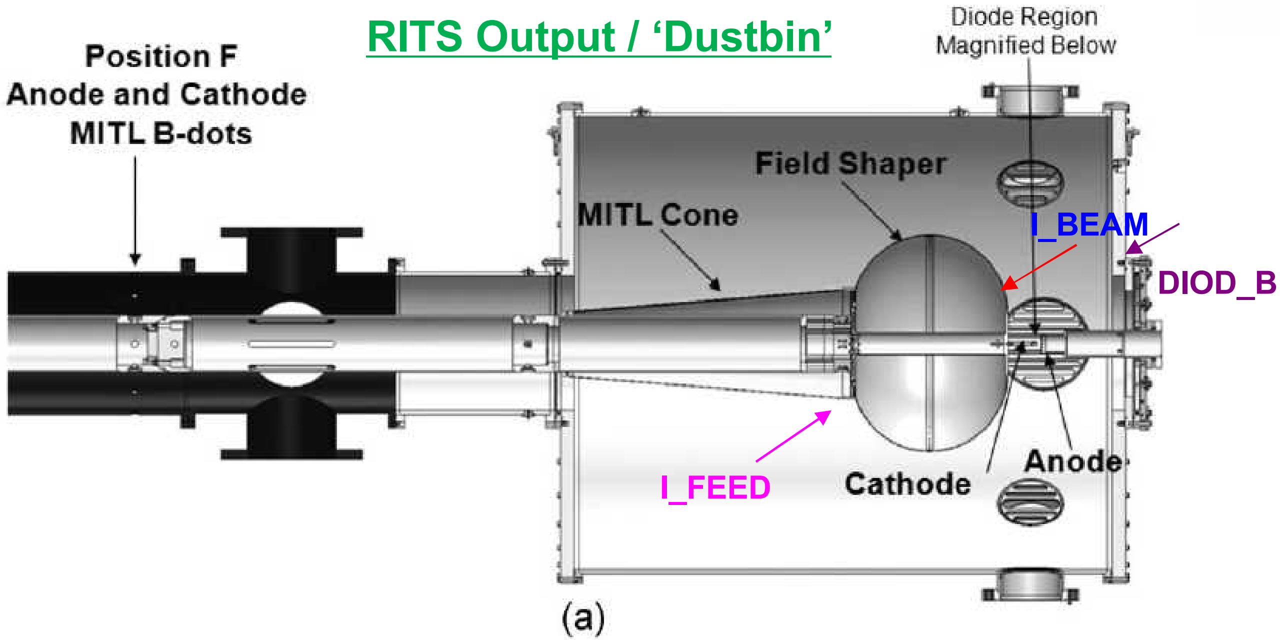


RITS-6 is a 8-12 MV Marx driven six-stage Inductive Voltage Adder (IVA) capable of driving a variety of diode configurations

[1] D. Johnson, et al., in *Proc. 15th IEEE Int. Pulsed Power Conf* (IEEE, Jun. 13-17, 2005) pp. 314–317.

Schematic View of Load and SMP Diode Region

RITS Output / 'Dustbin'

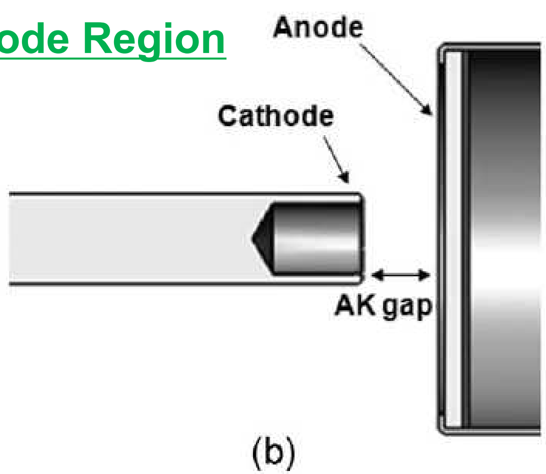


- Negative Polarity
- Current here measured at 3 locations: IFEED (before field shaper), IBEAM (R > cathode), and IDIOD (total current)
- 'Standard' diode hardware:
  - Silver-painted cathode
  - Al 'Reynold's' foil over 1 mm Ta plate, separation 0.8 mm
  - Al beam stop

Close-Up of Diode Region

Cathode materials

- Al tubular cathode with hollowed out end
- Silver emulsion paint applied to tip
- 'SMALL' and 'LARGE' cathode OD designs



Anode materials

- Al foil
- 1 mm Tantalum plate
- 16 mm Aluminum beam stop (3 spaced-out layers)

Photograph of anode in place

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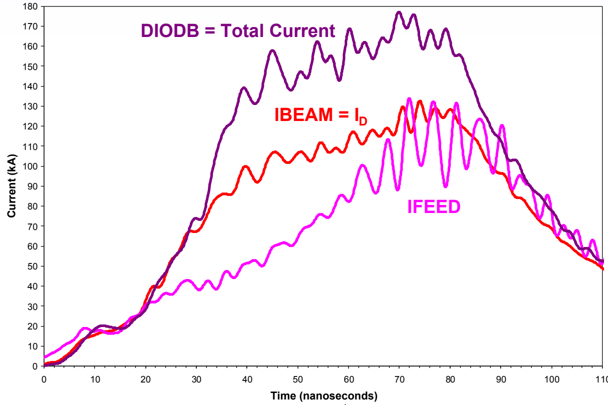
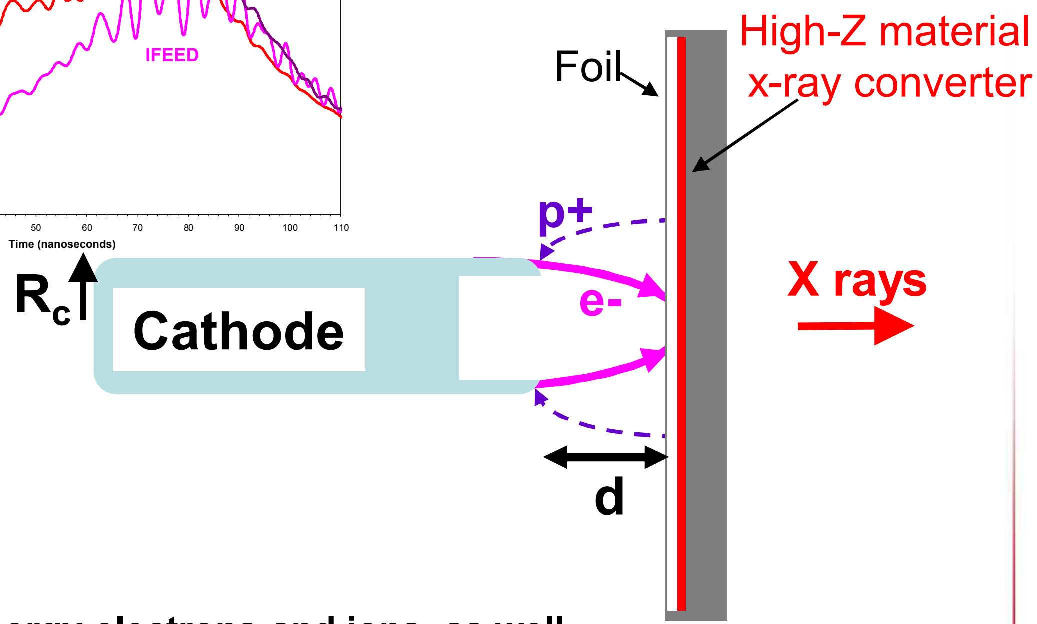
Goal of this work: improve impedance and decrease focal spot size by changing anode and cathode materials

Diode Parameters

- 6-8.5 MV
- 150 kA (~15% ions)
- 50 Ω Impedance
- 70ns Electrical Pulse
- 45ns Radiation Pulse
- A-K gap ~ 10mm, hollow cathode
- $2R_c/d$ ~ 1 for optimal operation





- SMP $Z_{load}(t)$ affected by evolution of high-energy electrons and ions, as well as by plasma evolution from anode and cathode
- (Above) Typical current evolution: IBEAM and IFEED increase gradually through power pulse, IFEED reaches IBEAM at end of pulse. For Z collapse, IBEAM shows inflection, followed by jump in IFEED.
- 'Large' cathode: little evidence of overt A-K collapse. 'Small' cathode: 50% of shots show this.
- 'Limited' anode: use small High-Z spot surrounded by low-Z, w/ and w/o foil.

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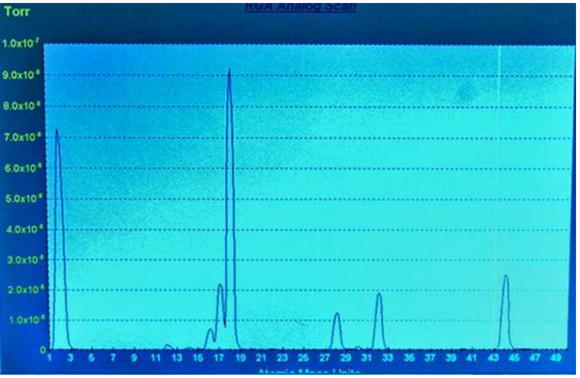
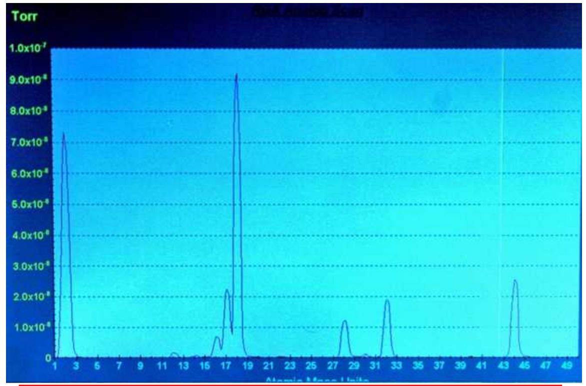
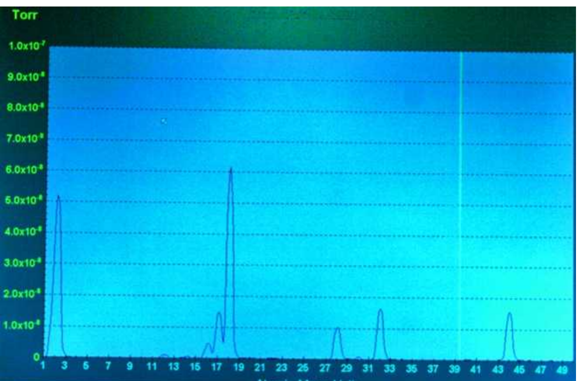
Study of contaminant evolution off 'Reynold's foil suggests replacement with cleaner foil could extend Z lifetime



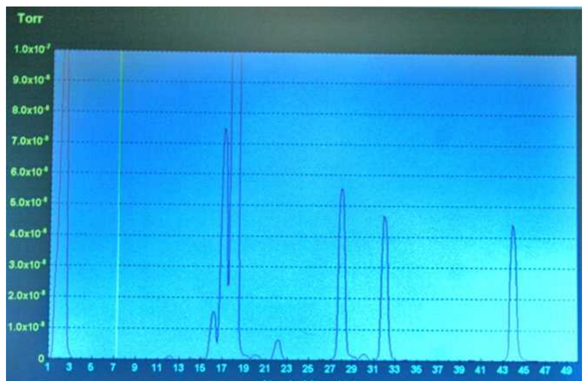
UHV Foil before 5 sec heating



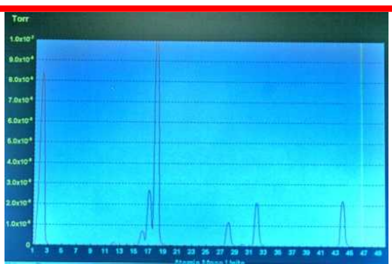
UHV Foil after 5 sec heating



Reynolds Foil before 5 sec heating



Reynolds Foil 1 min after 5 sec heating



2 mins

- **Samples of UHV-grade Al foil and Reynold's Wrap (10 cm long ~few mm wide) mounted in RITS and pumped down, removed and each mounted separately in offline vacuum tank. Base pressure ~ 2e-7 Torr (several days).**
- **Foil strip subjected to ~ 3A heating current for ~ 5 sec.**
- **(LEFT) Screen captures of RGA response. Vertical axis (all) peak 1e-7 Torr for partial pressures. AMU scan (horizontal) 1 - 49.**
- **(TOP) UHV Foil: NO CHANGE in RGA profile after heating.**
- **(BOTTOM) Reynold's Wrap: H, H_20 double, N_2 5x 1 minute after heating. Total partial pressure up by 5X. N_2, O_2, and CO_2 back to normal after 2 mins (below), H_2O only after 5 mins.**

Materials Study are a Work in Progress. Summary of results so far

- 'Large' cathode:
  - Replace 'Reynold's' Al with UHV foil. Based upon DC heating results (previous slide). Result: slight reduction in x-ray dose and pulsewidth.
  - Replace Reynold's Foil-bare Ta plate with Al coating (~ 1µm thick) directly on Ta surface. Result: 40% reduction in x-ray yield, slight reduction in pulsewidth. Little evidence of A-K gap closure.

- 'Small' cathode:
  - Replace Reynold's Foil-bare Ta plate with Al coating (~ 1µm thick) directly on Ta surface. Result: Best shots equivalent to Reynold's baselines. Average: reductions in x-ray pulsewidth. Clear evidence in every configuration of A-K gap closure on ~ 50% of shots.
  - Remove Reynold's Foil, leave bare Ta plate as-provided (one datapoint). Result: slight reduction in x-ray dose, reduction in pulsewidth. Longer pulsewidth than Al-coated Ta.

- 'Limited' anode:
  - Ta center buttons of 1, 2, and 3mm diameter within Al or C substrates, behind foil. Result: reductions in spot size, equivalent impedance to Reynold's baseline.
  - Ta or W center buttons of 1-3 mm diameter within Al substrates, no foil. Result: reductions in spot size, good impedance behavior.
  - Ta or W center buttons of 1-3 mm diameter within C substrates, no foil. Result: as-provided C, early impedance collapse. Al-Coated C, impedance behavior as good or better than Reynold's baseline.

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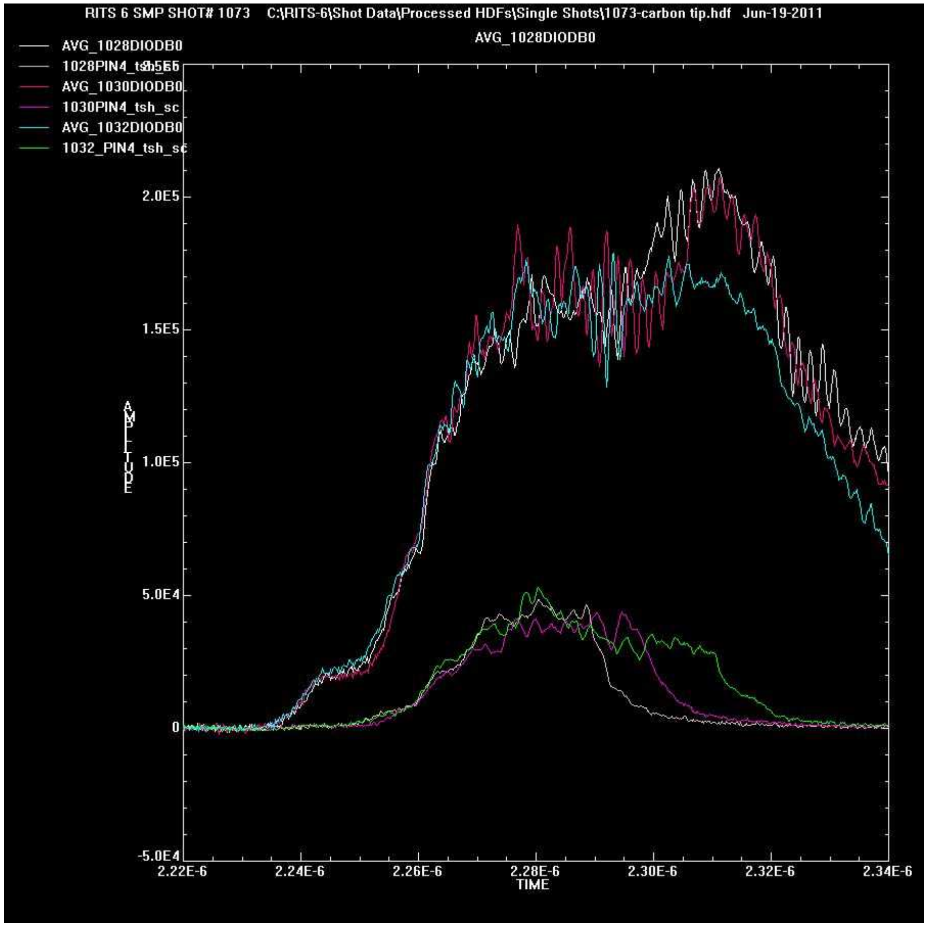
Summary of results so far (continued)

- **Cathode paint changes:**
  - **Replace paint with carbon suspension. Result: early impedance collapse.**
  - **Remove paint (as-provided Al surface). Result: early impedance collapse.**
  - **Replace paint with deposited silver coating. Result: early impedance collapse.**
  - **Replace paint with deposited carbon coating. Result: early impedance collapse.**

- **Summary of summaries:**
  - **Al-coating on Ta cathodes produces same performance at best, average worse performance compared to Reynold's foil baseline.**
  - **A bare Ta cathode provides reasonable impedance performance.**
  - **Al-Coating a carbon substrate (limited anodes) produces clear benefit as compared to as-provided carbon substrate.**
  - **Every substitute for silver paint emulsion on cathode tip produces inferior impedance performance.**

Reynold's Baseline cathode compared to 1) Al-coated Ta and 2) Bare Ta cathode

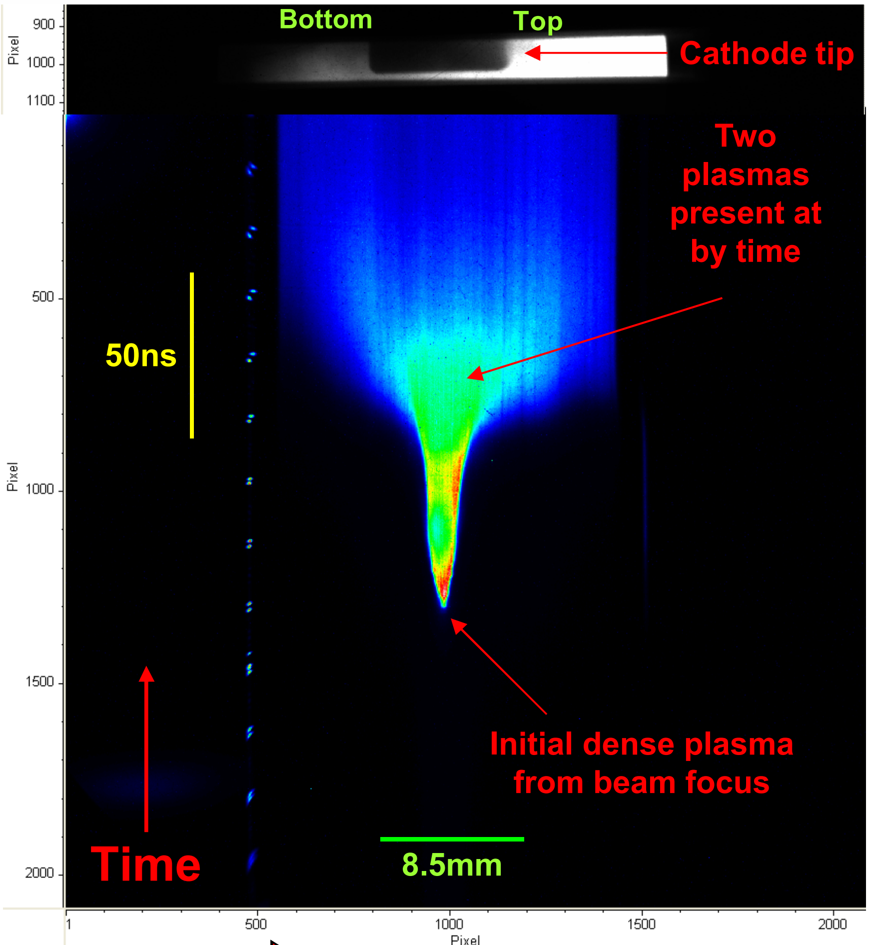


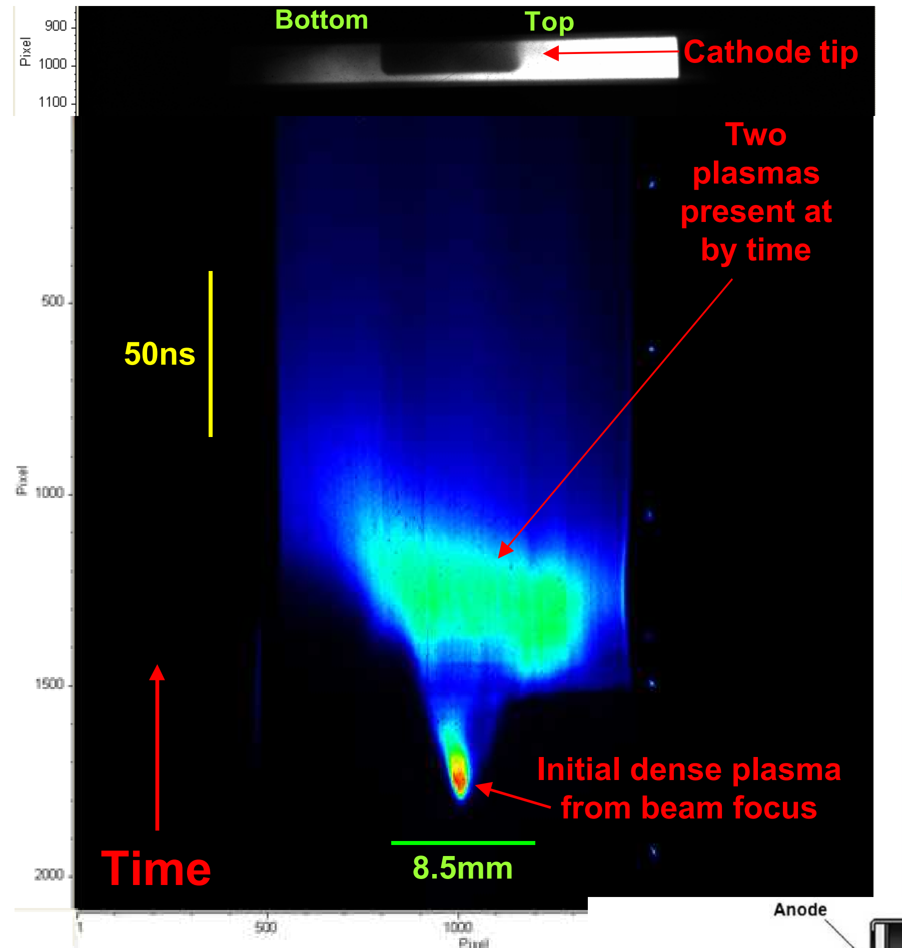
- (LEFT): IDIODE(ave) and scaled P-I-N output (PIN4) waveforms compared for three Small cathode shots
  - Shot 1032 - Reynold's baseline
  - Shot 1028 - Al-coated Ta
  - Shot 1030 - Bare Ta as-provided
- 1032 IDIOD (Blue) shows flat-top current, longest duration PIN4 (green)
- 1030 IDIOD (red) shows late-time rise, correlated with earlier drop in PIN4 compared to 1032
- 1028 IDIOD (white) rises sooner than 1030, and PIN4 drops sooner. 1028PIN4 has shortest duration of the 3 shots.
- IBEAM and IFEED comparisons similar to IDIOD
- High-frequency oscillations caused by cavity oscillations in 'Dustbin', not connected with impedance performance

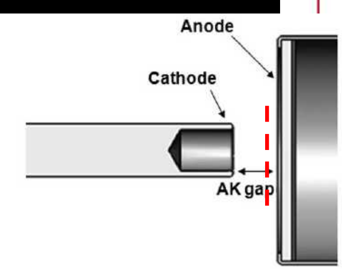
Imaging Streak Camera data for 1032 Reynolds (left) and 1028 Al-coated Ta show tighter cathode pinch on 1032

250ns sweep
F/8
20ns Combs
44ns FWHM

500ns sweep
F/11
50ns Combs
25nm FWHM

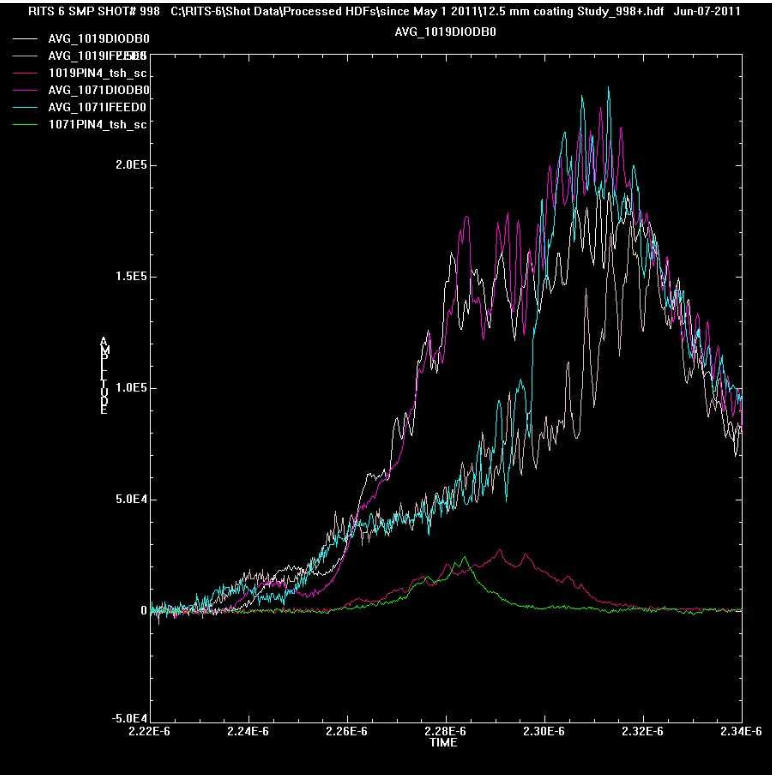






Slit positioned radially, in-front of anode surface

Al-coating on carbon substrate improves impedance lifetime

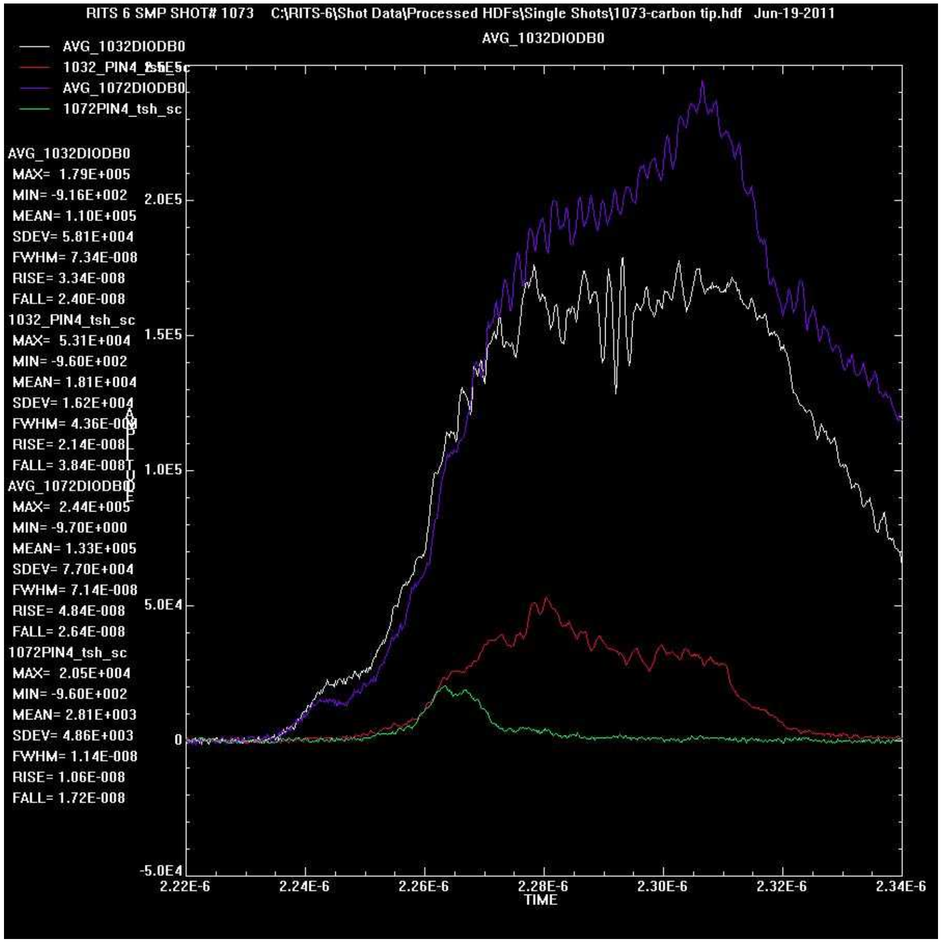


- (LEFT): IDIODE(ave), IFEED(ave) and scaled P-I-N output (PIN4) waveforms compared for two Large Cathode shots:
  - Shot 1071 - Ta button 2mm on carbon as-provided substrate, Ta protrudes 0.5 mm out of surface
  - Shot 1019 - W button 2 mm on Al-coated carbon substrate, W protrudes 0.5 mm out of surface
- 1019IFEED increases quickly late in pulse, and DIOD shows similar late-time rise
- 1071IFEED rises quickly ~ 20 ns before 1019IFEED increase. 1071IDIOD has similar quick rise ~ 20 ns earlier than 1019IDIOD
- Both PIN4 signals drop before these features (above) appear on their respective waveforms.
- 1019PIN4 - triangular in shape, indicates beam wander off 2 mm W button
- 1071PIN4 - drop is much quicker after peak.

Photograph of Limited Target

Raised Limited Target (0.5mm)

Pure Ag-coated cathode tip produces much shorter impedance history than Reynold's silver emulsion paint baseline



- (LEFT): IDIODE(ave) and scaled P-I-N output (PIN4) waveforms compared for:
  - Shot 1032 - (Small cathode) Reynold's Baseline
  - Shot 1072 - Silver emulsion paint replaced with pure silver coating ~ 1 micron thick
- 1032IDIOD shows faster turn-on and rise intially, then overtaken by 1072IDIOD
- 1072PIN4 early-time rise matches 1032PIN4, but drops quickly after

Summary and future work

- Coatings if successful have the potential for improved diode dimensional control and repeatability compared to emulsion paints and foils.
- Experiments to date show mixed performance for coatings tested. At best, they can duplicate baseline performance. At worst, performance shows significant deterioration.
- So far, only clear superiority of (Al) coatings is on carbon substrate for limited anode.
- Neither current diagnostic data nor simulations can explain this difference in performance.
- Future diagnostic fielding and intercorrelation of data, as well as improved simulations (including contaminant characterization, temperature thresholds for surface emission, etc), is best hope for understanding behavior reported here.