Mechanism of Ignition of Jet A by Silver Oxide Deposits*

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Outline

- Objectives
- Experimental Procedure
- Deposit Growth and Ignition Test Results
- Thermal Model and Surface Temperature Measurements
- Deposit Composition Analysis
- Conclusions

Objectives

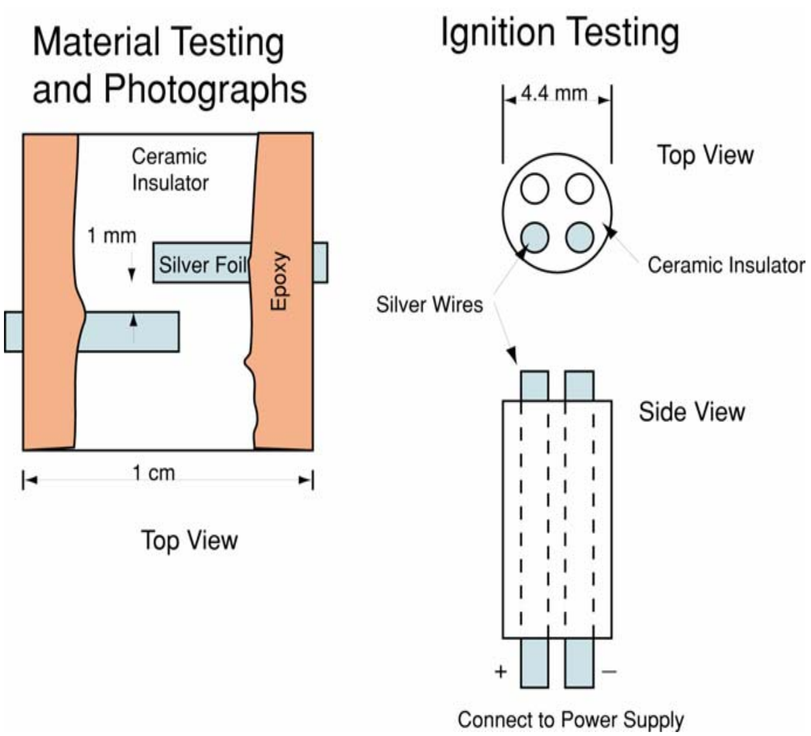
- Determine if Fuel Quantity Indicating System (FQIS) deposits pose an ignition hazard
- Determine the ignition mechanism
- Quantify the electrical input necessary to cause ignition

Experimental Approach

- Grow silver oxide deposit with water electrolysis
  - V = 6-20 vdc; constant
- Test deposit for ignition
  - Place deposit in flammable vapors in flash point tester
  - Dip deposit in the Jet A in the flash point tester
  - Increase voltage across the deposit at a rate of 1 V/s.
    - If there is measurable current, continue test until voltage reaches 35 volts
    - If no measurable current, terminate test
  - If resistance becomes too high, perform a water electrolysis step to lower resistance

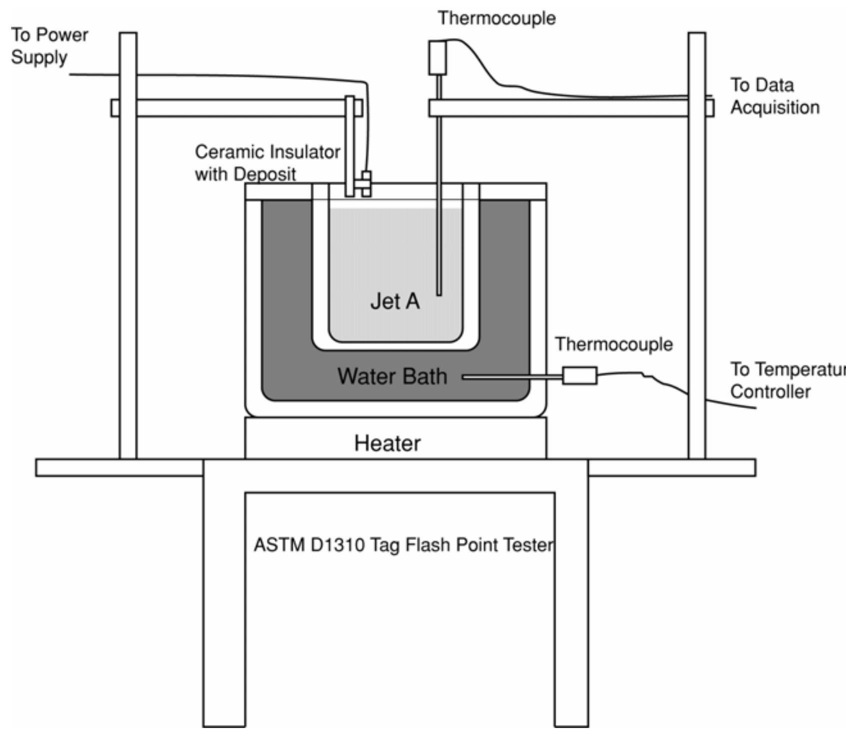
Ceramic Insulator Configurations

- Flat ceramic insulator used for imaging and material testing
- Cylindrical ceramic insulator used for ignition testing



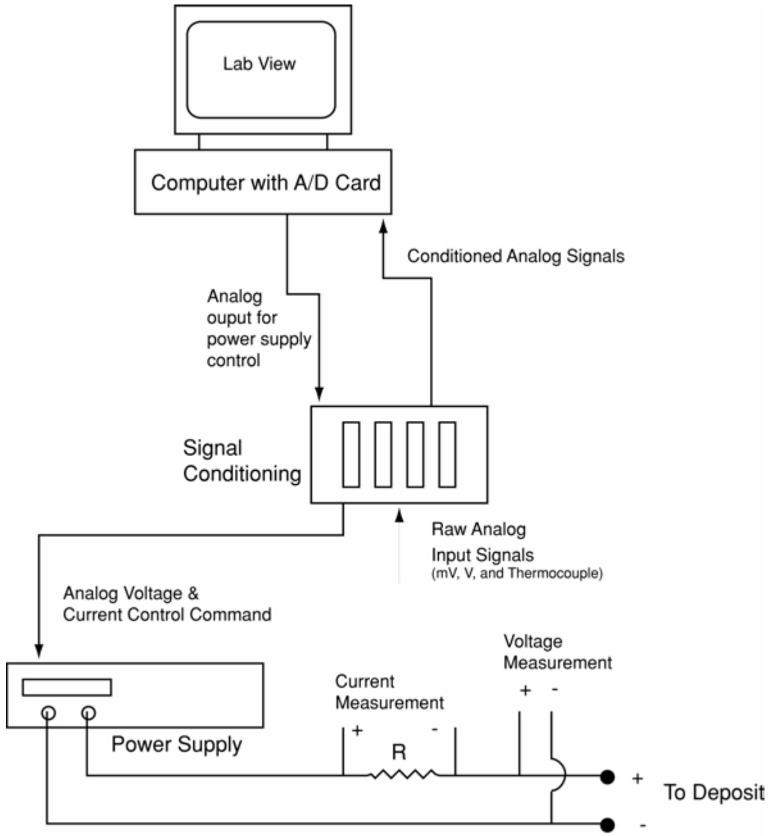
Flash Point Tester

- Tag Open-Cup Flash Point Tester
- Jet A Flash Point = 131 °F
- Jet A Temperature = 140 °F
- Deposit replaces the flame ignition source used for flash point test



Data Acquisition System

- National Instruments Data Acquisition System
- Power supply controlled by analog output
- LabView data collection
- Sample rate of 30 Hz
- Current measured using a current sense resistor
- D.C. power supply; 35 volts and 6 amps max.



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Typical Deposit Growth Sequence

Step	*Liquid Applied*	*Pre-test R (Ω)*	*Post-test R (Ω)*	*Ignition*
1	Water	–	3	–
2	Jet A	3	18,000	N
3	Water	18,000	14	–
4	Jet A	14	2.4	N
5	Jet A	2.4	42	N
.				
.				
18	Jet A	47	3,000	Y
.				
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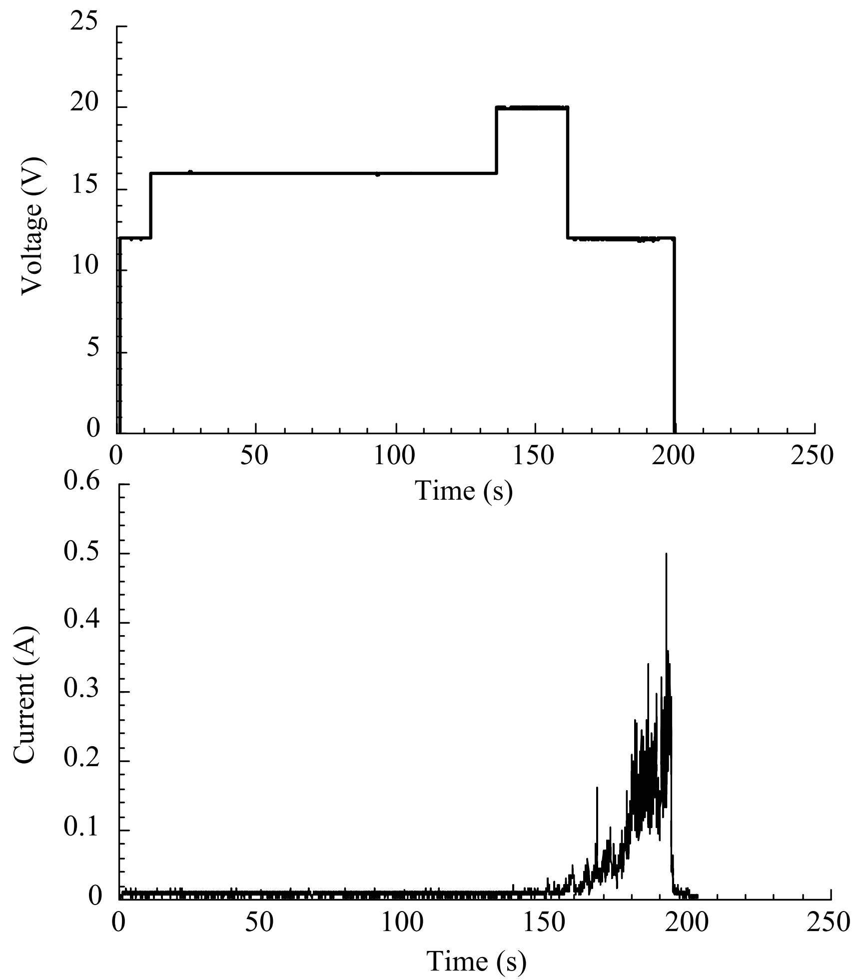
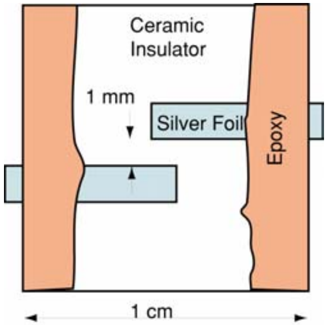
Initial Electrolysis Step

- Drop of water between silver wires
- Voltage adjusted to maintain a reasonable fast electrochemical process

Pre-Test Resistance	Post-Test Resistance
∞	10 ohms



Initial Silver Oxide Deposit

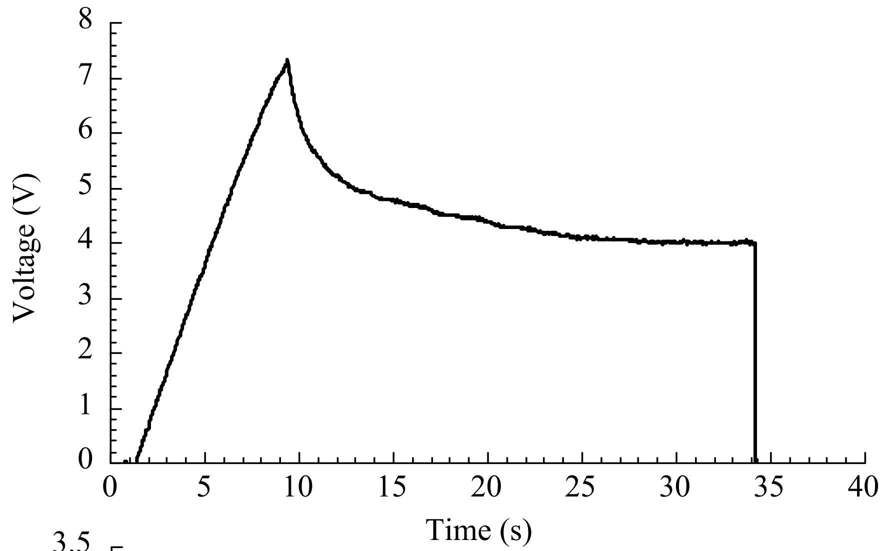


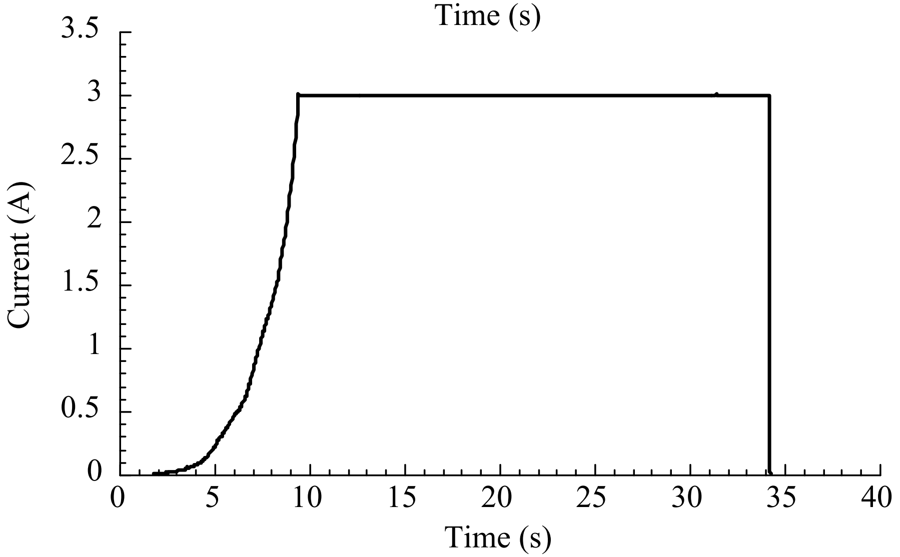
Mature Silver Oxide Deposit

Typical Ignition Attempt

- Deposit wetted with Jet A
- Voltage ramped at 1 V/s
- Current is limited to 3 amps in this test

Pre-Test <u>Resistance</u>	Post-Test <u>Resistance</u>
50 ohms	400 ohms





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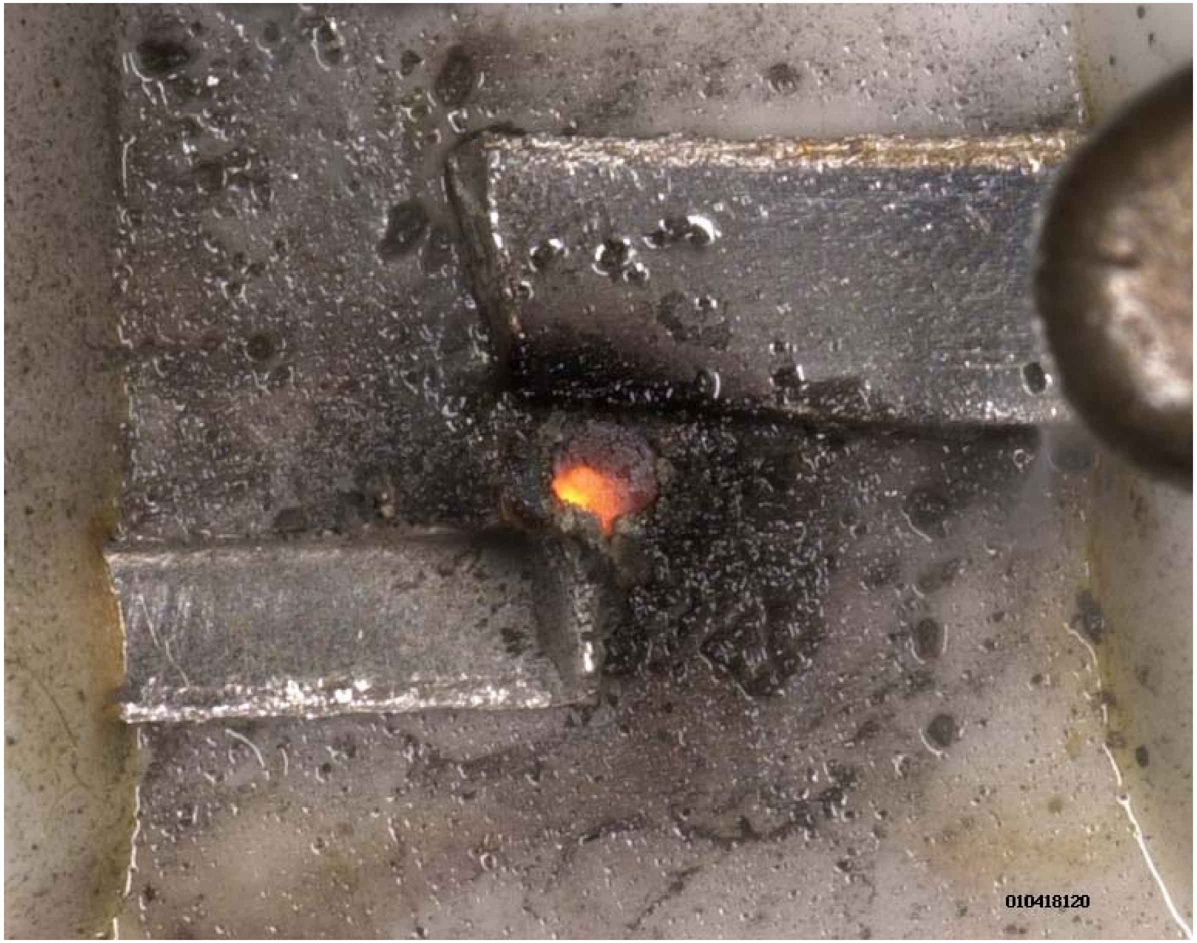
Ignition Test - 5 W

Ignition Test - 8 W

Ignition Test - 10 W

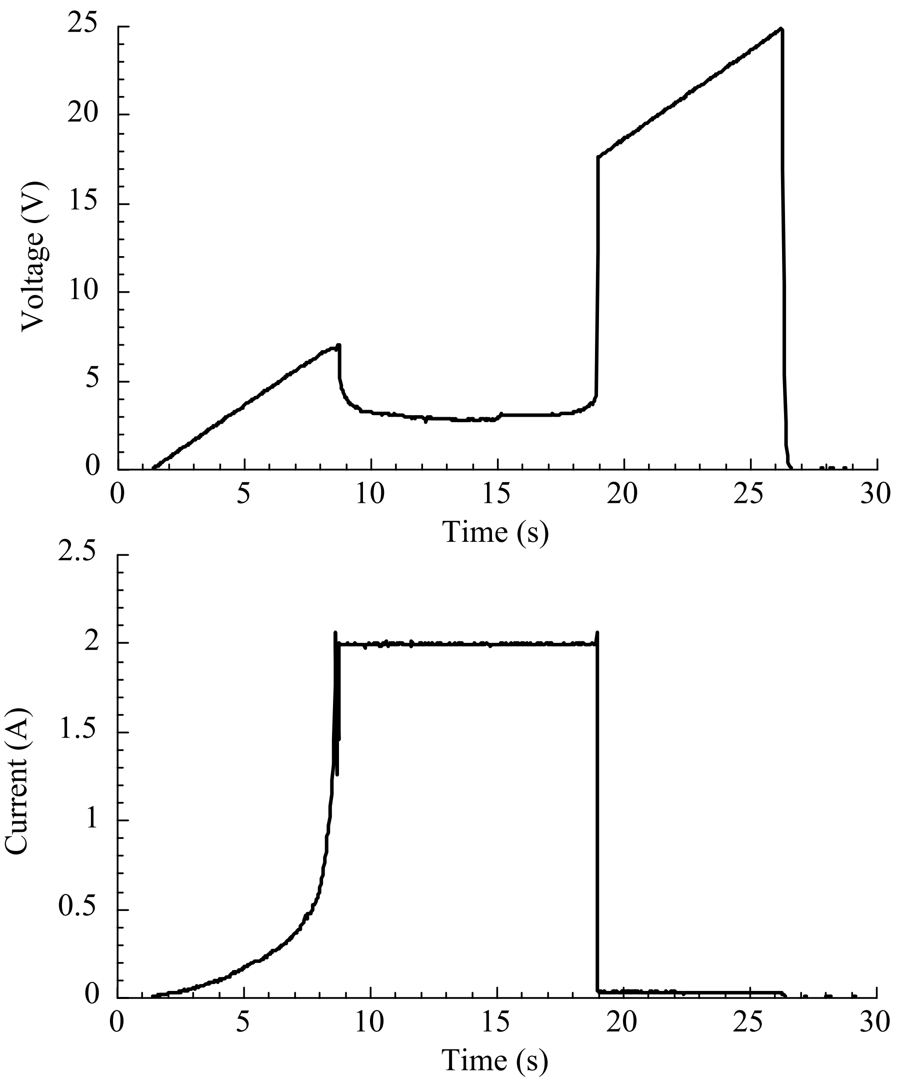


Ignition Test - 13 W

Typical Voltage and Current - No Ignition

- Voltage is increased at 1 V/s
- Current is limited to 2 Amps
- Deposit resistance appears to suddenly increase
- Apparent resistance (V/I) varies from about 1 ohm to 1000 ohms during test

Pre-Test <u>Resistance</u>	Post-Test <u>Resistance</u>
30 ohms	360 ohms



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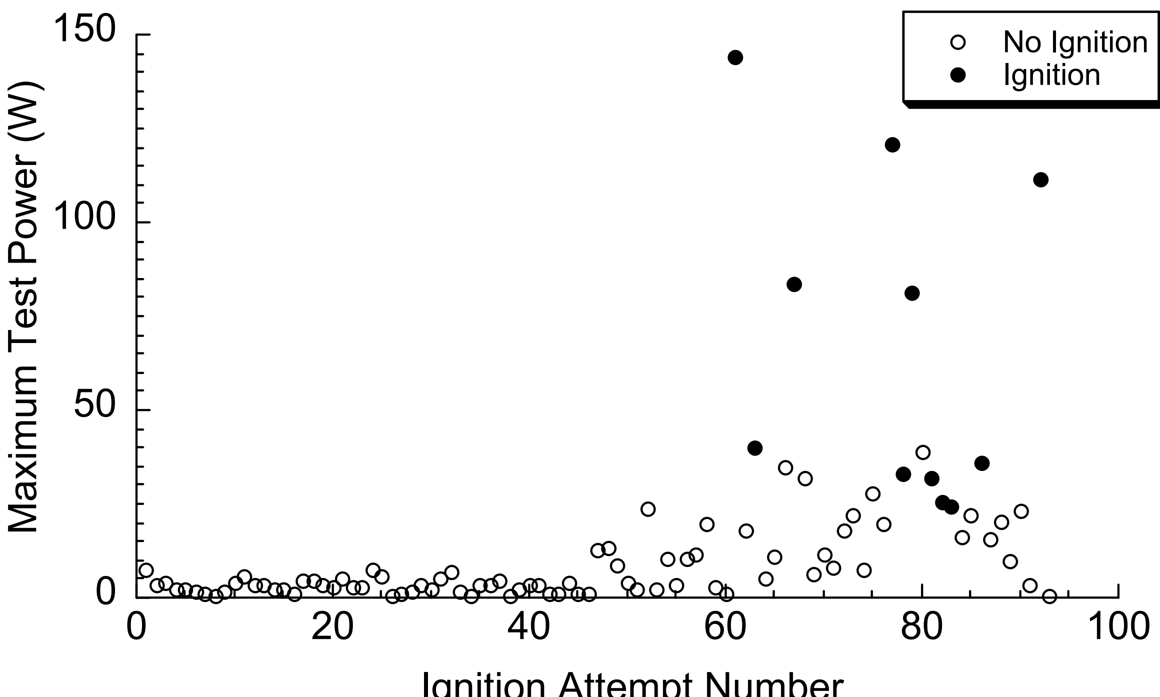
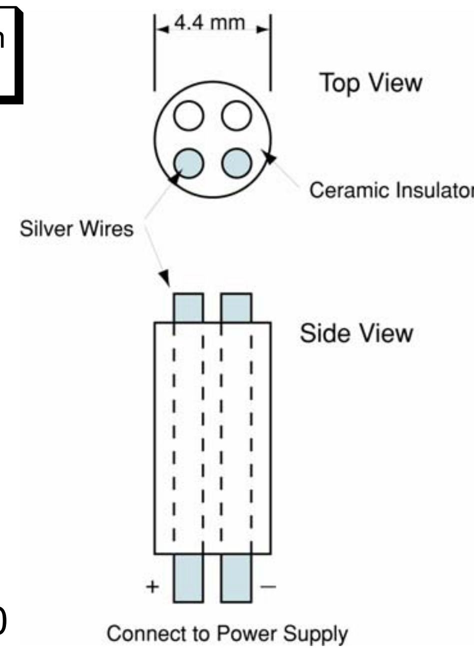
Power Versus Ignition Attempts
Deposit 1

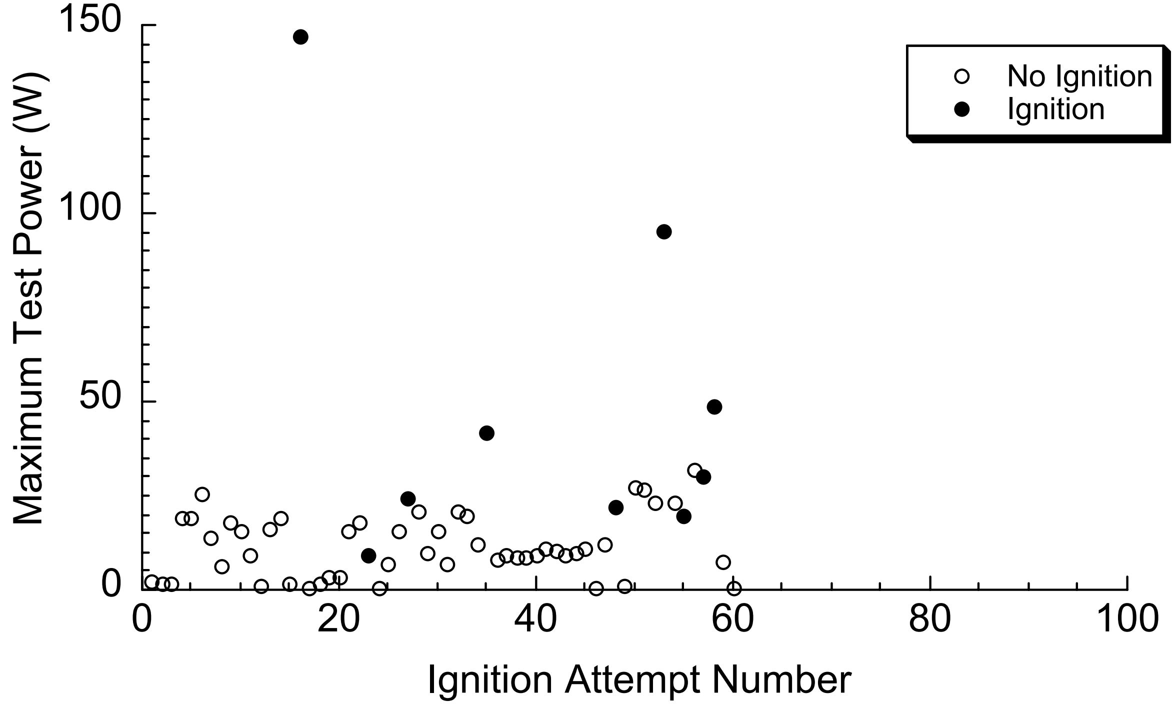
- Power dissipation increases with cumulative ignition attempts





Power Versus Ignition Attempts
Deposit 2

- Power dissipation behavior varies from one deposit to another



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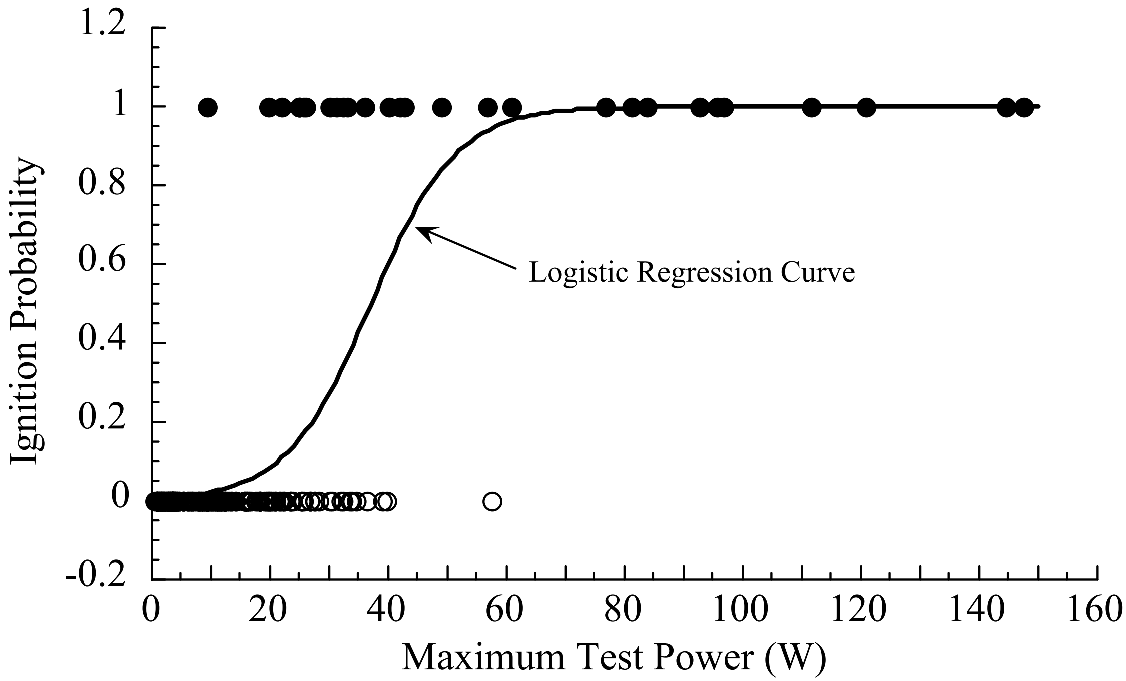
Logistic Regression Results

- 221 Ignition attempts
- Data is fit to the form

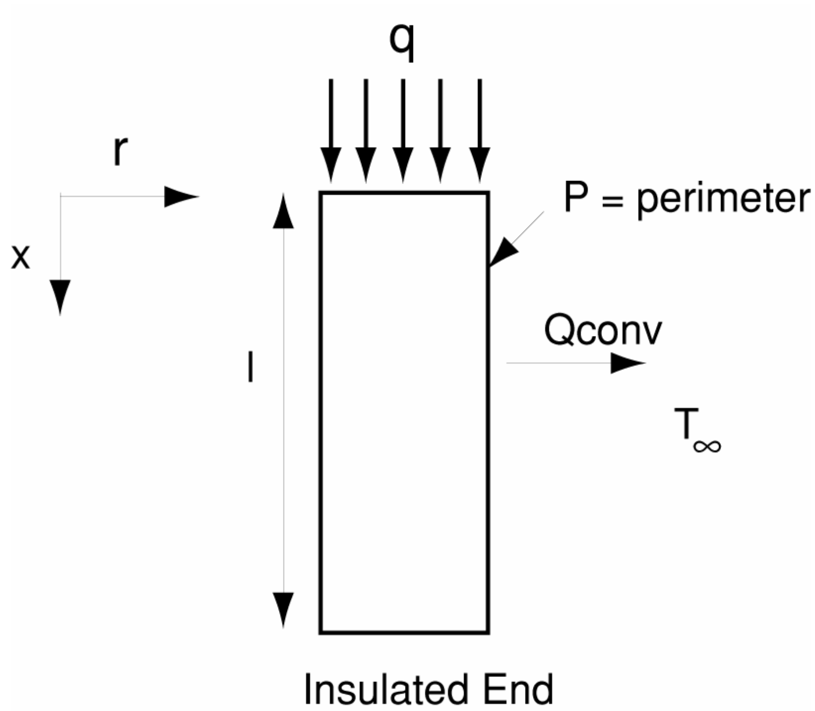
$$E[Y] = \frac{\exp(\beta_0 + \beta_1 X)}{1 + \exp(\beta_0 + \beta_1 X)}$$

- Chi-squared goodness-of-fit *P*-value = 0.66
- Power is a relatively good predictor of ignition



Thermal Model

- Determine the surface temperature of the ceramic insulator
- Electrical power is uniformly distributed across the top cross-section
- Heat loss is by convection
- Bottom surface is insulated
- Solution is:



$$T(t,x) = -\frac{q}{km}\sinh(mx) + \frac{q}{km}\frac{\cosh(ml)}{\sinh(ml)}\cosh(mx) + T_\infty$$
$$-\frac{q}{klm^2}e^{-(hP\alpha/kA)t} + \sum_{n=1}^{\infty}\frac{-2q}{kl(m^2+\lambda_n^2)}e^{-(hP\alpha/kA+\alpha\lambda_n^2)t}\cos(\lambda_n x)$$

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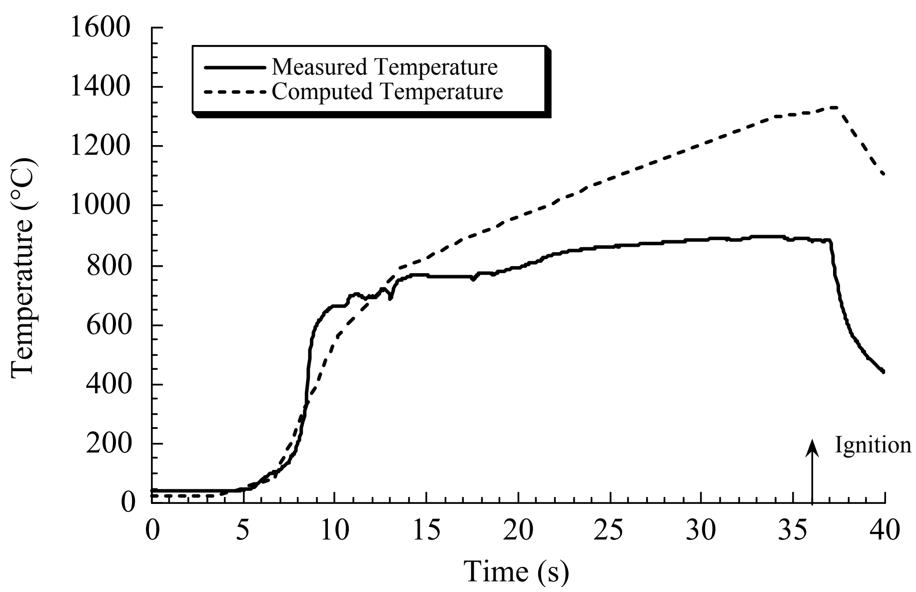
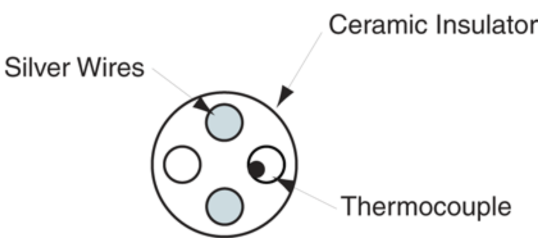
Measured and Computed Surface Temperature

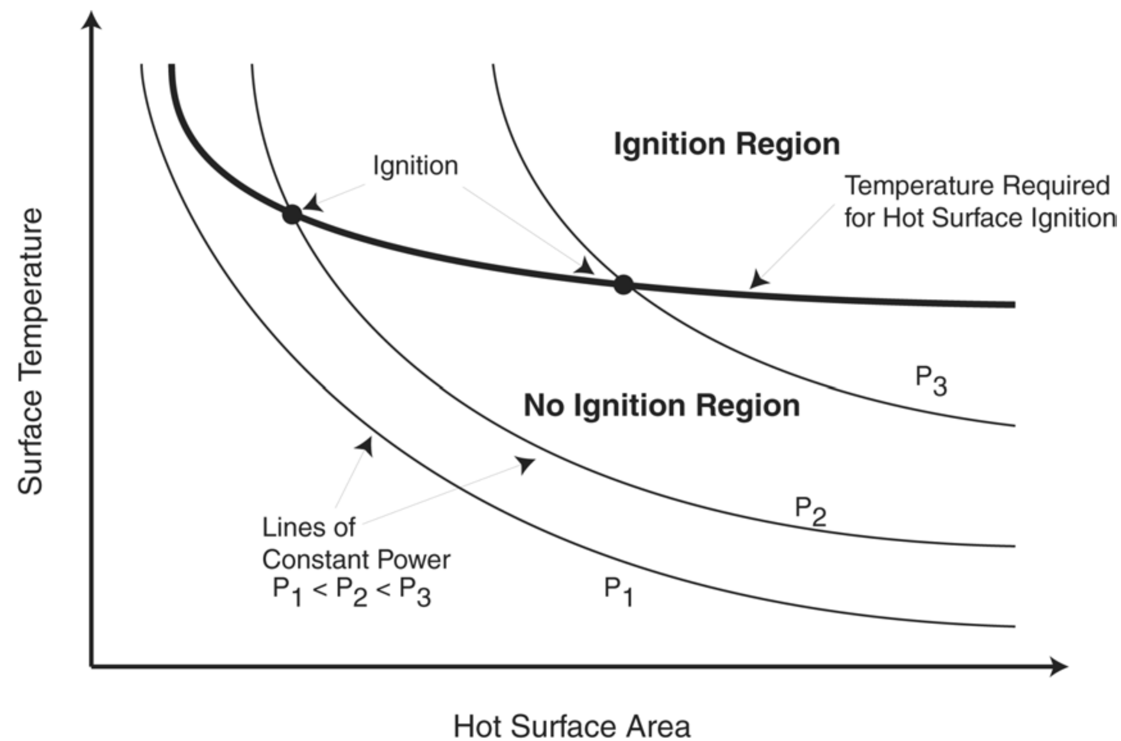
- Measured temperature exceeds the hot surface ignition temperature of Jet A
- Computed temperature indicates that electrical power alone could be responsible for observed temperature
- Model could be improved: 2D effects; radiation; phase changes





Minimum Power for Ignition

- Ignition model - area dependent
- Thermal model - area dependent
- May be a point of minimum electrical power



Curves are dependent on: fuel type, equivalence ratio, orientation, ambient pressure, ambient temperature and exposure time

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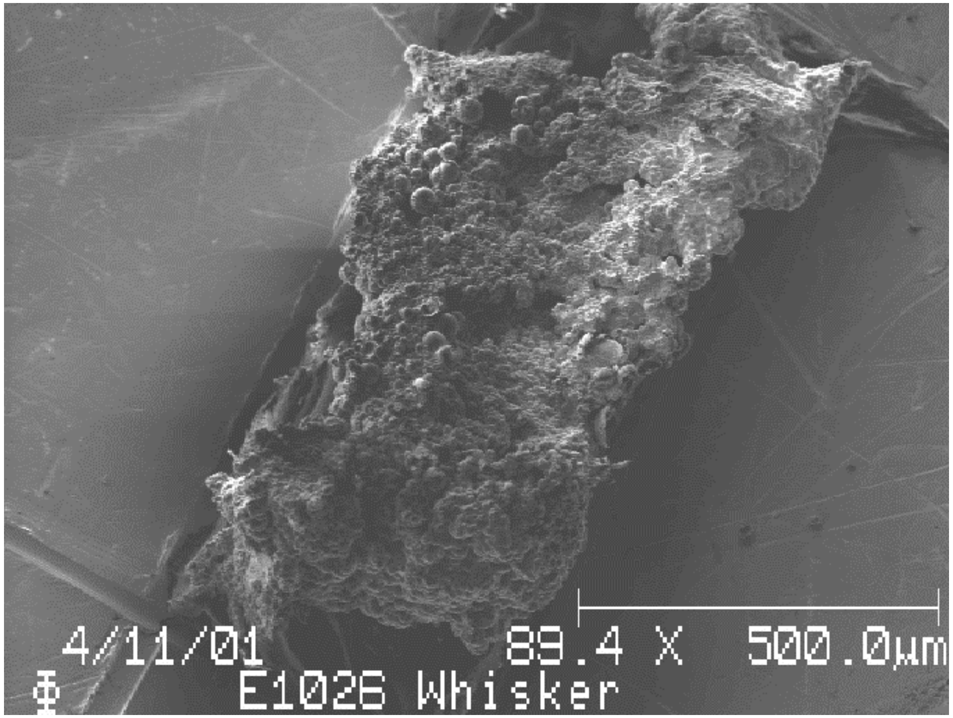
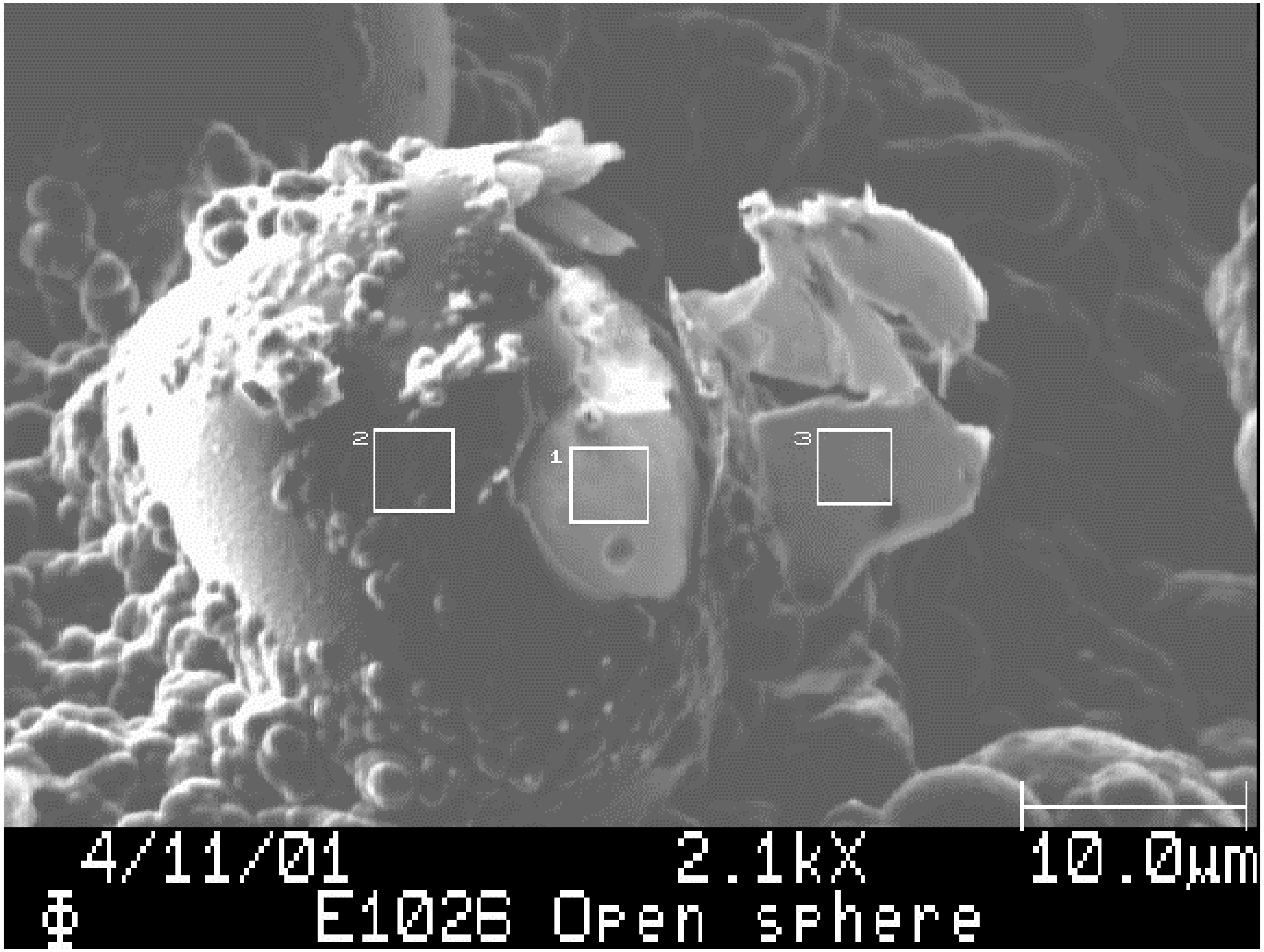
Deposit Composition

- Initially the deposit is silver oxide
- After numerous ignition tests, the deposit is very durable
- Deposit can be removed from ceramic in a single piece
- Surface is carbon with spherical features



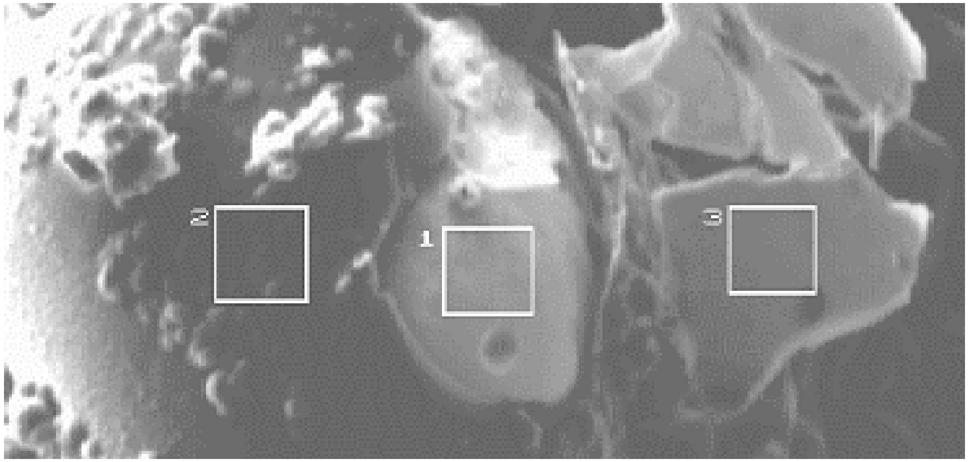
Open Sphere – Analysis Areas Indicated



Auger Analysis of Sphere and Shell

Area	Description	% Silver	% Carbon	% Oxygen
1	Sphere	91.8	--	8.2
2	Outside of shell	0.6	97.2	2.1
3	Inside of shell	12.8	85.5	1.8

Note: Auger analysis technique cannot detect elements of molecular weight less than 5 (boron) or determine whether carbon is a hydrocarbon.



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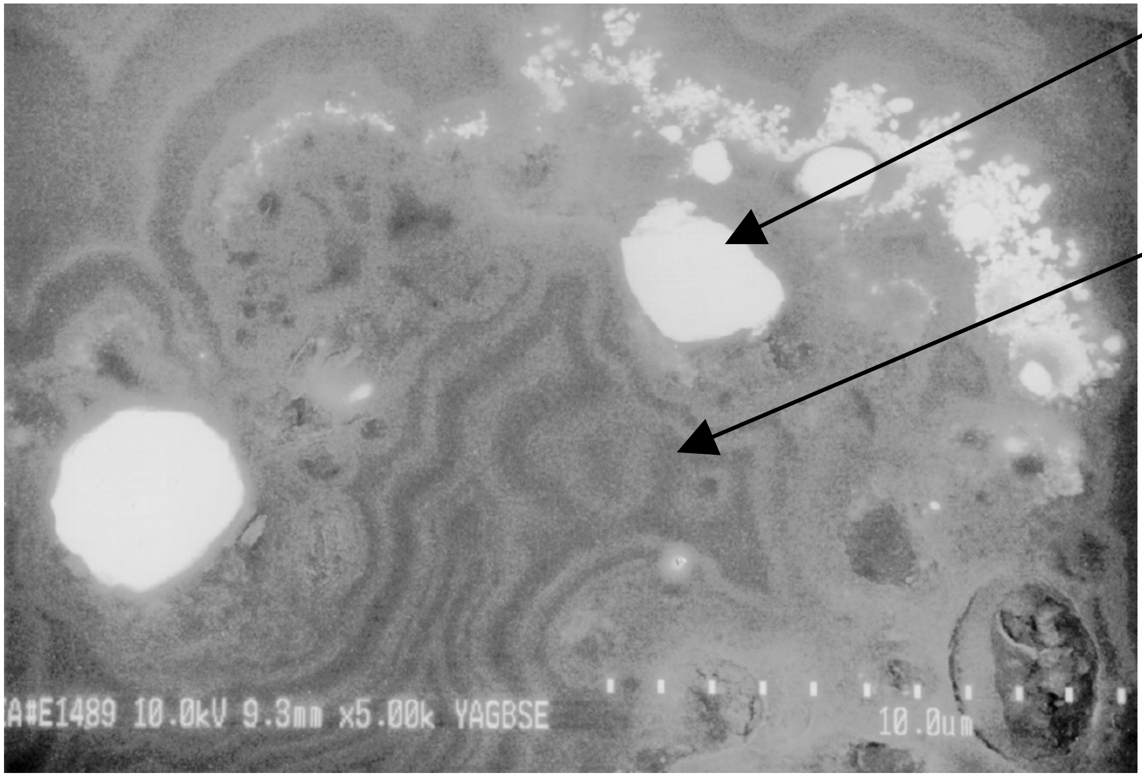
Cross-Section of Deposit



- White areas are silver or silver oxide (EDX)
- Gray areas are disordered and graphitic carbon, no hydrocarbon detected (EDX, Raman, FTIR)
- Carbon layering is consistent with multiple ignition tests

Conclusions

- Silver oxide deposits do pose an ignition hazard
- Electrical power dissipation is a good predictor of ignition
- The ability of the deposit to dissipate power depends on the number of ignition attempts
- Deposit composition changes from silver oxide to graphitic carbon
- A thermal model indicates that electrical power alone could be responsible for the observed surface temperatures
- This conversion of electrical power to heat can yield a hot surface capable of causing ignition of flammable Jet-A vapors
- To date no ignitions observed with electrical input limited to 30 mA and 35 VDC