Conductive Anodic Filament (CAF) Formation:

A Potential Reliability Problem for Fine-Line Circuits

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Outline

- Introduction & Background
- Factors Affecting CAF Formation
- CAF Formation
  - Catastrophic Field Failure of Military Hardware
  - Laboratory Experiments
- Conclusion

Electronic Packaging Drivers

- Reduced feature size on chips
- Increased I/O count per chip
- Increased clock speed
- Smaller leads and finer pitch
- Higher power dissipation
- Lighter weight
- Higher functionality

Progression of Electronic Circuitry

- Increasing Power

Power: Single Chip Package (watts)	1995 - 1998	2001 - 2003	2004 - 2006
Commodity	1	1	1
Hand-Held	2	2	2
Cost/Performance	16	22	28
High-Performance	80	120	140
Automotive	3	3	3

- Increasing Chip I/O Density

Chip Pad Count	1995 - 1998	2001 - 2003	2004 - 2006
Commodity	208	324	420
Hand-Held	300	675	880
Cost/Performance	540	1200	1600
High-Performance	900	2000	2600
Automotive	132	300	400

Progression of Electronic Circuitry

- Decreasing Conductor Width and Spacing

Conductor Width & Spacing (μm)	pre-1997	1997 - 1999	2000 - 2010
Hand Held	125-75	75-50	50-25
Business/Industrial/Test	150-100	100-75	100-50
Automotive/Underhood	200-125	150-100	125-75
Military/Aero-Avionics	125-75	75-50	50-20
Computer Workstation/Server	125-50	75-50	25-20

Values listed are upper and lower limits
for conductor width and spacing in microns.

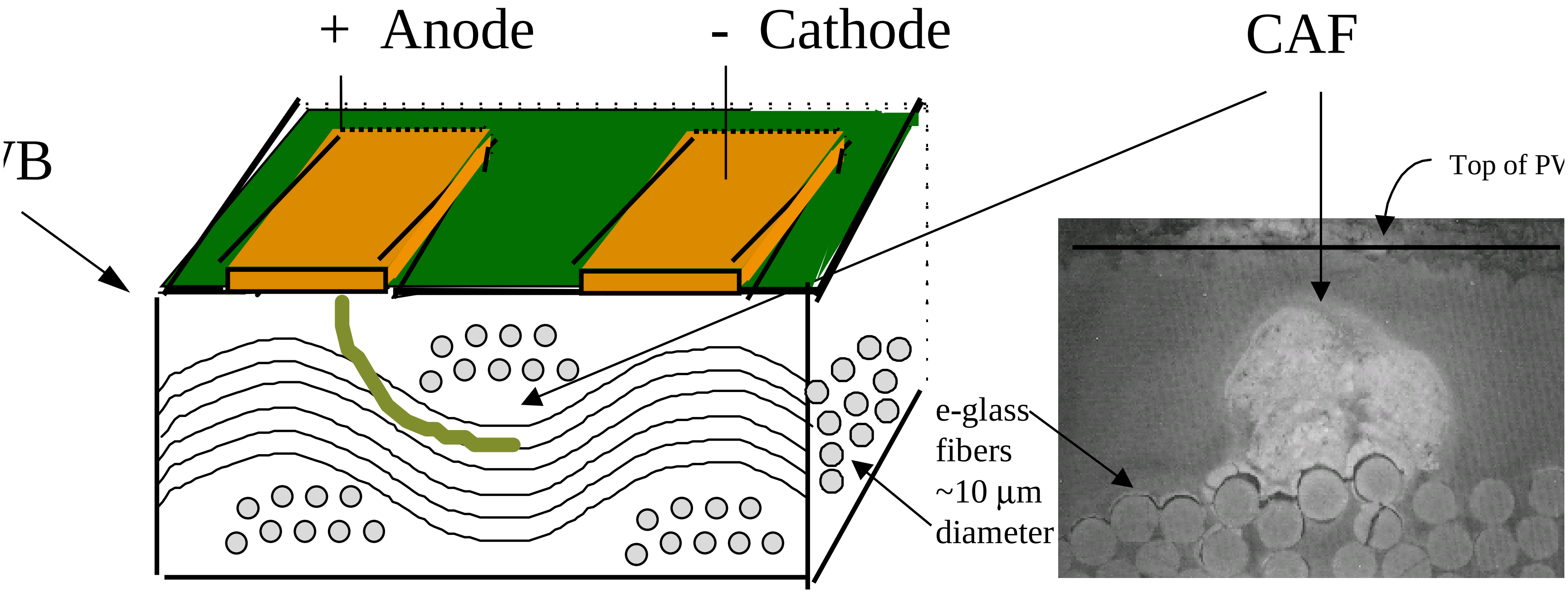
1 micron = 1μm = 10^{-6} m = 0.000039 in. = 0.039 mil
typical human hair diameter = ~100μm

CAF Introduction

- First identified by Bell Labs in 1976.
- Conductive, subsurface filament emanating from anode in high voltage (400V) PWBs exposed to high humidity (>80%).
- Can cause catastrophic failure if allowed to bridge between anode and cathode.

What exactly is CAF?

- Conductive Anodic Filaments are copper corrosion by-products that emanate from the anode of a circuit and “grow” subsurface toward the cathode, frequently along separated fiber-epoxy interfaces.



CAF Background

- Two step process.
- $t_{failure} = t_1 + t_2$
  - t_1 is related to the degradation of fiber/epoxy interface.
  - t_2 is related to the rate of the electrochemical corrosion reaction.
  - $t_1 >> t_2$

t_1, *Degradation of Interface*

- Mechanical stress.
- Poor quality coupling agent.
  - » Promotes adhesion between fiber and epoxy during PWB/MLB “lay-up” operations.
- Thermal stress.
  - » Multiple soldering excursions cause thermal fatigue.
- Moisture attack.

t_2, Electrochemical Reaction

Anode:

$$Cu \rightarrow Cu^{n+} + ne^-$$

$$H_2O \rightarrow \tfrac{1}{2}\, O_2\uparrow + 2H^+ + 2e^-$$

Cathode:

$$2H_2O + 2e^- \rightarrow H_2\uparrow + 2OH^-$$

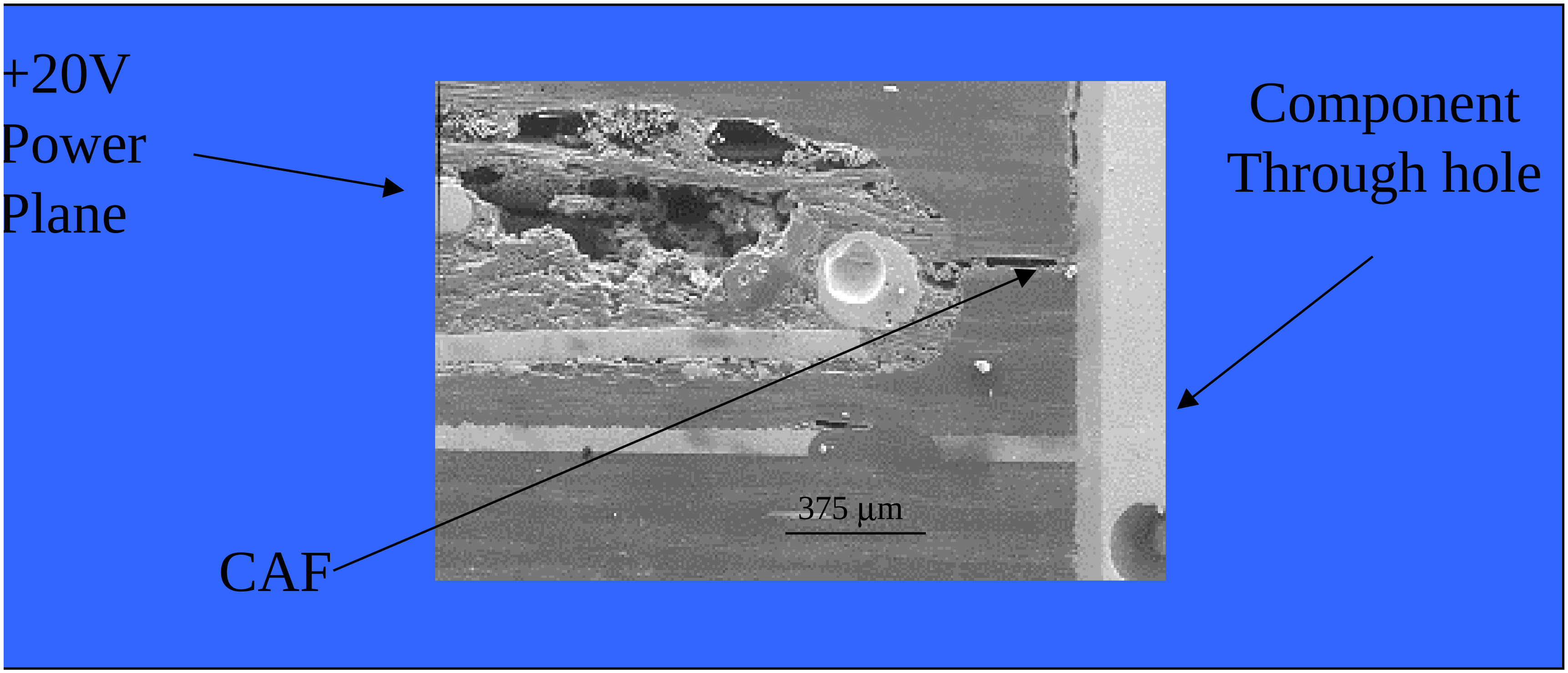
$$Cu^{n+} + ne^- \rightarrow Cu$$

Factors Which Enhance CAF Formation

- High humidity (~80% RH anytime during life of product).
- High voltage gradient between anode and cathode (~3-8 V/mil.).
- Certain soldering flux ingredients.
- Hole drilling.
- Multiple thermal cycles during processing.

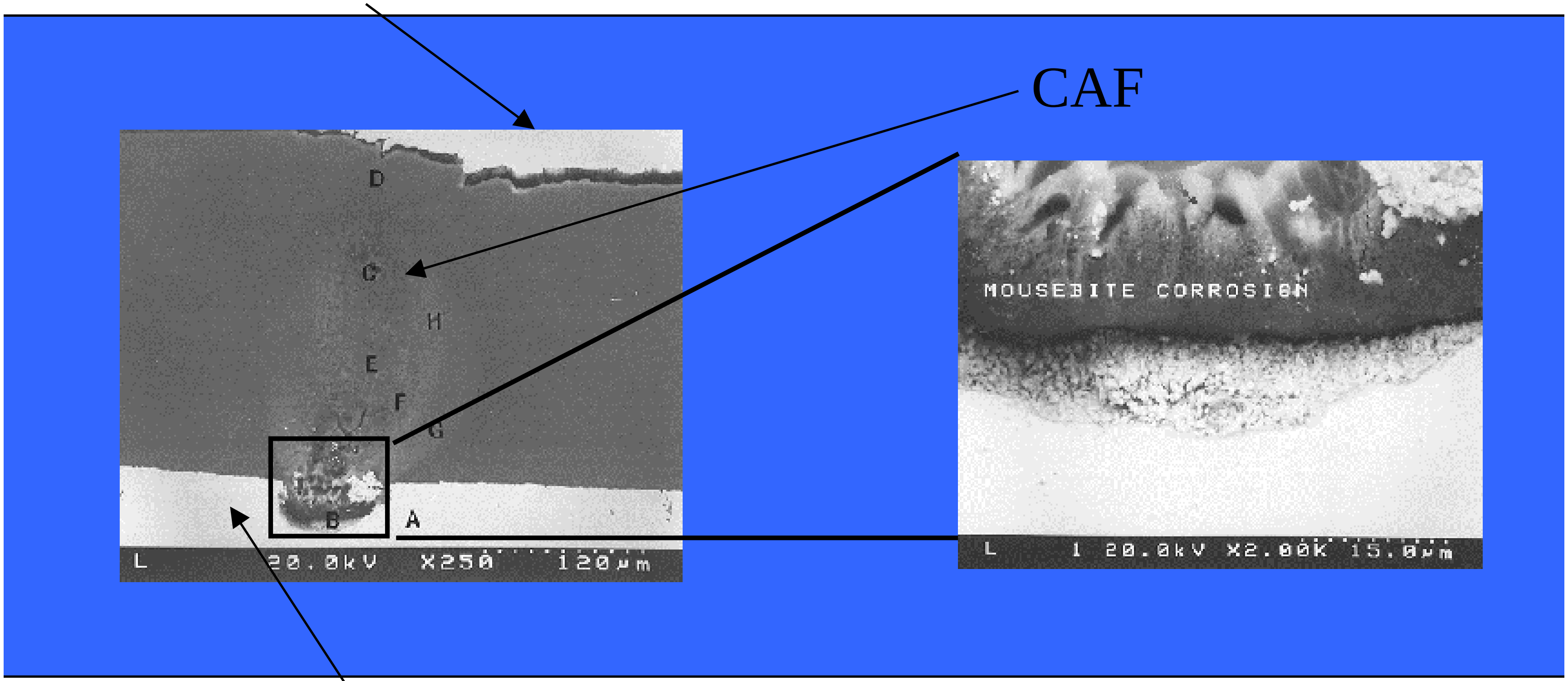
Catastrophic Field Failure of Military Hardware, Flux Enhanced Degradation

- CAF, if allowed to bridge the gap between anode and cathode of the circuit, will create a “short” in the assembly.



Catastrophic Field Failure of Military Hardware

Component Through Hole

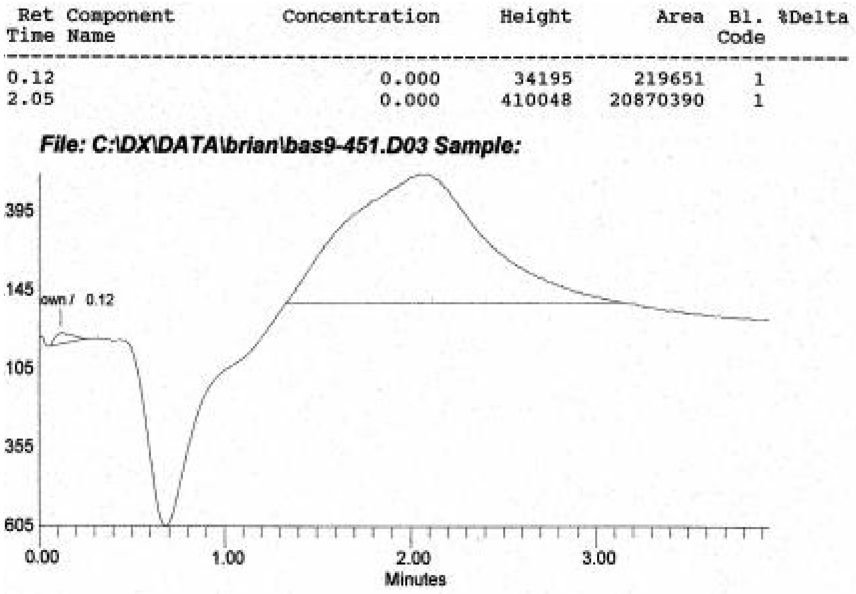


CAF

+20 V Power Plane

Catastrophic Field Failure of Military Hardware

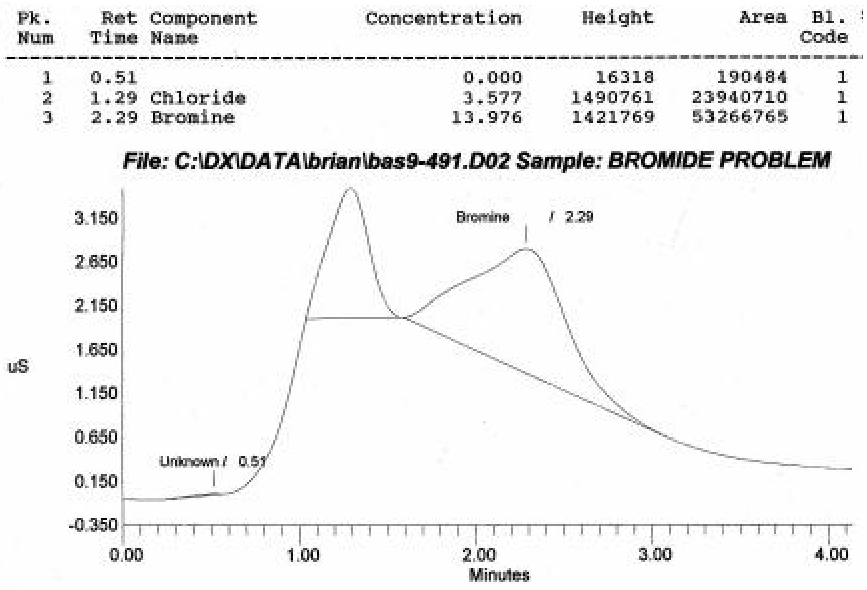
Ion Chromatography Spectra



```
 Ret Component               Concentration      Height         Area  Bl. %Delta
Time Name                                                            Code
--------------------------------------------------------------------------------
0.12                                 0.000       34195       219651    1
2.05                                 0.000      410048     20870390    1
```

File: C:\DX\DATA\brian\bas9-451.D03 Sample:

Failed Hardware



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Pk.    Ret Component                 Concentration       Height          Area  Bl.
Num   Time Name                                                                Code
-----------------------------------------------------------------------------------
  1   0.51                                   0.000        16318        190484    1
  2   1.29 Chloride                          3.577      1490761      23940710    1
  3   2.29 Bromine                          13.976      1421769      53266765    1
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File: C:\DX\DATA\brian\bas9-491.D02 Sample: BROMIDE PROBLEM

Soldering Flux

Laboratory Experiments

	Flux 1	Flux 2a.	Flux 2b.	Flux 2c.
pH	2.75	3.2	3.2	3.2
Ingredients and Percentages as Listed in MSDS or in Product Literature	Isopropyl Alcohol (75 - 90%)	Isopropyl Alcohol (75 - 85%)	Isopropyl Alcohol (75 - 85%)	Isopropyl Alcohol (75 - 85%)
	HBr (<5%)		Amine HBr	Amine HCl
	Polyglycol	Triisopropanolamine	Triisopropanolamine	Triisopropanolamine
		Polyol	Polyol	Polyol
Color	clear to pale yellow	clear to pale yellow	clear to pale yellow	clear to pale yellow
Flash Point	60°F	59°F	59°F	59°F
Specific Gravity	0.87	0.83	0.83	0.83
Use	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole	foam, wave, or spray flux for SMT or Through Hole

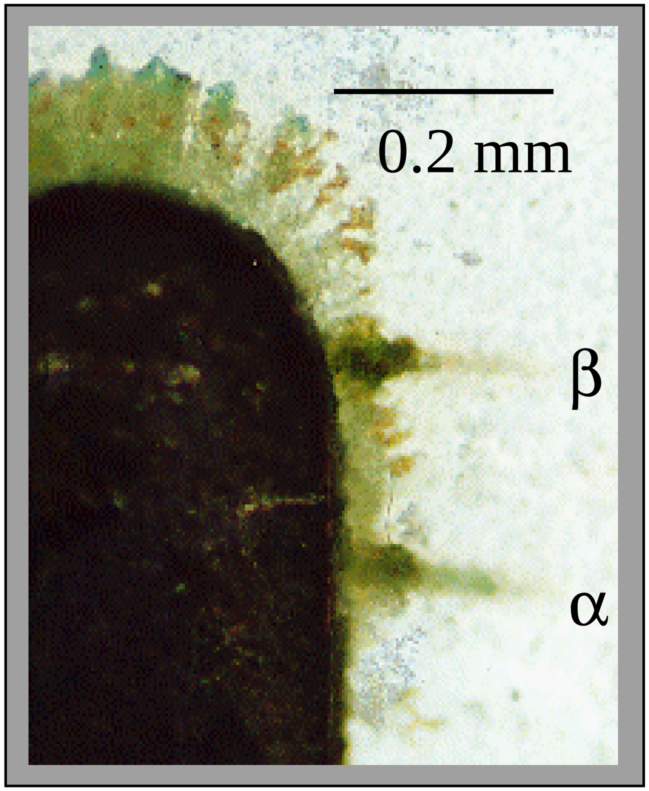
Laboratory Experiments

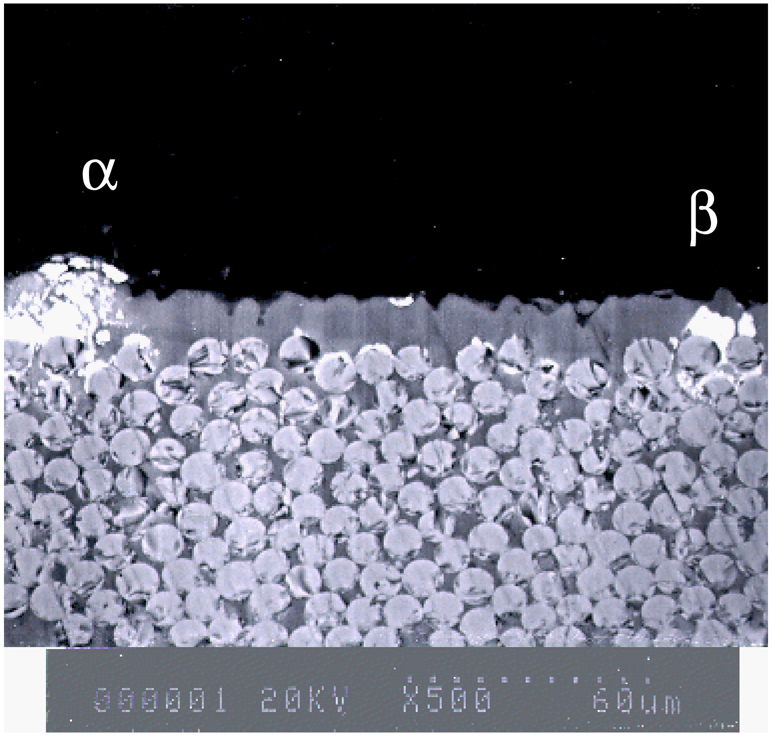
	Flux 3	Flux 4	Flux 5	HASL 1
pH	6.8	2	2	<3.0
Ingredients and Percentage as Listed in MSDS or in Product Literature	2-Propanol (64%)	Ethoxylated Polyoxypropylene (35%)	Isopropyl Alcohol (70%)	
	Chloride (2%)	HBr (15%)		HBr (10%)
	Surfactants	Polyalkylene Glycol (35%)		Nonionic Surfactant (75%)
	Glycerol (11%)	Polyglycol (15%)		
	Organic Acids			
Color	pale amber to amber	clear to light yellow	clear to pale yellow	clear to dark amber
Flash Point	60°F	525°F	60°F	600°F
Specific Gravity	0.9	1.08	0.92	1.09
Use	wave flux	HASL / SMT	IR flux	vertical HASL

Flux used in field failure.

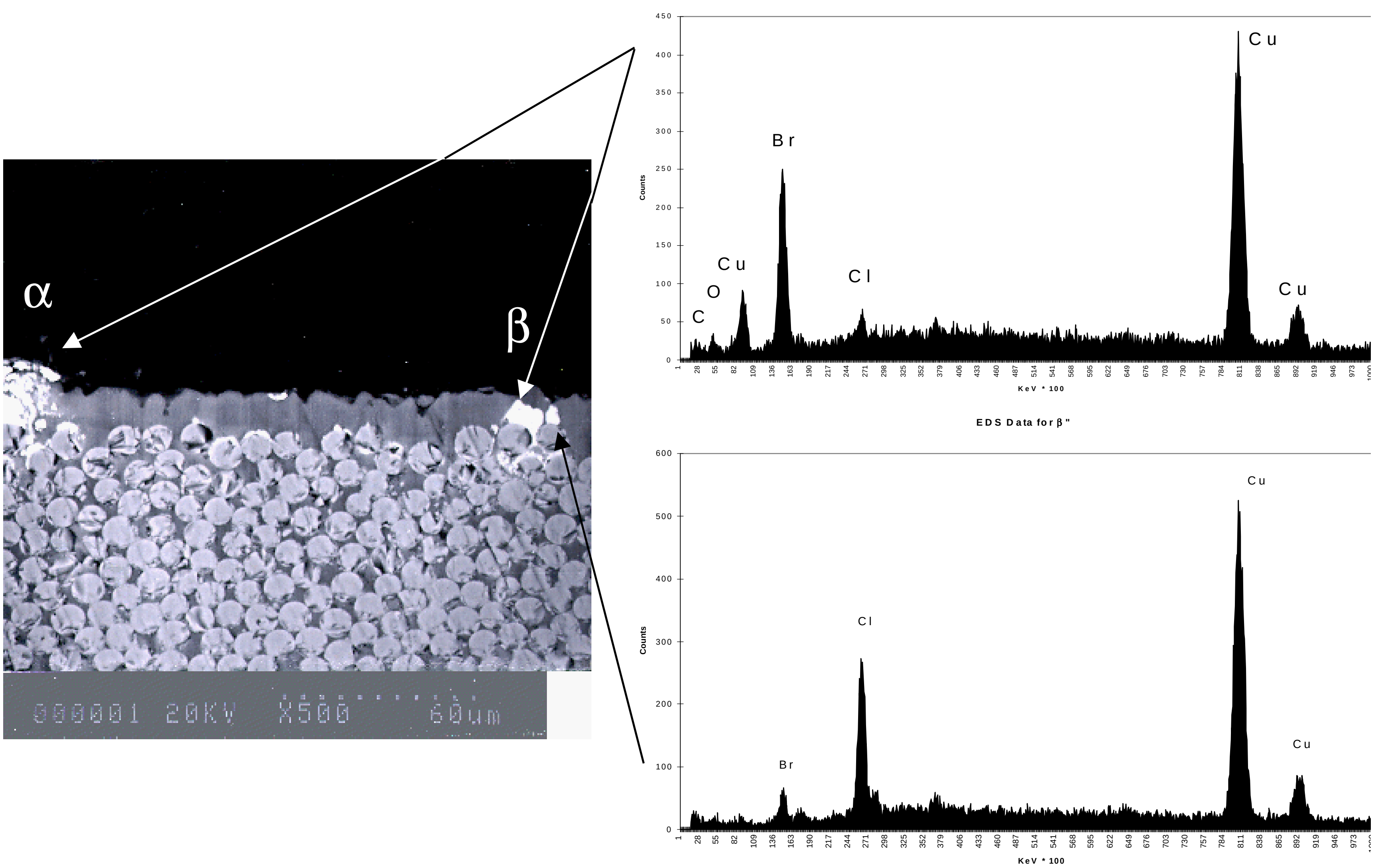
Laboratory Experiments

CAF formed with *same* flux (Flux 4)
that caused military field failure.



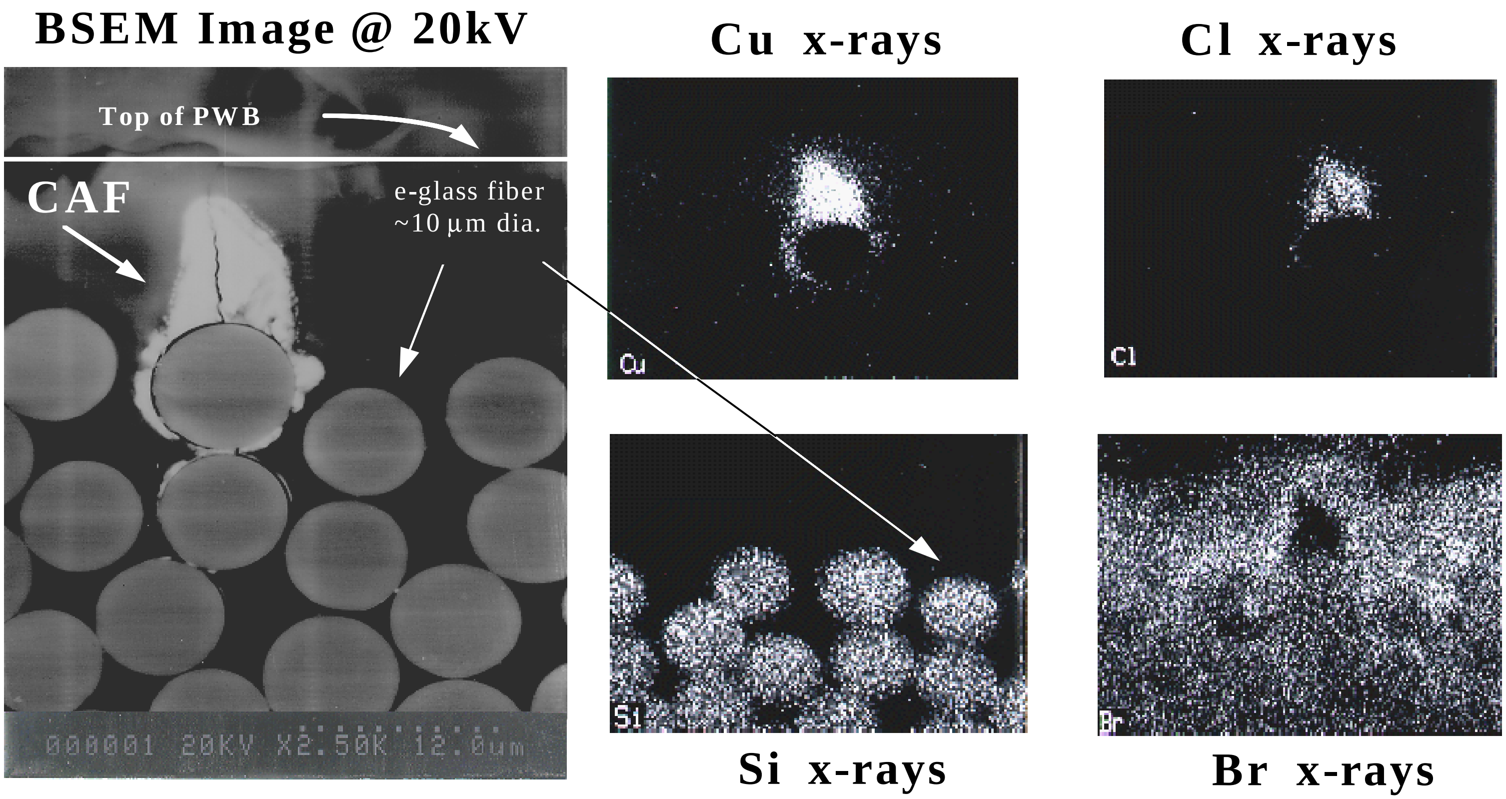


Laboratory Experiments



Laboratory Experiments

Wave Soldered FR-4 PWB
Treated with Flux 1



Laboratory Experiments

- Flux Chemistry Dependence
  - » CAF is frequently copper - chloride containing, but copper - bromide containing CAF has also been observed.
  - » All polyglycol containing fluxes (1,3,4 & 5) exhibited CAF.
  - » HBr and HCl in flux formulations were only deleterious when coupled with a polyglycol.

Conclusions

- High density circuits have voltage gradients that make CAF formation a possibility.
- Catastrophic field failures can be linked to the flux and HASL used in manufacture.
- Tests on 5 flux chemistries reveal CAF when certain polyglycols were present.
- Future work is focusing on identifying the “bad” polyglycols.

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