Catastrophic OLED failure and how to fix it

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Project Summary

Timeline:

Start date: Sept. 1, 2016

Planned end date: Aug. 31, 2018

Key Milestones

1. Image nascent shorts (8/31/17)
2. Identify origin of shorts (12/15/17)
3. Demonstrate anti-shorting strategies (8/31/18)

Budget:

Total Project $ to Date:

- DOE: $1,003,565
- Cost Share: $250,892

Total Project $:

- DOE: $1,087,981
- Cost Share: $271,996

Key Partners:

PennState

OLEDWorks Naturally Illuminating

Project Outcome:

Develop a basic scientific understanding of how incipient shorts in an OLED originate and grow to a catastrophic level. Formulate and test anti-shorting measures capable of achieving the DOE MYPP target of 0.01% OLED panel failure rate.

Team

Key players:

Roles:

- PSU: imaging, physical, and chemical analysis, model development, anti-shorting strategy development
- OLEDWorks: commercial panel supply, accelerated fade and short testing, R&D line tests of anti-shorting strategies

Unique expertise:

- PSU: Established track record in OLED device physics and operational degradation modeling.
- OLEDWorks: Sole US manufacturer of OLED lighting panels, 25 OLED experts in Rochester, NY and over 400 person-years of experience in device manufacture and testing.

Challenge: Killer Shorts

OLED panels that short catastrophically:

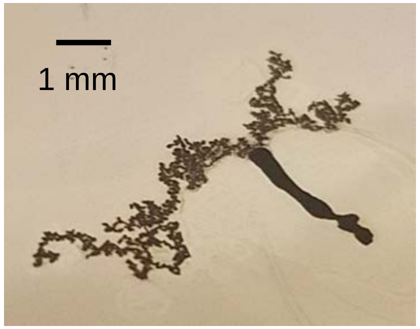
- Decrease manufacturing yield
- Increase warranty expenses
- Decrease customer satisfaction

Highly localized current flow → heating & irreversible damage

Origin of shorts presently unknown

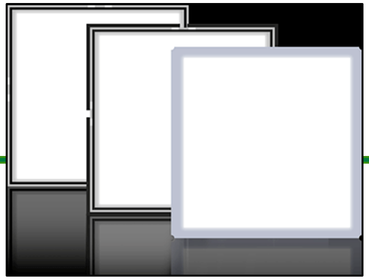
To solve this problem:

- Identify incipient shorts early & determine physical origin
- Model their evolution/growth toward catastrophe
- Predict failure & develop mitigation strategies



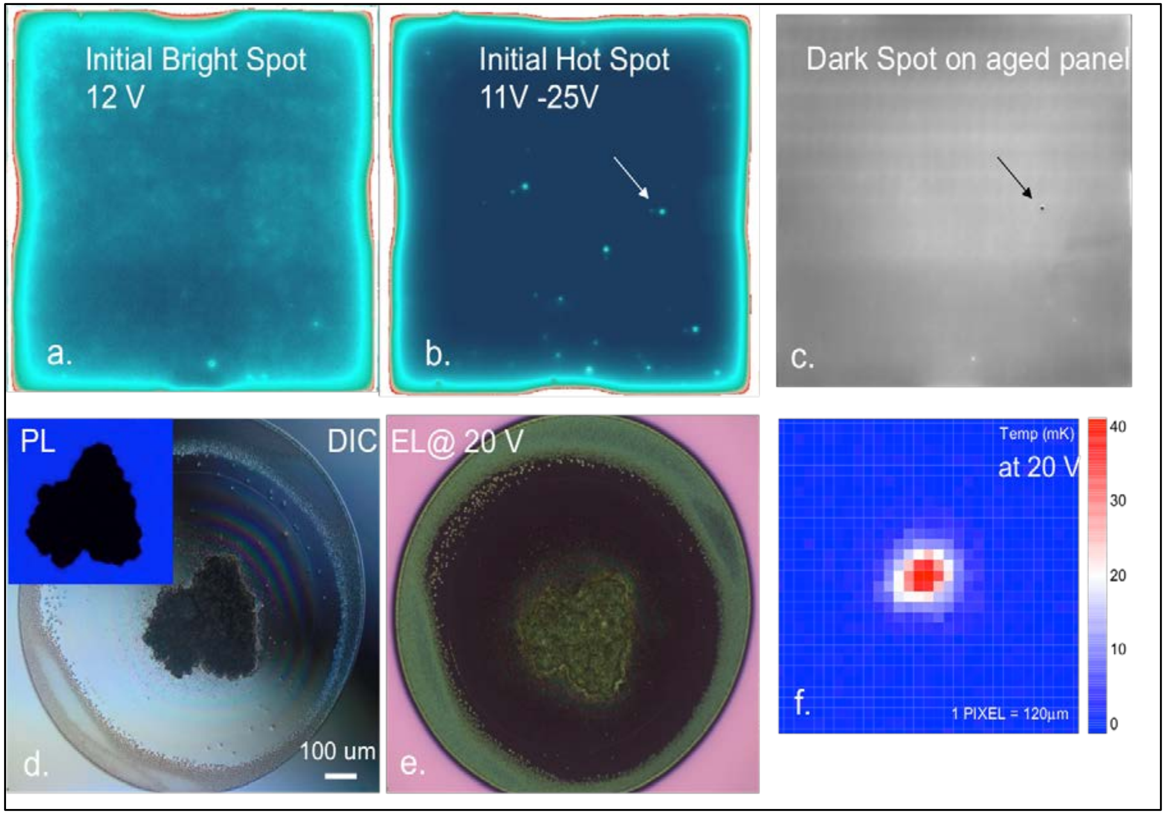
Residue of a short

Approach & Results



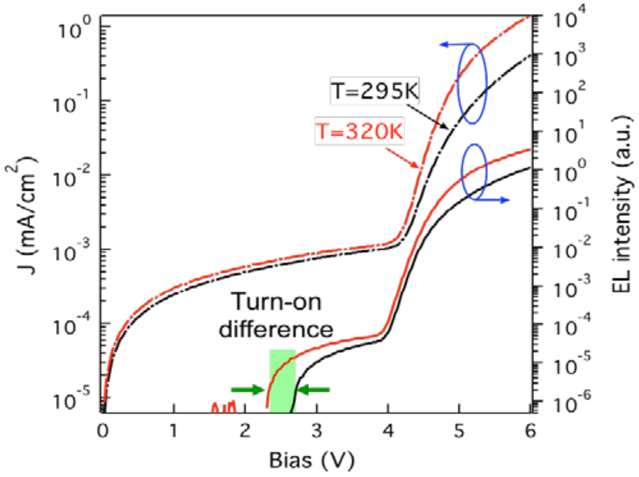
Step 1: Locate 'baby' shorts before they go catastrophic

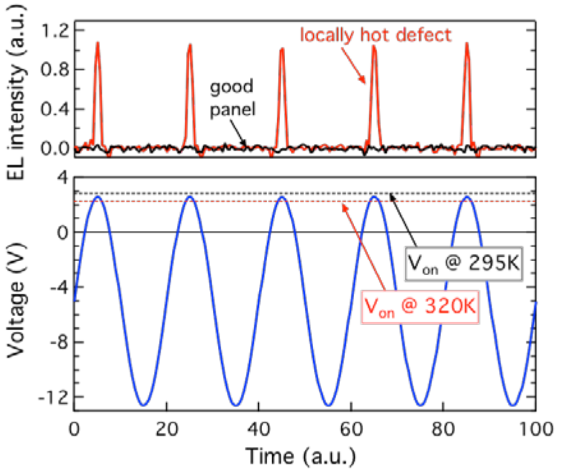
Bright spots vs. Hot spots



Hot spots are short precursors

Temperature-selective EL imaging

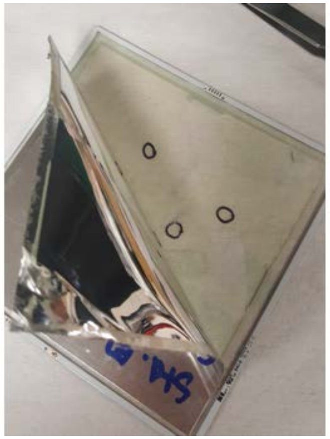


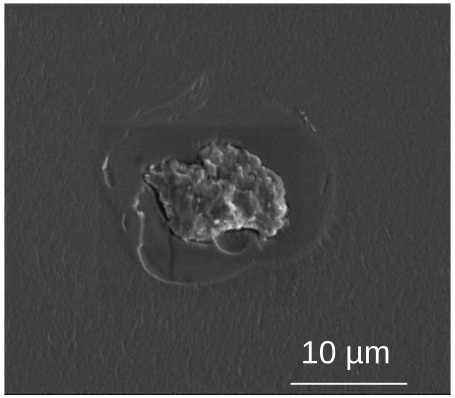


Approach & Results

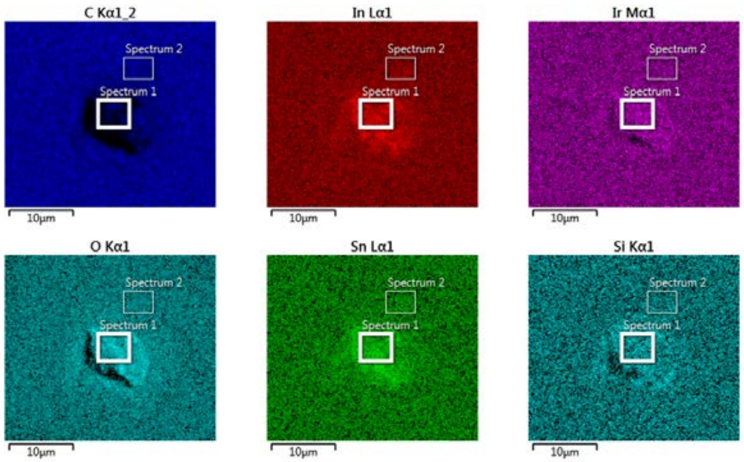
<u>Step 2</u>: Identify physical origin of shorts & how they grow over time

Bright spots: ITO agglomerations



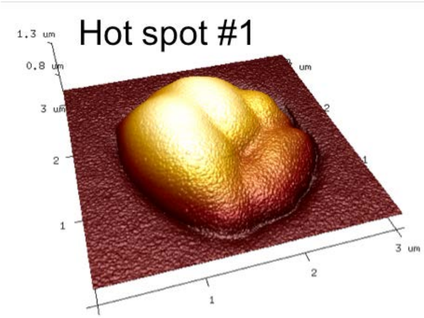


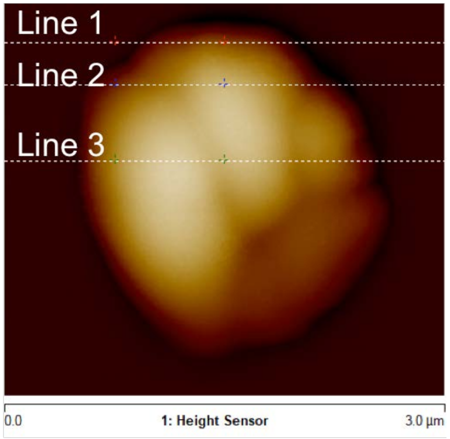
SEM image of bright spot

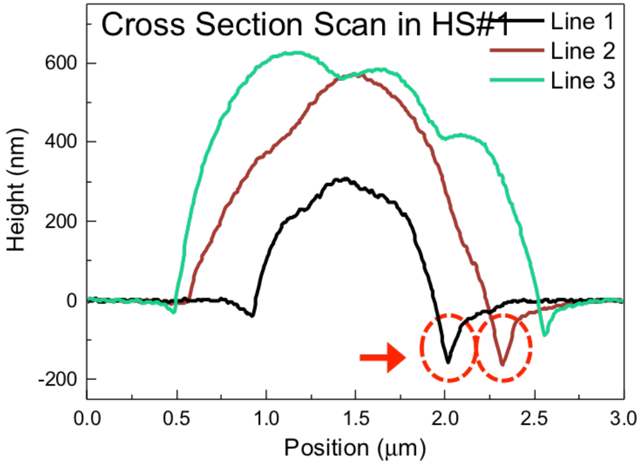


EDS elemental mapping

Hot spots: organic microparticles



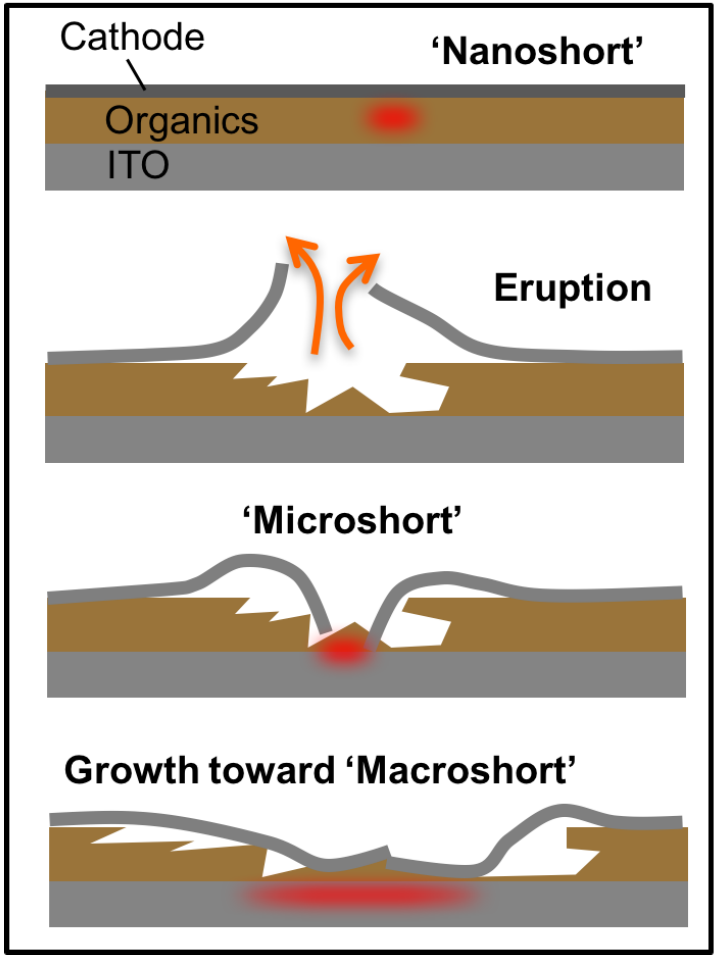




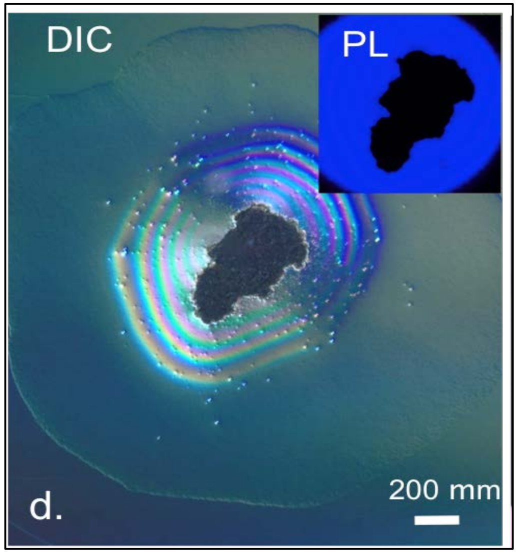
Approach & Results

Step 3: Model how shorts grow over time

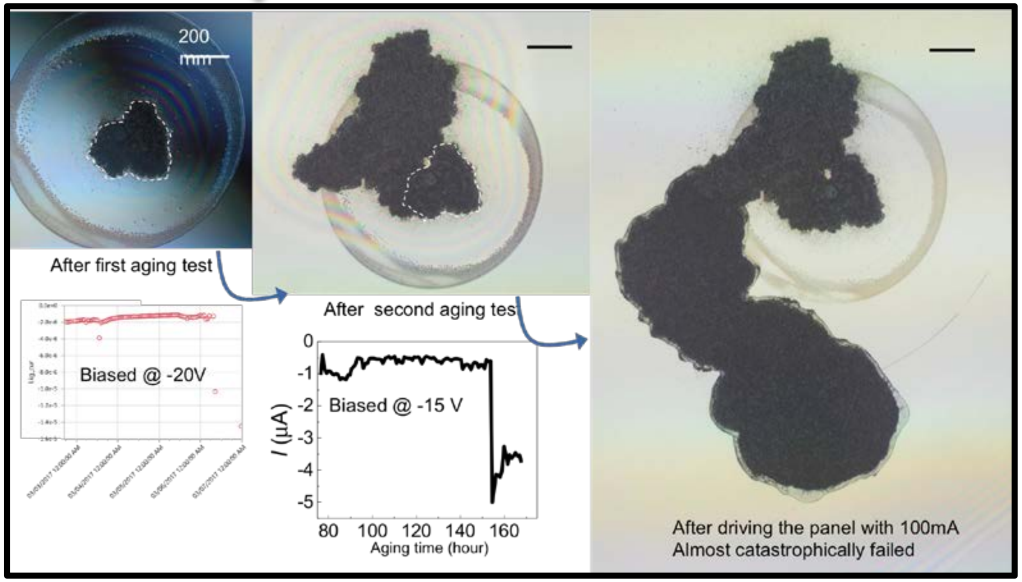
Volcano model



Microshort



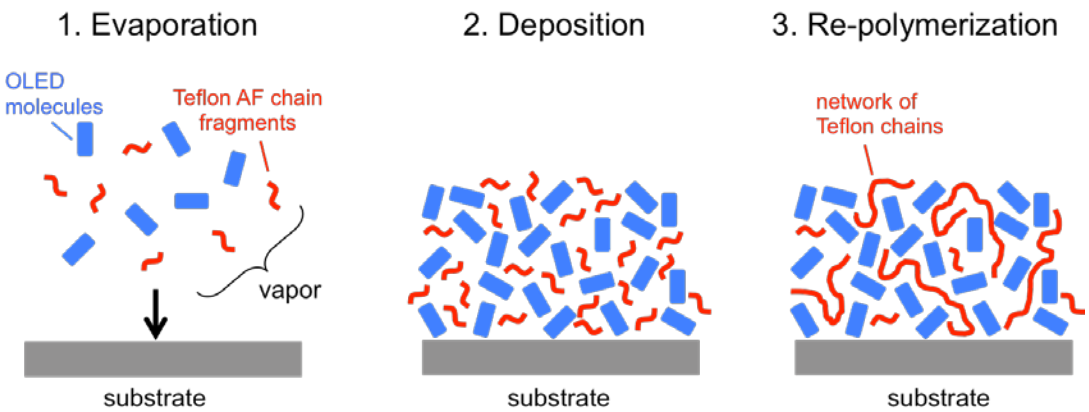
Evolution of micro to macroshort

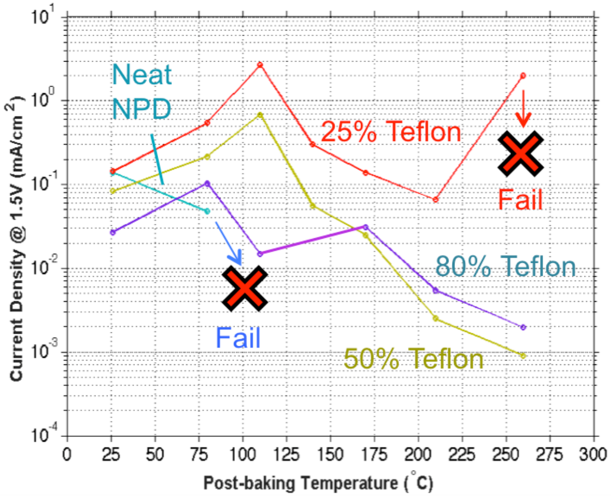


Approach & Results

Step 4: Formulate and test mitigation strategies

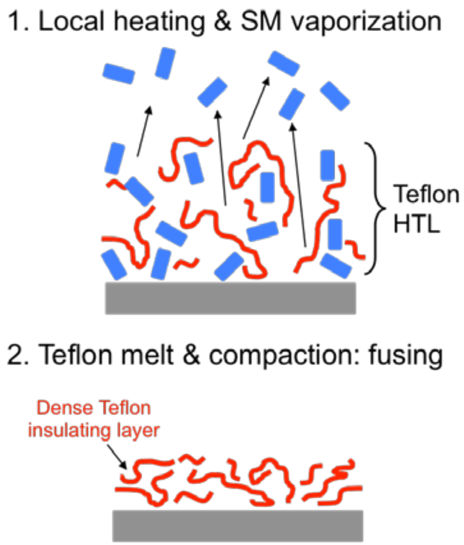
Example: fuse-like transport layers

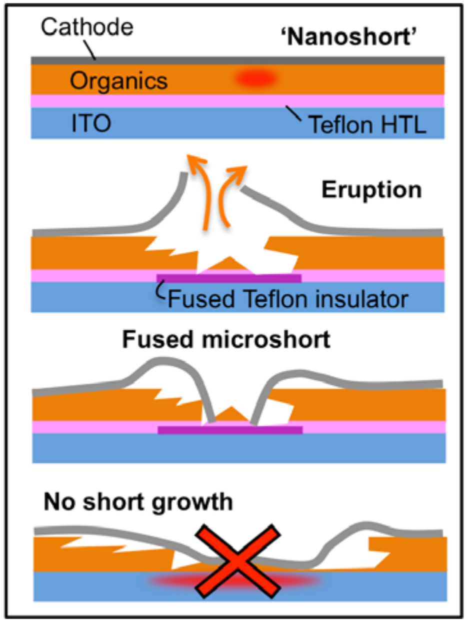




Summary

Hole-only device (50 nm)	Voltage at 10 mA/cm² (25°C)	"Shorted" Temp
Neat NPD	3.4 V	110°C
25% NPD/ Teflon	2.2 V	250°C
50% NPD/ Teflon	2.7 V	>260°C
80% NPD/ Teflon	4.0 V	>260°C





Impact

- Reduced warranty expenses (beta error = panels shipped as good that fail during lifetime)
- Reduced alpha error (good panels that are not shipped, but scrapped in error, reducing yield)
- Successful anti-shorting measure will enable cost savings by:
  - Enabling the use of lower cost substrates, e.g. without insulator layers, lower quality glass
  - Enabling the use of lower-cost but rougher anode processes like silver nanowires
  - Enabling lower cost bus metal grid pattern (e.g. printed metal) without insulator layers on top
  - Enabling lower cost manufacturing and cleaning processes
  - Enabling new products like plastic-based lighting panels where the substrates or their anodes are rougher or have more particles.
- Ability to grade product according to reliability enables new opportunities to offer panels with known but “lesser than perfect” reliability at lower cost for use in markets not requiring 50,000 hour lifetime (e.g. portable products).

Meet DOE 2020 goal of 0.01% failure rate

Progress

Task 1: Locate 'baby' shorts before they go catastrophic

- Temperature-selective imaging detects hot spot precursors

accomplished

Task 2: Identify physical origin of shorts & how they grow over time

- Bright spots: ITO agglomerations
- Hot spots: Organic microparticulates

accomplished

Task 3: Model how shorts grow over time

- Volcano model of growth, nano → micro → macroshort
- Turning hot spot images quantitative

80% complete

Step 4: Formulate and test mitigation strategies

- Fuse-like transport layers & other strategies
- Presently being tested on OLEDWorks R&D line

50% complete

Stakeholder Engagement

Project stage: Near completion

Engagement plan:

- Manufacturing stakeholders: OLEDWorks can directly implement results of this work in production
  - → Anti-shorting strategies developed in this program
  - → Imaging analytics – how to identify bad panels
  - → Modeling – how to predict the likelihood that a panel will short

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- Customer stakeholders: Reduced cost and improved customer satisfaction with OLED lighting

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- Government stakeholders: Expanded OLED lighting improves energy efficiency, furthers DOE goal

Remaining Project Work

1. Demonstrate reduced rate of panel shorting in OLEDWorks R&D line panels

   Status: In progress, multiple anti-shorting strategies being pursued in parallel.

2. Turn temperature-selective EL imaging into a tool to predict panel beta risk

   Status: In progress, using TSELI to quantitatively map nascent short temperature and local shunt magnitude

Thank You

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REFERENCE SLIDES

Project Budget

Project Budget: Outline the project budget and history.
Variances: None
Cost to Date: 92% of budget expended to date
Additional Funding: None

Budget History					
FY 2017 (past)		FY 2018 (current)		FY 2019 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
658,131	164,533	429,850	107,463	N/A	N/A

Project Plan and Schedule

Milestone color code:

- = accomplished
- = deferred
- = upcoming

ACTIVITY	Sept 2016-Aug 2017				Sept 2017-Aug 2018			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Locating microshorts				M1.1				
3.1 EL imaging system	M1.1.1		M1.1.2					
3.2 LIT imaging system			M1.2.1					
3.3 LBIC/FIPLQ imaging system		M1.3.1		M1.3.2				
Task 2: Physical analysis of shorts					M2.1			
Task 3: Modeling & validation							M3.1	M3.2
Task 4: Anti-shorting strategies				GNG1		M4.1		M4.2