Innovative High-Performance Deposition Technology for Low-Cost Manufacturing of OLED Lighting

2015 Building Technologies Office Peer Review

DOE Agreement Number DE-EE0006263

Images show Sunic G5 VTE deposition tool and nozzle array for deposition of 3 components – OLEDWorks equipment is proprietary and won't be shown.

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Project Summary

Timeline:

Start date: 10/1/2013

Planned end date: 03/31/2015

Key Milestones

1. Design, and fabrication of vaporizer system for attachment to R&D coater, 9/30/2014
2. Design, and fabrication of full width deposition system for attachment to production coater, 3/31/2015
3. Full width deposition of multiple materials simultaneously in one layer, 3/31/2016

Budget:

Total DOE $ to date: $330,000

Total future DOE $: $380,000

Target Market/Audience:

Use of OLED lighting for general lighting requires lower-cost production. Luminaire makers have early designs, but need more affordable panels.

Key Partners:

Bauer Associates : Thermal Modeling	Arnprior Manufacturing: Precision Fabrication
Joel Shore: Plume/Nozzle Modeling	Axenics : Precision Fabrication
Kurt J Lesker Company : Vacuum Hardware	NexThermal Inc.: Heater Fabrication
MachineCraft : Precision Fabrication	PolyShot Inc: Assembly Brazing

Project Goals:

To design and build a set of innovative organics vapor generation sources, distributors, and controls focused on reducing the manufacturing cost of OLED lighting through:

1) Reducing the depreciation cost
   a) Lower capital cost
   b) Higher throughput speed
2) Reducing the organic materials costs
   a) Higher material usage efficiency
3) Allow use of thermally sensitive materials for higher performance

Purpose and Objectives

Problem Statement: Current large-substrate continuous in-line coating machines are expensive and slow. Our vaporizer design for organic materials will enable a large coating machine with:

Higher throughput for lower cost product.
Higher material usage efficiency for lower cost
More gentle thermal treatment of organics, allowing new materials
Lower Capital costs. The Sunic Gen 5 shown has a $60/m2 deprecation*, too much for $100/m2 COGS.

Target Market and Audience: Luminaire makers (our Audience) are starting to make both consumer and commercial OLED fixtures. OLED lighting is predicted to be 1.5% of lighting in 2019, growing exponentially from there with luminaire efficacies similar to LED. If in 2025, OLED lighting is 5% as large as LED, then OLED lighting will save ~10TWh/year.

Impact of Project: By the end of this project, we will have designed, built, started, debugged the new vaporizer, and then demonstrated it in production operation making good OLED lighting product (endpoint) in Rochester NY.

Impact Path:

a. Near-term – operate with 1 new vaporizer and 1 existing vaporizer (~3x current capacity). Learn any deficiencies and correct.
b. Intermediate-term – Install 3 new vaporizers and retire existing vaporizers (~6x current capacity).
c. Long Term - Design and build large continuous in-line machine with 25-40 new vaporizers – as demand grows.

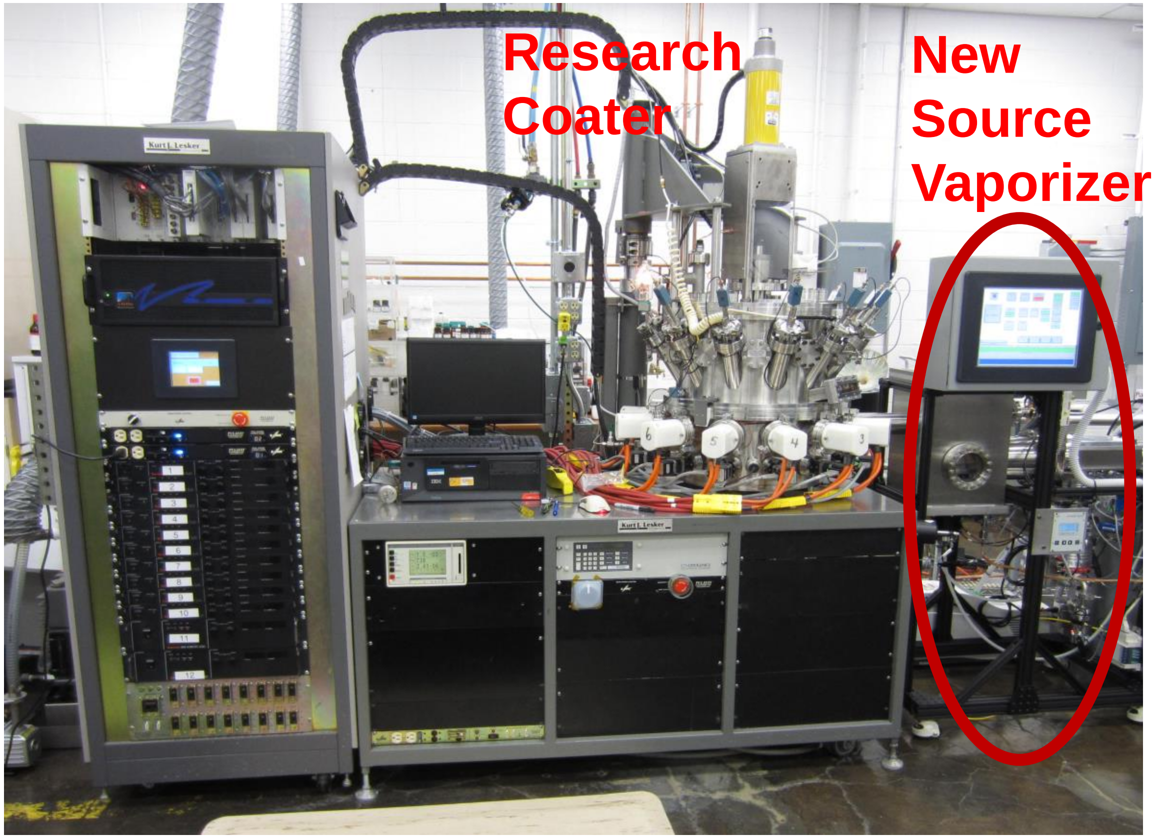
*** Industry standard assumptions of 1 min TAC, 80% uptime 80% yield, 80% glass usage efficiency, 8 year deprecation, $180M cost (from LG Chem)**

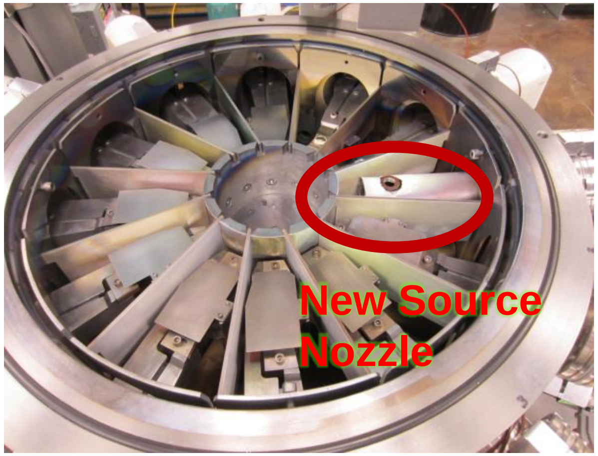
Approach and Outcomes

Design Approach	Desired Outcome and Comparison to Baseline Technology
Relocate the nozzles closer to the substrate	• To improve the material usage efficiency • The goal is to reduce by 50% of current machine
Move the nozzles are closer together	• To maintain the overlapping plumes, less gradient effect through coated layers. • The goal is to reduce by 66% of current machine
Shorten the coating window	• To allow a smaller lower cost coating machine • The goal is to reduce by 70% of current machine
Locate all vaporizer components on one side of machine	• Allows two sources to overlap, with each using half the chamber space. • The goal is to reduce machine length by 50%.
Develop novel rate measurement and control system for vapor generation rate	• Improves accuracy of rate control for both dopants (minor components) and hosts (major components) to eliminate binning and improve yield. • The dynamic range of the measurements will increase by 3x. The improved controls will simplify the design and operation (fewer parts).
Develop novel crucible and vaporizer design.	• Allows more gentle thermal treatment of materials, enabling use of less-thermally-stable materials for higher performance and reduced cost. • All commercially available machines are limited in their operating duration by material degradation. This will increase duration by 2x-3x.

Progress and Accomplishments

Accomplishments:
A new method of evaporating, controlling, sensing, and conducting vapor has been designed, built, and tested using a research coater.





Progress and Accomplishments

Accomplishments:

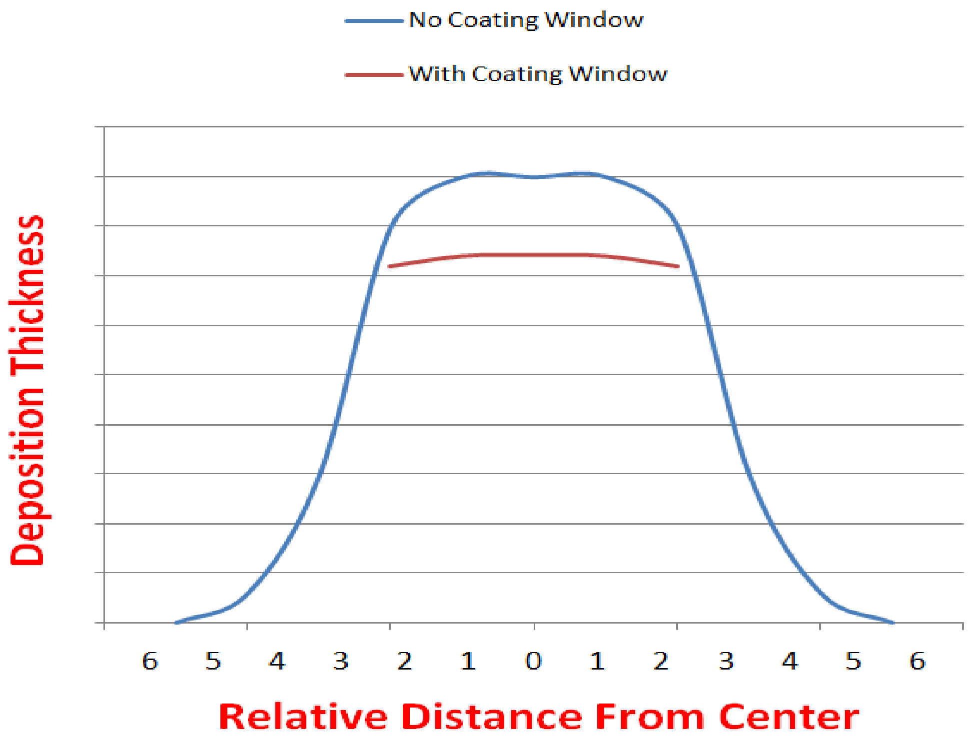
Physical testing showed the following results

- Target - Deposition Rate Range – 0.01-10g/hour - 1,000:1
- Demonstration - Deposition Rate Range - 0.0042 – 10g/hour – 2,400:1

Good dynamic control was achieved over the entire rate range.

Plume modeling and Nozzle Engineering

- Predicted widthwise uniformity of <+/-2%



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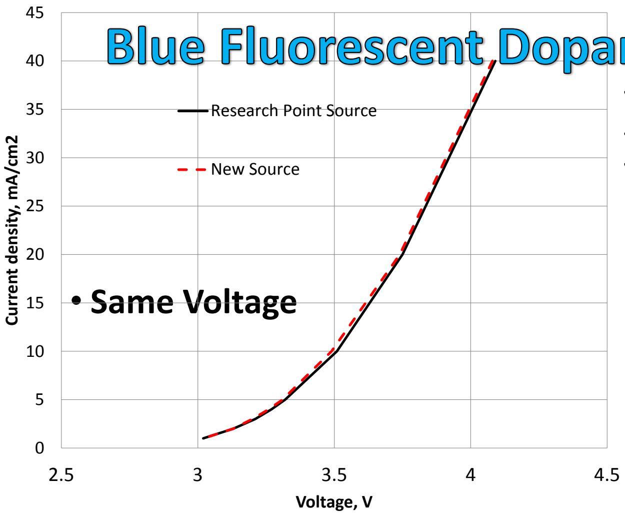
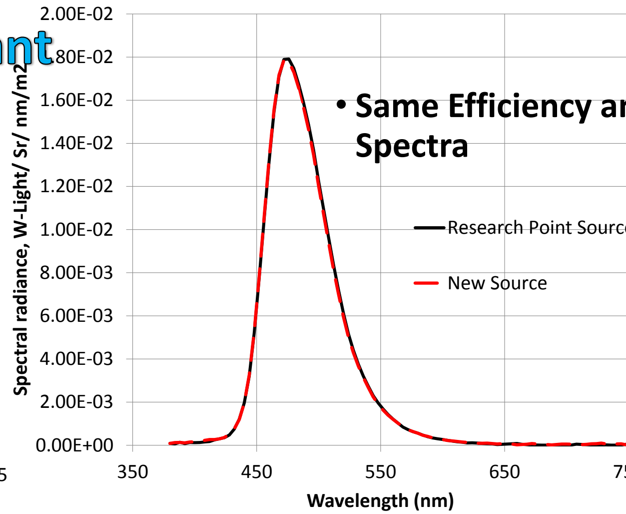
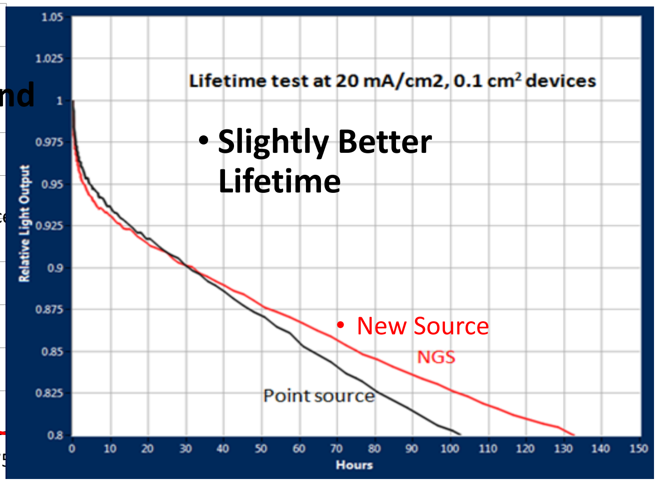
Progress and Accomplishments

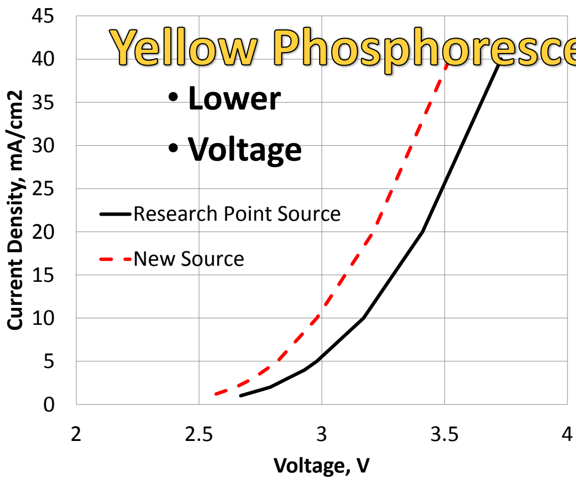
Experiment were done depositing host and dopant materials from point sources and Next Generation Sources – No difference in voltage, efficiency, spectra or lifetime.

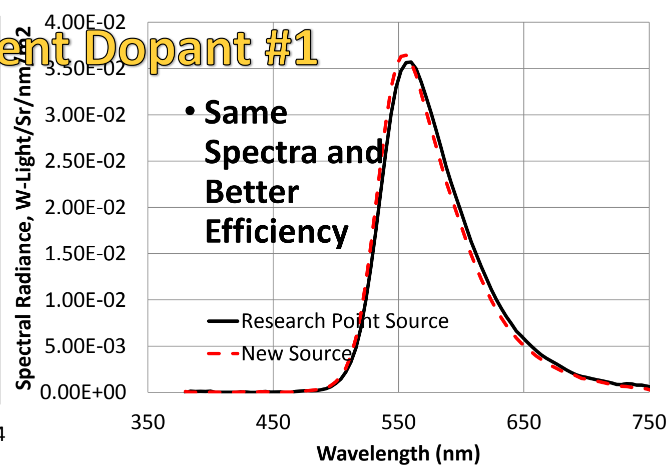


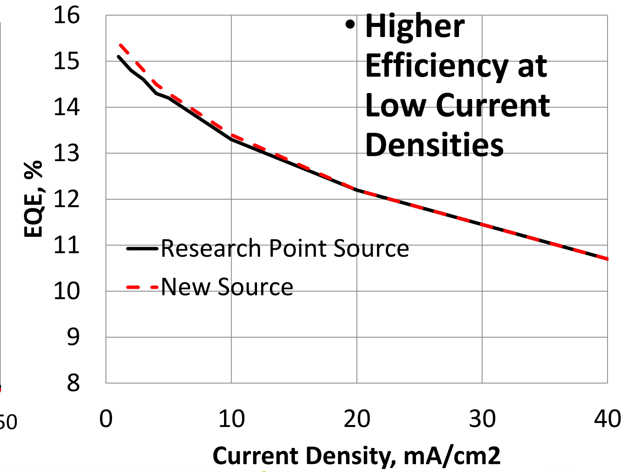




The work was also done with 2 yellow phosphorescent dopants – both are examples of thermally sensitive materials - No difference







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Progress and Accomplishments

Accomplishments:

An improved design for distributing, combining, sensing the vapor has been developed, fabricated, and assembled. The "out of vacuum" testing (motors, rate sensors, temperature sensors, pressure sensors) has been successfully completed.

The design phase made extensive use of 3D transient thermal modeling and modeling of gas flows and plume distribution profiles.

This will be tested in our production coater starting in April.

The production machine has been tied up making product in preparation for the Lightfair International trade show at the Javits Center May 3-7.

This improved design will allow higher materials usage efficiency (2x), better sensing (3x dynamic range), while preserving the advantages of widthwise uniformity and high-performance controls we have with our current system.

Equipment costs are lowered through the use of "Off the Shelf" components where possible, and enabling a smaller overall machine.

The details are proprietary and cannot be shown.

Progress and Accomplishments

Lessons Learned:

- PROBLEM: The integrity of the vaporization crucibles has been more challenging to achieve than originally anticipated. We have experienced some material leaking during high vaporization rate trials.
  ACTION: We are working with the supplier to develop a new design and fabrication process which seals well and does not leak.

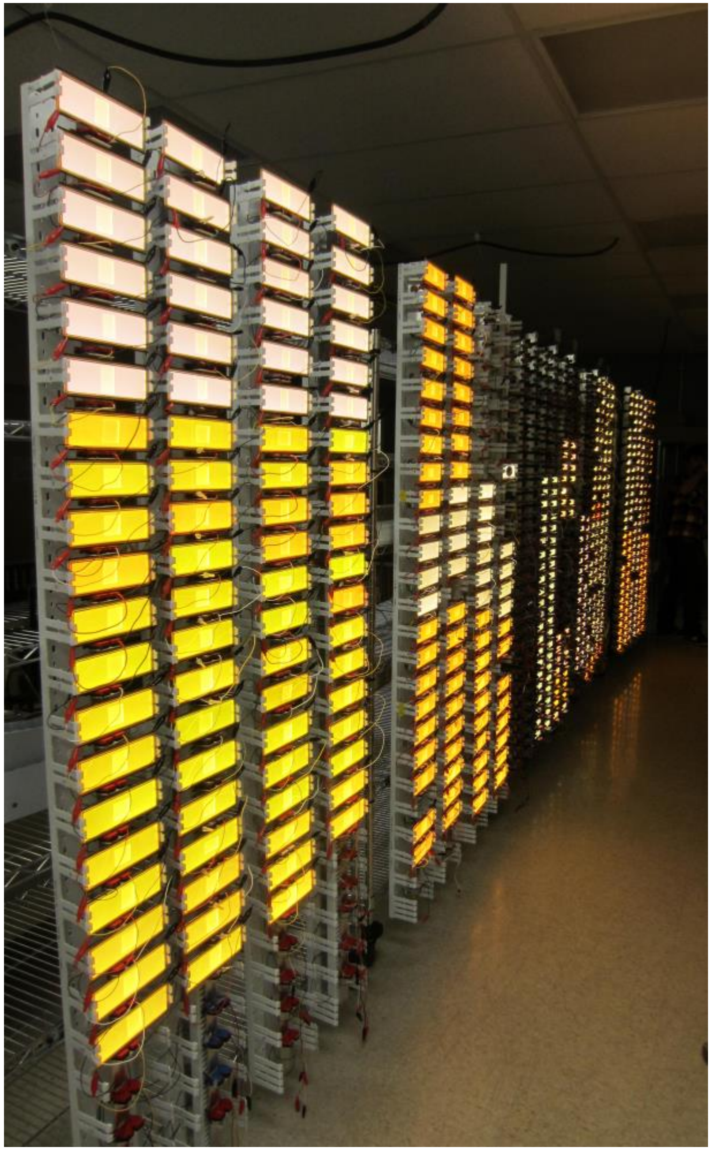
- PROBLEM: Fabrication of the production nozzle block proved to be very difficult in part due to the geometry of the block and the manufacturing processes required to minimize leakage between nozzles.
  ACTION: This was accomplished through a combination of welding and brazing various joints. Future nozzle blocks may utilize alternative manufacturing methods in order to further reduce costs.

- PROBLEM: System heater installations have been tricky due to complex geometry of the system and the necessity to maintain good conduction with the heaters while in vacuum.
  ACTION: Working with several of our outside partners, we feel we have developed a system which can be heated consistently and reliably.

Progress and Accomplishments

Awards/Recognition:

- New York State Energy Research and Development Authority (NYSERDA) grant under Transformative Technologies for Energy-Efficient Manufacturing (TTEEM) PON 2736 for funding of part of OLEDWorks match – Agreement number 35375.



Panels in Testing Racks at OLEDWorks

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Project Integration and Collaboration

Project Integration:

- Formal presentations to industry at DOE SSL Manufacturing and R&D workshops
- Participation in OLED Coalition and OLED Association, including lobbying efforts for to increase funding for OLED lighting R&D.
- Co-sponsor for OLED Lighting Stakeholder meetings in Rochester NY, an industry forum for problem discussion and priority setting.
- Close communication with other manufactures in the industry on industry-wide problems.

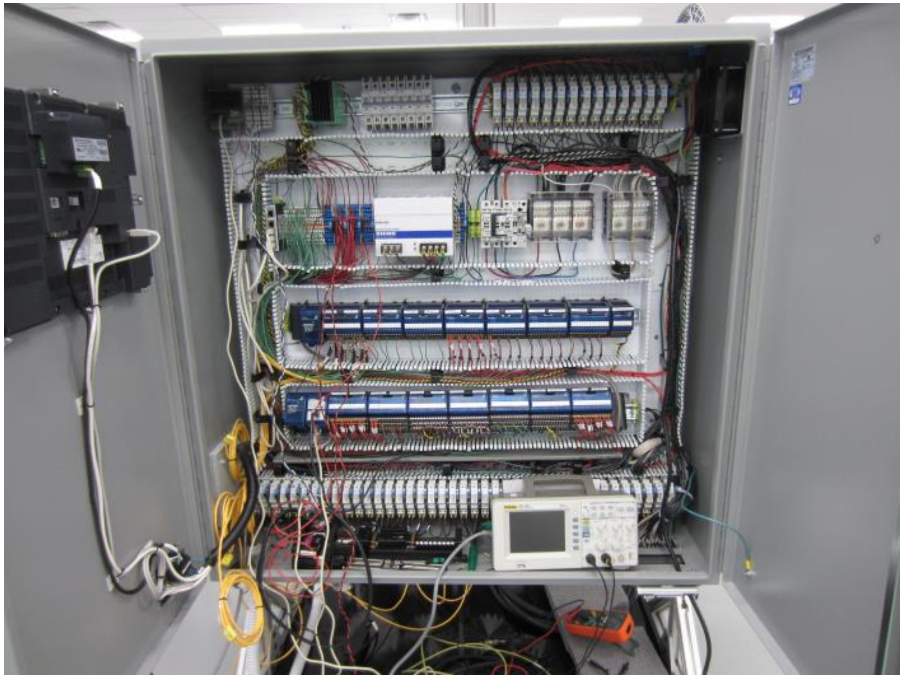
Partners, Subcontractors, and Collaborators:

- Bauer Associates: Thermal modeling from SolidWorks CAD models
- Arnprior Manufacturing: Fabrication of production nozzle
- Joel Shore: Plume and Nozzle Modeling for production source
- Axenics: Precision Fabrication from source and nozzle parts
- Kurt J Lesker Company: Vacuum Hardware for evaporation source
- NexThermal Inc.: Heater fabrication for entire system
- MachineCraft: Fabrication and welding of vaporizer source
- PolyShot Inc: Brazing of production nozzle

Communications:

- DOE SSL Manufacturing Workshop Jan 2014, San Diego
- DOE SSL R&D Workshop Jan 2015, San Francisco

Next Steps and Future Plans



The vaporizer is ready to be inserted into the production machine:

- The fabrication is done
- The assembly is done
- The wiring is done
- The controls software is done
- The production machine becomes available starting in April

Tests start with:

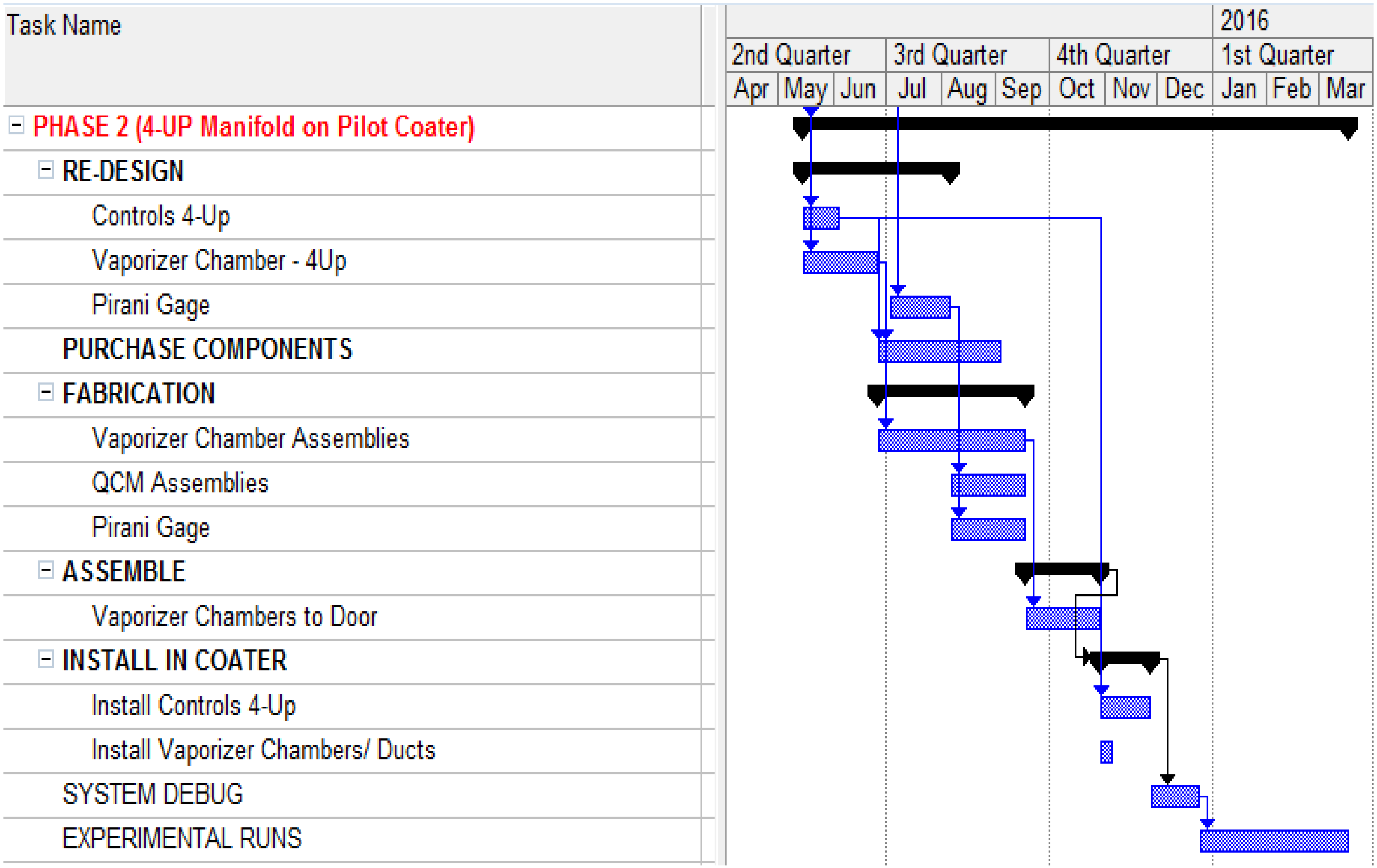
- Physical testing
  - Vapor rate generation rate range
  - Controllability
  - Uniformity across the width of the machine
- Deposition of single component layers in OLED’s vs controls
  - Efficiency, voltage, lifetime, emission spectrum

Then expand vaporizer for multi-component layers.

Project Budget

	BUDGETED	PROJECTED	ACTUAL	GOVT SHARE	PERF SHARE	TOTAL	% of BUDGET
Project to Date	$876,189	$680,000	$656,278	$328,139	$328,139	$656,278	**75%**
Budget Period 1 3/31/15	$876,189	$680,000		$340,000	$340,000	$680,000	**78%**
Budget Period 2 3/31/16	$1,216,715	$1,216,715		$608,358	$608,358	$1,216,715	**100%**
TOTAL	**$2,092,904**	**$1,896,714**		**$948,358**	**$948,358**	**$1,896,714**	**91%**

Project Plan and Schedule



Summary

- This project will help significantly reduce the Cost of Goods Sold for OLED lighting through:
  - Higher throughput, lower cost equipment – for lower depreciation
  - Better sensing and control – for higher yield
  - Higher material usage efficiency – for lower Bill of Materials cost
  - Enabling a more reasonably priced large continuous machine to be designed and built in the US.
- Many more steps are required for OLED lighting to grow to fill its potential in the market, and save significant energy.
- These further steps include continued and increased support for
  - Materials R&D for increased efficiency and lifetime
  - Improved substrates for higher performance and lower cost
  - Encapsulation for lower cost and flexible lights.
  - Manufacturing R&D for process improvement for cost reduction.