# Inkjet Technology For OLED SSL Mass Production


Conor Madigan, PhD, President

January 28, 2015

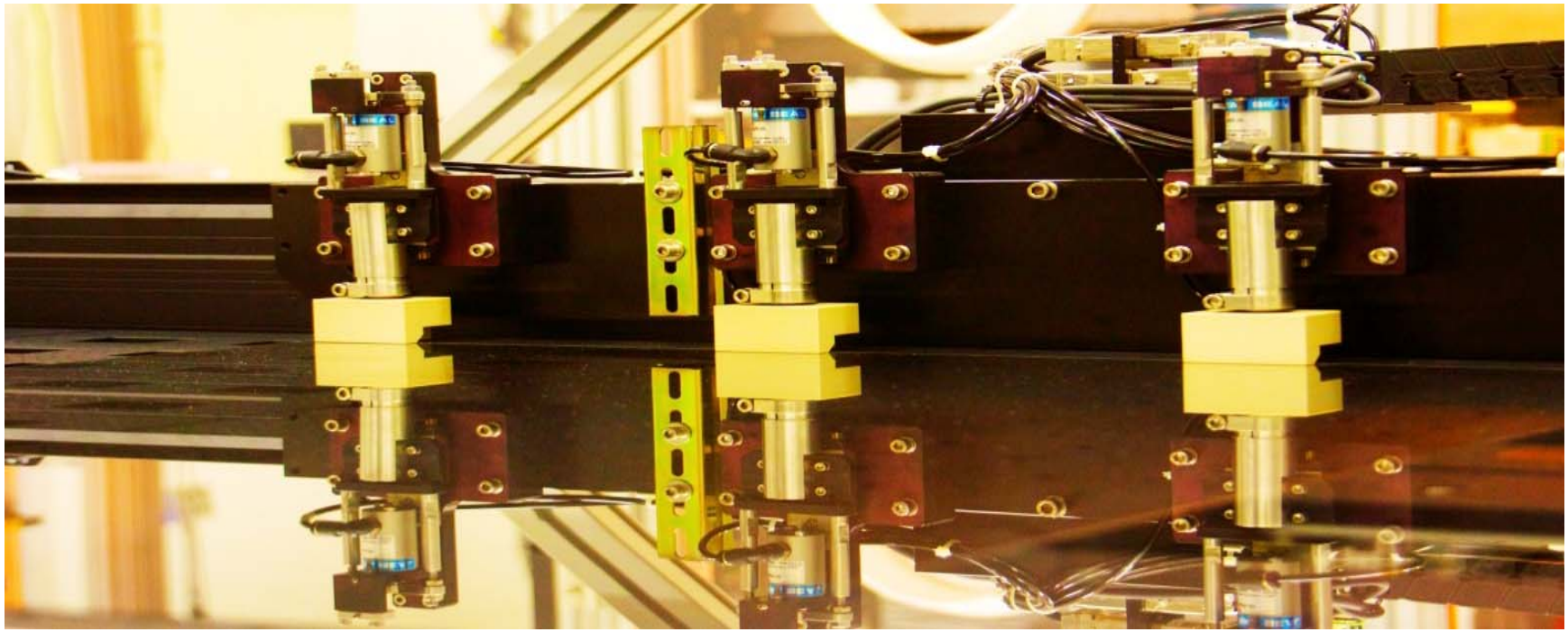
# Flexibility – A New Frontier for Lighting

- **Flexibility gives OLED high-value differentiation over LED in lighting market – enabling striking and beautiful products**

Flexibility also a natural parallel with the goal to move to roll to roll processing for OLED SSL.

# Kateeva Mission

## Enable low-cost mass production of OLEDs with Inkjet Printing



# About Kateeva

- **Developer of Precision Deposition equipment, leveraging innovative Inkjet Printing technology**
- **Founded in 2008**
- **Headquartered in Silicon Valley**
- **Backed by Samsung Venture Investment Corporation, Veeco, Sigma Partners, Spark Capital & Madrone Capital**
- **Headcount: 85+ growing**
- **Robust patent portfolio**

# Kateeva HQ / Silicon Valley



Kateeva, Inc.
Menlo Park, California

In the heart of Silicon Valley; surrounded by tech start-ups and established companies like Facebook, Google, Apple, Oracle, Cisco, Intel and AMAT, and prestigious universities, Stanford & UC Berkeley

# Kateeva Leadership

**Alain Harrus, Ph.D. | Chief Executive Officer**

**Semiconductor Capital Equipment / Venture Capital**

AT&T Bell Laboratories · NOVELLUS · Lam RESEARCH · CROSSLINK CAPITAL · COMPASS TECHNOLOGY PARTNERS

**Conor Madigan, Ph.D. | President & Co-founder**

**OLED Enabling Vision**

kateeva® · MIT Massachusetts Institute of Technology · TR35 MIT's Technology Review Top 35 Innovators Under 35

**Steve Van Slyke | Chief Technology Officer**

**OLED Co-Inventor**

Kodak · CE Consumer Electronics Hall of Fame · SID Fellow

**Eli Vronsky | Executive Vice President of Product Development**

**Inkjet Guru**

PiXDRO · scitex · Aprion

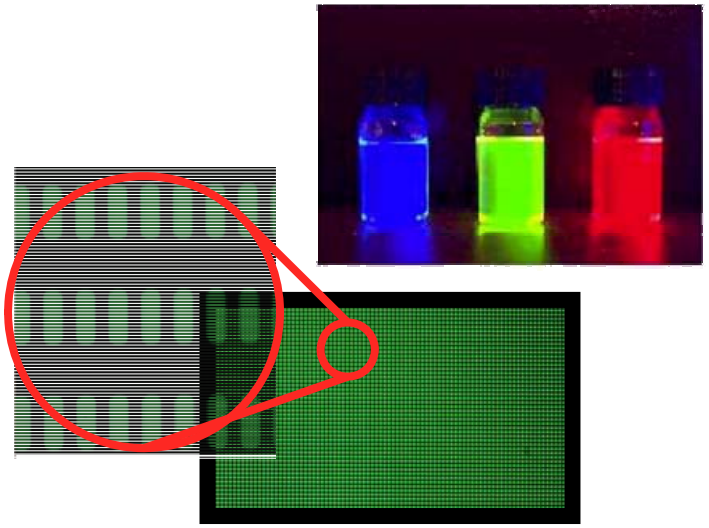
**Larry Timm | Senior Vice President of Customer Satisfaction**

**Capital Equipment Sales and Support Expert**

NOVELLUS · KLA-Tencor

# Advanced Inkjet Process Expertise and Facility

- **OLED front-plane lab for VTE, Encap, and solution device fab/test.**
- **Print process lab with 5 inkjet systems (up to 15” panels).**
- **Ink lab for comprehensive ink evaluation.**



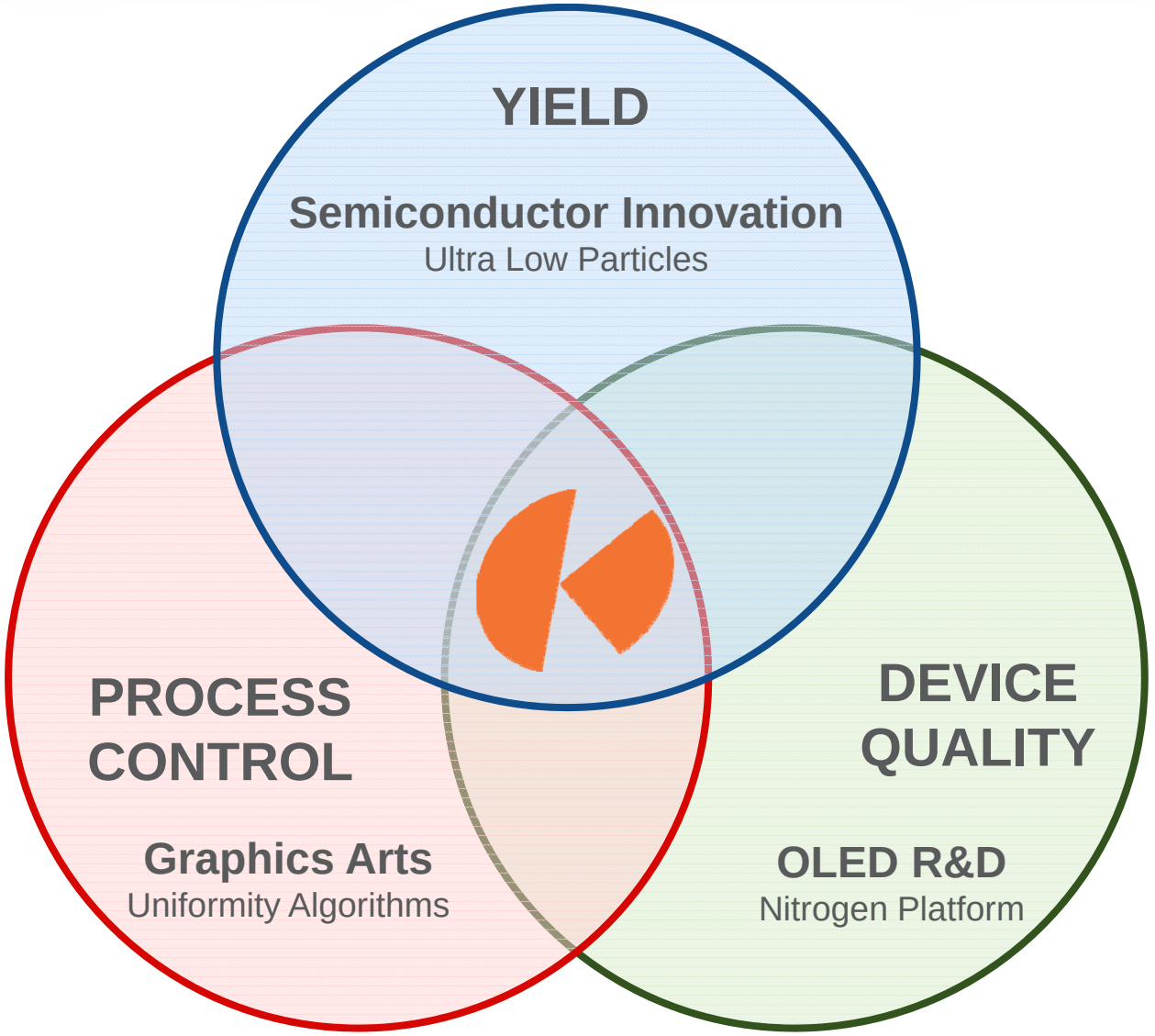
All facility and capability in-house for inkjet OLED development

# Kateeva's YIELDjet™ Platform

**First inkjet platform developed from the ground up for OLED mass production.**

YIELDjet platform introduced one year ago for glass plate substrate display applications. Customer reception has been extremely positive.

# YIELDjet™ Advantage



# Kateeva YIELDjet Platform for MP – Unique and Differentiated Technology

- **Unique "floating glass" printing approach**
  - Enables reduced $N_2$ enclosure volume
  - Best thermal uniformity (to avoid variations in film uniformity due to thermal non-uniformity of the chuck, a.k.a. "chuck mura")
- **Production-worthy $N_2$ enclosure integration – fast recovery after maintenance and no air exposure for routine maintenance**
  - No air exposure for routine maintenance (even head replacement)
  - Fast recovery in rare cases when tool is opened
- **Ultra-low particle printing in $N_2$**
  - Specially tuned $N_2$ flow around printer to minimize turbulence
  - Unique shielding/exhausting technology for head array, cable tray, and other critical printer components
- **Proprietary printing algorithms enabling excellent uniformity with wide process window**

# Addressing Key OLED Applications

- **YIELDjet™ Platform developed for both thin film encap (TFE) and RGB patterning (RGB) of OLED display**
  - Focus on glass plates, especially large size (up to G8)

- **Core technologies also applicable to OLED SSL**
  - TFE a key technology for flexible OLED SSL
  - Inkjet printing of OLED active layers cheaper than VTE for SSL
  - Inkjet is well suited to roll to roll processing
  - Inkjet in particular attractive (vs other solution coating technologies) due to capability for precision patterning (edge bezel), support for non-square shapes, and ease of rapid pattern modifications (short runs)

Kateeva aiming to help enable high performance, low cost OLED SSL manufacturing.

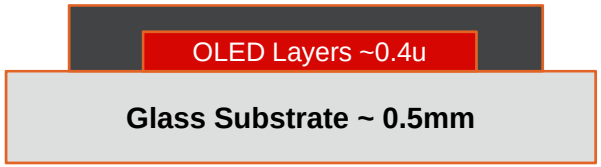
# Flexible Challenge: Thin Film Encapsulation (TFE)

## Encapsulation addresses OLED sensitivity to O2 and H2O


**Standard Rigid**

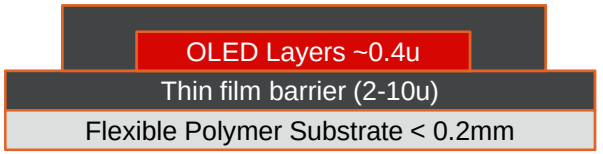
## Thin Film Encapsulation needed for thinness and flexibility

Thin film encapsulation (2u -10u)




**Thin Rigid**

Thin film encapsulation (2u-10u)




**Thin Flexible**

**TFE requires organic coatings and the current technology is shadowmask evaporation…**

# Flexible Challenge: Thin Film Encapsulation (TFE)

- **Two main TFE approaches: (1) directly deposited inorganic and organic multi-layer stacks; and (2) lamination of flexible barrier films (which are usually multilayer coatings on plastic)**

- **If optimized properly, directly deposited inorganic/organic multi-layer is superior: lowest cost and finest bezel edge**
  - Lamination of film is expensive due to carrier film cost, coating cost, and lamination cost
  - If done right, direct deposited TFE only has the coating cost

# Using Direct Coated TFE in OLED SSL

- **For organic/inorganic stack, each layer as different purpose:**
  - Inorganic layer provides a barrier to oxygen and moisture
  - Organic interlayer helps integrate the structure

- **When depositing TFE over the OLED SSL cell, need method to pattern the stack in such a way that electrodes are exposed and edge is fully sealed by inorganic**

Option 1:
Deposit Patterned Organic and Inorganic

Option 2:
Deposited Patterned Organic
Deposit Blanket Inorganic (and etch at the end)

# Using Direct Coated TFE in OLED SSL

- **In plate processing, the inorganic layer can be deposited in vacuum and patterned using shadowmask**
  - For PECVD this is production proven technology
  - For ALD this is still under development to achieve production throughput
  - Note: sputtering has been largely rejected for TFE due to higher defect rate

- **We'll come back to what should be done in R2R…**

- **Before discussing organic layer, important to review why the organic layer is there (since it does not provide the barrier)**

# Why Use TFE Organic Interlayer?

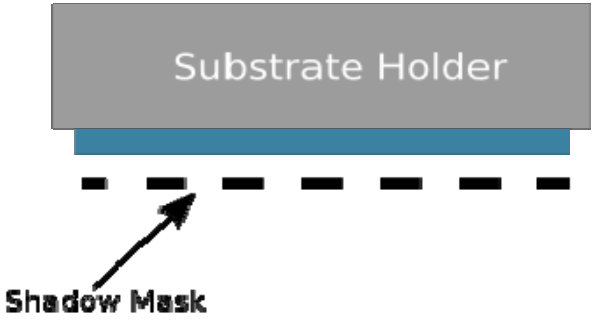
- **Planarization: Inorganic layer quality is improved when the deposition surface is smooth and flat**
  - It's most desirable to planarize substrate topology and particles before depositing primary barrier layers
  - Conformal coating is not good enough. Features are coated but not smoothed out, causing the quality of the inorganic layer to suffer

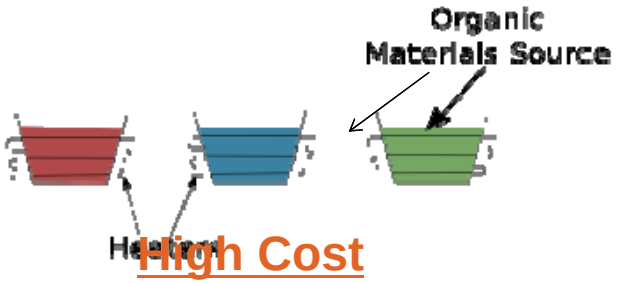
- **Stress Dissipation and Defect decoupling: Stop defects from propagating through stack**
  - Thick, compliant organic layers reduce crack formation when the structure is under stress and prevents defects in one inorganic barrier layer from propagating throughout the structure

- **Typical material is organic monomer mixture (liquid at RT) that crosslinks into solid polymer under UV illumination**

# Why Kateeva Inkjet for TFE Organic Layer?

## Old Technique: Shadowmask Flash Evaporation

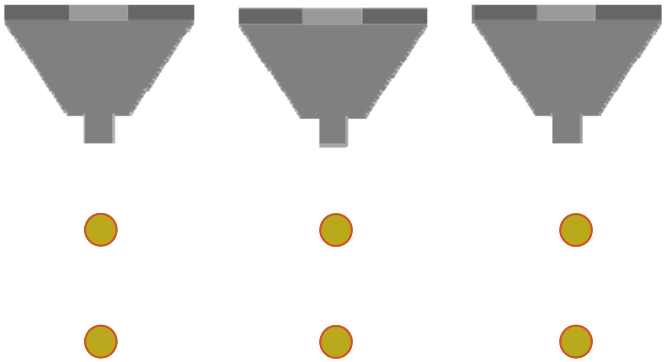


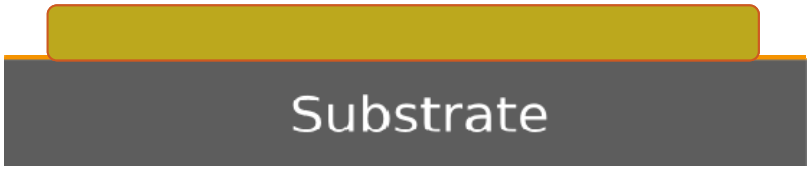




**High Cost**

**Slow (thin films); Poor Planarization; Many Particle Defects; Low Material Utilization; Poor Scalability; Difficult Maintenance**

## New Technique: Kateeva Inkjet



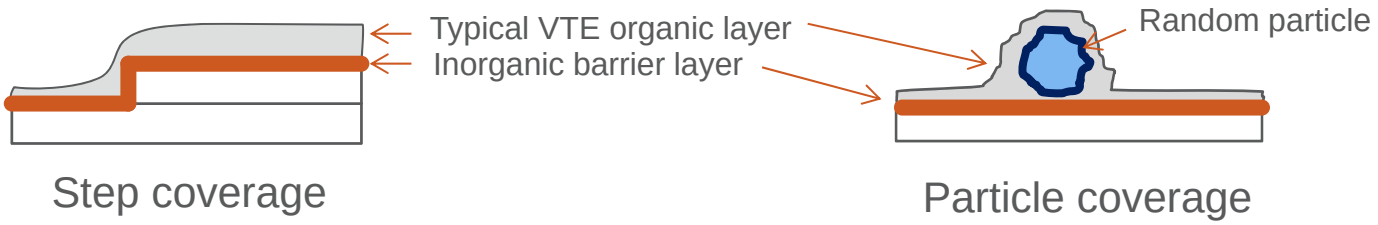



**Low Cost**

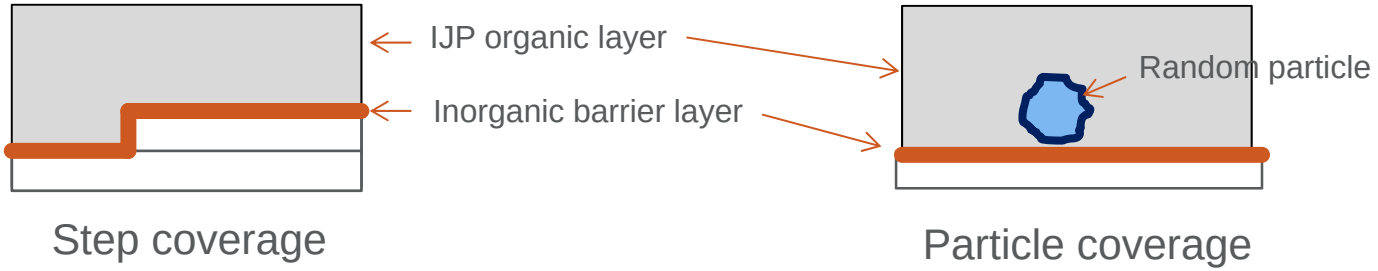
**Fast (thick films); Good Planarization; Few Particle Defects; High Material Utilization; Good Scalability; Easy Maintenance**

# Kateeva Inkjet Planarization Advantage

- **Typical VTE Organic Layer (thinner, partially conformal)**




- **Typical Kateeva IJP Organic Layer (thicker, non-conformal)**



# Kateeva Inkjet Organic Layer Ideal for TFE

- **Thick films at high speed with few defects**
  - Excellent planarization and particle coverage
  - Elimination of shadowmask sharply cuts coating defect rates
- **High uptime, high speed and roll to roll compatibility**

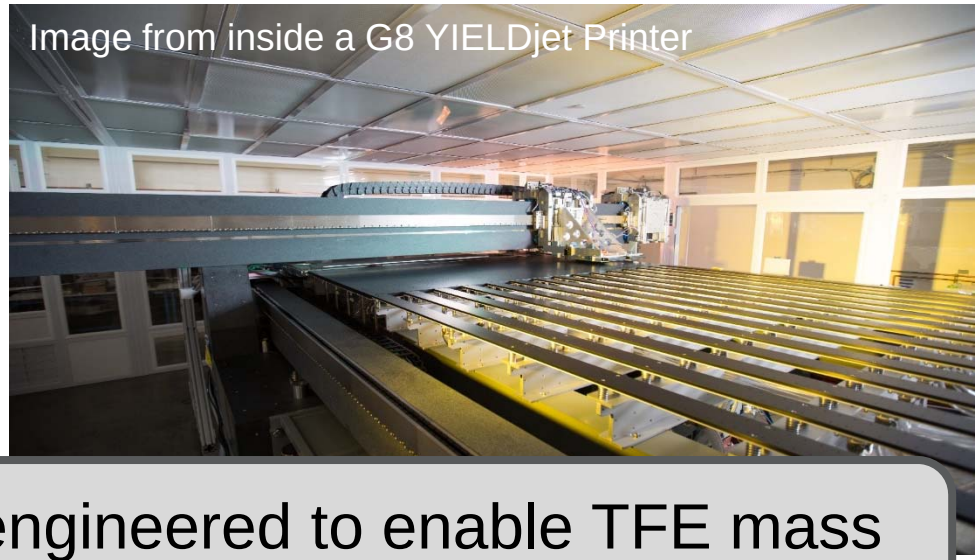
- **Why not screen printing or slot die coating?**
  - TFE integrity extremely sensitive to defects – screen printing (due to contact mask) produces too many defects
  - Need patterning – slot die coating of organic layer and subsequent etching/laser removal leaves organic exposed encap edge
  - Patterned slot die coating is not precise enough – bezel edge width is compromised
  - Pattern flexibility is critical with minimal tool downtime – this is a problem for both screen printing and patterned slot die coating

# Applying Direct Coated TFE to R2R

- **Inkjet already well suited to R2R – so same approach applies well for the organic layer**
  - Kateeva roadmap includes R2R
- **For the inorganic layer the only option in R2R is blanket coating followed by removal material at the end of the process (Option 2 stack)**
- **There are a variety of ways to do this: (1) laser (if it is fast and clean enough); or (2) IJP etch mask and dry etch**

# YIELDjet FLEX Introduced in Q4/2014

- **A complete integrated deposition solution for TFE organic layer optimized to meet demanding uptime and TACT requirements for flexible display mass production; including:**
  - YIELDjet N2 Printer
  - UV Curing Module
  - N2 Transfer Module
  - Substrate Buffering Module

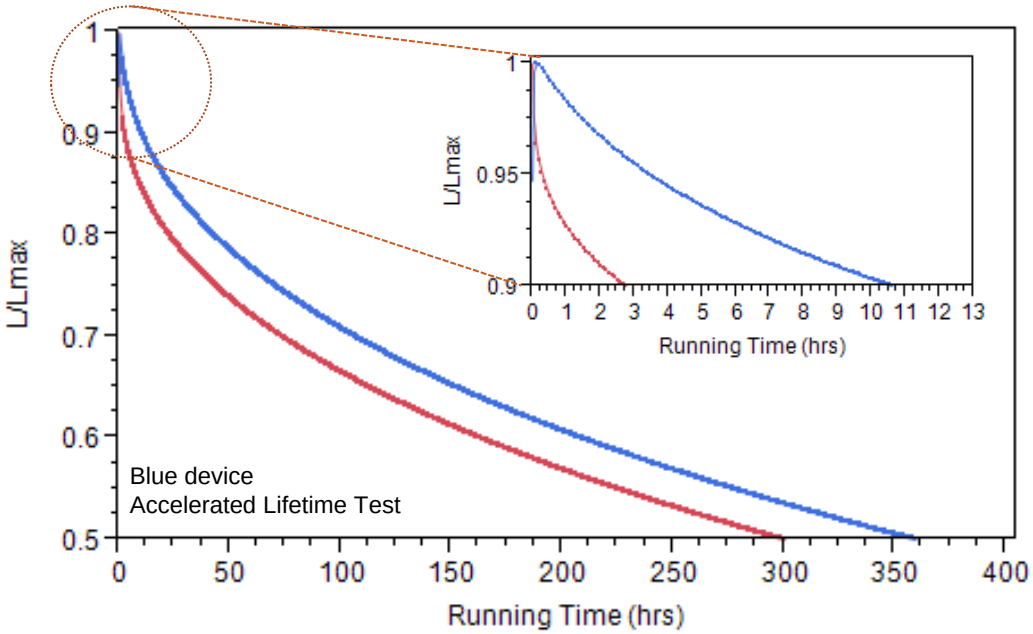



First inkjet printing system engineered to enable TFE mass production. A mature, customer-proven technology.

Available today for OLED SSL plate processing; R2R product planned (timing depends on customer pull.)

# Printing the OLED Active Layers – N2 Essential for Long Lifetime

- **Kateeva has become the world expert on N2 printing for mass production due to six year focus on N2 printing**
- **Extensive data demonstrating that N2 is essential for the best T90 – especially as solution lifetimes start to approach VTE**




Comparison devices fabricated in same run.

N2 is essential for long lifetime inkjet OLED. This is one of Kateeva's unique strengths.

# Why is N2 Important?

- **Air has many chemically active impurities (ozone, water, oxygen, etc.) These impurities can invade OLED layers during coating**
  - Printing in Air is the same as using VTE with poor vacuum – to achieve long lifetime, exceptional environmental purity is crucial

- **Historically, IJP device performance has been poor, often due to degradation pathways besides Air impurities, e.g.**
  - Low intrinsic material stability; ink contaminants/impurities

- **For the latest materials with the longest lifetimes, we see the biggest impacts from N2 processing**

Kateeva's N2 technology, combined with the best materials can acceleration commercialization of IJP OLED SSL.

# Summary

- **Inkjet well suited to reduce cost of OLED SSL: lower cost than vacuum techniques, direct patterning, ideal for R2R**

- **Kateeva's YIELDjet platform ideal for OLED SSL applications, including:**
  - TFE
  - OLED Layers

- **Kateeva is new to the OLED SSL industry, and just now starting to explore how to participate and help**