Inkjet Technology For OLED SSL Mass Production

kateeva

Conor Madigan, PhD, President

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Exhibit
6
06/04/2025

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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.

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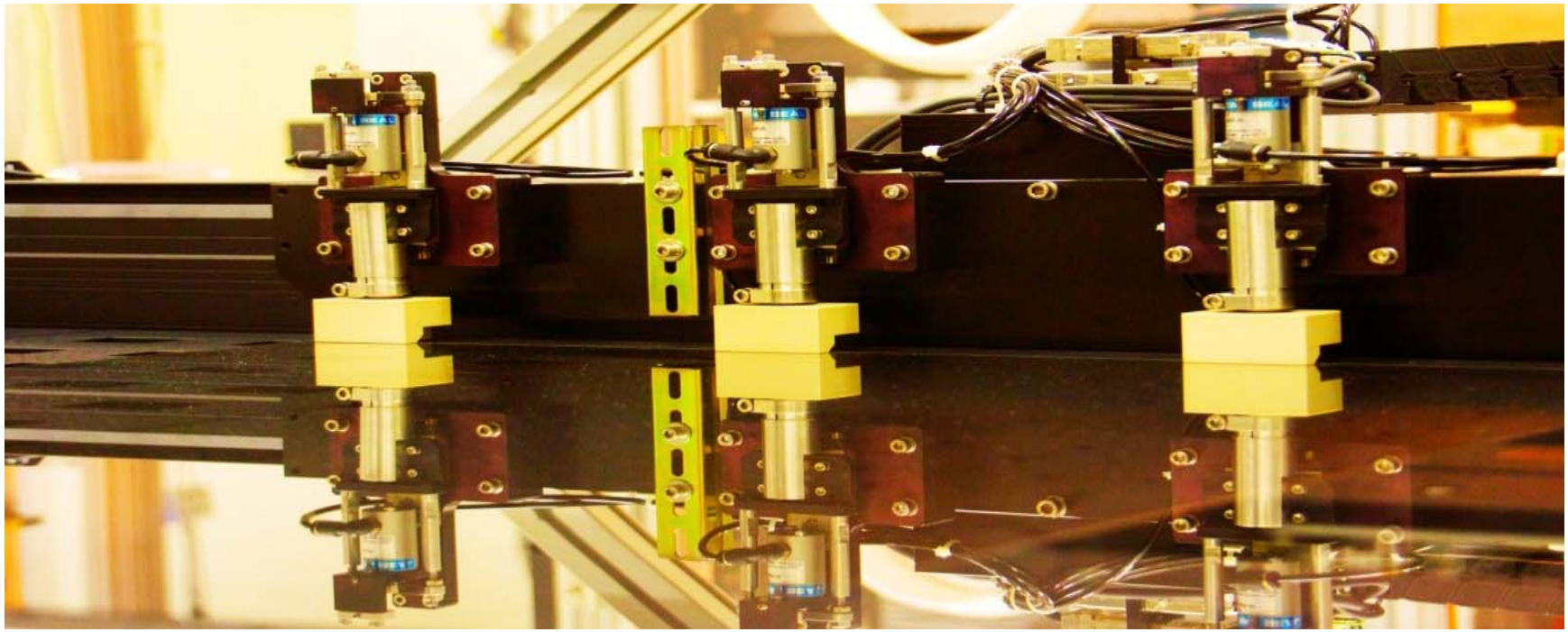
Kateeva Mission

Enable low-cost mass production of OLEDs with <u>Inkjet Printing</u>



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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

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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

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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

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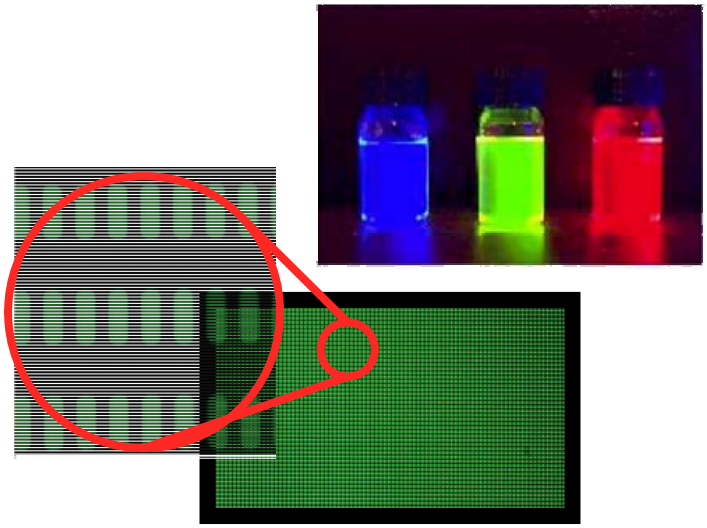
Advanced Inkjet Process Expertise and Facility

- **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

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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.

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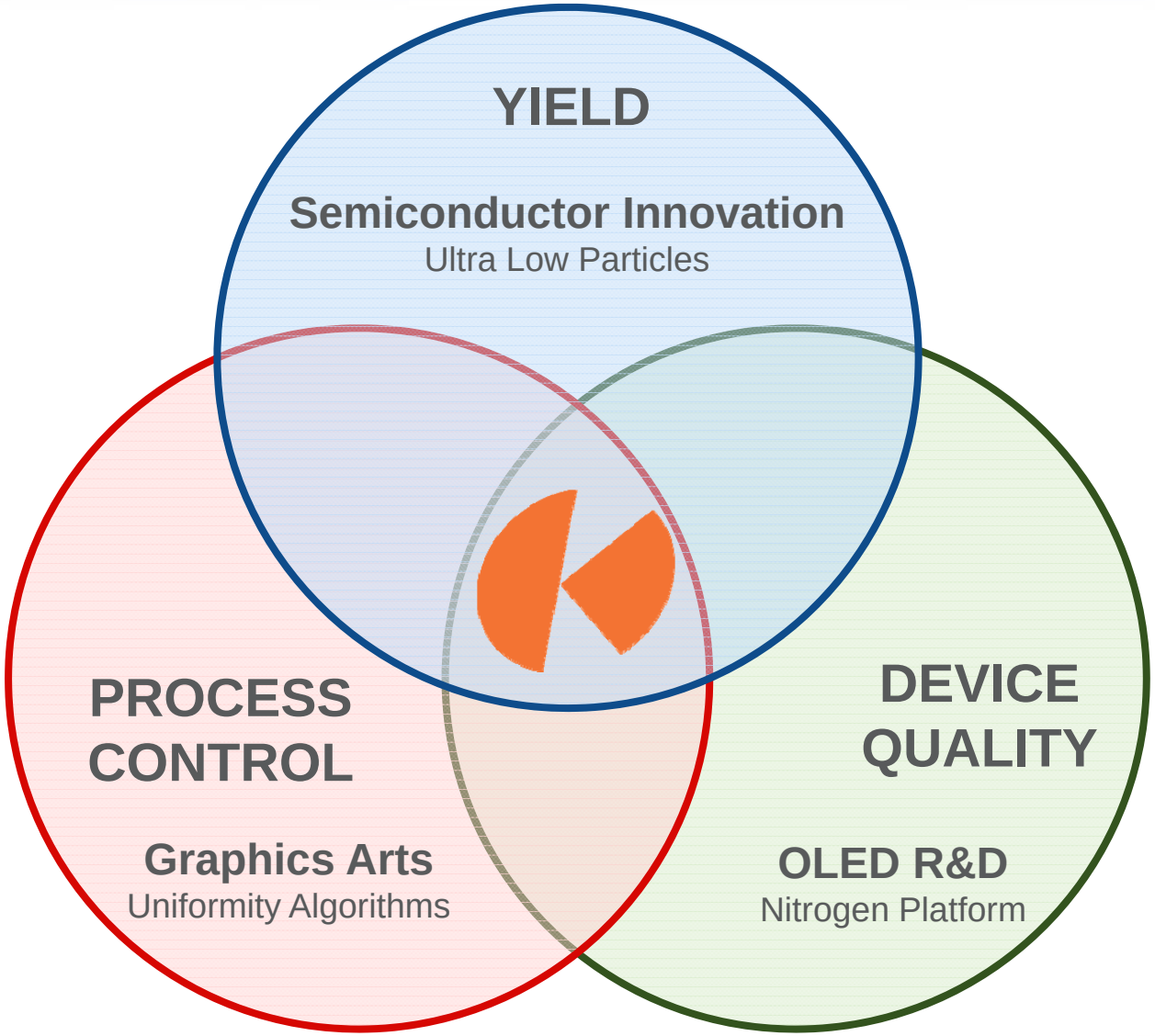
YIELDjet™ Advantage



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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**

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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.

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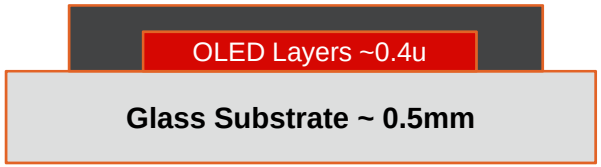
Flexible Challenge: Thin Film Encapsulation (TFE)

Encapsulation addresses OLED sensitivity to O2 and H2O

Standard Rigid

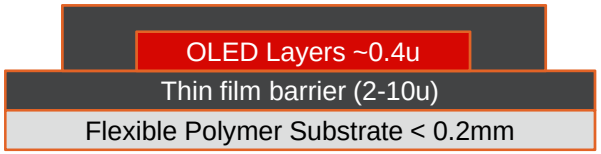
Thin Film Encapsulation needed for thinness and flexibility

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…

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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

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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)

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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)**

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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**

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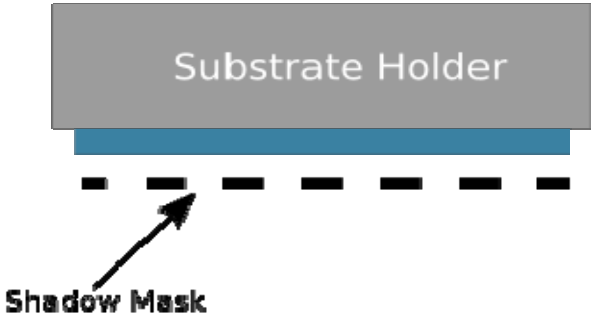
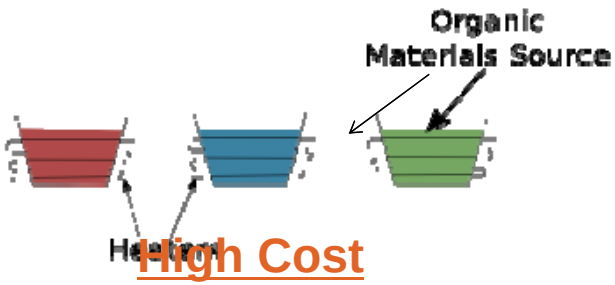
Why Kateeva Inkjet for TFE Organic Layer?

Old Technique: Shadowmask Flash Evaporation

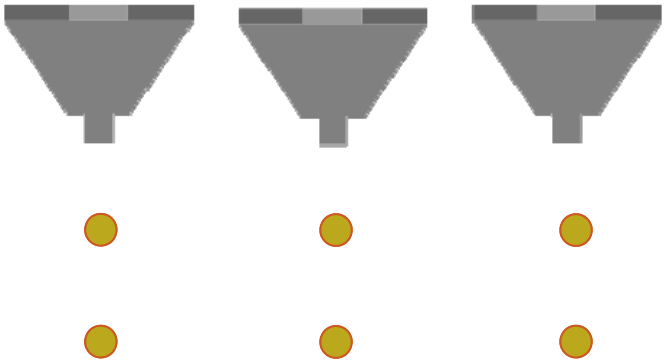


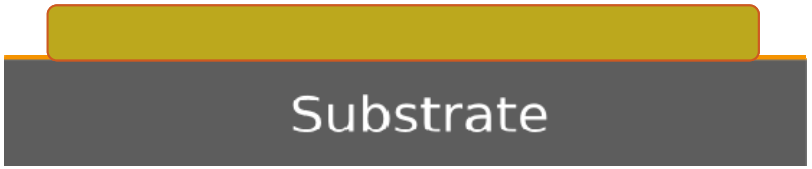


High Cost

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

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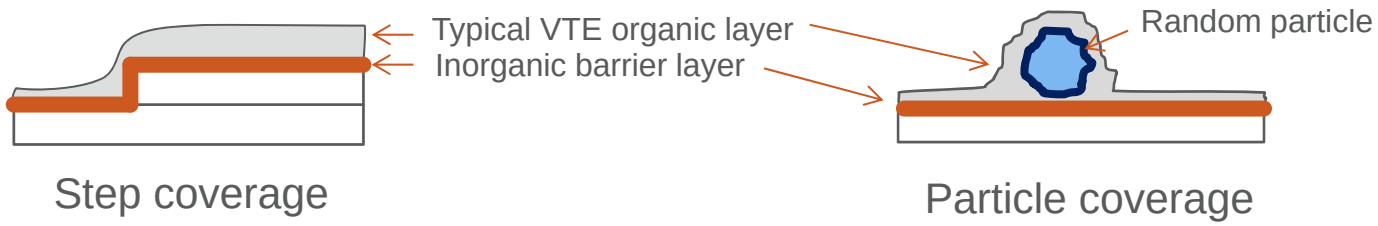
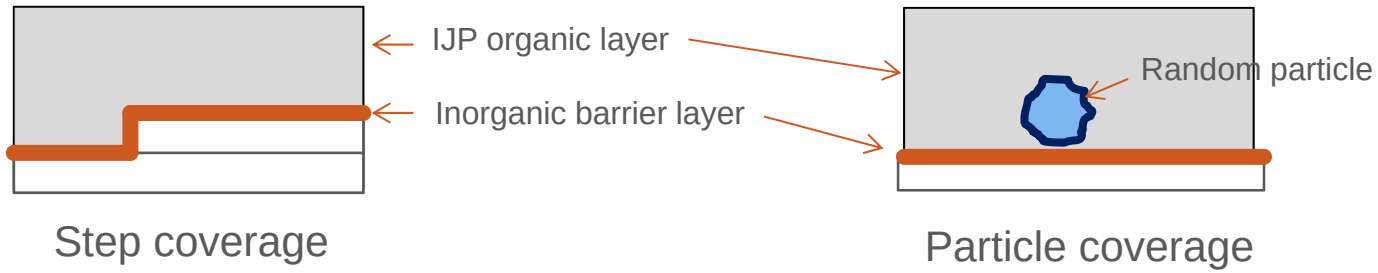
Kateeva Inkjet Planarization Advantage

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



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



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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

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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**

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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

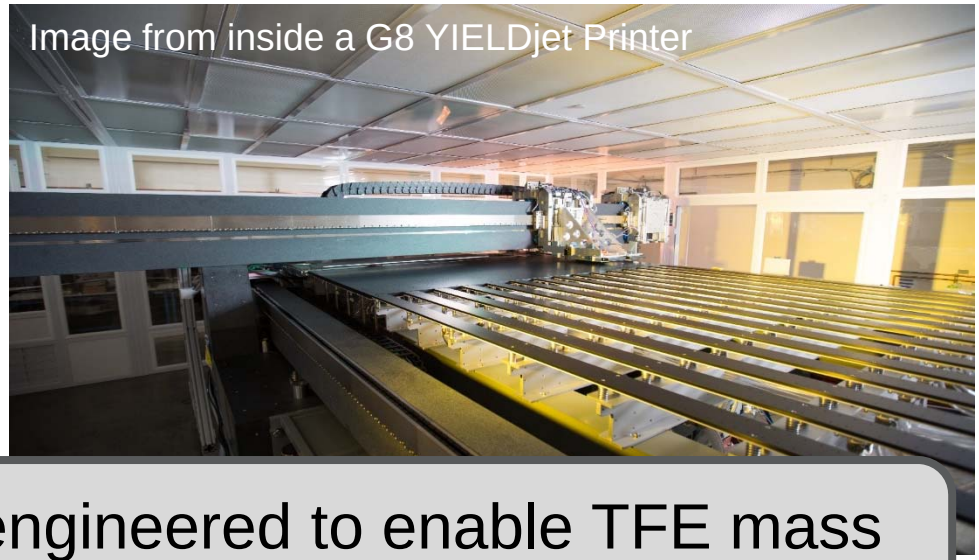
Image from inside a G8 YIELDjet Printer

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.)

YIELDjet is trademarked by Kateeva

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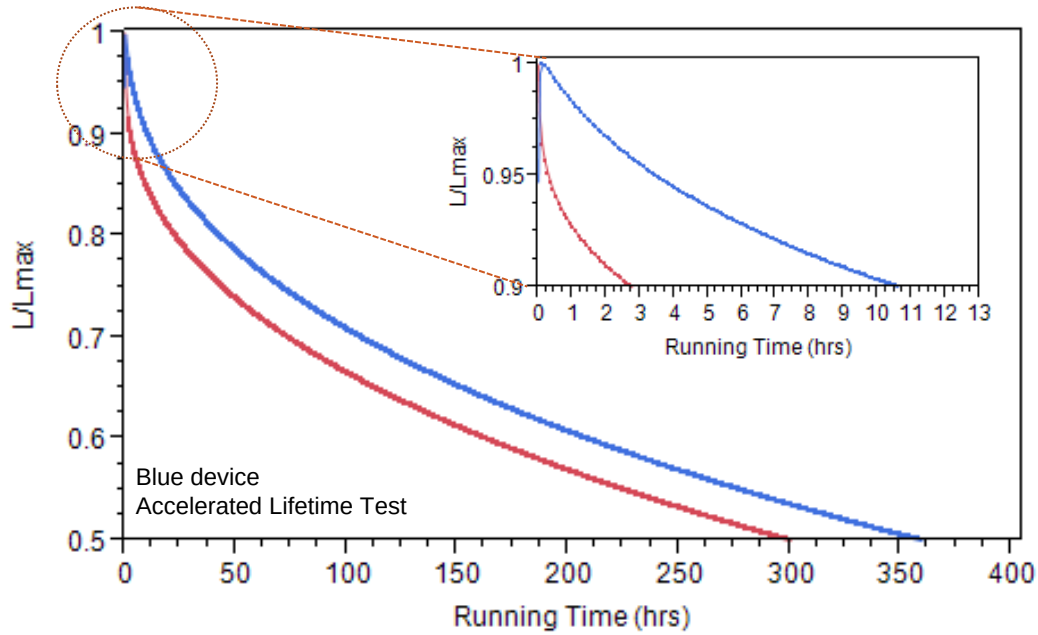
Printing the OLED Active Layers – N2 Essential for Long Lifetime

- **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.

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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.

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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**

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