Market-leading wide color gamut narrow-band phosphors by GE Path to enabling next-generation displays





Rachel Cassidy, Ph.D., M.B.A. (rachel.cassidy1@ge.com) James Murphy, Ph.D. (murphyj@ge.com) GE Licensing uses industry leading, repeatable and scalable plays, proven to unlock value, drive innovation, and accelerate growth by leveraging technology investments and IP assets.

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PFSphosphor Mobil SHC[®]



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GE Potassium Fluorosilicate (PFS/KSF) red phosphor strong market adoption in display



(ge)

9 Companies (and counting) licensing PFS/KSF for display

into display technology

Countries

Major display sectors that have
adopted PFS/KSF
(TV, laptop/monitor, tablet, mobile)

"It's no secret that this high-performing phosphor has been a challenge for QDs to compete with" – Display Daily 2020

"Although there has been lots of talk about QD and OLEDs, there has been a real <u>revolution in phosphors</u>" – Display Daily 2020

"Advances [in] narrow-band red (PFS-KSF) and green phosphors... will accelerate their integration into these next generation display applications." –Display Daily 2021

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"KSF has been <u>incredibly successful</u>over the last few years, based on its substantial cost advantage over QDs and because it can be used 'on-chip' on LEDs." –Display Daily 2021

"KSF phosphor is the <u>unsung hero</u> of WCG + HDR" – Hendy Consulting, 2020

Structures Requiring A Display License to GE PFS/KSF Patents



with LED or miniLED array

Magenta LED Package for Display – PFS/KSF remains in LED package

LCD with Phosphor & LED will maintain the leading position in displays





https://doi.org/10.1002/msid.1117 DSCC, Information Display, 2020

 LCD remains <u>the dominant</u> technology by display area

> "Even with WOLED cost reductions, LCD will remain much lower cost." -DSCC, Display Week 2020



Source: Yole report 2019

• OLED costs remain high compared to LCD, limiting penetration

 2020 Cost to produce 65" LCD:
 \$285

 2020 Cost to produce 65" OLED:
 \$890



Source: Yole report 2020

 Wide Color Gamut continues to gain momentum - reaches 33% of TVs by 2025

"It costs roughly 2-3x more to make a WOLED module than a standard LCD on a full module basis." -Ian Hendy & Paul Gray , Information Display 2020

LED + Narrow Band Phosphors (PFS/KSF) will continue to penetrate further in display industry

PFS/KSF is implemented across all display sectors





HP, Lenovo, Dell, Asus, Apple, Microsoft, Razer, MSI, Samsung, LC MSI, Samsung, LG



2D backlit monitors/laptops
Gaming Laptops: <u>300 Hz refresh rate</u>



Apple, Samsung Lenovo, Huawei Microsoft, Asus







Samsung, LG, Sony, Vizio, TCL, Hisense, Toshiba, Insignia, Sharp





- FALD 4K HDR TVs
- DCI P3 > 96%

Current Lighting Solutions and GE Announce Collaboration Agreement



CLEVELAND, May 10, 2021— Current Lighting Solutions, LLC ("Current") and GE (NYSE:GE) today announced they have signed a collaboration agreement on small-size Potassium Fluorosilicate (PFS/KSF) phosphor for MiniLED and MicroLED applications for improved display technologies.





Innovation, IP, Licensing

Current Lighting Solutions, LLC dba:

Current Chemicals

Manufacturing, Sales







Small size KSF phosphor for next-generation displays

GE Research: Vertical Integration & Collaboration to Create the µLED Value Chain



Cassidy & Murphy, SID Display Week Business Conference, 2022

8

GE Narrow Band Green Powder

GE Narrow Band Green Phosphors

-GE is developing narrow band green phosphors to enable on chip or remote part wider color gamut displays.

- -Enables 100% DCI-P3 and Adobe
- -Absorbance is equivalent or higher than B-Sialon

-Good reliability: 100% HTHH (high temp./humidity) stability

-No loss in efficiency when incorporated into films

-Customer Sampling is underway.

material	QE	Dominant	PL decay (μs)
B-Sialon	100	556	2
QD	<70	540	(ns)
GE Comp 1	95	549	90
GE Comp 2	100	547	85
GE Comp 3	100	531	520





GE's new narrow band greens can hit all requirements for next generation displays

Evolution of KSF phosphor: commercialized in multiple form factors/architectures

Application	High Efficacy Lighting	WCG Display edge lit	WCG Display direct lit	WCG Display micro-LED	
Implementation	On LED (~3 mm)	On LED (~1 mm)	On mini-LED (~100 um) or remote film	On µLED with longer pathlength (inks)	On µLED with shorter pathlength (inks)
Commercial Status	Commercialized 2014	Commercialized 2014 (>50 billion LEDs)	Commercialized 2020	Sampling	In development
Product Example			Bue light illumination		
Avg Particle Size	25-30 um	15-20 um	3-9 um	Sub-micron	Nano-KSF
Challenges	High flux & long product life	Only moderate flux & reliability specs. 😊	Cost (easy flux & reliability)	Absorbance (thicker film architectures)	Reliability & Absorbance
Microscopy	10 um	10 um	10 um	10 um	<u>200</u> nm 0.5 µm

Decreasing particle size to meet display industry needs

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KSF vs. InP QDs for MicroLED

KSF wider color gamut, better reliability & no self-absorption





3 Regions:

- = most thin films (<10 μm). QDs absorb more strongly, so will convert more blue photons to red.
- 2 = moderate thickness (10-20 μm). QD self absorption begins to decrease EQE while KSF can now absorb enough blue to surpass QD %EQE.
- 3 >20 microns. The higher IQE, no self absorption, improved reliability & color quality of KSF makes KSF films superior.



KSF vs. InP QDs for MicroLED

KSF wider color gamut, better reliability & no self-absorption





KSF Phosphor Improvements in 2022:

- 1. Synthesis: smaller size, higher %Mn, minimizing defects to improve IQE & 450nm Absorbance.
- 2. Surface chemistry: reduced agglomeration/better dispersion.
- 3. Ink & film deposition/printing optimization





GE Patented technology enables small size, high absorption KSF



Examples of architectures using combination of down-converters



Properties that can be enhanced by combining down-converters **Color Brightness Efficiency Uniformity Response time Cost Marketability**



Cassidy & Murphy, SID Display Week Business Conference, 2022

Example 6 – Narrow-band phosphors and QDs in harmony



Unique combination of down-converters including: KSF Red, Green Phosphor (on chip) QD red and green (remote part)











GE Alternative Red Phosphor in Development First Public Announcement



- Emission shift towards higher energy vs. KSF is ideal for lighting applications.
- Photoluminescent decay time is about four times faster than KSF for fast response time displays.
- Absorbs more strongly than KSF.
- Blending with KSF for display: Tradeoff of improved response time and less phosphor loading for color gamut.
- Optimization in progress.
- Customer sampling in Q3 2022.



Questions? Collaboration Interest?

- For technical inquiries please contact James Murphy: murphyj@ge.com
- For licensing inquiries contact Rachel Cassidy: rachel.cassidy1@ge.com



Thank you for your attention!

Exemplary Patent Assets involving PFS/KSF phosphor family

US7358542, US7453195, US7497973, US7648649, US7847309, & other issued and pending patents worldwide



- KSF is the leading wide color gamut red emitting phosphor
- GE Licenses KSF phosphor for display applications
- GE Research's focus on innovation includes:
 - 1. Narrow band green phosphor development
 - 2. Small size KSF for films & direct lit/MiniLED market
 - 3. Submicron KSF inks/films & printing for MicroLED market
 - 4. Alternative GE Red Phosphor for fast response time



