NASDAQ
LWLG

LIGHTWAVE LOGIC®

Reliability of Electro-Optic Polymers for High-Speed Silicon Photonics Modulators

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OIP Conference – June 16, 2026

Forward Looking Statements

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The company does not undertake to update any forward-looking statement, whether written or oral, that may be made from time to time by company or on behalf of the company except as may be required by law.

The Challenge of Powering AI: Density, Power, Reliability

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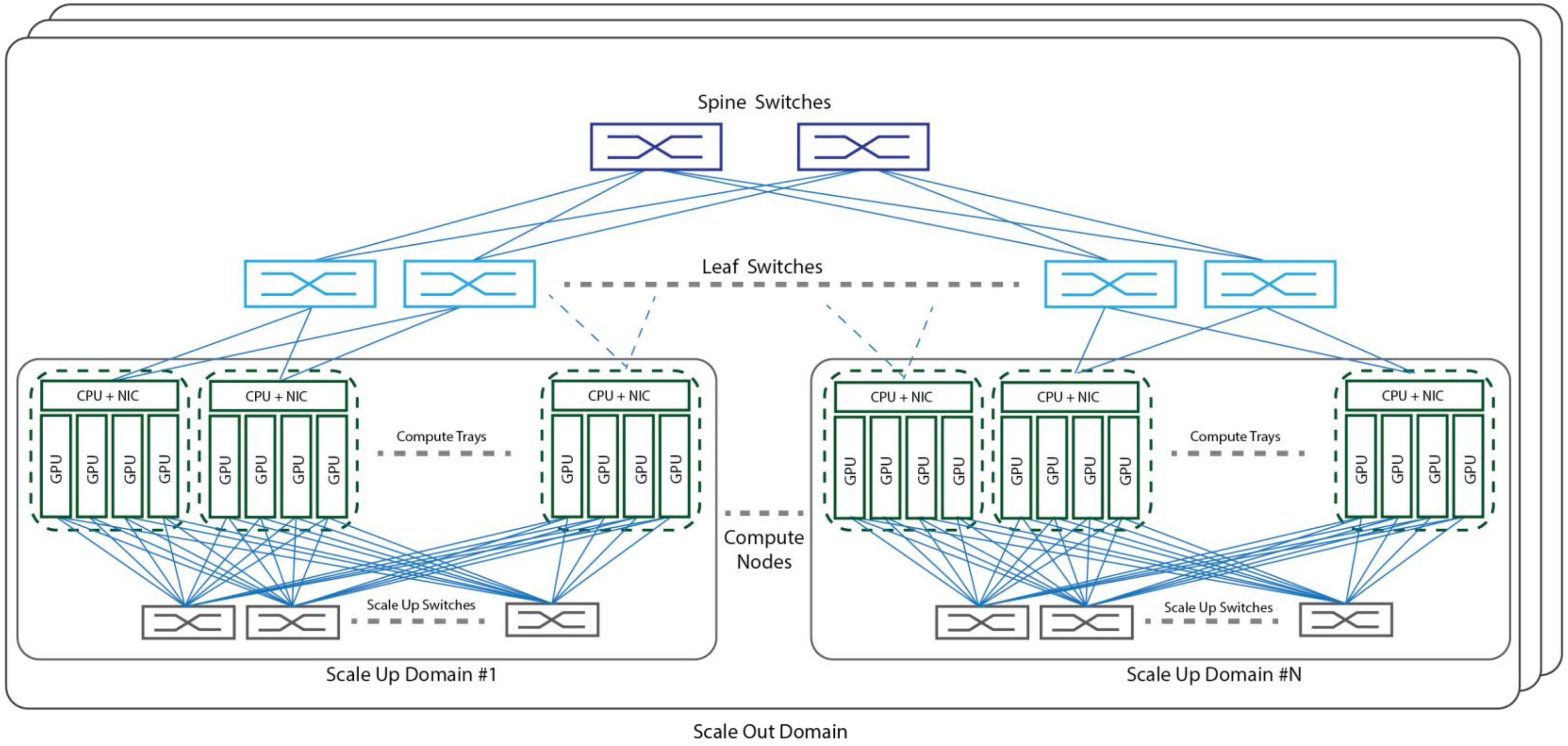
Explosive growth in AI connectivity requires advanced optical modulators:

- Denser Integration
- Higher Bandwidth
- Reduced Driving Voltage
- Reduced Insertion Loss
- High Reliability



Possible solutions include enhanced silicon photonics devices:

1. **Inorganic EO Materials**
   - Thin-Film Lithium Niobate (TFLN), Barium Titanate (BTO), etc.
2. **Organic EO Materials**
   - **EO Polymer SOH Modulators**

Data Center Power Consumption Continues to Grow Exponentially with AI Connectivity Demands

LWLG at a Glance

Leveraging proprietary electro-optic polymers to enable high-speed optical modulators for AI scaling and data communications

Englewood, CO
Global HQ

LWLG
NASDAQ Listed

1997
Founded

~40
Employees[1]

67
Granted Patents[1]

>$100M
R&D Investment

$75M
Cash Balance[2]

Proven Technology

- >$100M cumulative investment in technology platform since inception
- 2,000+ hours of damp heat stress testing in AI data center heat/humidity conditions show thermal stability, high performance and exceed industry standards
- Polymer, processes and designs are ready for 400Gb/s device developments

Fully Domestic Supply-Chain

- Specialty chemical precursor suppliers are all U.S.-based
- Proprietary EOP materials are synthesized and processed in Colorado
- 100% U.S.-based operations and labor
- Supply-chain is 100% free of rare Earth elements

Robust Patent Portfolio

- 80+ U.S. and international patents that are issued or pending[1]
- Issued patents cover all stages of operations from molecular structure of polymers to device designs, fabrication, and packaging (encapsulation)
- Essential IP protection to scale licensing revenue model

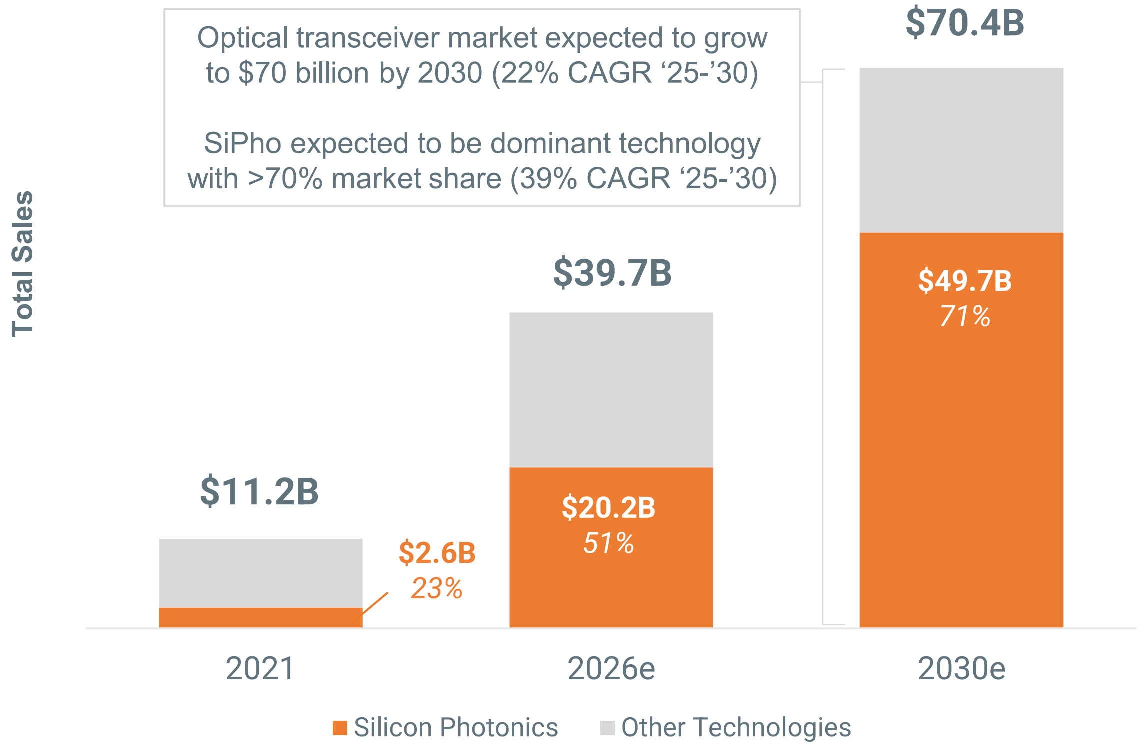
(1) As of Dec 31, 2025
(2) As of March 31, 2026

Silicon Photonics is Winning

LIGHTWAVELOGIC®

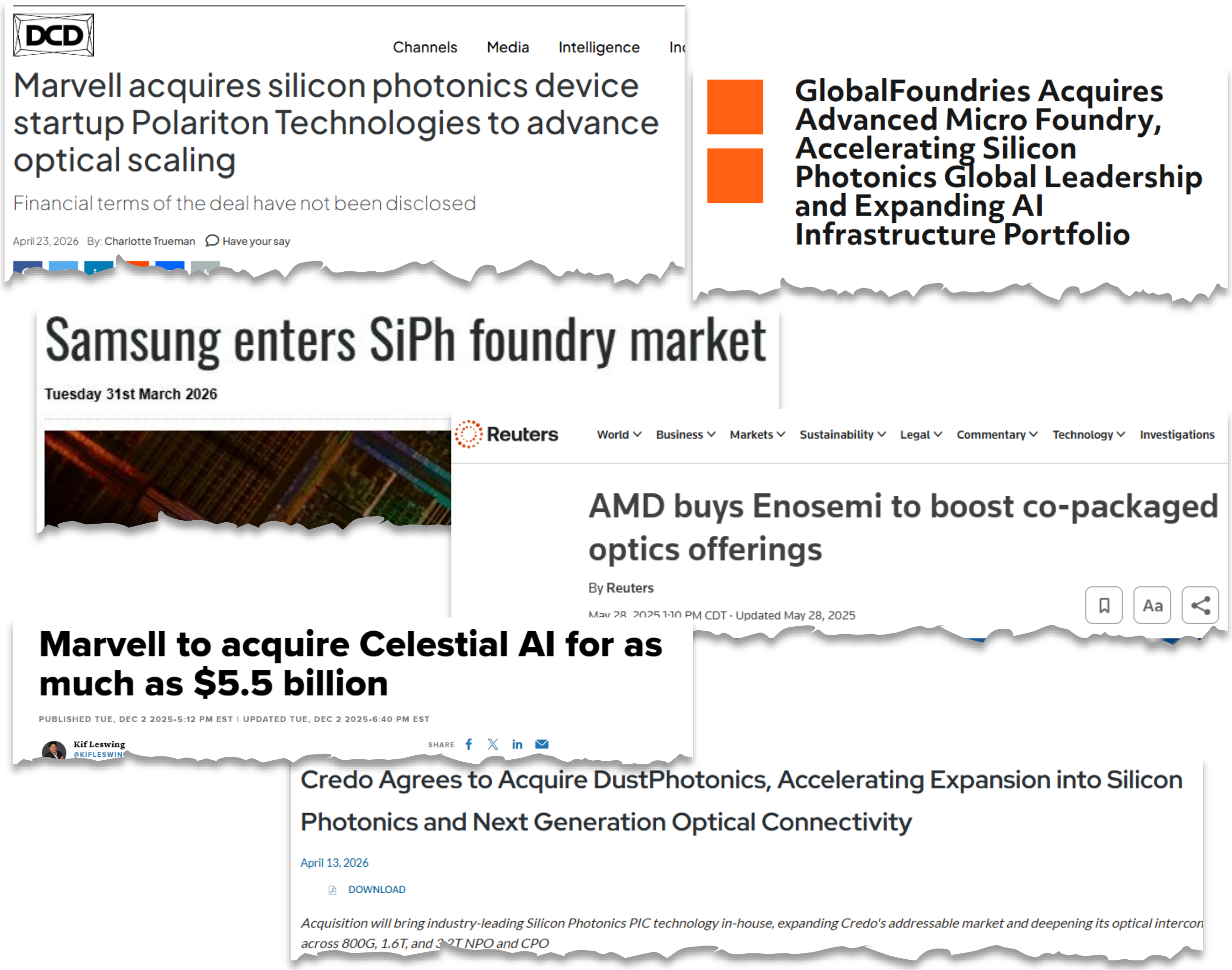
Total Optical Transceiver Market[1]

(by technology)



Optical transceiver market expected to grow to $70 billion by 2030 (22% CAGR '25-'30)

SiPho expected to be dominant technology with >70% market share (39% CAGR '25-'30)



Marvell acquires silicon photonics device startup Polariton Technologies to advance optical scaling

Financial terms of the deal have not been disclosed

April 23, 2026 By: Charlotte Trueman Have your say

GlobalFoundries Acquires Advanced Micro Foundry, Accelerating Silicon Photonics Global Leadership and Expanding AI Infrastructure Portfolio

Samsung enters SiPh foundry market

Tuesday 31st March 2026

AMD buys Enosemi to boost co-packaged optics offerings

By Reuters

May 28, 2025 1:10 PM CDT · Updated May 28, 2025

Marvell to acquire Celestial AI for as much as $5.5 billion

PUBLISHED TUE, DEC 2 2025•5:12 PM EST | UPDATED TUE, DEC 2 2025•6:40 PM EST

Kif Leswing

Credo Agrees to Acquire DustPhotonics, Accelerating Expansion into Silicon Photonics and Next Generation Optical Connectivity

April 13, 2026

DOWNLOAD

Acquisition will bring industry-leading Silicon Photonics PIC technology in-house, expanding Credo's addressable market and deepening its optical intercon across 800G, 1.6T, and 3.2T NPO and CPO

Silicon photonics is winning the integration platform battle for hyperscale and AI networking

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[1] Lightcounting: Total Optical Transceiver Market by Technology; April 2026
News sources: Data Center Dynamics, Credo, GlobalFoundries, PIC Magazine, Reuters

Unlocking the Power of Silicon Photonics with EO Polymers

Perkinamine®

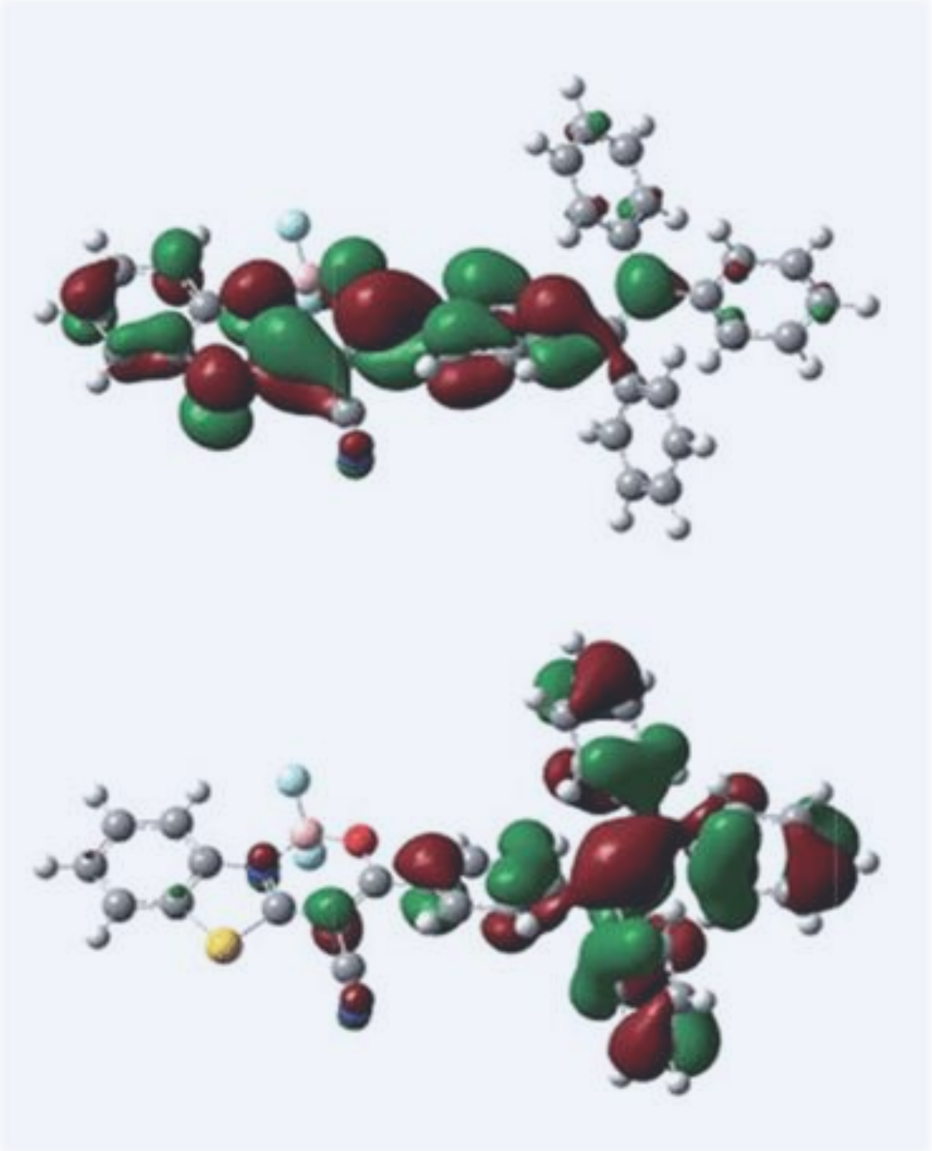
The Fastest Way to Convert Electrical Signals to Optical Signals

AI infrastructure **depends on high-bandwidth optical connectivity**

Silicon photonics enables optical connections at CMOS scale, **but performance is limited**

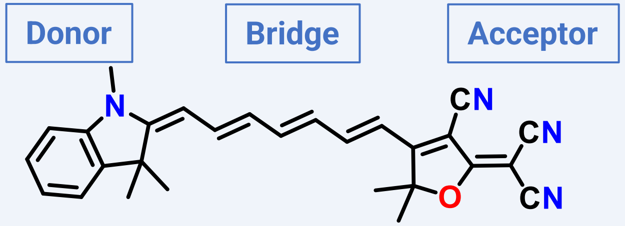
Lightwave Logic's **Perkinamine electro-optic polymers unlock the bandwidth, size, and power efficiency limitations** of silicon photonics

Perkinamine enables the **highest performing photonic integrated circuits for AI**

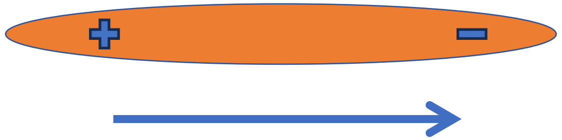


EO Polymer: Mechanism of Operation

General chromophore structure



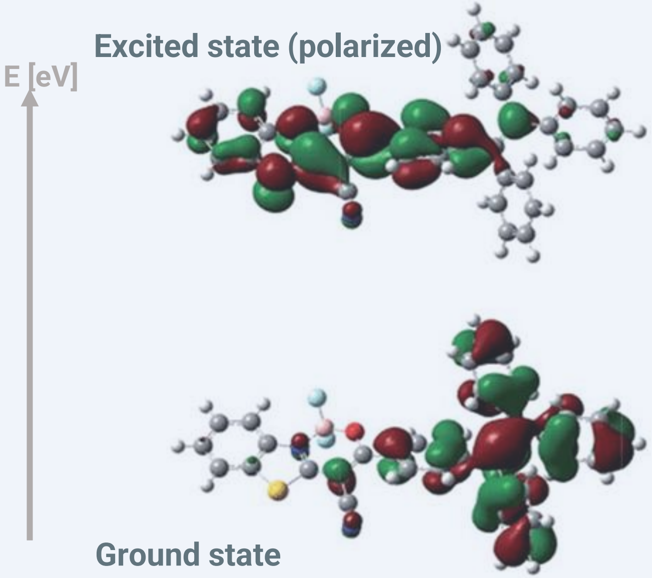
Chromophores are dipolar molecules



Chromophores are aligned in the host polymer through a poling step

Pockels Effect:

- Linear electro-optic effect with THz response frequency
- Refractive index change directly proportional to applied electric field
- Occurs in non-centrosymmetric materials

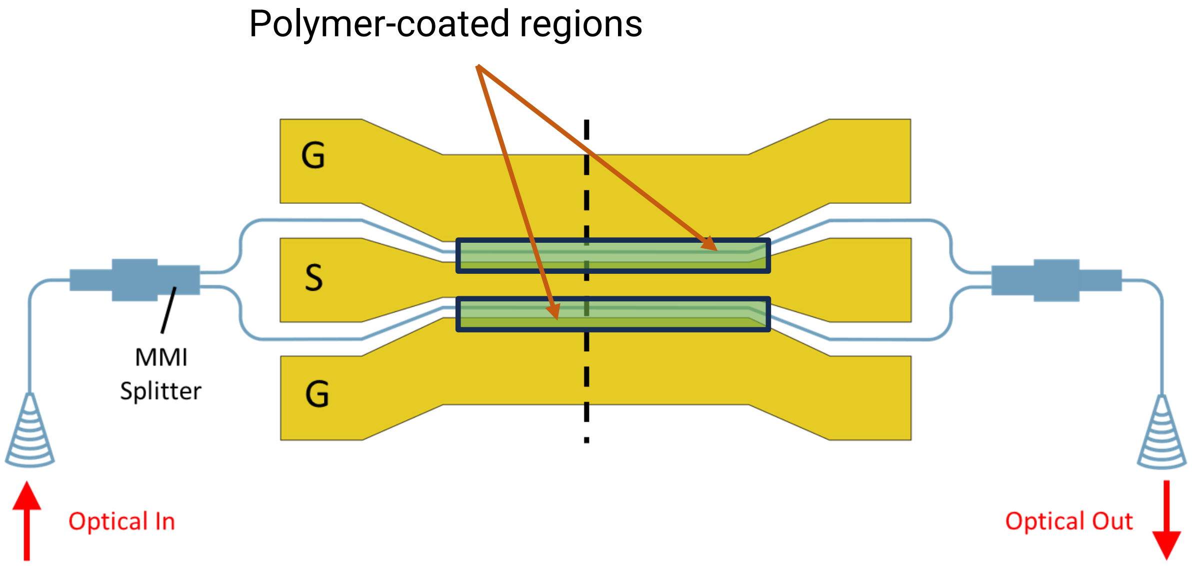


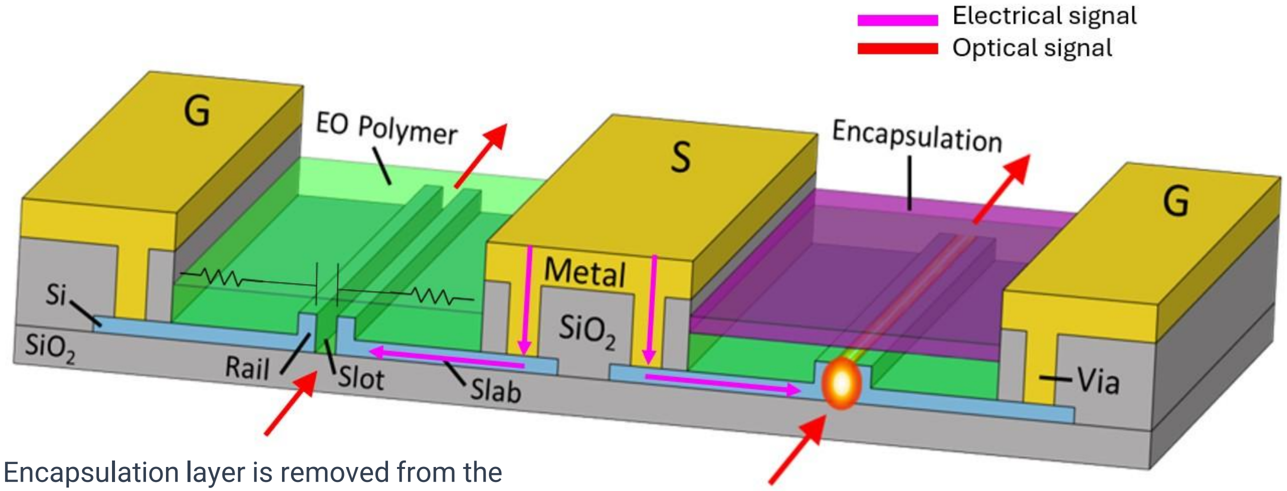
The electric field shifts the electron cloud to the excited-state molecular orbitals. This alters the refractive index of the electro-optic material, which in turn causes a phase change to any transiting optical signal.

RSC Adv.. 7. 1348-1356. 10.1039/C6RA25871A.

EO Polymer’s Refractive Index Changes Proportional to Applied Field (Pockels Effect)

EO Polymer SOH MZI Slot Modulator: Structure





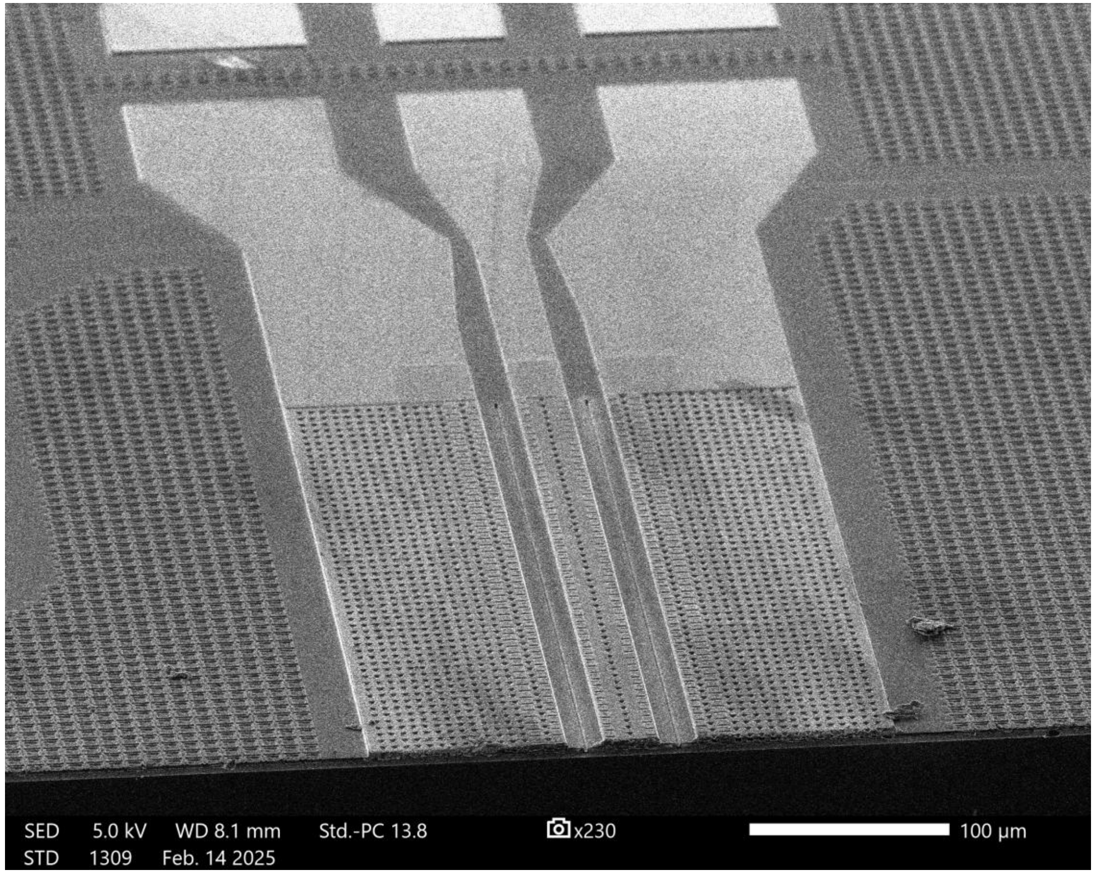
Encapsulation layer is removed from the left slide here for better slot WG visibility

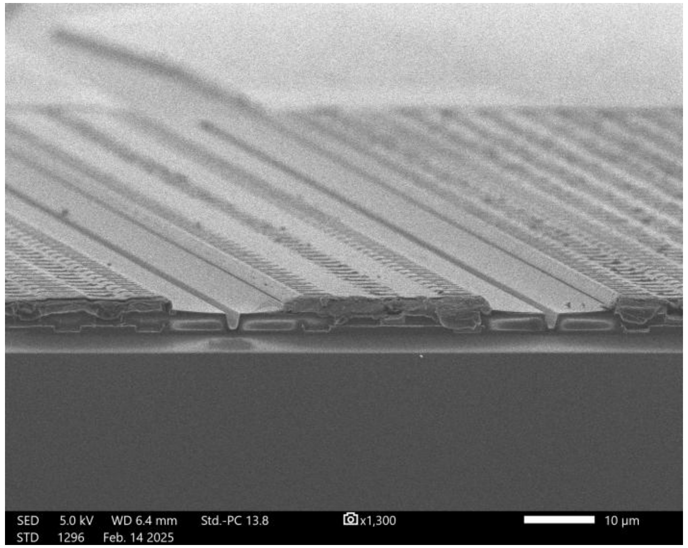
The SOH Advantage:

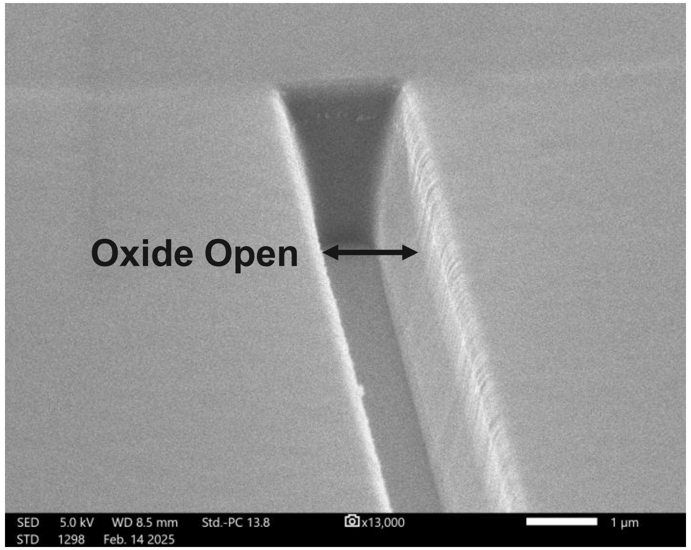
- Combines the **maturity** of Silicon Photonics with the **strong EO response** of polymers
- Offers significant promise for scalable deployment in the **datacom and telecom spectrum** (O- and C-bands)
- Core technology is **CMOS compatible** and **mass-scalable**

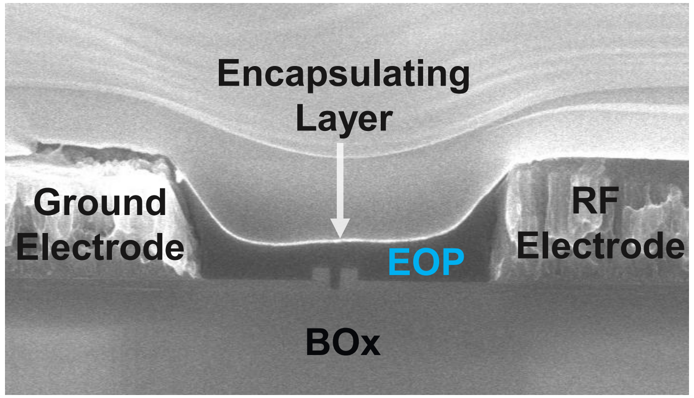
J.A. Drisko et.al. Frontiers in Optics, pp. FM1C-1.Optica Publishing Group (2024)

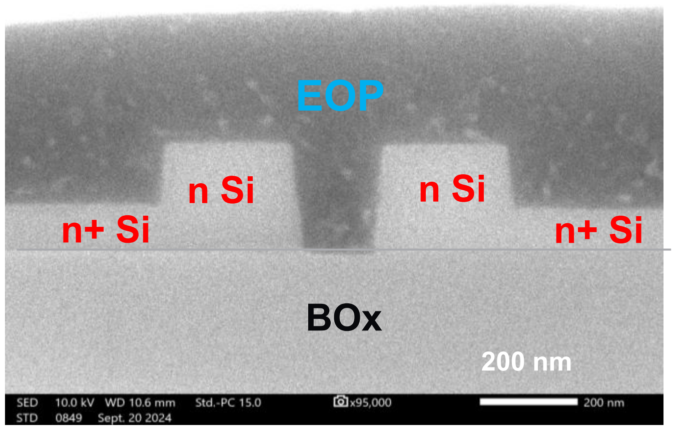
Demonstration in Mass-Producible Foundry Node











EOP: Electro-Optic Polymer
BOx: Buried Oxide

Reliability Story of OLEDs

OLED in the Early 2000s: The Crisis of Confidence

A Revolutionary Material Met with Deep Skepticism

In the early 2000s, Organic Light-Emitting Diodes (OLEDs) promised perfect contrast and paper-thin form factors. However, early commercialization attempts faced massive reliability barriers.

- **Extremely Short Lifetimes**: Early blue emitters degraded in less than 1,000 hours, shifting display color balance rapidly.
- **Catastrophic Burn-In**: Static images left permanent ghost patterns on screens, leading to swift consumer returns.
- **Extreme Moisture Sensitivity**: Standard air exposure destroyed unprotected cathodes, causing expanding black spots.

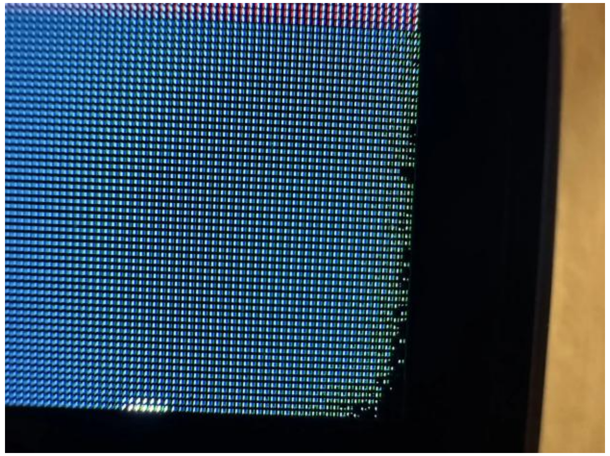


Image credit: s.co.tt, avsforum.com

Degradation Kinetics & Early Blue OLED Failure

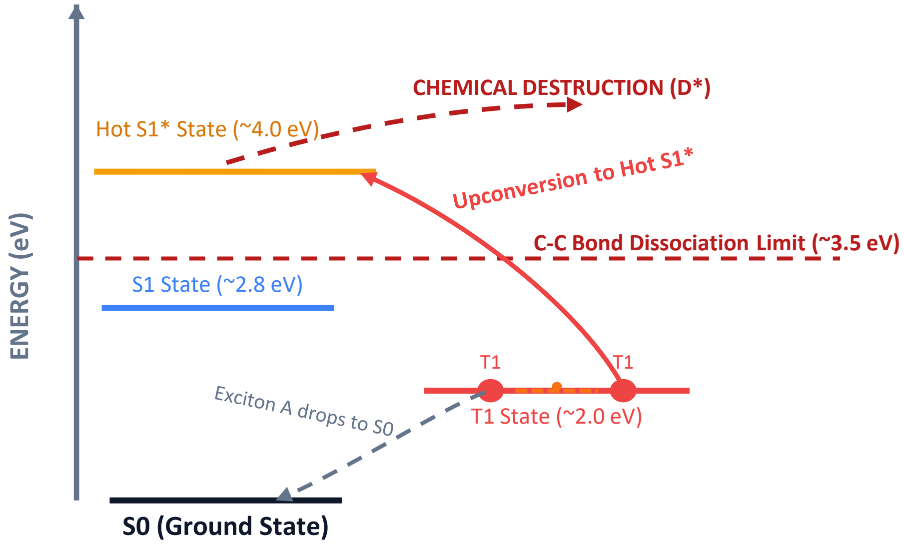
The Chemistry of Triplet-Triplet Annihilation (TTA)

- **Energy Pooling Dynamics:** Under high drive currents, long-lived triplet excitons ($T_1 \approx 2.0$ eV) interact. One exciton returns non-radiatively to the ground state (S_0), transferring its complete energy payload to the second.
- **Hot State Generation:** The receiving exciton is upconverted into an extremely volatile, highly excited "hot" singlet state ($S_1^* \approx 4.0$ eV).
- **Homolytic Cleavage (Chemical Destruction) :** Because this localized energy accumulation (4.0 eV) directly breaches the host matrix's covalent bond dissociation energy limit (≈ 3.5 eV), it triggers spontaneous molecular bond breaking, forming permanent non-radiative traps (D*).

TRIPLET-TRIPLET ANNIHILATION (TTA)

$$T_1 + T_1 \rightarrow S_1^* + S_0 \rightarrow D^*$$

Generates defect states (D^*) acting as non-radiative quenchers (Energy >3.5eV).

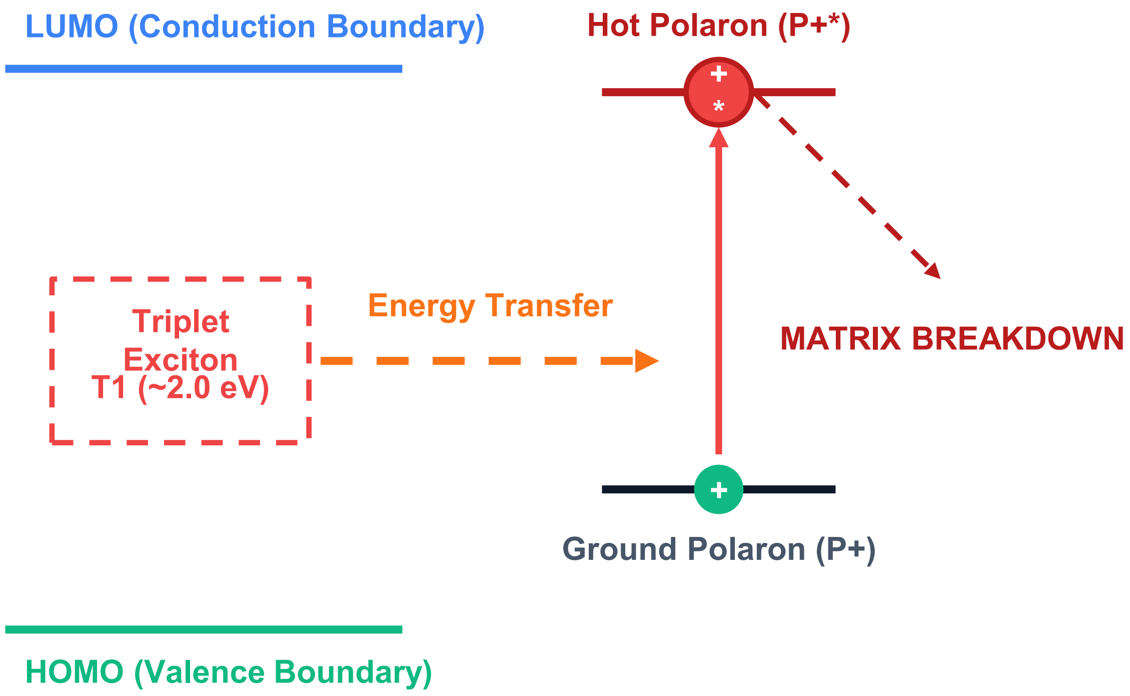


Solution: Exciton Scavengers & Tandem Stacks

Degradation Kinetics & Early Blue OLED Failure

The Chemistry of Polaron-Exciton Quenching (PEQ)

- **Non-Radiative Charge Couplings**: Mobile charge carriers (polarons, P+*) collide with neutral triplet populations instead of driving balanced radiative recombination events.
- **Hot Radical Energy Harvesting**: The triplet exciton undergoes an uncompensated collapse, transferring its full excitation potential directly to accelerate the charge carrier
- **Host Matrix Dissociation (Chemical Destruction)**: The newly spawned "hot polaron" (P+*) enters an aggressively unstable electronic energy level. This excessive electronic and thermal state quickly attacks and fractures the adjacent conjugated host polymer network.



POLARON-EXCITON QUENCHING (PEQ)

$$T_1 + P^{\pm} \rightarrow S_0 + P^{\pm *} \rightarrow \text{Defect}$$

Creates hot radical ions initiating polymer chain degradation.

Solution: Wide-Bandgap Hosts

Moisture Damage to OLEDs

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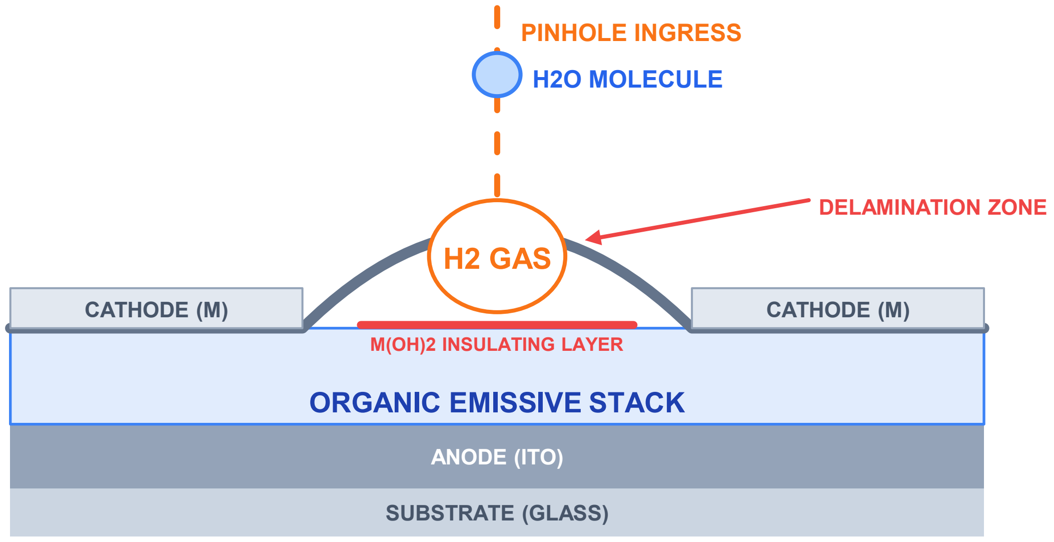
Cathode Oxidation & Delamination

Moisture ingress through encapsulation pinholes initiates a catastrophic failure chain at the reactive metal interface.

- **Hydroxide Formation:** Metal cathode (M) reacts with water to form non-conductive oxides/hydroxides.
- **Hydrogen Evolution:** Reaction byproduct (H2 gas) accumulates at the organic interface.
- **Delamination**: Gas pressure causes delamination (peeling), cutting off electrical injection.



CORROSION REACTION MECHANISM:

$$M + 2H_2O \rightarrow M(OH)_2 + H_2 \uparrow$$

where M: Mg/Ag/Ca/Ba

Solution: ALD Encapsulation

Moisture Damage Mitigation

Thin-Film Encapsulation (TFE) & ALD

OLED active layers demand an “impossibly” strict Water Vapor Transmission Rate (WVTR): $WVTR \leq 10^{-6} \mathrm{g/m^2/day}$

- The solution was a dyadic multi-layer approach using Atomic Layer Deposition (ALD) alternating dense inorganic oxides (diffusion barriers) and organic polymer buffers (stress relief and pinhole decoupling).

Encapsulation

Improved blue emitter lifetime

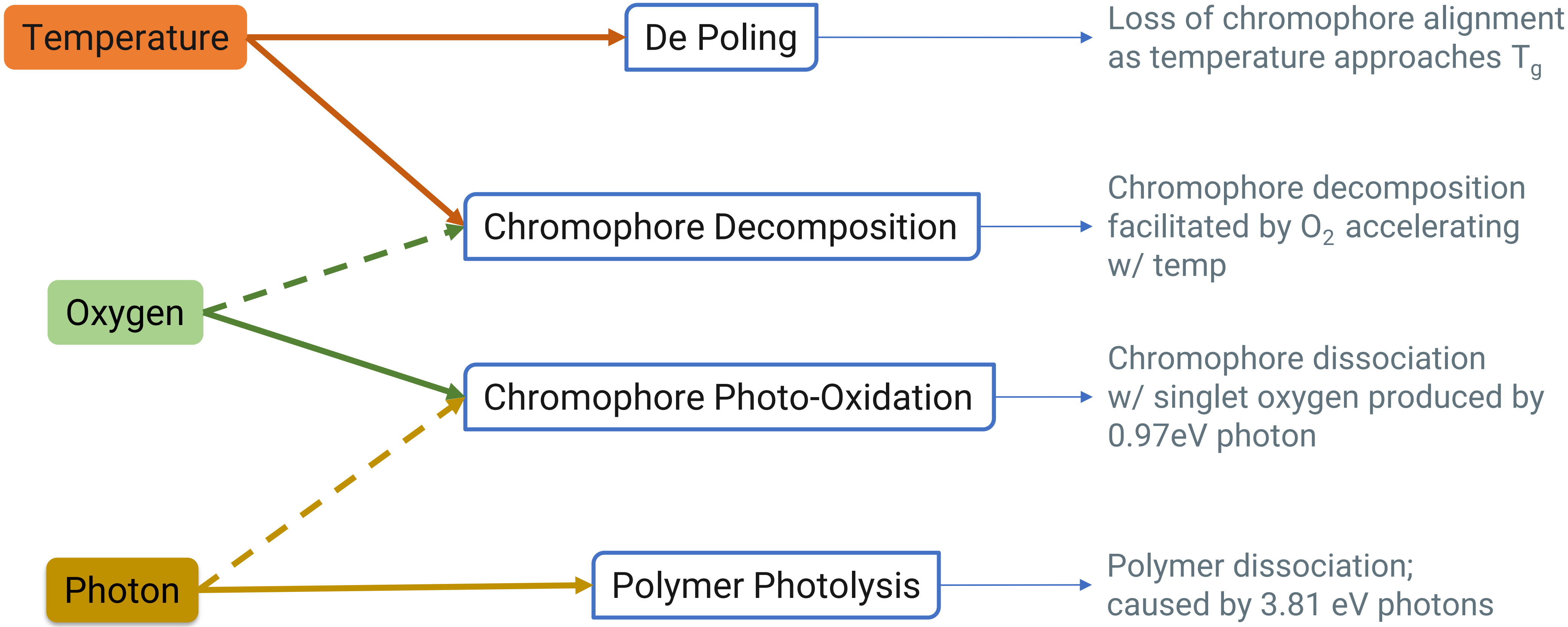
Layer optimization (industry adoption)

Lifetime > 100,000hrs

Most Advanced Displays in the world

Image credit: Apple.com

Understanding Reliability Challenges for EOPs



Temperature

Oxygen

Photon

De Poling

Loss of chromophore alignment as temperature approaches T_g

Chromophore Decomposition

Chromophore decomposition facilitated by O_2 accelerating w/ temp

Chromophore Photo-Oxidation

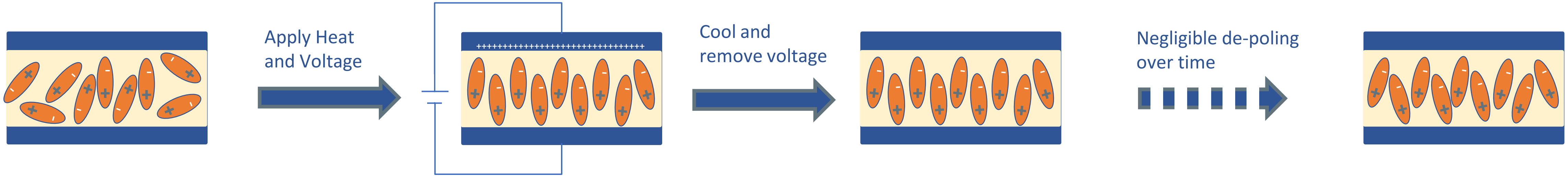
Chromophore dissociation w/ singlet oxygen produced by 0.97eV photon

Polymer Photolysis

Polymer dissociation; caused by 3.81 eV photons

Temperature and Oxygen are the Primary Stressors in Application

Poling of EO Polymers



The electro-optic coefficient r_{33} of an unpoled material is zero since all chromophores are randomly oriented

Material is heated to T_g (glass transition temperature) and an electric field is applied to align the chromophores

Polymer is quickly cooled to freeze alignment

Chromophores may re-orient over time if heated to temperatures close to T_g

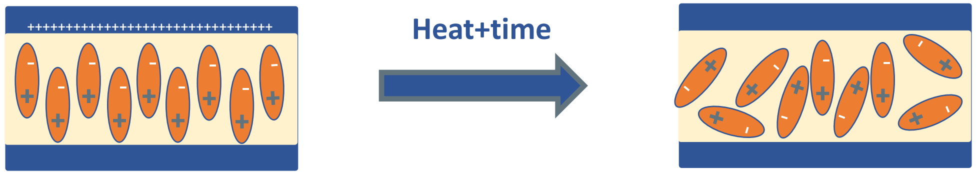
Key Requirements for EO Polymers:

- Negligible de-poling at 85°C continuous operation (stable r_{33})
- High photo-stability

Poled LWLG EO polymers have r_{33} values above 150pm/V at poling fields of 100 V/um

Mechanism of De-Poling

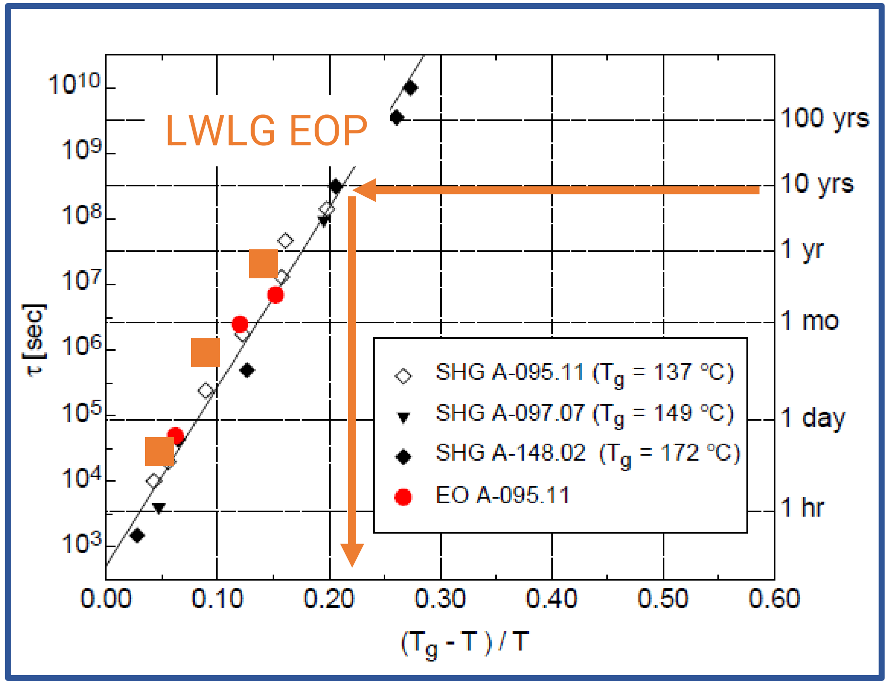
As the polymer temperature approaches T_g, the chromophore alignment gets lost (de-poling)



A high T_g (close to 100°C above operating temperature) is essential for long EO Polymer lifetimes

$$Depoling\ speed = \frac{1}{\tau_g} * e^{-\frac{E_{aAG} * (1-\frac{T}{T_g})}{k*T}}$$

(Adam-Gibbs equation on viscosity of frozen liquid)



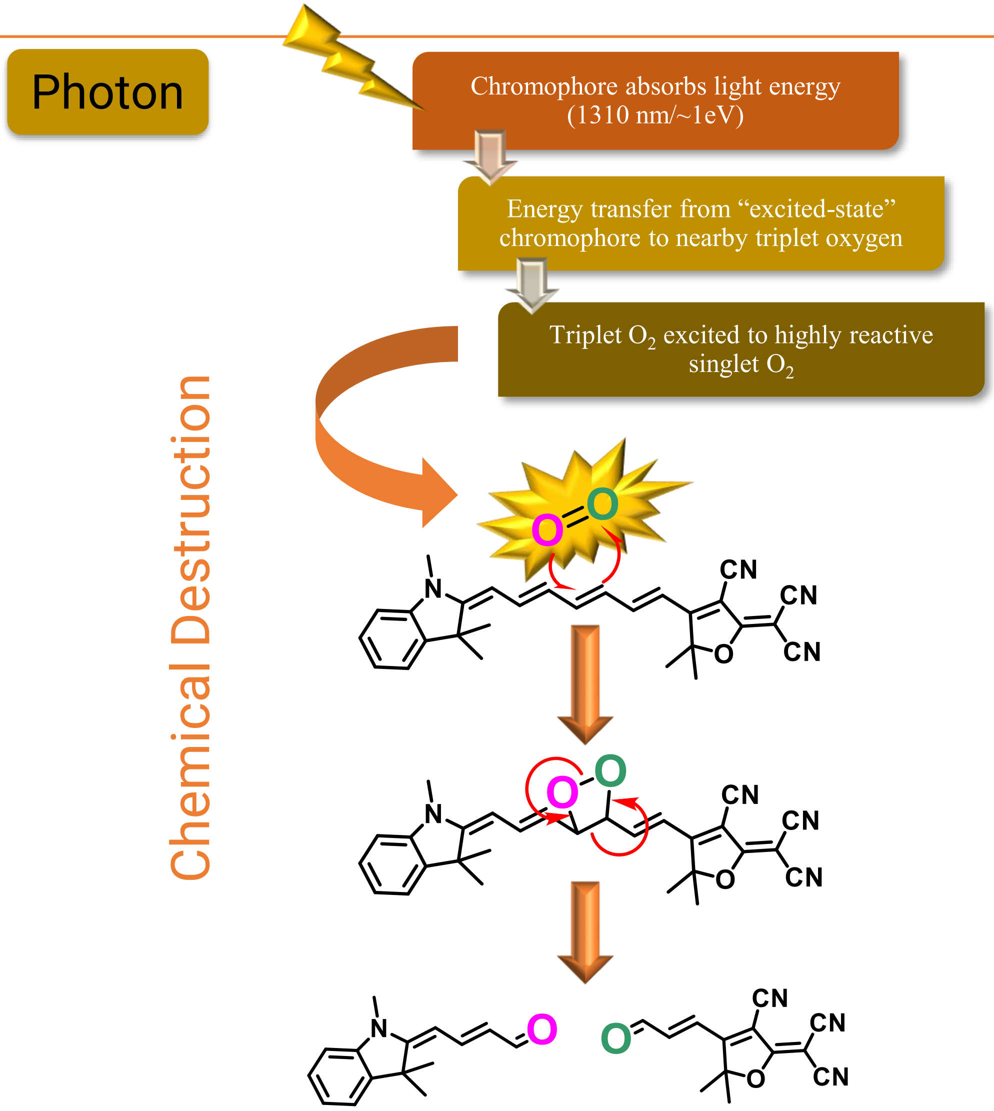
Based on theory, T_g of >164°C is required *
for 10+ years lifetime at 85°C operation

* $\frac{164 - 85}{273+85} = \sim 0.22$

LWLG EOP follow or exceed reported AG-Arrhenius slope

Martin Bösch, Diss. ETH No. 14192, Electro-Optic Polymers: Photochemical Stability and In-Line Modulator

Basics of Photostability



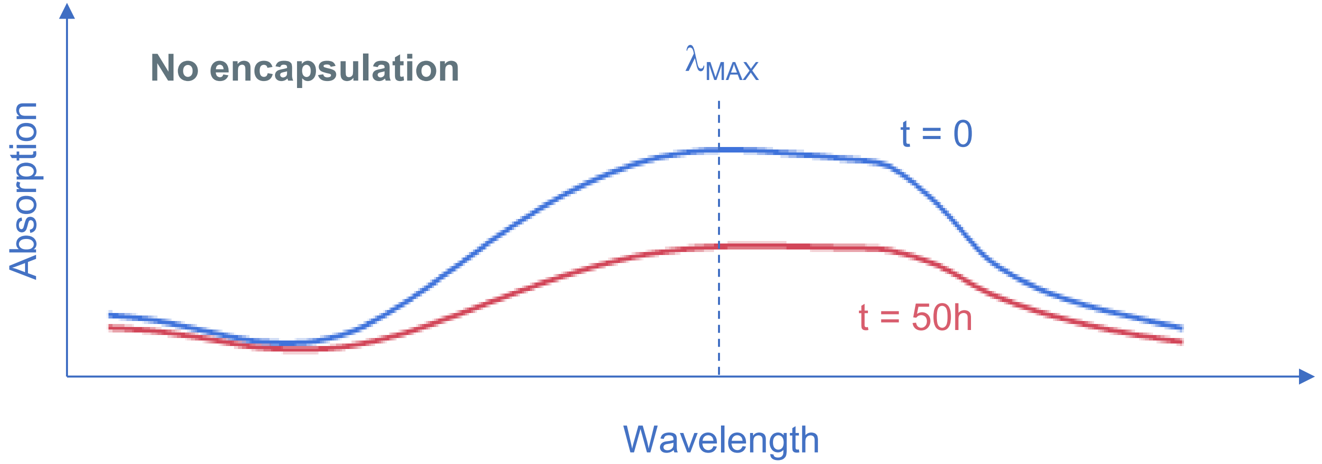
Photon

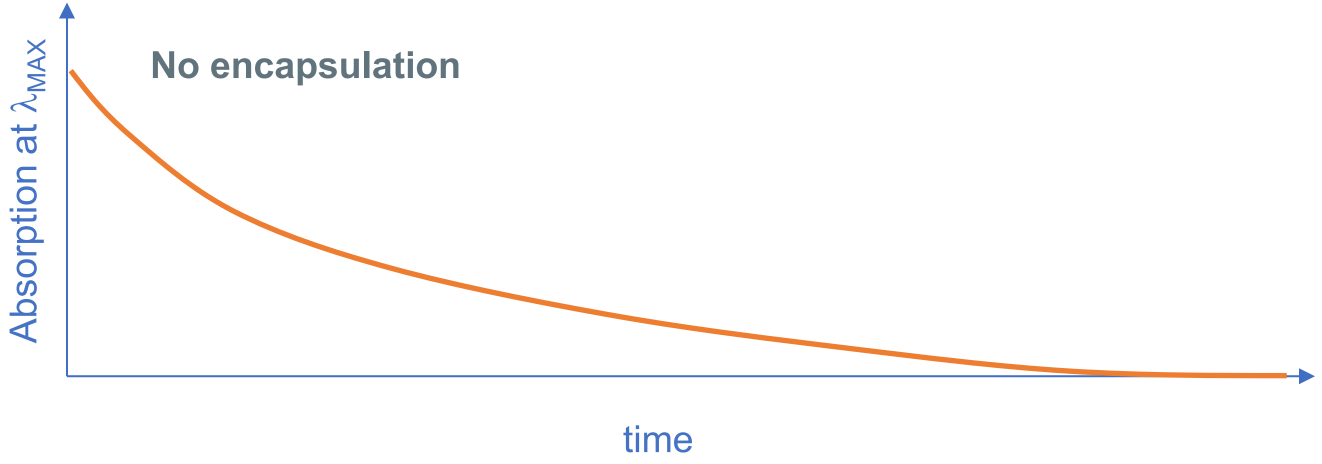
Chromophore absorbs light energy (1310 nm/~1eV)

Energy transfer from “excited-state” chromophore to nearby triplet oxygen

Triplet O_2 excited to highly reactive singlet O_2

Chemical Destruction

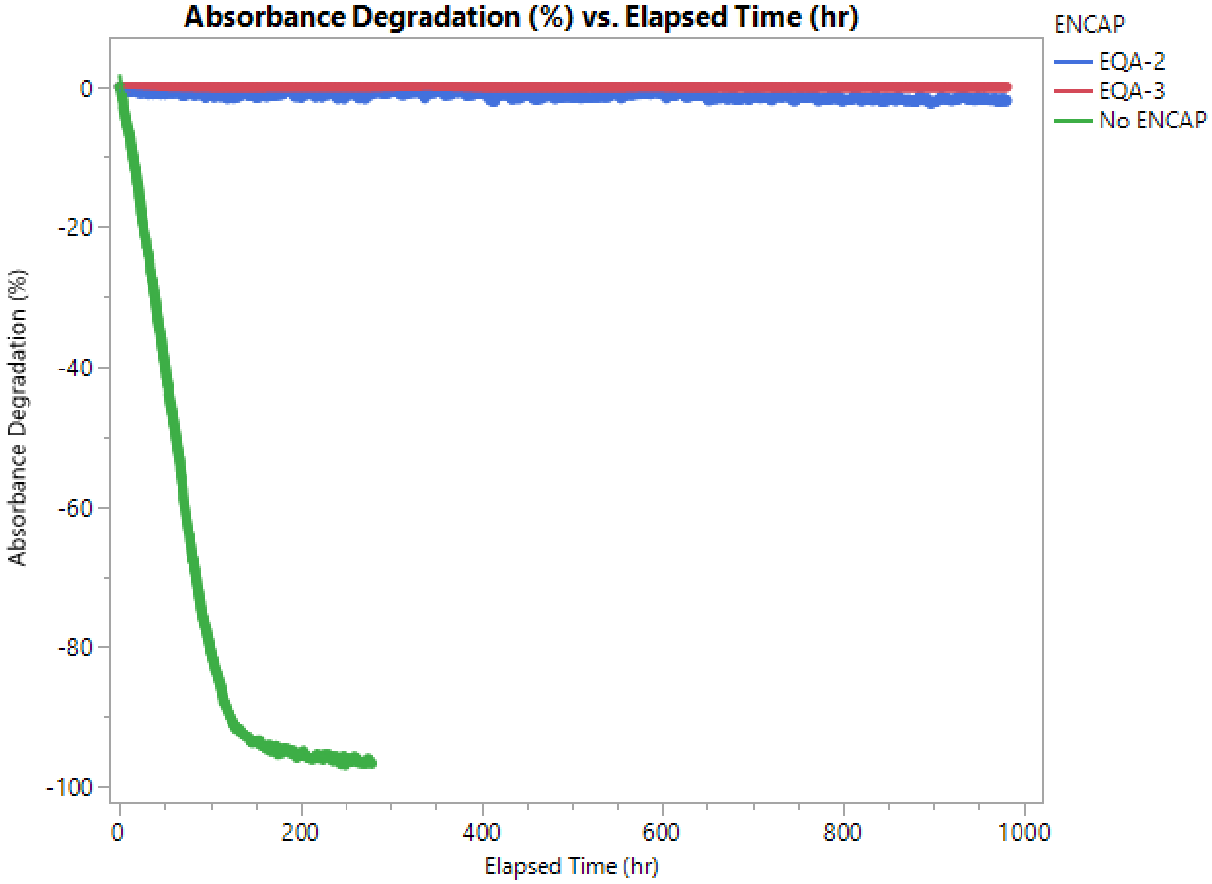




Organic chromophores will degrade in the presence of oxygen without appropriate encapsulation

Broadband Photostability in Thin Film

Photon

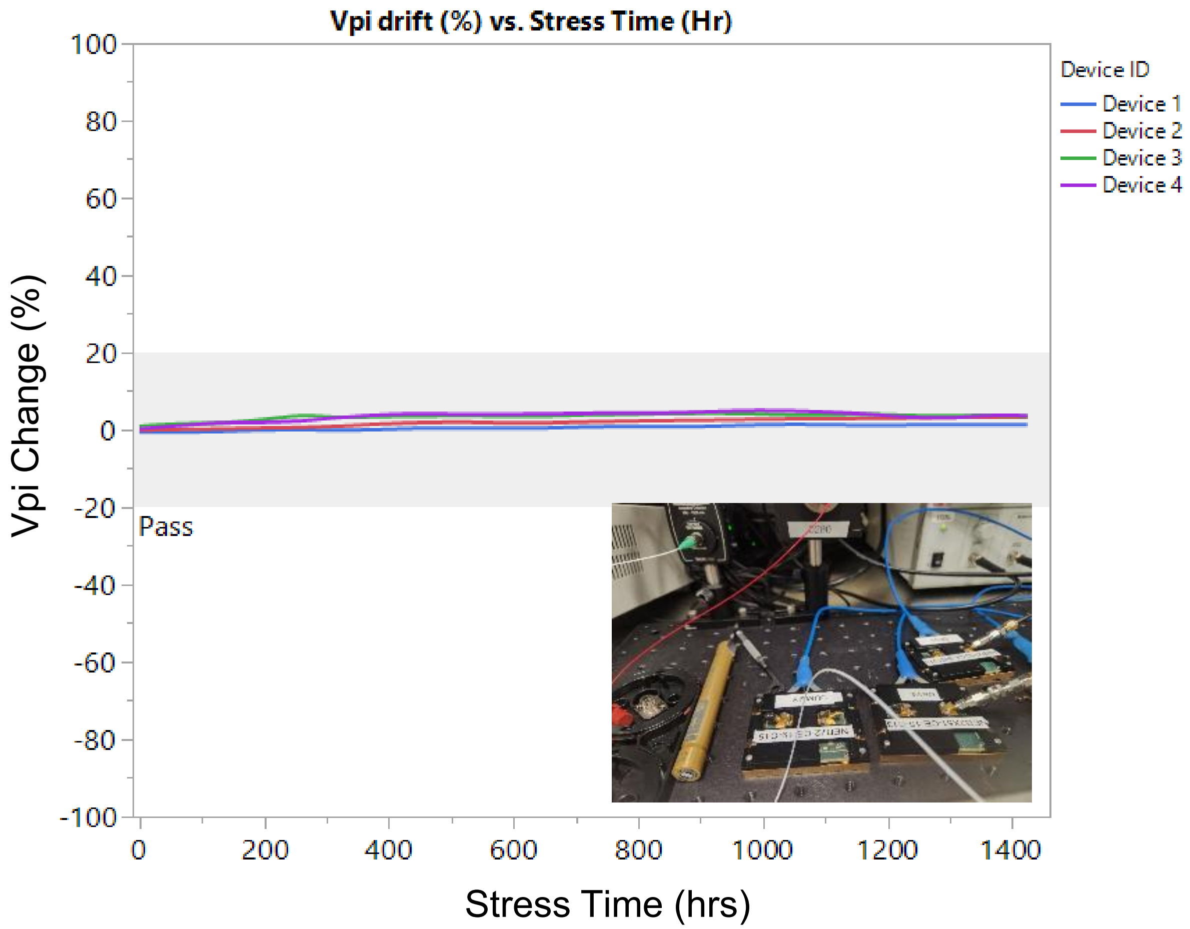


- 1,000 hrs at RT air environment with constant broadband light exposure
- Absorbance at λ_{MAX} is tracked
- After 1,000 hrs, EQA-2 ENCAP shows less than 2% chomophore degradation
- EQA-3 ENCAP shows zero chomophore degradation

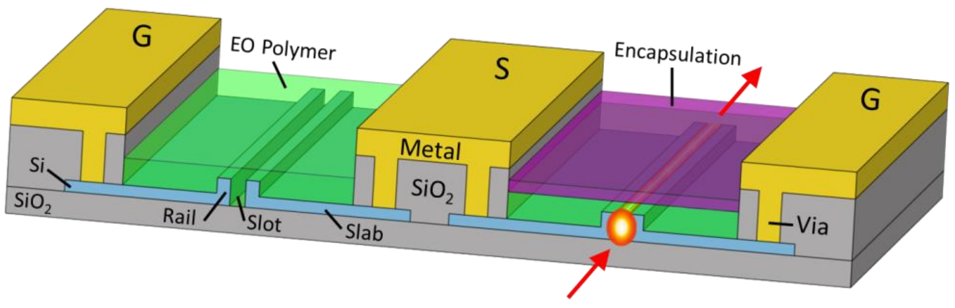
Stress Condition: Thin film, high power broadband light source, RT, ambient

Photostability of SOH Devices in N2: Change in V_π

Optical Power = 20 dBm, 1550nm



- High optical input power stress test (20dBm)
- V_π is stable over 1,400 hrs
- The average shift over ~1,400 hrs is 2%



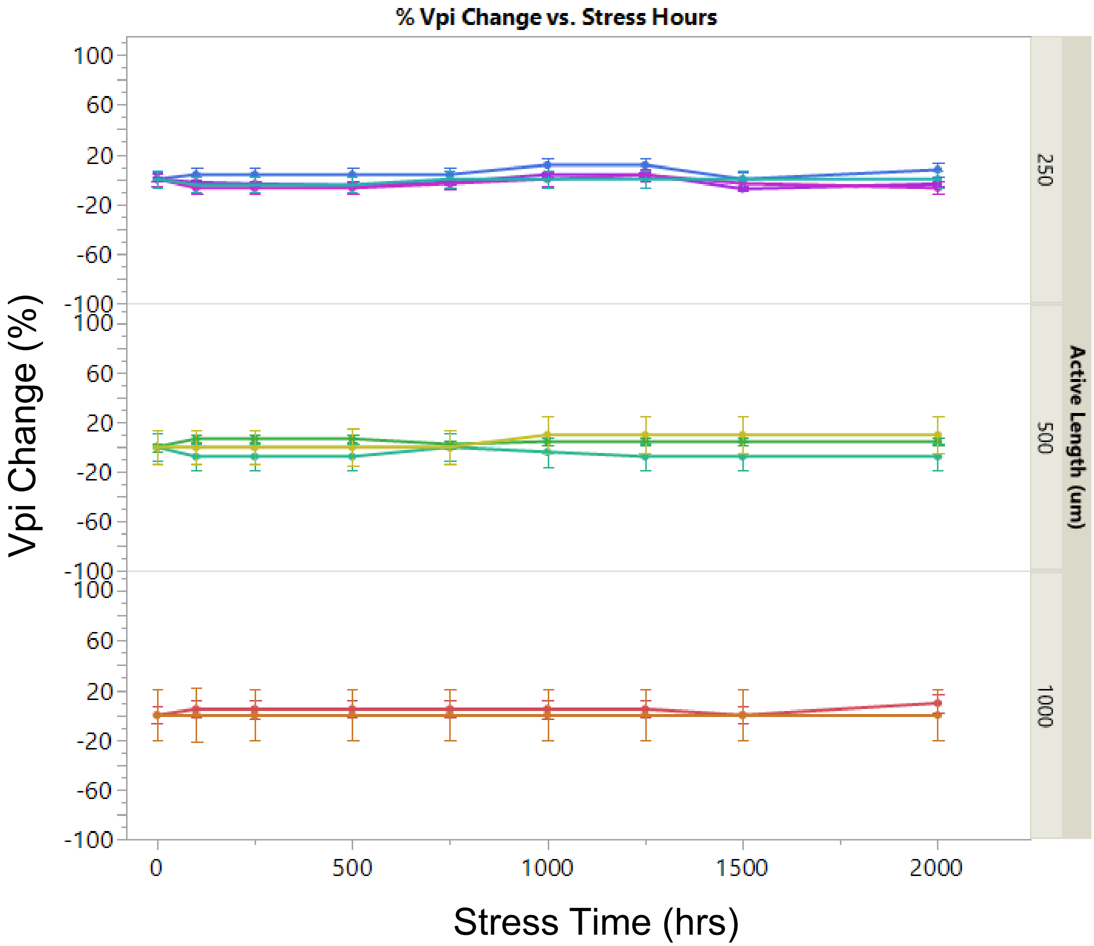
Very Low Photodegradation in SOH Devices in N2 Atmosphere

Stress Condition: Slot device, RT, 20dBm at 1550nm, N_2 purge

85°C - 85%rh with SOH Devices: Change in V_π

Temperature = 85 °C

Humidity =85%rh



- SOH Device Structure:
  - EO Polymer with ENCAP protection
- Stress Condition:
  - 85°C – 85% rh
  - 4 devices- 250um length
  - 3 devices- 500um length
  - 2 devices- 1mm length
- Spec:
  - < 20% variation in V_π for 2,000 hrs
- Result:
  - No measurable V_π degradation for 2,000 hrs

EO Polymer SOH Devices with ENCAP Passing Damp Heat Stress

Stress Condition: Slot device. 85%rh-85°C

Translating the OLED Playbook to EOP

Reliability Challenge	Modern OLED Solution	Electro-Optic Polymer Equivalent
Moisture/Oxygen Ingress (Damp Heat)	Dyadic Thin-Film Encapsulation (TFE / ALD)	Atomic layer deposition (ALD) directly over the EOP slot waveguide; passes 85/85 damp heat testing.
Thermal Instability	Stable guest-host matrices, high glass-transition temperature (T_g)	High-T_g polymer-host matrix. Material is engineered with a Tg≈ 185°C (100°C above max operating limits), providing a projected lifetime >100 years at 85°C.
Photo Oxidation	Exciton / Oxygen Scavenger materials	ALD barrier layers engineered for ultra-low oxygen transmissivity rates, completely isolating the core and eliminating photo oxidation pathways.
Photolysis (Host Matrix / Chromophore Decomposition)	Wide-bandgap host matrices to prevent exciton upconversion	Highly photostable organic chromophores at operating wavelengths. Synthetically tailored so bond dissociation energies strictly exceed operating telecommunication O-band photon energies.

Conclusion

Summary

- LWLG has developed EO polymer, BEOL and SOH modulator device technology
- EO polymer material and encapsulation achieved Telcordia reliability performance at thin film and device level. Additional reliability studies underway for various reference devices
- 200 and 400Gb/s devices designed and in Fab at multiple foundries with multiple PDKs

Key Takeaway

- Co-optimization with foundries for slots, slabs, rails, doping, and other fabrication specific parameters is underway for 400Gb/s performance in EO polymer-based SOH modulators for both O- and C-band

Lightwave Logic EO Polymer, Processes, and Designs are Ready for 400Gb/s Device Developments

LIGHTWAVELOGIC®

Thank you

Manoj Manjare, Director of Reliability

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www.lightwavelogic.com

UNLOCKING THE POWER OF SILICON PHOTONICS WITH EO POLYMERS