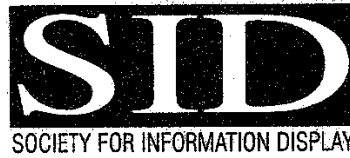


SOCIETY FOR INFORMATION DISPLAY



SHORT COURSE S-1:

Fundamentals of OLEDs

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Eastman Kodak Co.
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Ewing, NJ**

**SUNDAY, MAY 23, 2004
WASHINGTON STATE CONVENTION
AND TRADE CENTER
SEATTLE, WASHINGTON**

Lifetime

Operating lifetime:

Fix	Measure
Constant voltage	$dL/dt, dI/dt$
Constant current	$dL/dt, dV/dt$
Constant luminance	$dI/dt, dV/dt$

Specify

- Initial luminance (burn-in?)
- Temperature (acceleration factor?)
- Humidity

"Lifetimes"

- Half brightness (at constant current)
- Time to catastrophic failure (short/open circuit)

NB differential ageing not acceptable in display

Visual inspection also helpful (spots, edge effects)

Fundamentals of OLEDs

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Fundamentals of OLEDs

1. Introduction/History of OLEDs
2. Basic OLED Mechanisms
3. OLED Materials
4. OLED Fabrication and color patterning
5. Improving OLED Performance
6. Measurement and Characterization
7. Reliability and OLED Degradation
8. OLED Architectures
9. OLED Display technology
10. Applications

Fundamentals of OLEDs

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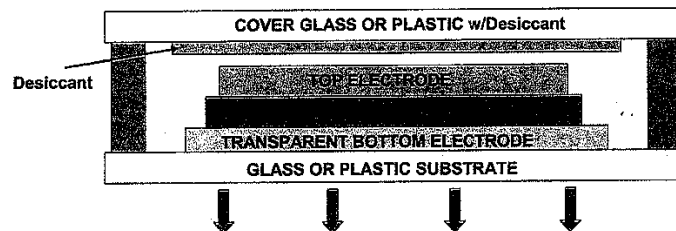
Primary OLED Architectures

- Bottom Emitter
 - The emitted light goes out through the device substrate
- Top Emitter
 - The emitted light goes out through the cover glass
- Transparent OLED
 - The emitted light goes out through both sides

Fundamentals of OLEDs

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Bottom Emitter



- The anode (bottom electrode) is transparent
- The cathode (top electrode) is highly reflective (opaque)

Advantages:

- Easy to fabricate $\Rightarrow$ presently most devices are made this way
 - Opaque desiccant may fill the entire cover glass surface without problem

Concerns:

- Aperture ratio limited for high resolution active matrix displays with advanced TFT structures

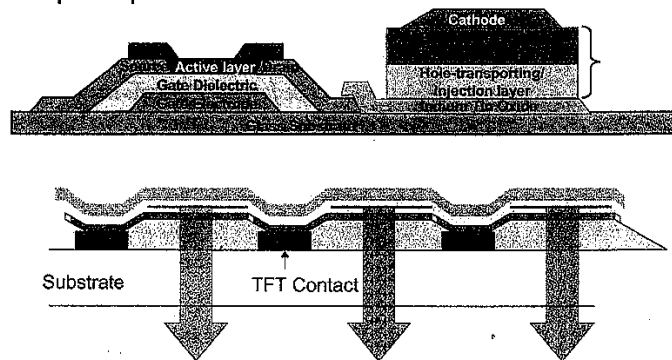
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Bottom Emitter AMOLED

Low Temperature Poly-Silicon (LTPS)

- Pixel-to-pixel non-uniformity $\Rightarrow$ multiple transistors needed to compensate for the non-uniformities
- More real estate is needed for TFTs at the cost of light emitting part of pixel area

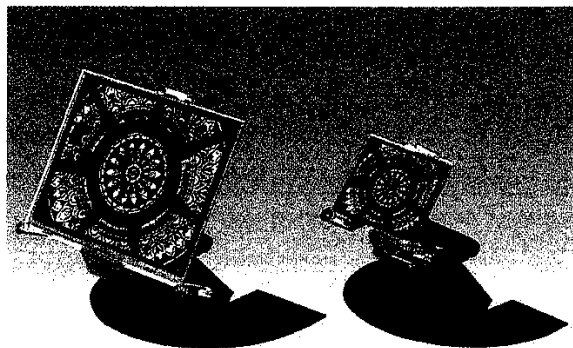


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Example of Bottom Emitter AMOLED

(Eastman Kodak Company/SANYO Electric Co.)



5.5 inch QVGA
SID 2000

2.4 inch
JES 1999

- RGB Patterned Emitters
- Poly-silicon

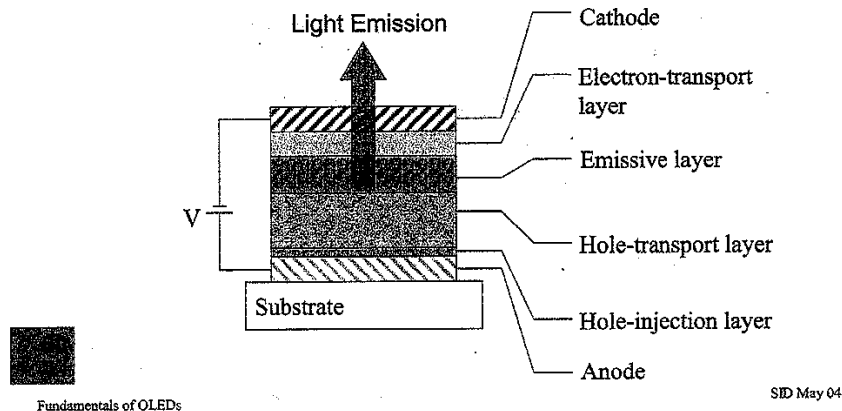


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Top Emitter Architecture

- Opens up the entire real estate below the OLED for advanced TFT circuitry
- However, new challenges need to be overcome
 - Transparent or semi-transparent cathode, desiccant-free encapsulation, etc



Top Emitter OLED

Advantages

- High aperture ratios can be realized $\Rightarrow$ brighter & higher resolution displays
- Advanced TFT circuitry can be used because more real estate available underneath the OLED device
- Transparency of device substrate not critical
- Higher luminous efficiency than bottom emission

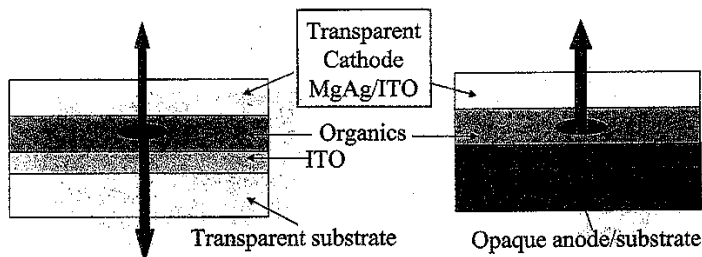
Disadvantages

- Need transparent or semi-transparent cathode
- No desiccant or transparent desiccant highly desirable for encapsulation

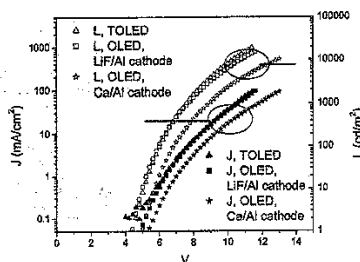
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Transparent and Top Emission OLEDs (TOLEDs)



Higher luminous efficiency
than bottom emission



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Thin Film Encapsulation For Top Emitter OLEDs

Thin layers of organic and/or inorganic material over the cathode can act as an encapsulant

Advantages

- Permits getterless devices
- Can allow fabrication of color filters directly over OLED layers
 - Especially important for high-resolution, smaller displays to avoid optical cross-talk between pixels
- Higher long-term reliability than epoxy sealed OLED displays
- High optical transmission
- Reduces perimeter area waste - more displays per substrate

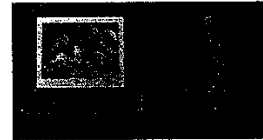
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Examples Of Top-Emitting Displays



SONY 24" tiled top emitting



SONY 13" top emitting



IDT/CMO/IBM 20" a Si top emitting

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Examples Of Transparent Displays



Courtesy of Dr. H.K.Chung
Samsung SDI

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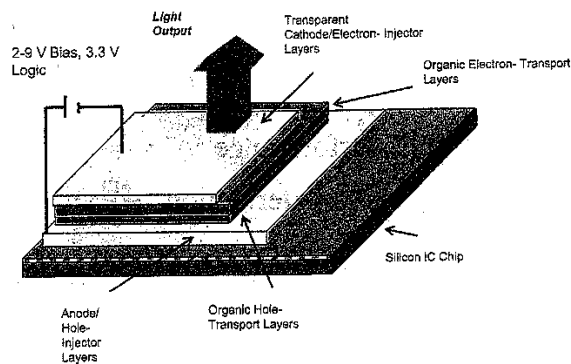
OLED on Single-Crystal Silicon

- 0.35 μ based CMOS circuitry $\Rightarrow$ high performance integrated drivers and circuitry
- Top-emitter architecture
- White with color filters
- Thin-film encapsulation $\Rightarrow$ color filters patterned directly over the OLED layers
- Stereoscopic image gives the feeling of 21" screen

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OLED-on-Silicon Microdisplay (Top Emitter)



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eMagin's OLED-on-Silicon Top Emitter Microdisplay



- Small, molecule based (Kodak)
- Top-emitting structure
- White OLED emitter
- Thin film seal
- Color filters built directly over thin film seal
- Integrated driver electronics

Source: eMagin Corp.

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Fundamentals of OLEDs

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OLED Display Technology

- Introduction
- Passive matrix vs Active matrix
- Backplanes for AMOLEDs
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- AMOLED Power Consumption

Fundamentals of OLEDs

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Introduction to Flat Panel Displays

EMISSIVE:

- FED's
- PDP's
- Inorganic EL
- OLEDs

NON-EMISSIVE:

- LCD's
 - Transmissive
 - Reflective
- DMD's
- Electrophoretic
- MEMS

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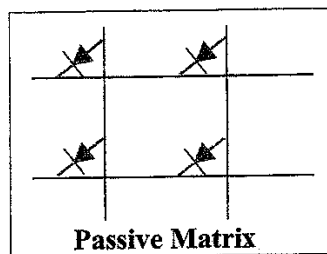
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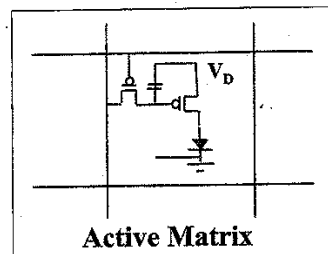
Fundamentals of OLEDs

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Addressing architectures



1 scan (row) line
1 column line

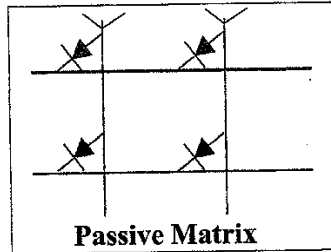


1 select line
1 data line
1 common power line
1 ground

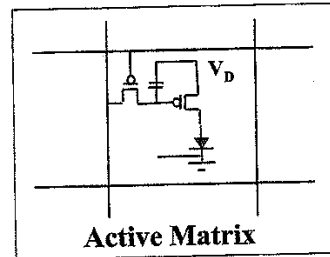
Fundamentals of OLEDs

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Addressing architectures



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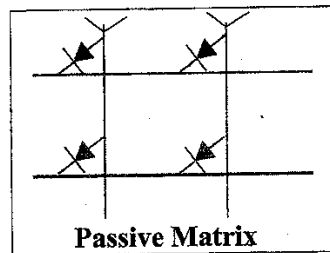


1 select line
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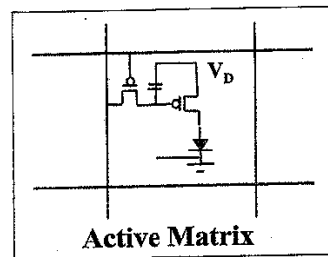
Addressing architectures



2 connections:
1 scan and 1 column line

- OLEDs pulsed at high drive current, low duty cycle (1/N)
- All display current flows instantaneously down a single scan line

Fundamentals of OLEDs

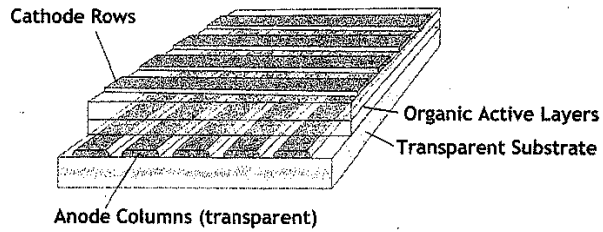


4 connections:
1 select, 1 data line
1 power line and 1 ground

- OLEDs driven dc
- Display current distributed through all power lines

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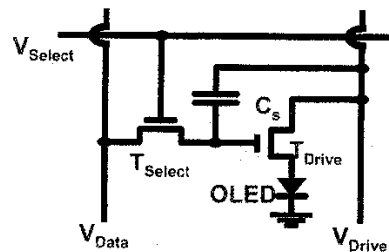
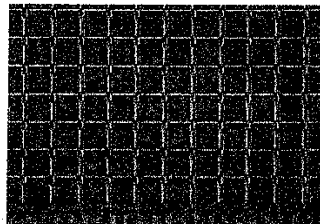
Passive Matrix Display Architecture



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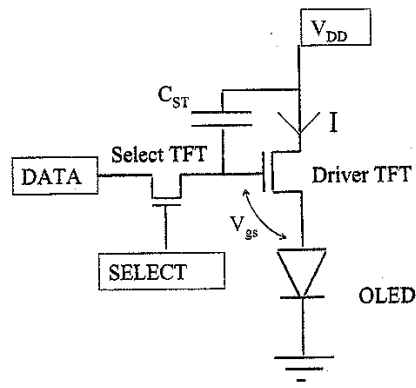
Active Matrix Display Architecture



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Generic AMOLED pixel circuit



• Shown here for NMOS TFTs

• Most pixel correcting circuits still contain a driver TFT, and a select TFT to store voltage (grey scale information) on gate of driver TFT.

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Driving Architectures

	AMOLED	PMOLED
Ease of fabrication	OLED deposited on backplane – isolated pixels, no cathode separator	OLED requires cathode separator
Module cost	Higher because of backplane – lower voltage driver IC Drive electronics integration ?	No backplane – higher voltage drive IC
Yield	Pixels isolated	Pixel shorts create line defects
Array size/resolution	Backplane limited, especially if top emission	Limited to <100 rows or < 3"
Power Consumption	Low	Higher – line losses and lower OLED efficiency
Lifetime	Higher – OLEDs driven dc	Lower – OLEDs pulsed
Uniformity	Very dependent on drive TFT threshold voltage	Direct current drive

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OLED Driving Requirements

	AMOLED	PMOLED
Data	Voltage or current driven – depends on pixel circuit	Current driven and higher voltage to drive OLED at peak brightness
Scan	Pulse select TFT	Pulse OLED
Line resistance	Low resistance lines	Very low resistance row lines – all current instantaneously flows down a single line
Grey scale	Generally analog	PWM or analog

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OLED Display Technology

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Backplanes for OLEDs

	Poly-Si	Amorphous Si	Organic TFT
Performance			
Mobility	Very good	OK for PHOLEDs	OK
Leakage	OK	Very good	OK
Stability	Good	Issue	Issue
Uniformity	Issue	OK	Issue
Manufacturability	Maturing	Excellent	N/A
Cost	> Medium	Medium	Low ??
Plastic compatibility	Under development	Good	excellent

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Max pixel currents for a-Si AMOLED Display

- Red pixel requires highest current
- Assume 300 cd/m² brightness and phosphorescent OLED performance
- For fluorescent doping, multiply TFT width by a factor of 3 - 4 (or increase V_{gs})

Display size (ins)	Resolution	Max pixel current (μ A) for red PHOLED (11cd/A)	Amorphous Si driver TFT W/L for $V_{gs}-V_{th}=4V$
2	160x120x3	0.53	10.1
5	320x240x3	0.82	15.6
10	800x600x3	0.53	10.1
20	1024x768x3	1.29	24.6

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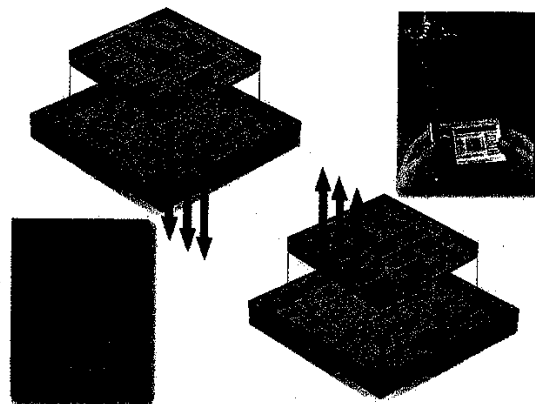
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Top Emission AMOLEDs

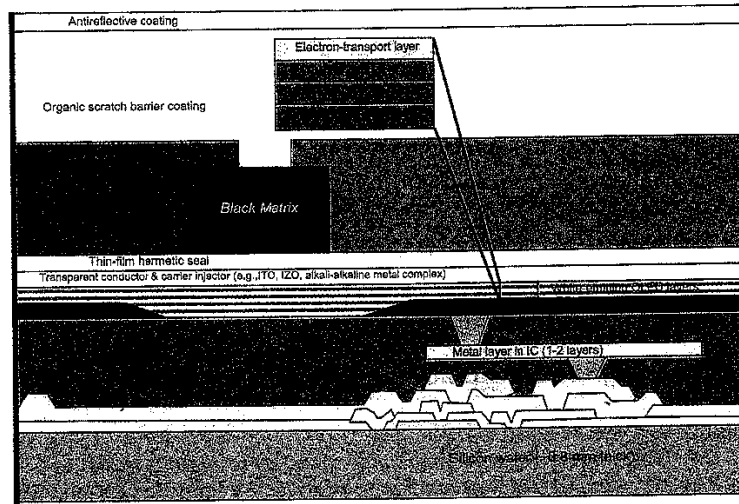


Top emitting AM-TOLED offers better fill factor than bottom-emitting OLED

Fundamentals of OLEDs

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Top-Emitting OLED on Silicon



Various Layers are Not to Relative Scale

Source: eMagin Corp.

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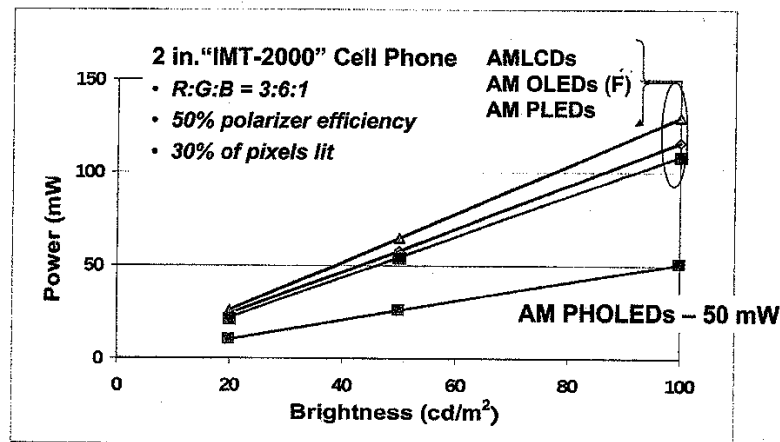
Introduction to Color Display Design

- Select 3 component CIE's to produce white:
 - Trade-off between color purity and power consumption
- Calculate sub-pixel currents based on optimizing OLEDs for luminous efficiency (cd/A) of "weakest" color at appropriate drive levels, accounting for;
 - aperture ratio,
 - color balance,
 - brightness,
 - polarizing filter,
 - multiplexing ratio ($=1/N$ for PM, usually 1 for AM), where N = # of scan lines
 - End of life characteristics
- Select voltage based on above considerations and TFT requirements
- Line resistances / widths:
 - For PM, row line voltage drop determined by total panel current
 - For AM, scan/select lines similar to AMLCD :Power and ground must support total pixel current of that line.

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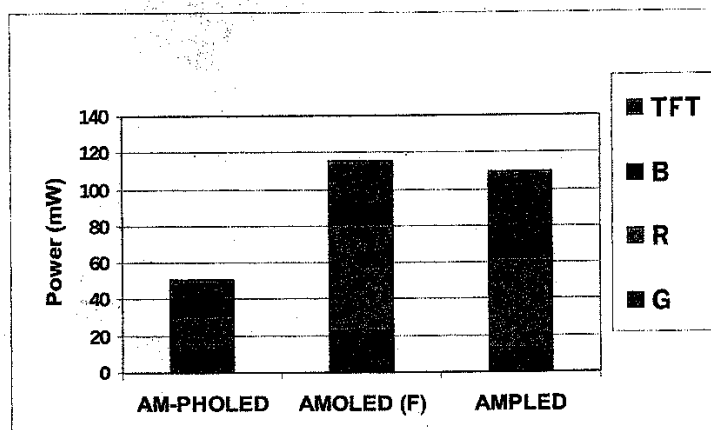
AMOLED Display Power Consumption



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Full-color AM OLED Power Analysis



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