#32.3

A Sheet-Type Scanner Based on a 3D Stacked Organic-Transistor Circuit with Double Word-Line and Bit-Line Structure

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Outline

- **Introduction**

- **3D stacked sheet-type scanner**

- **Circuit design of double wordline & bitline**

- **Experimental result**

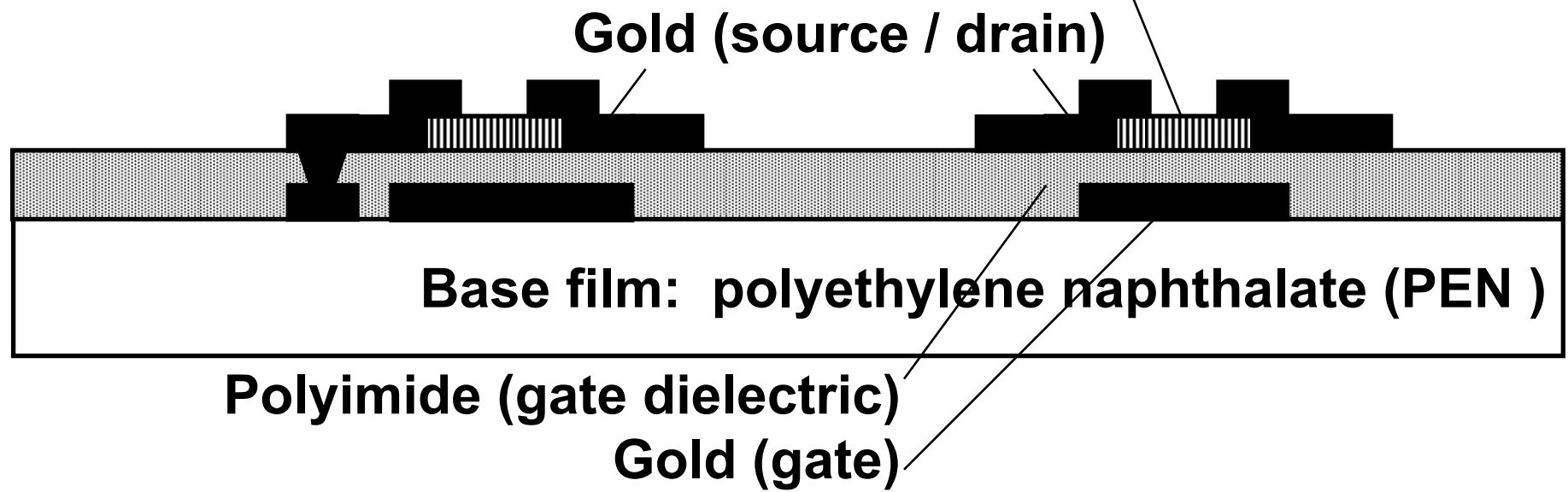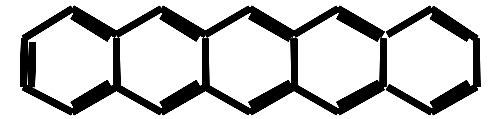- **Summary**

Organic FET (OFET)

Pentacene: organic semiconductor (p-type)

$\mu > 1cm^2/Vs$

$L > 20\mu m$

on/off $> 10^5$

Transistor yield > 99% @ t_{GATE} = 630nm

Gold (source / drain)

Base film: polyethylene naphthalate (PEN)

Polyimide (gate dielectric)

Gold (gate)

Sheet-type scanner

- **ISSCC 2004**

   Electronic artificial skin (e-skin)

- **IEDM 2004**

   Sheet-type scanner

- **Large area, low cost**
- **Mechanically flexible**
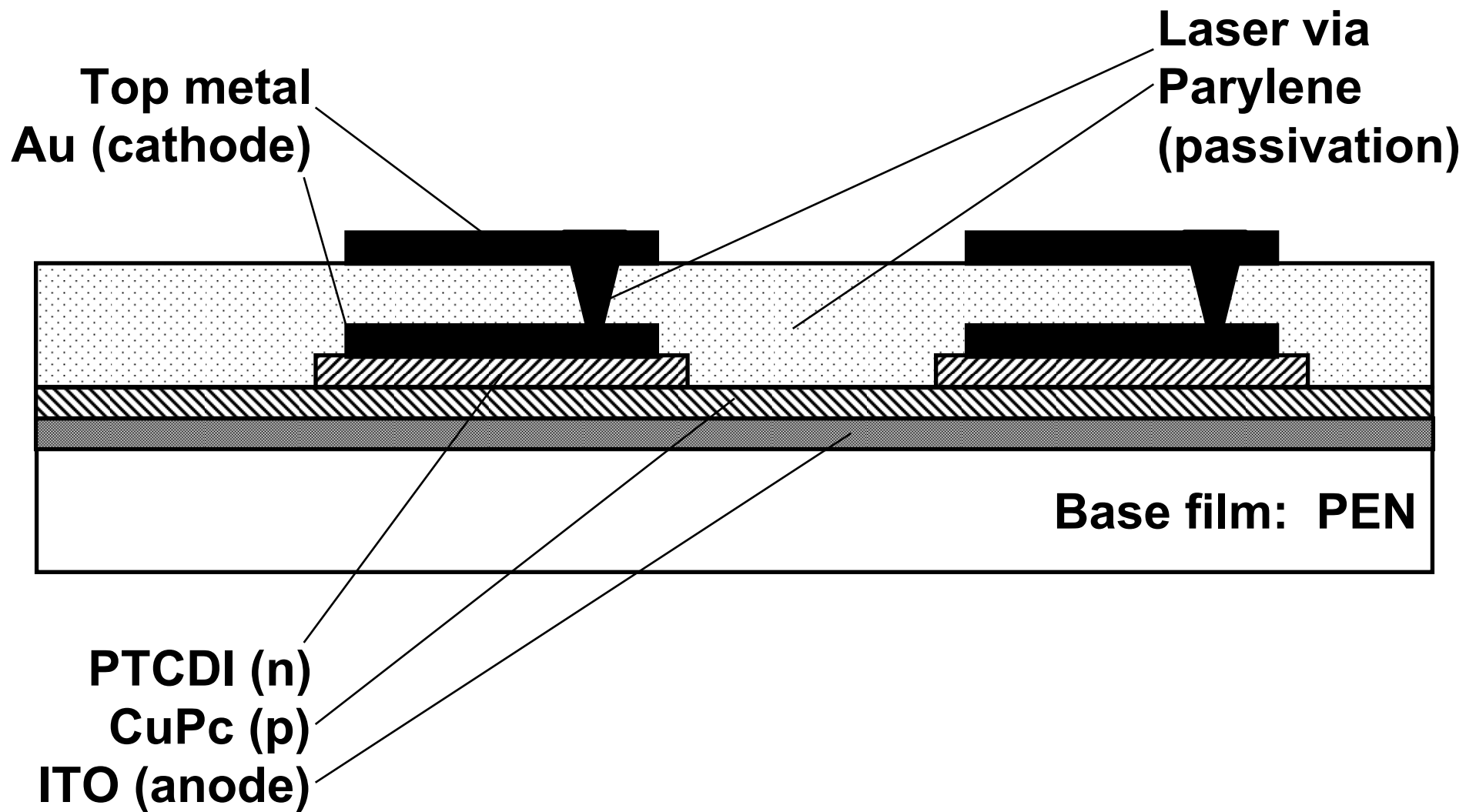   **=> fits on curved surface.**

- **Black-&-white image**
- **No mechanical parts / lens**
- **Weight: 1g**
- **Thickness: 0.4mm**
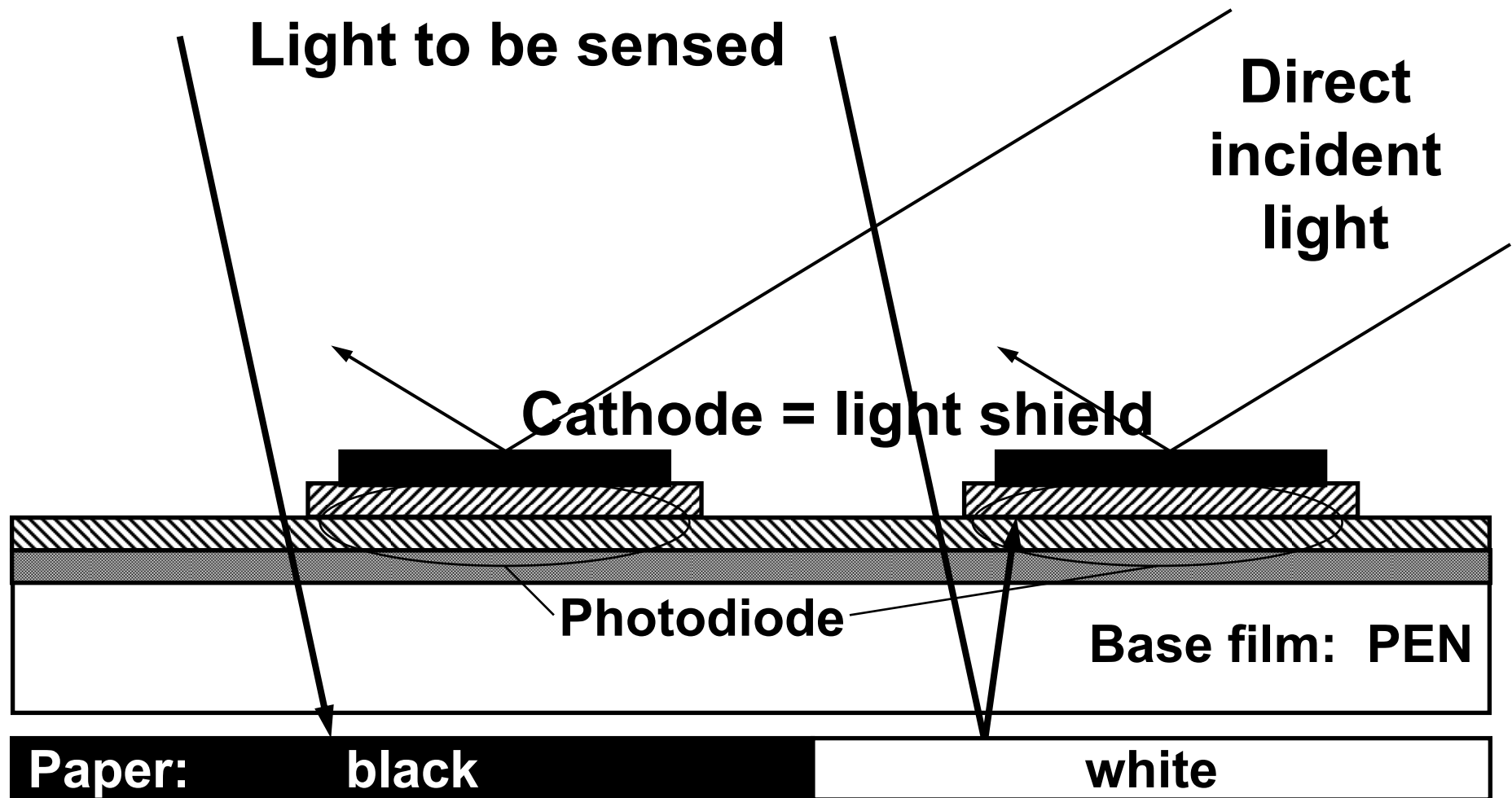- **Bending radius: 30mm**

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Novel features

- **Double wordline & bitline in large-area sensor**
  High speed
  Low power

- **3D stack integration**

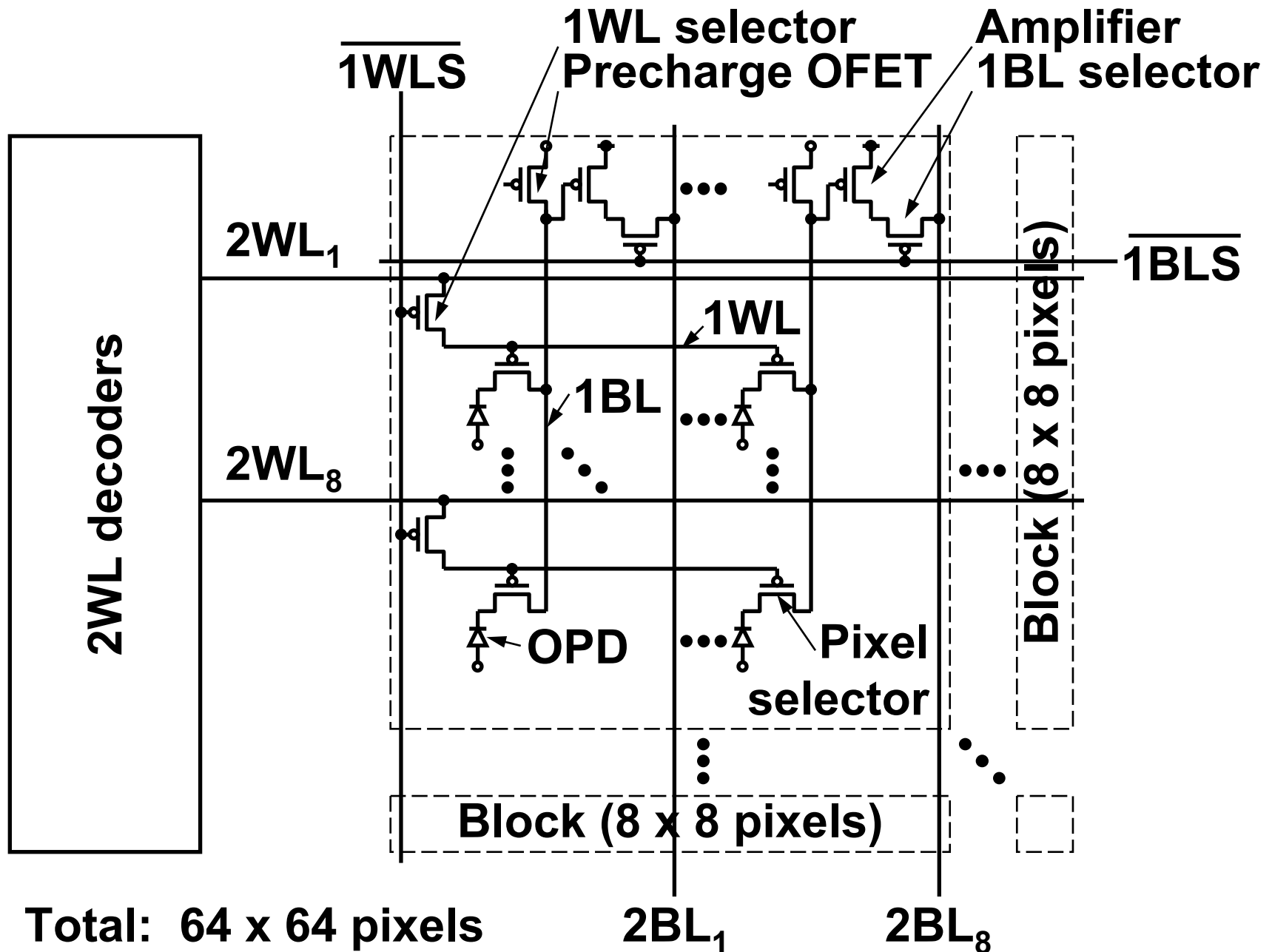- **New decoder**

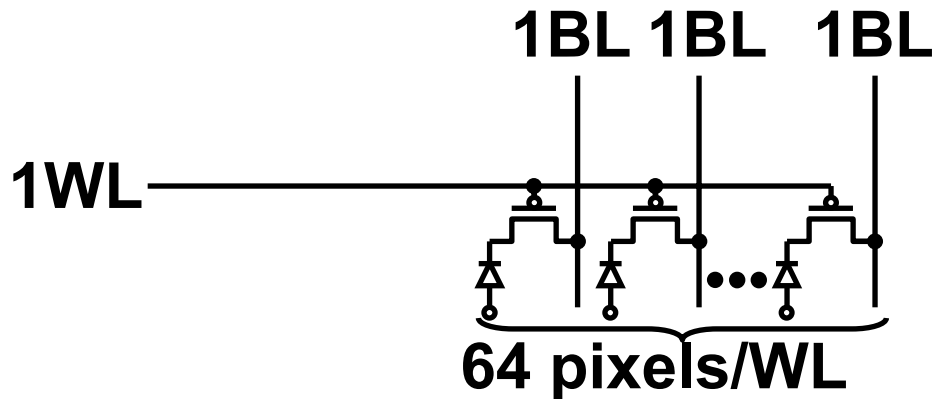- **Photocurrent sensing**

Organic photodiode (OPD)

Laser via

Top metal
Au (cathode)

Parylene
(passivation)

Base film: PEN

PTCDI (n)
CuPc (p)
ITO (anode)

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Operation principle

Light to be sensed

Direct incident light

Cathode = light shield

Photodiode

Base film: PEN

Paper: **black**   white

Double wordline & bitline structure

Total: 64 x 64 pixels

First wordline delay optimization

- **Single wordline**

1BL 1BL   1BL

1WL

64 pixels/WL

- **Double wordline**

$\overline{1WLS}$

2WL

k 1WL selectors

1WL

1BL 1BL 1BL

m pixels/WL

Delay [a.u.]

1

0

k (# of parallel OFETs driving 1WL)

4
3
2
1
0

m [pixels/WL]

2 4 8 16 32 64

single WL

6x faster

Double WL (delay = 0.16)
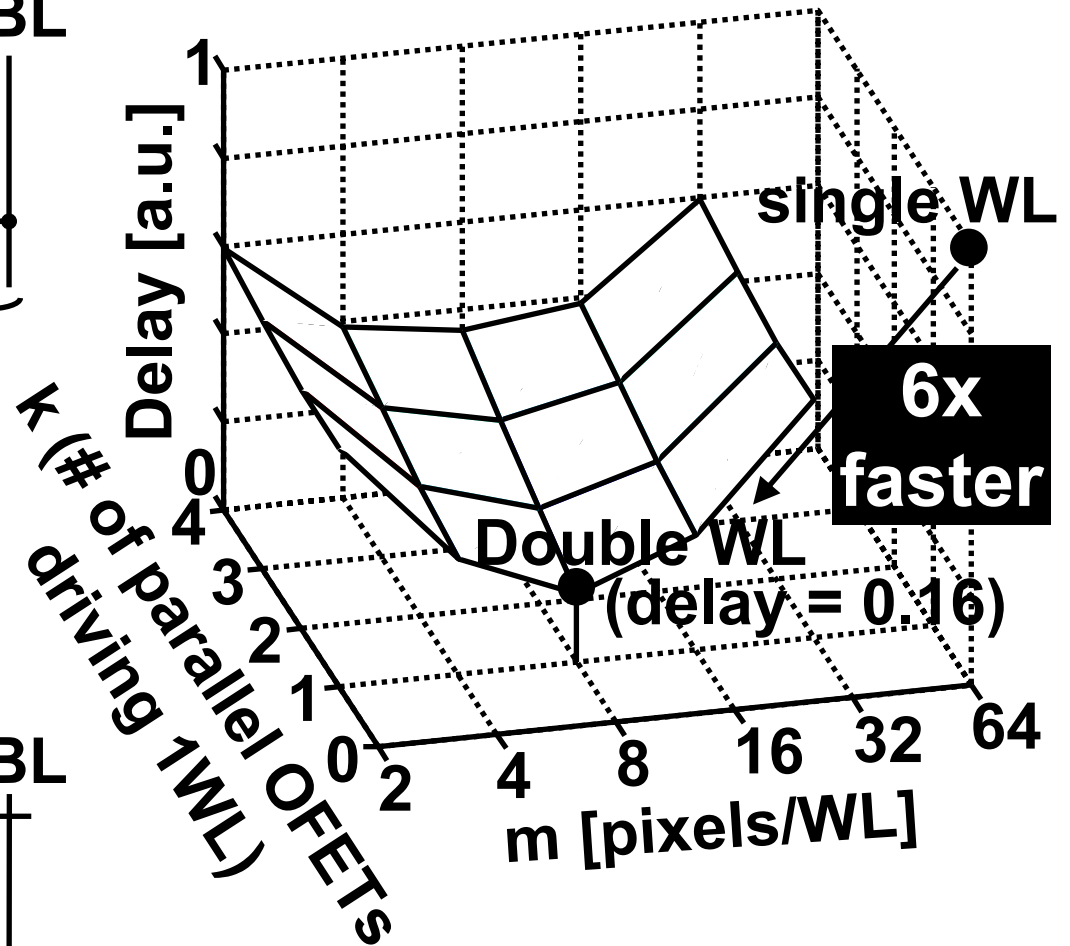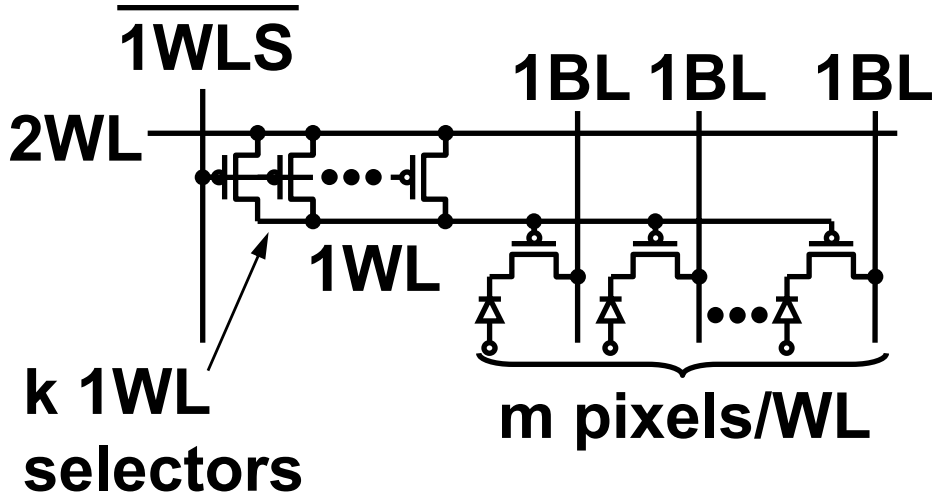
Double wordline can also reduce power.

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Scanner layout

Pixel selectors (Memory cells)

1WL selectors

PCs | AMPs
1BL selectors

Pixel selectors (Memory cells)

1WL selectors

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Pixel selectors (Memory cells)

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Pixel selectors (Memory cells)

1WL selectors

PCs | AMPs
1BL selectors

Separate & stack

1WL selectors

Precharge OFETs

Amplifiers

1BL selectors

#2

Pixel selectors   #1

- Logical device

- Physical device

Organic FET sheet#1

8 x 8 pixel selectors in a block

1WL

1BL

Pixel selector
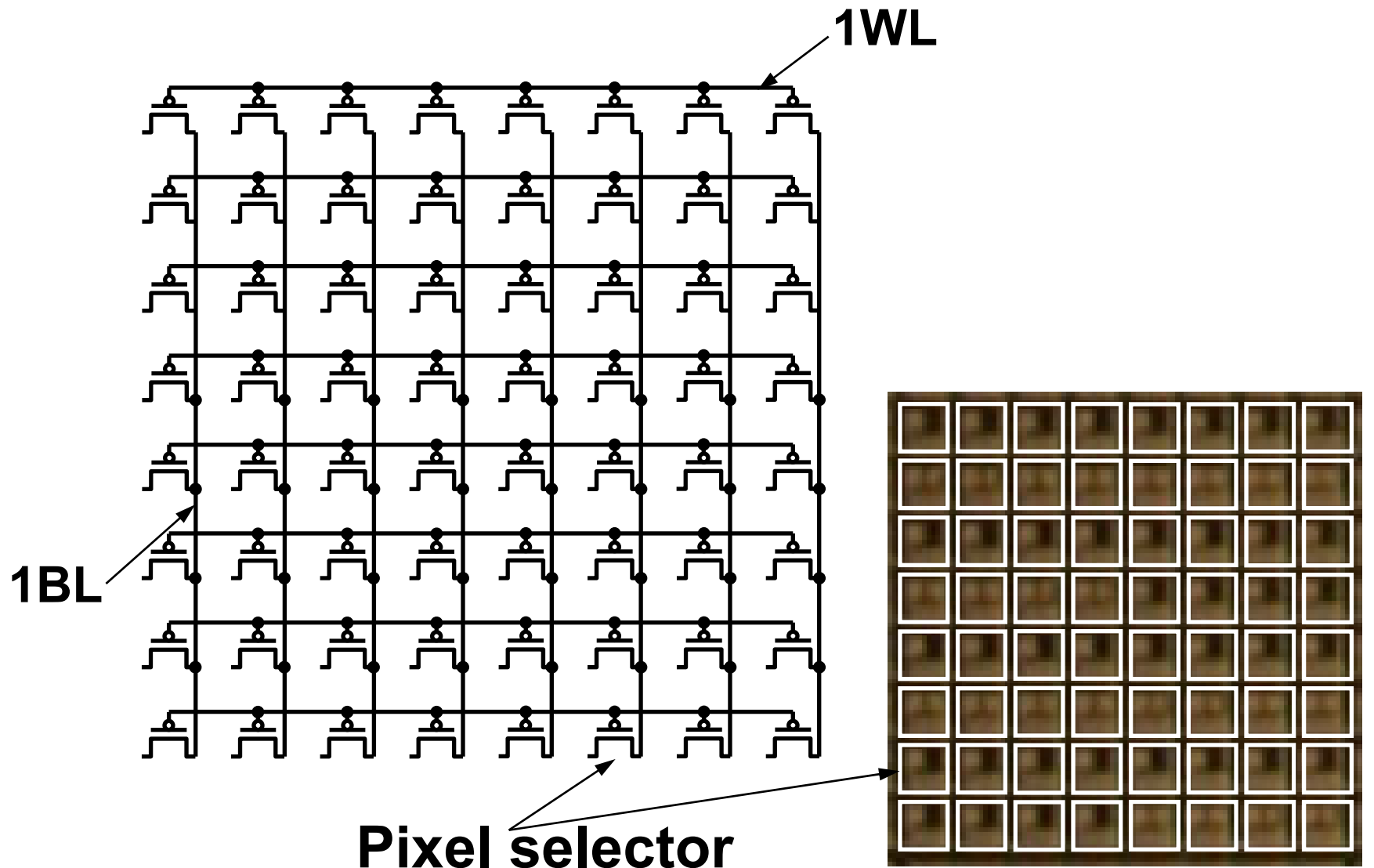
Organic FET sheet#2

32 OFETs in a block

$\overline{\text{1WLS}}$

2WLs

$\overline{\text{1BLS}}$

2BLs

1WL selector

1BL selector

Amplifier

Precharge OFET

<= Interconnect =>
<= Interconnect =>
<= Interconnect =>
<= Interconnect =>
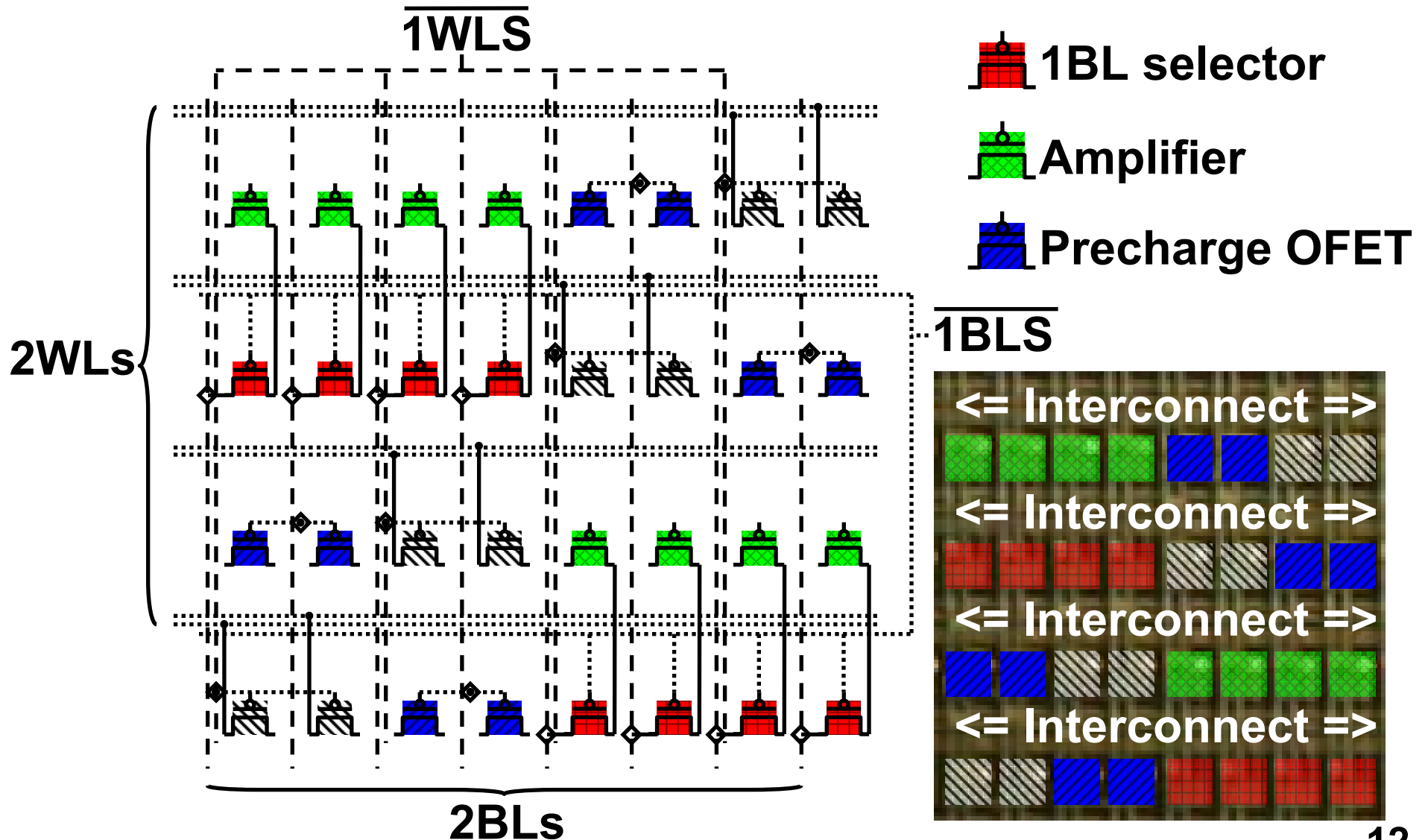
Scanner Picture

Pixel size:

$1.27 \times 1.27\text{mm}^2$

(20dpi)

80mm

80mm

64 x 64 pixels

OFET sheet#2

OFET sheet#1

OPD sheet

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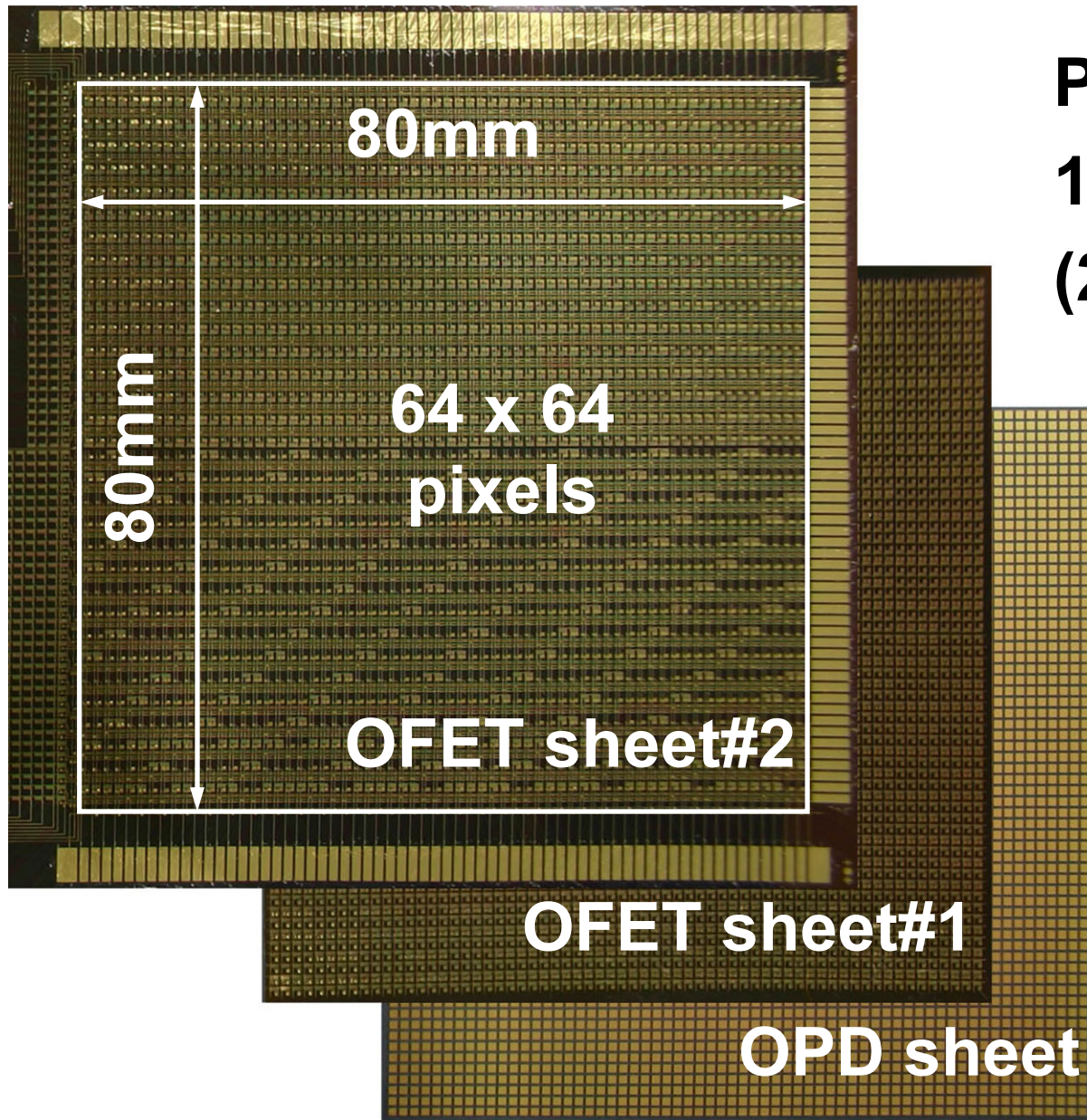
3D stack integration

- **Top view**

  Cathode:
  900 x 900μm^2
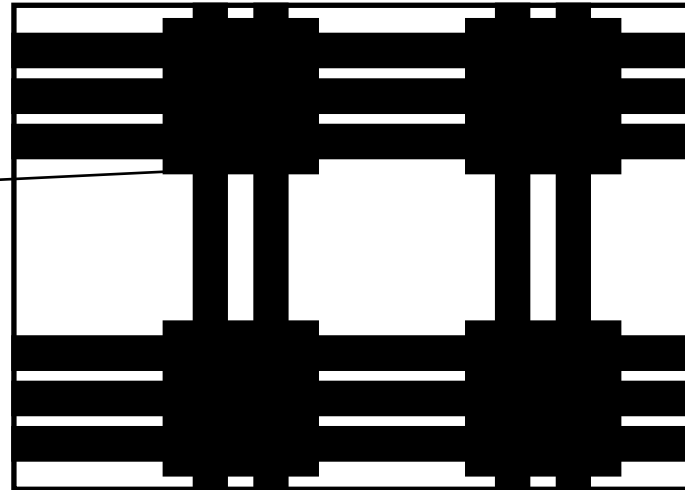
  Open-area ratio:
  45%

- **Side view**

  Silver paste

  Light

  OFET sheet#2

  OFET sheet#1

  OPD sheet

  Peripheral OFET

  Pixel selector

  Photodiode

  Paper: black   white

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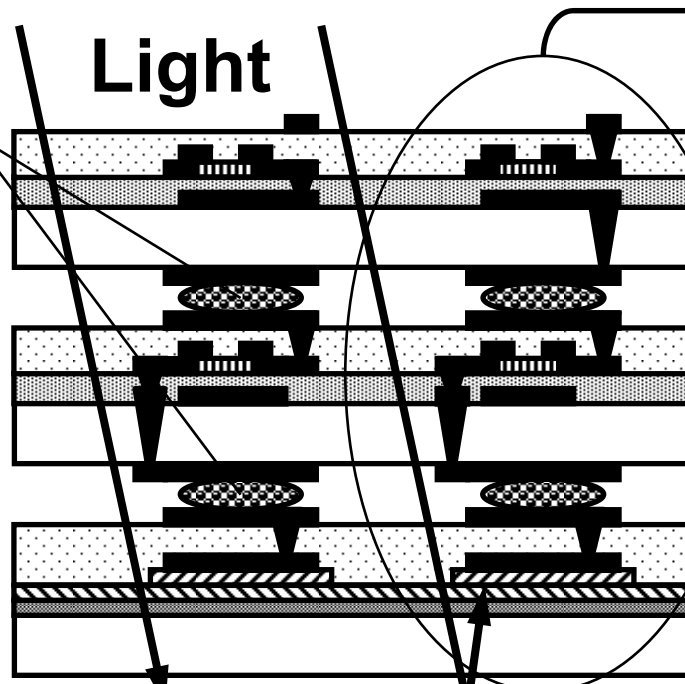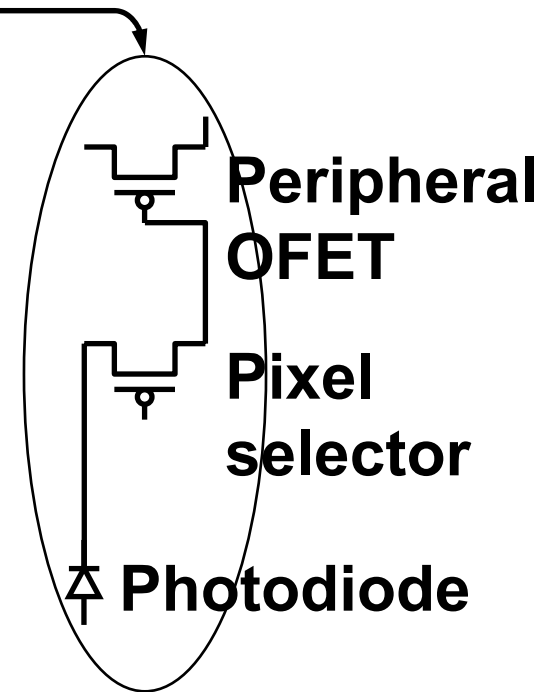
New dynamic decoder

- **Conventional**

Parallel

$\overline{A_1}$ — $\overline{A_2}$ — $\overline{A_3}$ — • • •

2WL

V_{BIAS} — **Small**

- **New**

$\overline{\phi}$ —

2WL

• • •
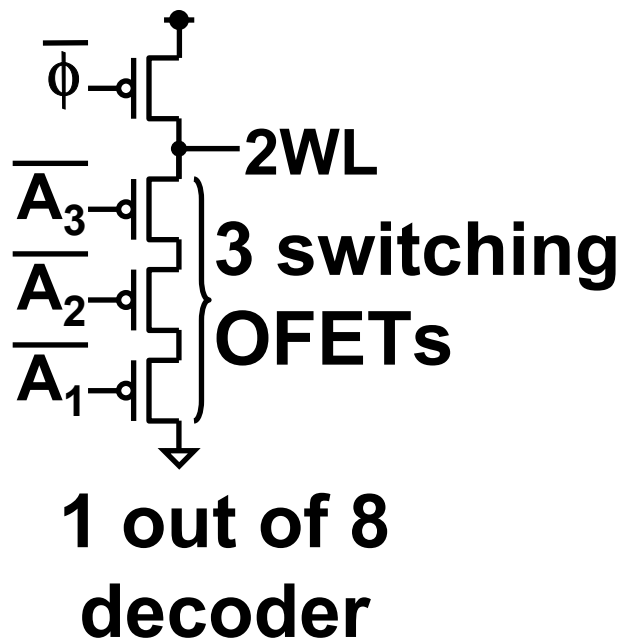
$\overline{A_3}$ —

$\overline{A_2}$ — **Series**

$\overline{A_1}$ —
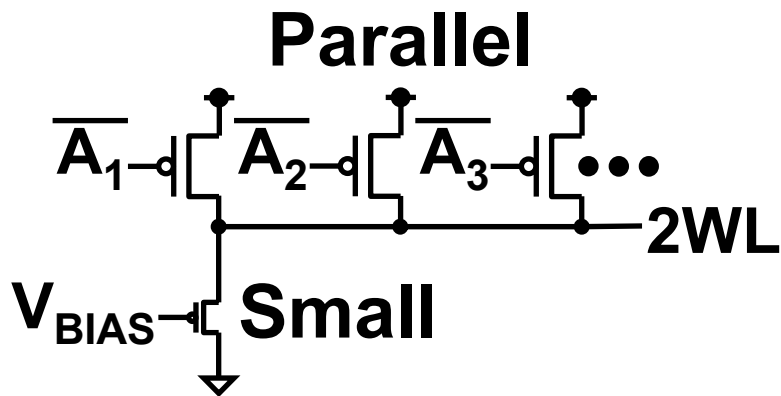
- **Sizing required**
- **Slow**
- **V_{BIAS} adjustment**
- **1µA active leakage**
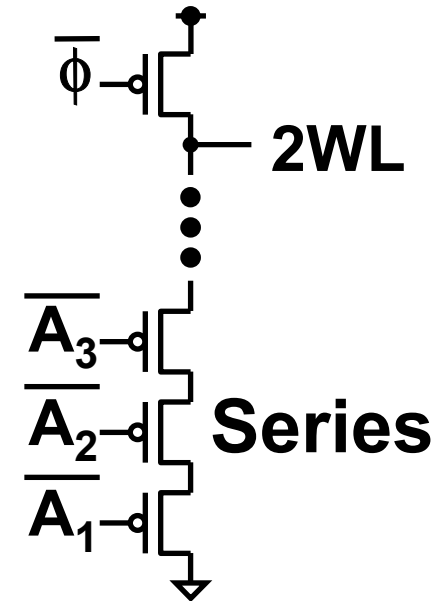
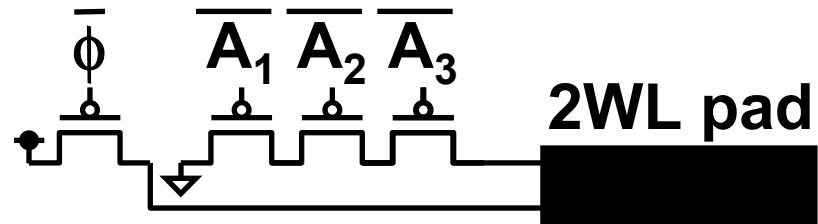- **No active leakage**
- **Fast**
- **Ratioless**
- **Wide margin**

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Cut-&-paste customization

1 out of 8 decoder

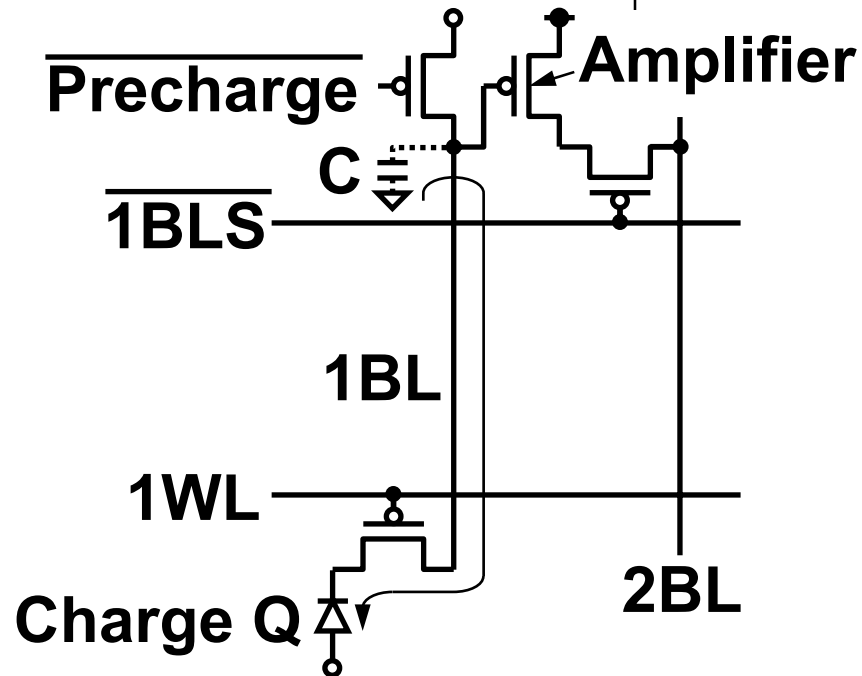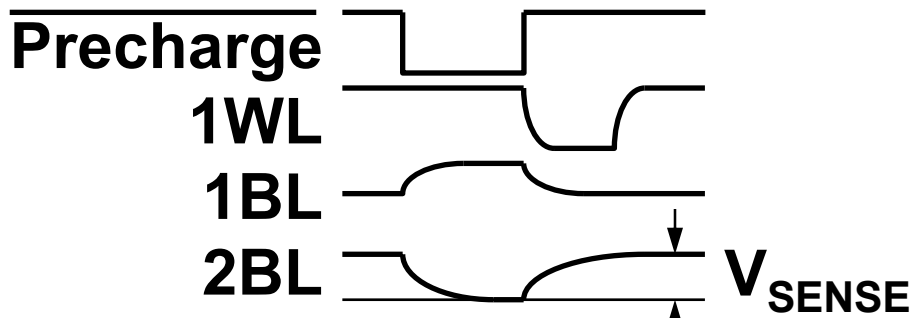- **Cut 3 switching OFETs out.**
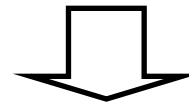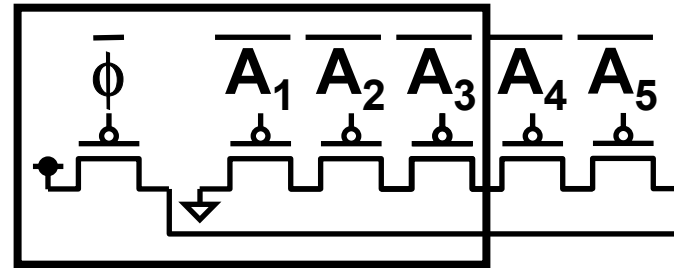
- **Paste them to 2WL pad.**

2WL pad

Reduces mask & NRE costs.

Photocurrent sensing

• **Charge transfer**
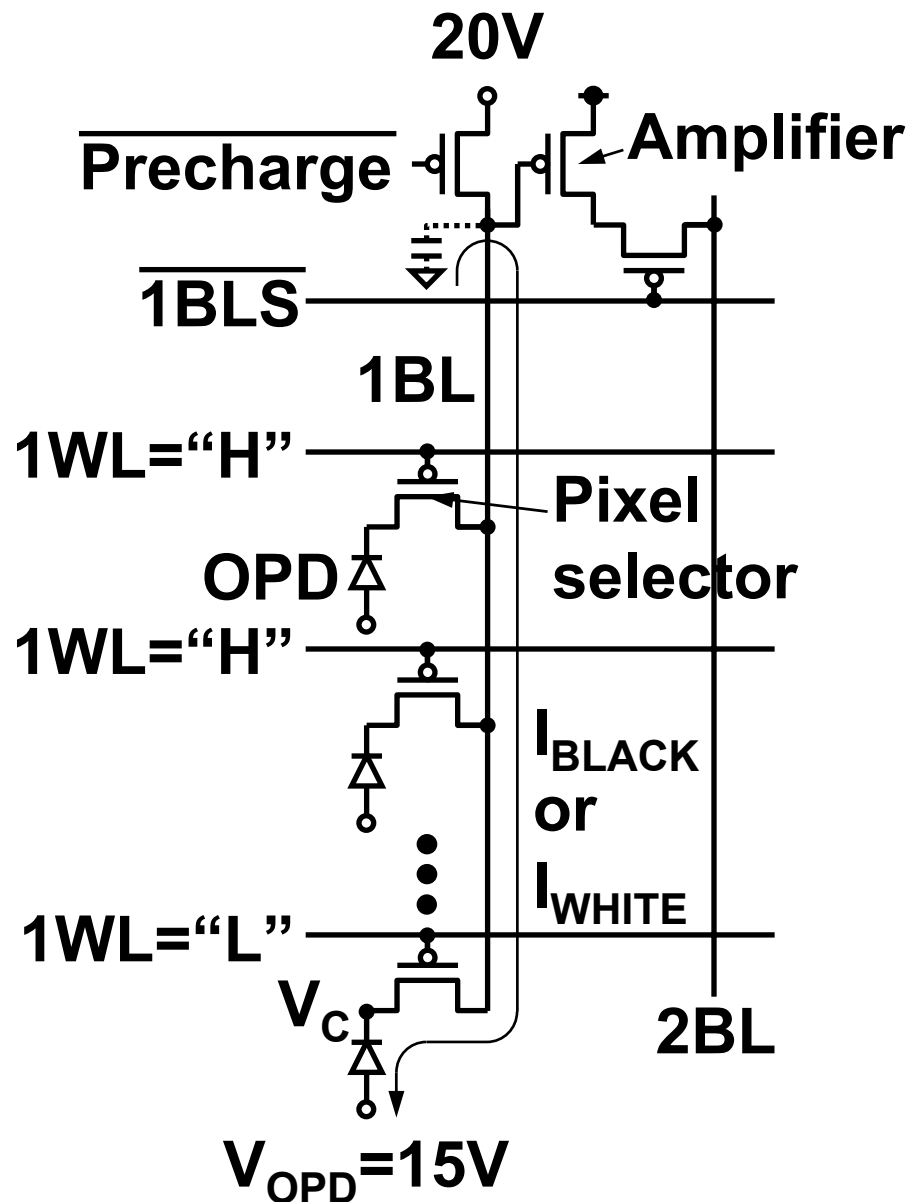
Precharge
1WL
1BL
2BL — V_{SENSE}

Precharge
Amplifier
C
1BLS
1BL
1WL
Charge Q
2BL

Charge-to-voltage conversion

• **Photocurrent**

Precharge
1WL
1BL
2BL — t_{SENSE}

Precharge
Amplifier
C
1BLS
1BL
1WL
Current I
2BL
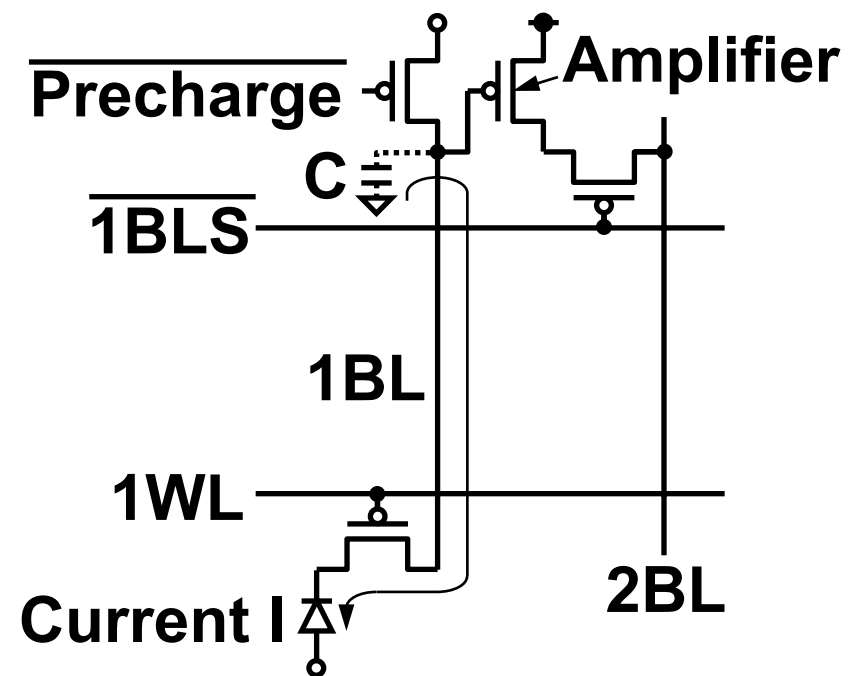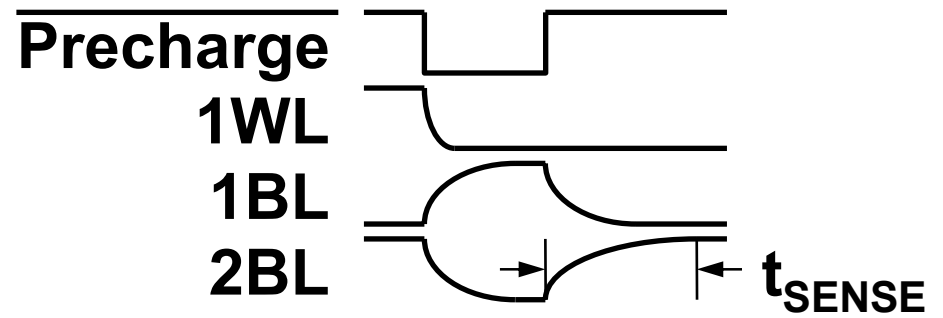
Current-to-time conversion

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Photocurrent

Pixel selector
(OFET)

Organic
photodiode
(OPD)

50

I [µA]

I_{WHITE}

0

I_{BLACK}

10   V_{OPD} 20

Cathode voltage
V_C [V]

20V

$\overline{Precharge}$

Amplifier

$\overline{1BLS}$

1BL

1WL="H"

OPD

Pixel
selector

1WL="H"

I_{BLACK}
or
I_{WHITE}

1WL="L"

V_C

2BL

V_{OPD}=15V
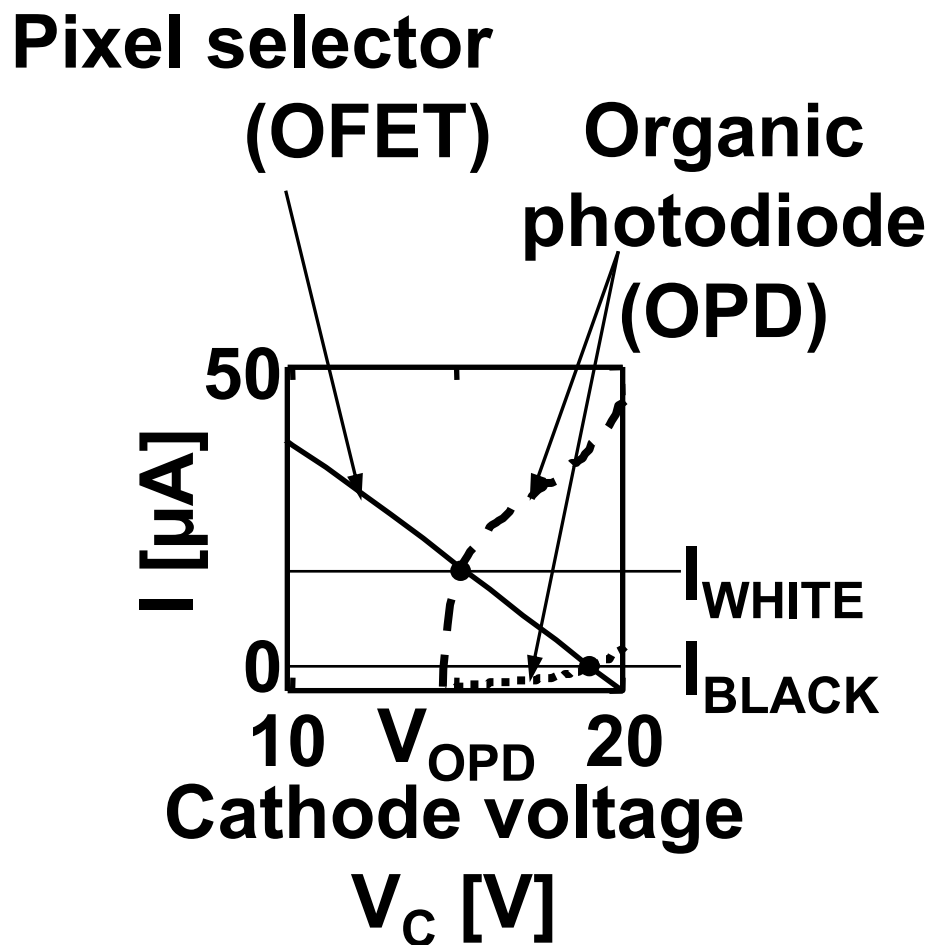
Scanned image

1. Scan pure black paper & pure white paper.
2. Scan image.
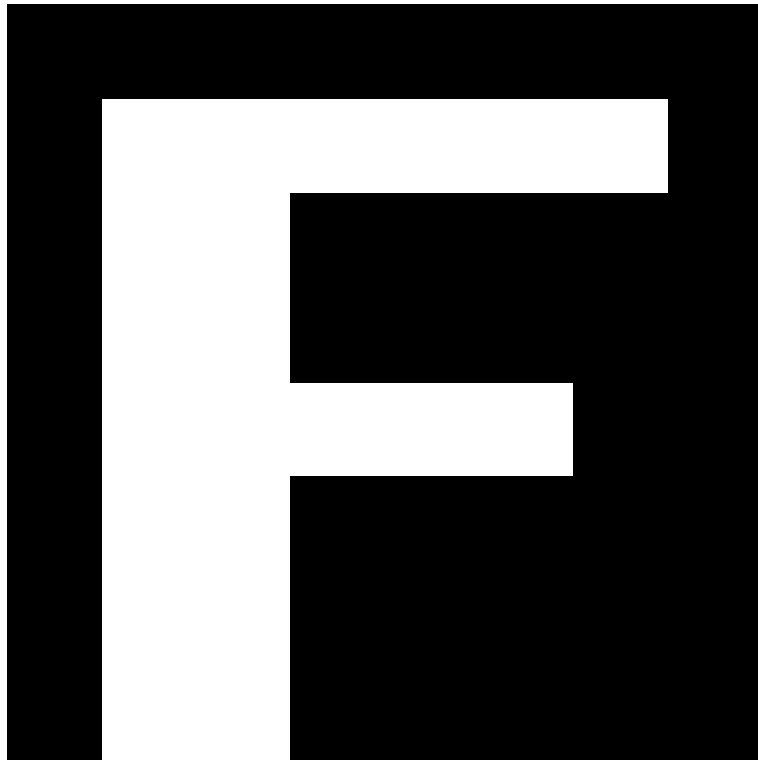3. Calibrate data by interpolating them between pure black & pure white.

- Original "F"
- Scanned "F"

First wordline delay

Double WL   Single WL

Voltage [V]

40
30
20
10
10%
0

3ms
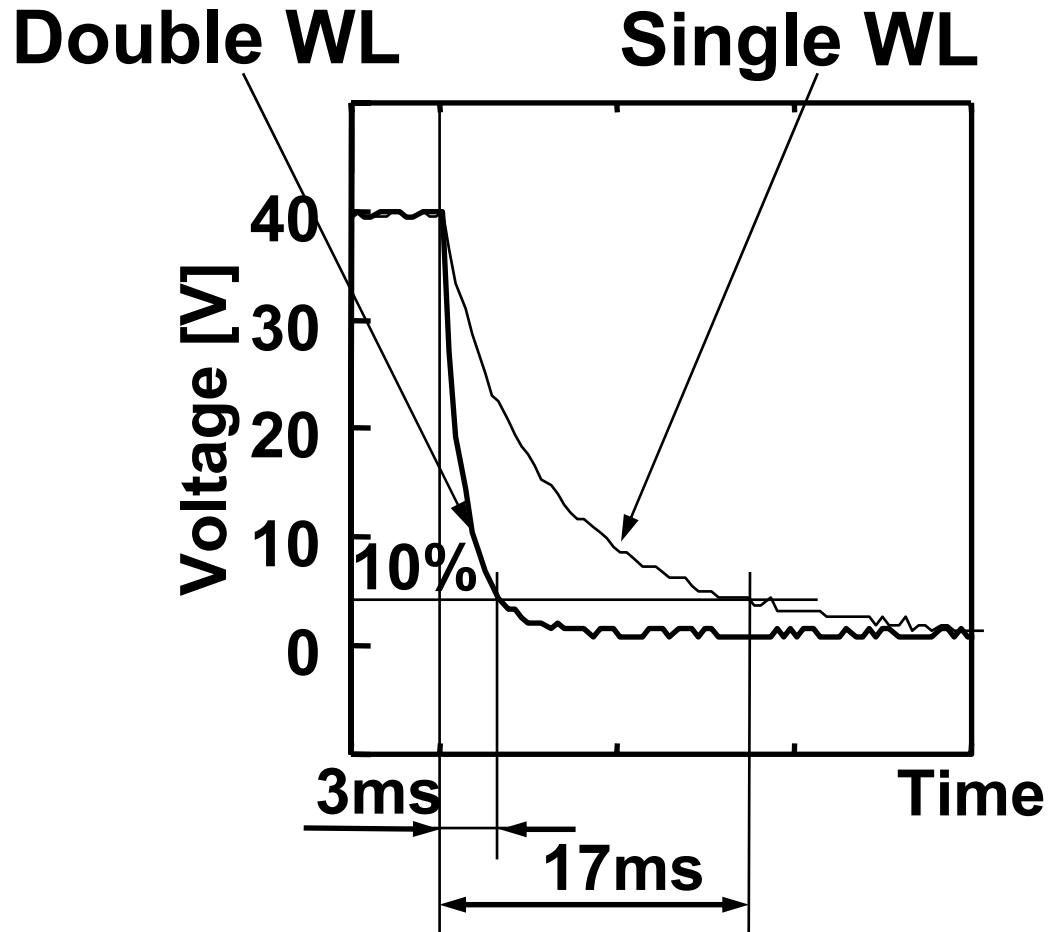
17ms

Time

- 6x faster
- Agrees with simulation.

Second bitline delay

Double BL (white)
Double BL (black)
Sense voltage
Single BL (white)
Single BL (black)
Voltage [V]
40
30
20
10
0
Time
3ms
18ms
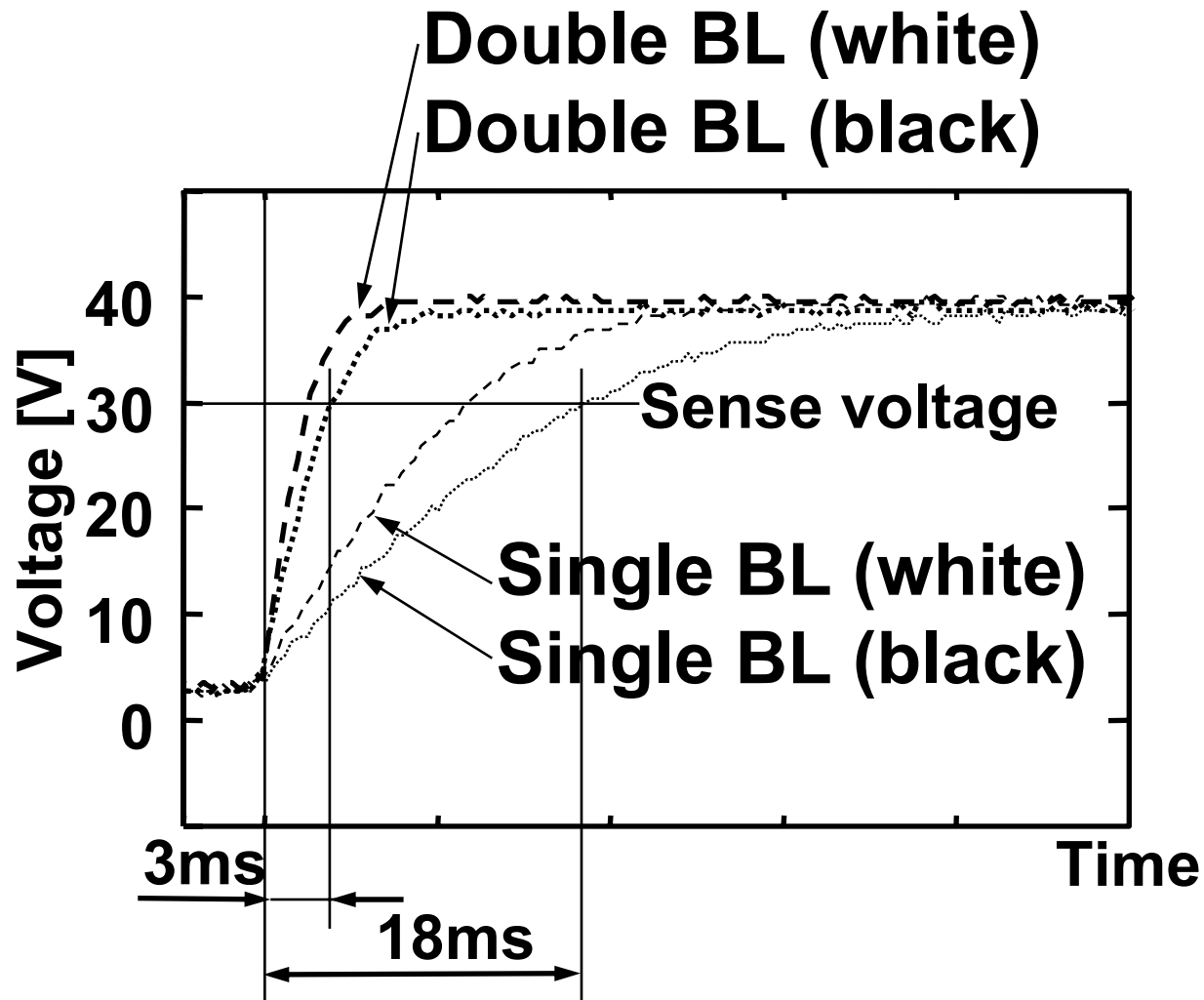
- 6x faster

Cycle time & power improvement

Cycle time

Single WL/BL: WL 17ms + BL 18ms + recovery 4ms = 39ms
Double WL/BL: WL   3ms + BL   3ms + recovery 1ms =   7ms

	Single WL/BL	Double WL/BL	
		High speed	Low power
Cycle time	39ms	7ms — **5x faster**	39ms
Total power	2.5mW	900µW — **7x less**	350µW

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Future directions

- **Organic scanner in future**

  Pixel size: 15x smaller => 300dpi

  # of pixels: 32x larger => 2048 x 2048 pixels

- **Compared to single wordline & bitline scheme, double wordline & bitline structure improves…**

  Scan-out time: 1000 seconds => 40x faster

  Power: 40x less

- **Double WL/BL is essential for large-area sensors.**

Summary

- **3D stacked sheet-type scanner**

    1 organic photodiode sheet &

    2 organic FET sheets

- **New high-speed, low-power & wide-margin decoder**

    cut-&-paste customization

- **Double wordline & bitline structure**

    Delay: 5x faster

    Power: 7x less

    Essential for future large-area sensors