An Optical/Potential/Voltammetric Multifunctional CMOS Image Sensor for On-chip Biomolecular/Neural Sensing Applications

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Outline

① Background and Objective of the work
② Measurement schemes
③ Development of functionalities
  • On-chip Light sensing
  • On-chip Potential sensing
  • On-chip Voltammetric measurement
④ Design of multifunctional CMOS image sensor
⑤ Conclusion
Background of the work

There are increasing interests in **Biosensing / Bioimaging** with LSI-based sensor chip.

We are developing CMOS, vision-chip based image sensors for:

- **On-chip cellular fluorescence imaging**
- **On-chip DNA microarray**
Concept of on-chip biosensing with CMOS image sensor (1)

Optical Sensing:
- Excitation/Illumination
- Light
- Photodiode

Capacitive coupling
- Target
- Electrode
- Metal layers

Potential Sensing:
- Electrode
- Capacitive coupling
- Voltammetric measurement
- Electrode (Au coat)

Excitation/Illumination
- Target
- Light
- Photodiode

Conductive coupling
- Opening
- Metal layers

Voltammetric measurement
Objective of this work

Develop the following three on-chip sensor pixel

1. Optical
2. Potential (Capacitive coupling)
3. Voltammetric (Electrochemical)

Design an optical / potential / voltammetric image sensor for on-chip biosensing applications
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Light sensing pixel

Based on conventional 3-Tr APS pixel with column reset mechanism
Potential sensing pixel

Sense the on-chip, local potential with an electrode which capacitively couples with the targets.
Optical / Potential dual-image sensor

Two pixel arrays are driven in a CMOS APS sensor platform

<table>
<thead>
<tr>
<th>Process</th>
<th>0.35µm 2-poly, 4-metal standard CMOS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel size</td>
<td>7.5µm x 7.5µm</td>
</tr>
<tr>
<td>Pixel number</td>
<td>88 x 144 (light sensing)</td>
</tr>
<tr>
<td></td>
<td>88 x 144 (potential sensing)</td>
</tr>
<tr>
<td>Operation voltage</td>
<td>3.3 V</td>
</tr>
<tr>
<td>Circuit size</td>
<td>1842µm x 1922µm</td>
</tr>
<tr>
<td>Readout</td>
<td>Analog current</td>
</tr>
</tbody>
</table>
Light sensing pixel

Feasible for on-chip fluorescence imaging

From the previous presentation
D.C. Ng, et al.

Light intensity [µW/cm²]

<table>
<thead>
<tr>
<th>PD discharge [%]</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light intensity</td>
<td>10^{-3}</td>
<td>10^{-2}</td>
<td>10^{-1}</td>
<td>10^0</td>
<td>10^1</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FPS</th>
<th>PD discharge [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50 fps</td>
<td>90</td>
</tr>
<tr>
<td>1.45 fps</td>
<td>80</td>
</tr>
<tr>
<td>5.5 fps</td>
<td>70</td>
</tr>
<tr>
<td>16.6 fps</td>
<td>60</td>
</tr>
</tbody>
</table>

KA response

2.5 mm

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Horizontal resolution in potential images

a) Microscope image

b) Optical image

Shadow of electrodes

0V
0V

0V
3V

-3V
5V

5V

-5V

Distance [µm]

Pixel position [pixels]

2000

0

-1000

-37.5 0 37.5

-5 0 5

Spot profile [a.u.]

d) Profile of the spot : ○

c) Potential images
Horizontal resolution in potential images
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On-chip Voltammetric Measurement

- Scan either Vin or Vc

\[
\text{Vout} = \text{Vin} - R \cdot \text{i}
\]

Measure i from Vout - Vin

Voltage follower with resistance feedback
A pixel consists of an electrode and a select SW

Pixels in a column can be selected by Y scanner

Feedback resistance: 1kΩ, 10kΩ, 100kΩ, 500kΩ
Design of an arrayed voltammetric image sensor
I – V range for voltammetric measurement

<table>
<thead>
<tr>
<th>Rfb (kΩ)</th>
<th>I_{\text{min}} (\mu A)</th>
<th>I_{\text{max}} (\mu A)</th>
<th>Sensitivity (kΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-110</td>
<td>265</td>
<td>0.969</td>
</tr>
<tr>
<td>10</td>
<td>-75</td>
<td>150</td>
<td>10.088</td>
</tr>
<tr>
<td>100</td>
<td>-18</td>
<td>16</td>
<td>93.3</td>
</tr>
<tr>
<td>500</td>
<td>-4</td>
<td>4</td>
<td>456.517</td>
</tr>
</tbody>
</table>
Cyclic Voltammogram with the sensor

Hokuto Denko HABF5001

The present CMOS sensor

C-V curves comparable with conventional potentiostats were obtained
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Optical + potential multifunctional pixel

Opt_Reset

Elec_Reset

PixelPower

PD

M1

M2

M3

M4

M5

M6

Select

Opt_Signal

Elec_Signal

V1

Sensing Electrode

Photodiode

2µm
Optical + potential columnar circuitry
Fabricated Optical / Potential / Voltammetric Mutifunctional CMOS Image Sensor

- **Process**: 0.35µm 2-poly 4-metal Standard CMOS
- **Pixel size**: 7.5µm × 7.5µm
- **Pixel number**: 320 × 240 (QVGA)
- **Operation voltage**: 3.3 V
- **Chip size**: 3980µm × 2980µm
- **Readout**: Analog voltage
Summary

An optical / potential / voltammetric multifunctional CMOS image sensor for bioscientific applications was developed.

[Results]
The basic following three functional pixels were designed, and characterized.
  • On-chip optical imaging
  • On-chip potential imaging
  • On-chip voltammetric measurement
The three functionality were implemented onto a new pixel and an QVGA optical + electric CMOS image sensor was designed.

[Future issues]
Demonstration of the on-chip imaging functionality of the fabricated sensor.
Acknowledgements

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