LAPIS’s SOI Sensor Technology

Jan. 21, 2016

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LAPIS Semiconductor’s SOI Features

LAPIS Semiconductor has developed and provided the fully depleted SOI devices for many years.

Advantages of SOI to bulk-CMOS
- Low parasitic capacitance ⇒ High Speed, Low Power
- Easy isolation ⇒ High Density

Advantages of FD-SOI
- Low off-leakage with low Vt ⇒ Low voltage operation

Basically focus on Low Power & Low Voltage operation Devices

Using experiences of FD-SOI device production, LAPIS Semiconductor is now expanding SOI technology to development of UV and X-ray sensors.
ROHM Group Light Sensing Technology

ROHM/LAPIS sensors offer broad spectral range.

<table>
<thead>
<tr>
<th>Market</th>
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</tr>
</thead>
<tbody>
<tr>
<td>-X-ray diagnosis</td>
<td>-Smart phone</td>
<td>-Camera for medical use and FA use</td>
<td>-Noncontact thermometer</td>
<td></td>
</tr>
<tr>
<td>Mammography</td>
<td>-Watch</td>
<td>-Surveillance camera</td>
<td>→Health care</td>
<td></td>
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<tr>
<td>-X-ray inspection</td>
<td>-Suntan sensor</td>
<td>-Surveillance camera</td>
<td>-Security sensor</td>
<td></td>
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<tr>
<td></td>
<td>-Weather station</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Asset</th>
<th></th>
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<tbody>
<tr>
<td>-Monolithic structure</td>
<td>-Embedded operational amplifier</td>
<td>-Wideband detection range: Visible light to Near infrared-rays</td>
<td>-Mass production by semiconductor process</td>
<td></td>
</tr>
<tr>
<td>-Without scintillator</td>
<td>-High noise robustness</td>
<td></td>
<td>-High vacuum package tech.</td>
<td></td>
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<tr>
<td>-Small, High accuracy</td>
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SOI UV Sensor
Influence of UV light

- UV-A penetrates into inner skin.
- UV-B is absorbed by scarfskin and not go farther.
- UV-A works to grow wrinkles, stains and freckles on face.
- UV radiation is though to be the major factor for most skin cancers.

<table>
<thead>
<tr>
<th>Category</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV-A</td>
<td>- Skin aging (wrinkle, freckle)</td>
</tr>
<tr>
<td>315-400nm</td>
<td>- Suntan</td>
</tr>
<tr>
<td>UV-B</td>
<td>- Sunburn</td>
</tr>
<tr>
<td>280-315nm</td>
<td>- DNA damage</td>
</tr>
<tr>
<td>UV-C</td>
<td>- Cutting DNA chain</td>
</tr>
<tr>
<td>&lt;280nm</td>
<td>- Skin cancers</td>
</tr>
<tr>
<td></td>
<td>- Immunity damage</td>
</tr>
</tbody>
</table>

UV-A: 35-50% reach to inner skin
SOI UV Sensor Structure and Sensitivity

- LAPIS UV sensor is using SOI technology.
- Only UV light can be detected by the depleted thin Si layer.
- SOI UV sensor can detect UV-A and UV-B together.

UV Diode Sensitivity Characteristics

Visible light
UV light

SiO2
Si Substrate

Current

UV Diode Sensitivity Characteristics

<table>
<thead>
<tr>
<th>Wave length (nm)</th>
<th>Sensitivity (A/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>280</td>
<td>0.04</td>
</tr>
<tr>
<td>320</td>
<td>0.06</td>
</tr>
<tr>
<td>360</td>
<td>0.08</td>
</tr>
<tr>
<td>400</td>
<td>0.10</td>
</tr>
<tr>
<td>440</td>
<td>0.08</td>
</tr>
<tr>
<td>480</td>
<td>0.06</td>
</tr>
<tr>
<td>520</td>
<td>0.04</td>
</tr>
<tr>
<td>560</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Features of UV sensor ML8511

- UV Sensor for UV-A & UV-B Detection
- Convert of the detected photo-current to voltage
- High uniformity of sensitivity by the individual trimming process
- Small current consumption 0.1uA (Standby)
LAPIS UV Sensor Development Roadmap

**ML8511**
- Voltage output
- Detecting UV-A and UV-B

- Supply Voltage: 2.7 to 3.6 V
- Low-power design
  - Operating: 300uA
  - Standby: 0.1uA
- UV Intensity Accuracy ±10%

**ML8523**
- Digital output
- Detecting UV-A and UV-B separately

- Supply Voltage: 1.65 to 3.6 V
- Low-power design
  - Operating: 500uA
  - Standby: 0.1uA
  - Power down mode: 0.1uA
- UV Index accuracy: ±1
- I2C fast mode: 400 kHz
- 10-bit ADC

**ML8524**
- Ambient light sensing
- Detecting UV-A and UV-B separately

- Supply Voltage: 1.65 to 3.6 V
- Low-power design
- UV Index accuracy: ±1
- ALS: 0.1-100,000 lx
- I2C fast mode: 400 kHz
- 16-bit ADC

ES: Q1 / 2016
MP: Q3 / 2016

ES: Q1 / 2017
MP: Q3 / 2017

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SOI X-ray Sensor
Features of SOI-Pixel Sensor

Structural feature of FD-SOI Pixel Sensor
(1) one chip monolithic X-ray pixel sensor device can be obtained.
(2) high radiation hardness for SET can be obtained.
(3) wider depletion sensor to various X-ray energy can be embedded.

FD-SOI is promising structure to realize high performance and reliable X-ray pixel sensors

Double-SOI (Option)
| Process                        | 0.2μm Low-Leakage Fully-Depleted SOI CMOS  
1 Poly, 5 Metal, MIM Cap, DMOS option  
⇒ Introduce the Buried P-well (BPW) under the Transistor  
⇒ LDD Dose Optimization to reduce RIGLEM*(Under Development) |
|-------------------------------|--------------------------------------------------------------------------------------------------|
| SOI wafer                     | Top Si : Cz, p-type, Low Resistivity  
Buried Oxide: 200 nm thick  
Handle wafer: High Resistivity Cz(700Ωcm) or FZ(≧2kΩcm)  
⇒ Prevention of Slip line generation (with SOITEC)  
⇒ Double SOI Wafer for Compensation of BOX charge (Under Development) |
| Backside                      | Thinned to 260 - 500 μm and Evaporated with Al (200 nm).                                        |

*RIGLEM: Radiation-induced gate length modulation in PMOS  
X-ray Sensor Development

Based on basic design of SOI pixel sensor technology by KEK, many kinds of sensors have been developed for variety of applications.

- **Integration-type and Counting-type Pixel Sensor (KEK)**
  - INTPIX: High Resolution X-ray Imaging with small Pixel Size (Min. 8um square)
  - CNTPIX: Photon Counting and energy dispersion, high S/N ratio
- **Sensors for X-ray Free Electron Laser (Riken)**
  - SOHPIAS: Large Dynamic Range Imaging Sensor
- **X-ray Sensor for Astrophysics (Kyoto Univ.)**
  - XRPIX: Low Noise, Trigger Driven Readout
- **X-ray Sensor for Stress Analysis (Kanazawa Univ.)**
  - INTPIX: High Speed, Portable Meas.
- **TOF Sensors for Automotive (Shizuoka Univ.)**
  - BPSPIX: High NIR Sensitivity
  - TOF(Time of Flight) Sensor

An example of X-ray image (small fish) taken by the integration-type SOI sensor (INTPIX4).
SOPHIAS (SOI Photon Imaging Array Sensor)

Utilization of SOPHIAS has been started for various experiments in SACLA@RIKEN.

- Dynamics of Atomic Structure
- Direct Observation of Chemical Reactions
- etc.

Another Application of SOPHIAS
- Heavy Particle Radiotherapy for Cancer Treatment (Gunma Univ. and RIKEN)

Results of the feasibility study. Direct observation of electron transfer will be observed with SOPHIAS. Current limitation: Observation is limited to the bond formation.

SOI X-ray Sensor for X-ray Astronomy

XRPIX for X-ray astronomy is developing by Kyoto Univ. It is intended to be equipped with next generation X-ray satellite.

XRPIX Features

- Event Driven Readout Mode
- Low Readout Noise
- High Energy Resolution

Each pixel has its own trigger and analogue readout CMOS circuit.

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SOI X-ray Sensor for Stress Analysis

The X-ray stress measurement method is widely used for investigation of Residual stress and crystal grains of metallographic structure to evaluate their quality and durability.

Stress Measurement by INTPIX4
- High-speed measurement
- Portability of equipment

Kanazawa Univ.

Soft X-ray

INTPIX4

Metal Material

S.Mitsui et al., the 17th iWoRID, 2015.
TOF (Time of Flight) sensor is developing by Shizuoka Univ. Fully depleted Si more than 100um thickness can be obtained the high Q.E. around 950nm IR region.

SOI X-ray Sensor

**Shizuoka Univ.**

870nm Low Q.E.
950nm High Q. E.
Improved by 4
Summary

- LAPIS has developed and provided the FD-SOI for low power and low Vcc operation application.

- LAPIS is now expanding FD-SOI to sensor technologies such as UV and X-ray Sensors.

- UV sensor ML8511 can be used for detection of UV intensity and next generation ML8523 is now under development for accurate UV index measurement.

- X-ray sensors have been developing with many collaborators (KEK, Riken, Shizuoka Univ., Kyoto Univ., Kanazawa Univ. etc.). It is starting to use for many application fields.