Optical Solutions for Light Intensity Enhancement in Large Pixel Size SPAD Sensor

VisEra / Ken Wu
Outline

- VisEra introduction
- Planar Lens process
- Giant Micro lens process
- VisEra for SPAD development in future
Location: Hsinchu Science Park in Taiwan

- Total Land Area 18,000 m²
- Total Floor Area 65,700 m²
- Total Clean Room Floor Area 13,500 m² (including available space)
VisEra at a Glance

**PROFESSIONAL FOUNDRY AND MANUFACTURING SERVICE**

### 4 Major Service
- On-chip color filter and microlens
- Mask design and simulation
- Image sensor testing & WLQE/AR for engineering
- On-chip multi-film

### 10 Certification
- IECQ QC080000
- ISO/IEC 27001
- EICC VAP
- ISO 14064-1
- ISO 50001
- TS16949
- ISO 9001
- ISO 14001
- OHSAS 18001
- ISO/IEC 17025
- IECQ QC080000
- ISO/IEC 27001
- EICC VAP
- ISO 14064-1
- ISO 50001
- TS16949
- ISO 9001
- ISO 14001
- OHSAS 18001
- ISO/IEC 17025

**MILESTONE**

- **2003**: 3um CF
- **2004**: 3um CF
  - Acquired CF equip. from TSMC.
  - Shipped over 100M Sensors.
- **2005**: 1.75 um CF/ML
- **2006**: 12" CF/ML
  - Move to new Fab/HQ
- **2007**: 8" BSI CF
  - MP Tech.
- **2009**: 12" CF/EBML & CVD Clear Pixel Sensor
- **2012**: 1 um CF
- **2014**: Phase II Area Ready
- **2015**: On-Chip Multi-Film Mass Production
- **2016**: On-Chip Multi-Film Mass Production
- **2017**: On-Chip Multi-Film Mass Production
ToF Sensor Application

- Rangers
  - Laser focus, proximity sensor for mobile
  - Human-machine interfaces and gaming

- Lidar: Automotive application
  - Pedestrian safety, pre-crash detection
  - Cabin driver monitoring & gesture

- Arrays: Facial recognition
Limited Active Area of SPAD Sensor

- Electronic Layout

~30% for Active area

Should need Micro-optics component for SPAD enhancement !!!
Preliminary Optical Simulation for NIR Collection

QE peak @ 850nm, Active area=25%

(1) Planar Lens with Binary
- MLH: 3.0um
- UL: 3.0um

(2) Spherical ML
- MLH: 3.0um
- UL: 3.0um

We are interested in Planar lens owing to its thinner structure height.
Electrical Fields vs Incident Angle

- Planar lens got better angular response compared with STD-ML form analysis electrical fields.

Focal length: 3.0um
Lens height: 0.3um

MLH: 3.0um
UL: 3.0um

Incident light

Center Shift (nm) vs Incident angle (deg)
Planar Lens with Muti-film

Planar Lens scheme

Multi-film

One pixel size

Lens height
Focal length

PD

PD

On chip multi-film

Planar lens

PD

PD

T%

0

850nm

Wavelength

FZP (Shorter optical path) & Multi-film upon Si Wafer might be be good for angle shifting !!!
Efficiency Comparison vs. Phase Level

Spatial Domain

- 2 level (binary)
- 4 level
- 8 level
- 16 level

Fourier Domain

- w/o Si response, 850nm, active area is 25%

\[ \eta = 1X \]
\[ \eta = 1.9X \]
\[ \eta = 2.2X \]
\[ \eta = 2.3X \]
Process for Planar Lens

**Test Vehicle**

- BSI wafer with 1.1\(\mu\)m pixel size
- Emulate SPAD’s pixel size=9.9\(\mu\)m

**Top view and cross-section**

Min. design rule: ~0.3\(\mu\)m
QE Result of Planar Lens

- 3.1~3.3 times DN (Digital number) was observed via on-target structure
- Sensitive for focus length

DN values (Before / After THK Adjustment ; Design @ 850nm )

![Diagram showing DN values and focus sensitivity](image)
New Test Vehicles for SPAD

1.1um pixel size

Planar lens: 0.5um
Focal length: 3.0um
Mini. Design rules: ~0.3um

20um pixel size

Planar lens: 0.7um
Focal length: 15um
Mini. Design rules: ~0.3um
Test Result by SPAD Test Vehicle

- Planar lens’s testing result is out of expectation completely, we will revisit optical simulation and FZP design for large size pixel.
- GML (Giant micro lens) get the 1.4 times improvement (MLH=10um)

### Design @ 637nm

![Graph showing PDP (Normalize) vs Wavelength (nm) at 637nm with FZP, GML, and No ML comparisons.]

- +40% increase in PDP at 637nm compared to No ML.
- -10% decrease in PDP at 637nm compared to No ML.
Process Flow for GML

Coating:
- Spin coating
- Si wafer

EXP / DEV:

Reflow:
- Reflow ML Material
- Substrate
Cross-section for Achievable GML

Pixel size: ~25µm
MLH: ~14µm

Pixel size: ~100µm
MLH: ~25µm
# Metrology for GML

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<tr>
<th>Type</th>
<th>AFM</th>
<th>White light interferometer</th>
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<tr>
<td>Objective Magnification</td>
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<td>50X</td>
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<td></td>
<td>50X</td>
<td>100X</td>
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<td>Available Z distance</td>
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<tr>
<td>Available X-Y distance</td>
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<td>85 x 85um</td>
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<tr>
<td>Slope limit (deg)</td>
<td>&lt;90</td>
<td>&lt;28</td>
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**Profile**

- 1. Low WPH and high cost
- 2. Z distance limitation ≤ 30um
- 3. High accuracy measurement
- 4. Suitable for Eng. Study

- 1. High WPH and low cost
- 2. Limited Micro-lens slope angle
- 3. Suitable for in-line monitor
VisEra
For SPAD

Optical

Wafer Level Characterization

Material

Multi-Film (IRC/NBP/AR)

Process

Micro-optics

On chip multi-film

PD

Transmittance (%)

850nm

Wavelength

(ASML)

(TEL)
Thanks for your attention !!!