Some lithography challenges for Optical Sensors manufacturing

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Leti Lithography Workshop
SPIE Advanced Lithography San Jose 2019
Some Lithography challenges for Optical Sensors Manufacturing

Depth & Proximity Sensing

Large high resolution image sensors

ADAS autonomous driving

Color & micro lens process

Back side integration

3D stacking / Wafer bonding

Front side / Back Side OVL Color filter

Stitching

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SPIE Advanced Lithography San Jose 2019
Outline

- Optical Sensors
- Markets
- Optical sensors & lithography challenges
The leading provider of products and solutions for Smart Driving and the Internet of Things

- Dedicated Automotive ICs
- Discrete & Power Transistors
- Analog, Industrial & Power Conversion ICs

Portfolio delivering complementarity for target end markets, and synergies in R&D and manufacturing

- Smart Power: BCD & VIP
- Power MOSFET & IGBT SiC & GaN Discrete
- Analog Mixed Signal Silicon Photonics

- MEMS Specialized Imaging Sensors
- Digital ASICs
- General Purpose & Secure MCUs EEPROM
- FD-SOI FinFET through Foundry
- CMOS eNVM

Package technologies
- Leadframe
- Sensors
- Laminate
- Wafer level

* BCD: Bipolar CMOS DMOS
* VIP: Vertical Intelligent Power
* IGBT: Insulated Gate Bipolar Transistor
# Front-End Manufacturing CIS*

(*Cmos Image Sensor)

<table>
<thead>
<tr>
<th>Digital</th>
<th>Analog and Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crolles R&amp;D</strong></td>
<td><strong>Tours</strong></td>
</tr>
<tr>
<td>FD-SOI Logic</td>
<td>Power Discrete Passive integration</td>
</tr>
<tr>
<td>BiCMOS &amp; RF</td>
<td><strong>Catania R&amp;D</strong></td>
</tr>
<tr>
<td>Specialized Imaging</td>
<td>Advanced BCD MOSFET and Silicon Carbide</td>
</tr>
<tr>
<td>Embedded-NVM</td>
<td><strong>Agrate R&amp;D</strong></td>
</tr>
<tr>
<td>EEPROM</td>
<td>Advanced BCD MEMS</td>
</tr>
<tr>
<td><strong>Rousset</strong></td>
<td><strong>Singapore</strong></td>
</tr>
<tr>
<td>Embedded-NVM</td>
<td>Power Discrete BCD</td>
</tr>
</tbody>
</table>

*5 Front-End Manufacturing CIS sites, including 3 R&D centers*

- **Cronos**
- **Rousset**
- **Agrate**
- **Singapore**

**Tech Stack:***
- Smart Power: BCD (Bipolar - CMOS - Power DMOS)
- FD-SOI CMOS
- Analog & RF CMOS
- eNVM CMOS
- **Specialized Imaging Sensors**
- MEMS
- Discrete, Passive Integration, Power MOSFET, IGBT, Silicon Carbide, Gallium Nitride
- Vertical Intelligent Power

**Packaging Technologies:**
- Leadframe – Laminate – Sensor module – Wafer level
From traditional Imaging for handsets to strategic refocus on key fast growing applications
**ST Imaging Solutions**

<table>
<thead>
<tr>
<th>Time of Flight Today</th>
<th>Time of Flight Tomorrow</th>
<th>Global Shutter</th>
<th>Rolling Shutter</th>
<th>Image Signal Processors</th>
</tr>
</thead>
</table>
| • High accuracy & Low Power  
• Multi-zone & multi-object capability  
• 40 nm SPAD | • Increasing resolution  
• All-in-one & low power  
• 3D-BSI | • Lowest pitch global shutter  
• High MTF and QE including Near-IR  
• Small PCB footprint & low power | • HDR up to 140dB  
• In-pixel Flicker-Free, without trade-off  
• Automotive grades | Companion chip for ST Global & Rolling shutter sensors |

**Proximity & Ranging Sensors**  
Personal Electronics and Industrial

3D Sensing  
Smartphones, Smart home, Smart Driving (LiDAR*)…

Computer Vision  
Consumer 3D (Stereo, Structured Light)  
Smart Driving (In-cabin…)  
Industrial (Machine Vision…)

Human Vision  
Smart Driving (e-mirror, ADAS…)  
Security (HDR, flicker immune…)

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*LiDAR*: Light Detection & Ranging (measure distance to a target by illuminating the target with a pulsed laser light and measuring the reflected pulse with a sensor. Differences in time of flight and wavelengths is used to make 3D representations of the target)
CIS technologies at ST

Specialized CMOS Image Sensor
Rolling & Global shutter
Pixel $\geq 1.4\mu m$
Visible and Near IR

- 90/65nm FSI
- 90/65nm BSI
- 3D 90/65nm BSI top
  40nm CMOS bottom

FlightSense™
SPAD pixels

- 130/90nm CMOS
- 2D
  40nm CMOS
- 3D
  40nm CMOS

FSI: Front Side Illumination light comes from the top
BSI: Back Side Illumination light comes from the rear

SPAD: Single Photon Avalanche Diode

2D $\rightarrow$ 3D: Wafer / chip stacking (CIS is a strong driver for 3D integration)
Integration Time Impact on Moving Object
Rolling vs Global Shutter
Optical sensors drive for 3D integration

System On Chip (SoC)

System In Package (SiP)
Major Breakthrough

Back-Side Illuminated (BSI)

Principle

Avoid light interaction with BEOL interconnects

With Different TSV strategies

Resulting in higher quantum efficiency

Outline

 STMICROELECTRONICS
 FROM MOORE to MORE than MOORE

 Optical Sensors
 Markets

 Optical sensors & lithography challenges
Technologies and related litho challenges

- **Colorisation / micro-lens**
- **“Complex” OV distortions**
- **Bonded wafer OVL control**
- **Stitching**

BSI
STITCHING
## Image Sensors large product size range

<table>
<thead>
<tr>
<th>Die size</th>
<th>Stitching</th>
<th>Resolution, pixel size</th>
<th>Dies per 300mm wafer</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>397 cm²</td>
<td>2D</td>
<td>1 Mpix, 190 µm</td>
<td>1</td>
<td>Medical</td>
</tr>
<tr>
<td>100 cm²</td>
<td>2D</td>
<td>1.5 Mpix, 80 µm</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>33 cm²</td>
<td>2D</td>
<td>135 Mpix, 3.9 µm</td>
<td>6</td>
<td>High end Camera</td>
</tr>
<tr>
<td>18 cm²</td>
<td>2D</td>
<td>37 Mpix, 6µm</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>11 cm²</td>
<td>1D</td>
<td>24 Mpix, 6 µm, 40 Mpix, 4.6 µm</td>
<td>48</td>
<td>Automotive camera</td>
</tr>
<tr>
<td>60 mm²</td>
<td>No</td>
<td>1.2 Mpix, 3.75 µm, 2.5 Mpix, 3.2 µm</td>
<td>~ 1000</td>
<td>Consumer camera</td>
</tr>
<tr>
<td>35 mm²</td>
<td>No</td>
<td>8 Mpix, 1.4 µm, 12 Mpix, 1.1µm</td>
<td>~ 2000</td>
<td></td>
</tr>
<tr>
<td>10 mm²</td>
<td>No</td>
<td>2x1024 pix, 30 µm</td>
<td>~ 7000</td>
<td>SPAD ToF telemeter</td>
</tr>
<tr>
<td>2.4 mm²</td>
<td>No</td>
<td>2x144 pix, 16 µm</td>
<td>~ 28000</td>
<td>SPAD ToF prox. sensor</td>
</tr>
</tbody>
</table>
Stitching for large products

.product area > Max reticle size : 26 x 32 mm²

1D stitching

2D stitching

Huge Scanner TP penalty !!

For process uniformity

CD / OV and other process monitoring structures can only be present in black / yellow / pink areas
Stitching for large products

*product area > Max reticle size : 26 x 32 mm²*

Scanner OV stitching performance are good enough to not be seen in device
COLOR & µ Lenses
Color = additive reconstruction Pixel signal processing

Out of photo diode matrix, image is black & white

Get color from Red Blue
Green color filter matrix

Image Processing

Colour mosaic RGB
(Bayer pattern ) at sensor level

Additive Reconstruction

Image restitution

RGB Signal for each pixel
Color filters & μ-lens stack overview

Red Green Blue bayer pattern

Dual μ-lens

7 i-line litho steps
Color filters & µ-lens stack overview

- **GREEN**
  - Green patterning

- **BLUE**
  - Blue patterning

- **RED**
  - Red patterning

- **SPACER**
  - Planarization of color filters

- **ULENS1**
  - µlens small

- **ULENS2**
  - µlens large

- **Topcoat**
  - Topcoat deposition & patterning

**NEGATIVE PHOTORESIST**
- RGB = pigmented
- Planar = no pigment

**POSITIVE PHOTORESIST**
- Melt properties

**POSITIVE PHOTORESIST**
- Classic Litho

*Unlike classical lithography, these materials will stay on the device. Need to withstand ageing / reliability etc… Embedded monomers and high temperature baking leads to material prone to outgasing (bad for lenses and exhausts), and rework is not trivial.*
Color Material is a pigment dispersed into a negative type photo resist

1. Pigment: Organic Pigment (G & B have Copper)
2. Resin: Alkaline developer soluble polymer
3. Monomer: Photosensitive X-linker (some soluble bounds)
4. Initiator: Generate radicals under UV light
5. Solvent: Low toxicity Organic Solvent

➢ Baking T° are > 200°C

Due to film absorption i-line dose changes accross film thickness. This dose gradient depends on color resist absorbance. Different profiles & risk of lift-off
- Melted or Etched µlenses

Lithography step
- coating
- exposure
- developement

Melt step
- thermal resist reflow
- thermal resist crosslink

Etch step
- transfer in underlayer

• Specific challenge : MULTIPLE LENS SIZE
  • Multiple patterning flow sequence allows various µlens dimensions
  • Maximal width dimension is limited by material thickness availability
• Specific challenge: METROLOGY
  ➢ SEM contour method allows multiple measurements
    • Fill factor (lens coverage of pixel, %) linked to QE performance
    • Gap CD (nm)
    • Gliding reflow (nm)
    • ...

  See: B. Le Gratiet et al. “Contour based metrology, getting more from a SEM image”, 10959-56 SPIE 2019

• Specific challenge: DEFECTIVITY
  ➢ Automatic Defect Classification (ADC) required to track misprocessing (overmelt / undermelt)

Some OVL challenges
DTI / CDTI acts as a light Guide and also a barrier to avoid photons from one pixel to go into the next one (cross-talk).

This deep trench can be filled with different materials which can generate local stresses in the wafer.

This can induce strong / complex local OV distortion during Front End CMOS process.

See example next slide.
When performing color / µlens processes, wafer has been bonded to a wafer carrier and back grinded.

Stress level in wafer is high and OV distortion too.

Also alignment and OV measurement targets are buried at the initial surface of CMOS wafer.

Rear side Color filter and µlenses must be well aligned to the front side photo diode. Due to color materials the wavelength used for alignment need to be « tunable ».
CONCLUSION

• Image sensor technologies is providing a lot of diversity in terms of
  • pixel and product sizes
  • process complexity (from few masks to more than 80 masks levels with 3D stacks)
  • Technology nodes
  • new process bricks including lithography challenges

• New applications based on depth sensing are popping up driving a solid CAGR: growing demand & activity
  • Autonomous driving
  • AI / AR
  • Machine vision
Technology for Optical Sensors

Depth & Proximity Sensing

Large high resolution image sensors

ADAS autonomous driving

Color & micro lens process

Back side integration

Front side / Back Side OVL Color filter

3D stacking / Wafer bonding

Stiching

Acknowledgment to:

S. Lhostis / C. Tavernier / O. Noblanc / F. Roy / M. Yang / O. Mermet / X. Gerard / B. Mortini

and all image sensor process engineers