CMOS Sensor Technology
What is next in CMOS Sensor Technology?

• On-Sensor Polarization
• Curved CMOS Sensors
• Stacked CMOS Sensors
• QuantumFilm™
• Organic Photoconductive Film sensors
• 3rd Generation Sony Pregius
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Polarization of Light

• Light is an electromagnetic wave with oscillating electric and magnetic fields.

• Unpolarized light: light waves whose electric field vectors are randomly oriented w.r.t the direction of propagation.

• Polarized light: light waves whose electric field vectors are restricted to a single plane w.r.t the direction of propagation.

• Most light sources emit unpolarized light.
Polarization in Nature - Navigating

- Bees use the sun to navigate
- Sensing polarized light enables bees to sense the position of the sun on cloudy days
Light can be polarized by reflection

- Reflection is one way of polarizing light waves
- The magnitude of this effect depends on the material and angle of incidence of light
- Metals reflect the polarization of the light falling on them and hence there is minimal polarization.
- Non-metallic materials tend to reflect most vibrations on a single plane parallel to the plane of incidence.
Polarization in Nature - Hunting

- Predators use polarized light in different ways to help them hunt
- Cuttlefish and mantis shrimps are sensitive to polarized light which helps them hunt silvery fish
- Diving birds’ eyes block polarized light reflecting off water, enabling them to see below surface of the water more clearly
Polarization in Nature - Hiding

- Some fish have evolved scales capable of reflecting unpolarized light helping them avoid detection by predators using polarized light
Light can be polarized with filters

- Polarizing filters pass light which is aligned with their angle of polarization
- Polarizing filters block light which is not aligned with their angle of polarization
Common applications of polarized light

• Sunglasses are common use of polarizing filters
  • Their polarizers are aligned to block polarized light reflecting off horizontal surfaces
  • Passing or blocking different angles requires the filters to be rotated
Rotating polarizing filters

• Rotating a polarized filter changes the amount of plane polarized light the filter blocks or passes
• The transition is smooth and predictable
• The relationship between the maximum and minimum amount of polarized light is called the *extinction ratio*
IMX250MZR has on-sensor filters

- Sensor based on the popular IMX250
  - 3.45µm pixel
  - Global shutter
  - Low read noise
- Each pixel has its own polarizing filter/array placed on-chip
Micrograph of polarization grid
Effect on imaging performance

• Placing a polarizer in-front of the photodiode reduces the quantum efficiency of the sensor

• Sony Pregius sensors feature low read noise enabling high gain without a significant noise penalty
Greyscale values are tightly correlated to angle of polarization

- Rotating a plane polarized light source results in a predictable change in pixel gray values

![Polarized Pixel Value vs Shifted Angle](image-url)
Degree of Linear Polarization

• The Degree of Linear Polarization (DoLP) is the amount of light which is polarized at a particular point in the image.

• This information can be used to identify reflections by identifying regions with a high degree of linear polarization.
Angle of Linear Polarization

• The Angle of Linear Polarization (AoLP) is the average polarization angle at a given pixel in the image.
Stokes Parameter

\[ S_0 = I_0 + I_{\theta 0} \]

\[ 0 \leq S_0 \leq 512 \]

Poincaré sphere

\[ S_1 = I_0 - I_{\theta 0} \]

\[ -255 \leq S_1 \leq 255 \]

\[ S_2 = I_{45} - I_{135} \]

\[ -255 \leq S_2 \leq 255 \]
Interpolation of Polarized images

• When the sensitives of adjacent pixels to wavelengths or polarization angles differs, demosaicing is used to generate a full resolution image

• The goal is to preserve the highest spatial resolution and minimize artifacts of the interpolation process
Interpolation of monochrome images

• Interpolation between the four pixels of different polarization angles is very similar to RGB demosaicing
On-sensor polarization replaces mechanical solutions

• Capturing multiple angles of polarization in a single image eliminates the mechanical and software complexity of working with filter wheels
  • Reduce mass
  • Reduce power consumption
  • Reduce system complexity
  • Reduce development time
  • Increase system throughput
Applications
FLIR Blackfly S with IMX250MZ

• BFS-U3-51S5P coming Q3, 2018
• 29 mm x 29 mm footprint with an “ice cube” form factor
• 3.5W
• 75FPS on USB 3.1 Gen 1 Interface
• Spinnaker SDK supports demosaicing, and DoLP and AoLP measurements
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Curved CMOS sensors

• Curved sensors enable more compact and less expensive optics
• Eliminating the need to lens elements to flatten the image
• Fabrication is difficult the process requires thin silicon wafers to be bent without cracking
• Microsoft, Nikon, Canon and Sony all have curved sensor patents and have demonstrated devices
Curved CMOS reduces Chief Ray Angles

• Improve performance of sensor towards the edges by minimizing falloff caused by high Chief Ray Angles (CRA)
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Stacked CMOS

- Stacked CMOS adds layer of DRAM between the sensor and the output circuitry
Stacked CMOS

- Building an image sensor directly on top of DRAM memory enables high speed readout
- Image data can be transferred to on-sensor memory
- Image data can be transferred off the sensor at a slower rate
- This enables very high speed buffered bursts
- High speed rolling shutter readout can greatly reduce rolling shutter distortion
Advanced on-sensor functions

- Building on the stacked CMOS technology, Sony have demonstrated a sensor with separate sensing and output streams.
- On-sensor image processing can do basic object detection and motion vector at 1000fps.
- Low speed VGA output stream for monitoring.
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Quantum Dots

- QuantumFilm™ is based on quantum dot technology
- Can be tuned to wavelength by changing the size of the quantum dots
- The current version of this sensor uses a film sensitive to visible light covered by color filters in a Bayer pattern
Quantum Film

• Bayer pattern enables the use of existing color processing pipelines
• Sampling a 13 MP 1.1µm color sensor in 2015
• Targeted at the mobile phone industry, but no adoption
• In late 2016 InVisage started promoting a 13MP, 1.1µm NIR sensor for use with IR structured light
• Acquired by Apple in November 2017
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Organic Photoconductive Film Sensors

• Sensor technology developed by Panasonic
• Novel pixel structure replaces silicon photodiode with photoconductive film
• Sensitivity is dependent on voltage applied to photoconductive film
Advantages of OPF sensors

- Greater fill factor relative to traditional CMOS enables higher resolutions in smaller sensor sizes
- Varying the voltage applied to the OPF can act as an ND filter enabling a high saturation mode
- Global shutter can be realized by switching the sensitivity to zero at the end of the exposure across the entire array
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Third generation Sony Pregius

- Sony's third generation of high-performance global shutter machine vision image sensors introduces exciting new features
- Maintains the low read noise characteristic of Pregius sensors
- Improved dynamic range - 79dB
- Transition from LVDS to SLVS-EC interface delivers 18 Gbit/sec throughput
Self Trigger Mode

• A region of interest can be defined as a sensing zone
• The sensing zone can automatically trigger image acquisition in the capture zone
• Simplify systems by eliminating the need for external triggering
Dual trigger mode

- Capture two regions of interest at different exposure times with a single trigger input
- Eliminate the need for multi-exposure HDR imaging
New Pixel Size

• 3rd generation Pregius introduces a 4.5µm pixel
• Intermediate pixel size between 1st generation 5.86µm and 2nd Generation 3.45µm
• The first sensor in this line will be the 7.1 MP, 1” IMX420
• Greater saturation capacity than 2nd generation Pregius sensors
• Greater resolution than 1st generation Pregius sensors