Visible Light
CMOS Image Sensors

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Outline

- Introduction to CMOS image sensor pixels
- Examples of sensors
- Customer trends
- CMOS image sensor technology trend
- Thoughts on next 5 years
3Transistor (3T) CMOS APS

- Use source-follower “amplifier” to drive column bus
Voltage on 3T Pixel vs. Time

Pixel sampled twice to remove variations in threshold voltage of pixel source-follower and reset level.
Simplified Signal Chain

- **Photodiode Voltage**
  - Integration starts
  - Pixel reset level sampled
  - Signal sampled

- **Photon Diode Voltage**
  - 0V
  - 1V
  - 2V
  - 3V

- **Time**
  - 33 ms
  - 66 ms

- **Net Signal**

**Diagram Components**
- **Pixel**
  - VDD
  - RST
  - RS
- **Global Integration**
  - HOR BUS
  - VLP
- **Column BUS**
  - CS
  - SIG
  - SHR
  - SHS
  - RST
  - VLN

**Micron**
Imaging System on a Chip

Digital Logic for
• User Interface
• Sensor Setup
• Timing Generator
• Digital Signal Processing
  – Color Processing
  – White Balance
  – Image Enhancement
• Data Output Formatting

CMOS Active Pixel Color Imaging Array

Analog Signal Processing
• Data Sampling
• Noise Reduction
• Gain

Analog-To-Digital Conversion
Spectral Response of Eye and Silicon

![Graph showing the spectral response of the human eye and silicon. The graph plots wavelength (nm) on the x-axis and relative response on the y-axis. The human eye response is characterized by a peak around 600 nm, while silicon response shows a broad response across a wider range of wavelengths.]
Fill Factor

- A pixel is divided into a sensing portion and a readout portion
- Fill factor is the ratio of sensing area to total area and is typically about 20-30%
Color Filter Arrays and Microlenses

Microlens layer

Color filter layer

Metal opaque layer

Photodiode

Silicon substrate
Resolution and Sensitivity

- More pixels = high resolution
- Smaller pixels = less sensitivity
Optical Formats

Pixel Size (um)

Lens Format

7.8 mm
5.6 mm
3.6 mm
“1/4 in”
2.8 mm

CIF
VGA
1.3M
2.1M
3.3M
4.1M
Pictures from PC Camera Sensors

CIF Resolution (352 x 288)

VGA Resolution (640 x 480)
1.3Mpixel High Speed Sensor

- 1280 ADCs per chip
- 5T pixel
- 500 pictures per second at full resolution
- Shutter from 1/30th sec to 1/100,000th sec
- Shutter efficiency > 99.99%
- Rotating fan image

1/33,000 sec = 30 usec
Freeze frame shutter
Pill Camera

- **Pixel Format:** 256 X 256
- **Pixel Size:** 10 µm X 10 µm
- **Frame Rate:** 2 fps
- **ADC:** On-Chip, 8 bits
- **Power Supply:** 2.8 V
- **Power:** 3 mW

*Krymski 1998*
4 Mpixel sensor 240fps ERS

- 2352 x 1728
- 7 µm x 7 µm pixel pitch
- 16x10b digital output
- 240 fps ERS
- 960 Mbytes/sec at 66 MHz
- 4000 bits/lx-sec
- 3.3 volt operation

Krymski 2001
Customer Drivers

- Incredibly fast price point erosion (2Mpixel CCD now sells for $8 in Japan)
- Voltage scaling required to be compatible with companion chips (3.3V -> 2.8V ->...1.8V)
- Power dissipation <200 mW/megapixel for portable apps
- CCD performance sets benchmark for DSC applications (SNR, dark current, etc.)
- CMOS performance fine for PC and wireless applications
A Very Small Digital Camera in 1995

- 2nd generation APS camera
- JPL 256x256 element APS
- On-chip timing/control
- On-chip FPN suppression
- Separate 10-bit ADC
- Separate FPGA
- Serial digital camera I/O
Cell Phone Cameras Are Small
Technology Challenges

- Smaller pixels
- Maintain or improve SNR with smaller pixel
- Maintain or increase dynamic range with lower operating voltages
- Reduce dark current
- Reduce number of defective pixels
- Reduce power dissipation in analog and digital circuits while increasing functionality
Diffraction Limit

Airy Disk Diameter
\[ D = 2.44 \times F# \]

Cheap Lens Resolution (30 lp/mm)

High Performance Lens Resolution (120 lp/mm)

Wavelength (nm)

Size (microns)
Alignment to Mainstream Technology

- CMOS APS starts diverging from mainstream CMOS to improve pixel performance

Graph showing the cost of system miniaturization over time, with a window of opportunity for CMOS APS technology.
Buried Photodiodes

Conventional Photodiode

Buried Photodiode
4T Buried Photodiode

- Reset Pixel
- Integrate
- Readout
  - Reset FD
  - Read FD
  - Transfer Q
  - Read FD

BPD

FD

TG

Vfd
Comparison of Pixels

Three-transistor (3T) photodiode-type pixel

- fewer transistors
- easier to implement
+ better under good light
- poorer under low light

Four-transistor (4T) pinned-photodiode-type pixel

- more transistors
- challenge to implement
- poorer under good light
+ better under low light
Image Sensor Revenue Projections

Sources: CD analysis based on OEM and industry research reports
CMOS Image Sensor Market Growth

Sources: CD analysis based on OEM and industry research reports
CMOS Vs. CCD Market Growth

Percentage

2002 2003 2004 2005 2006 2007 2008

CMOS

CCD