Visible Light CMOS Image Sensors

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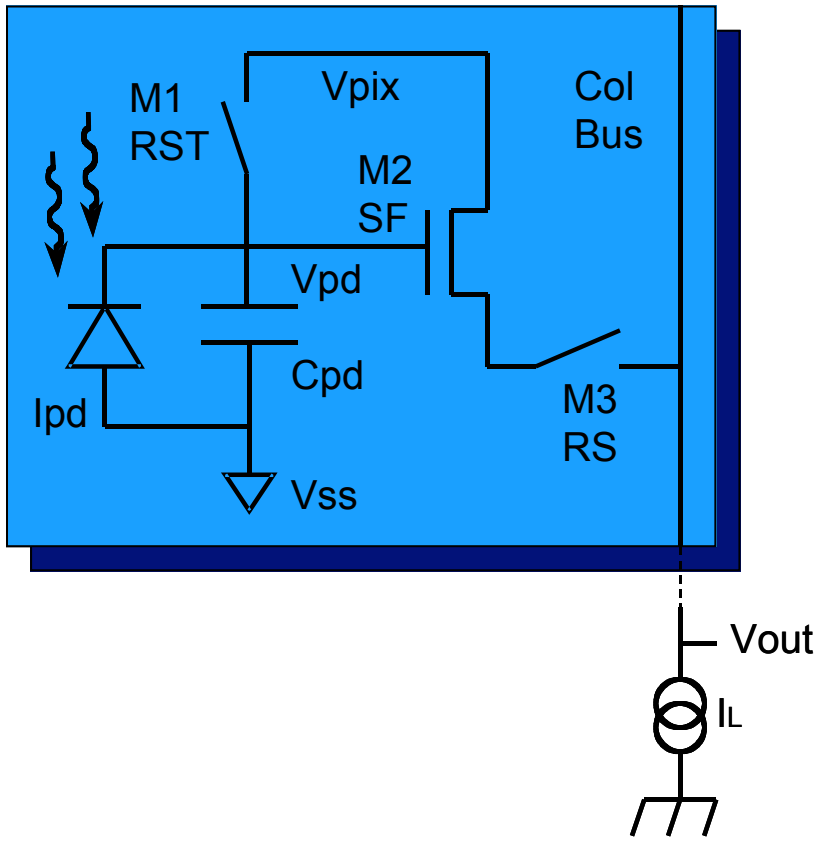
Outline

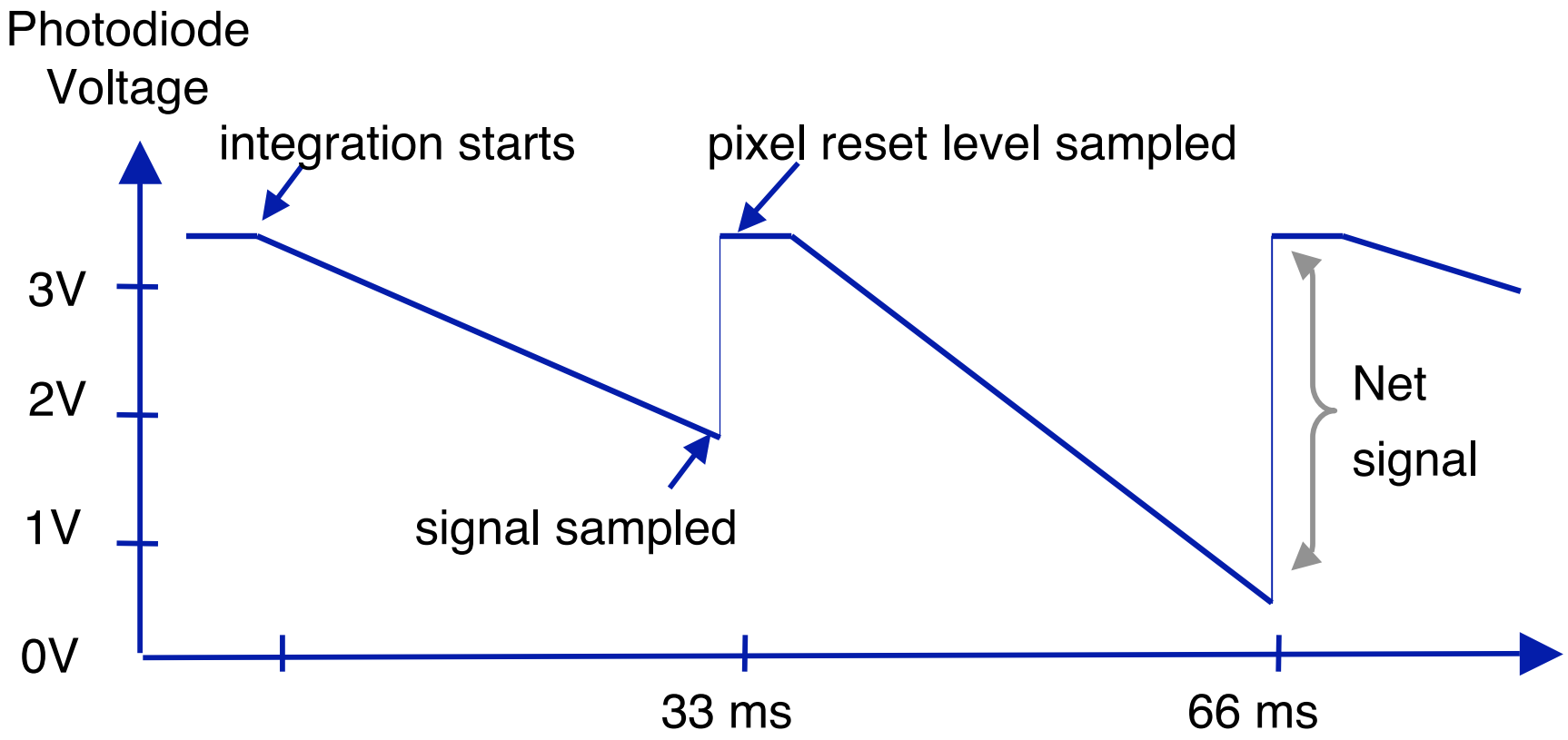
- Introduction to CMOS image sensor pixels
- Examples of sensors
- Customer trends
- CMOS image sensor technology trend
- Thoughts on next 5 years

3Transistor (3T) CMOS APS

- **Use source-follower "amplifier" to drive column bus**

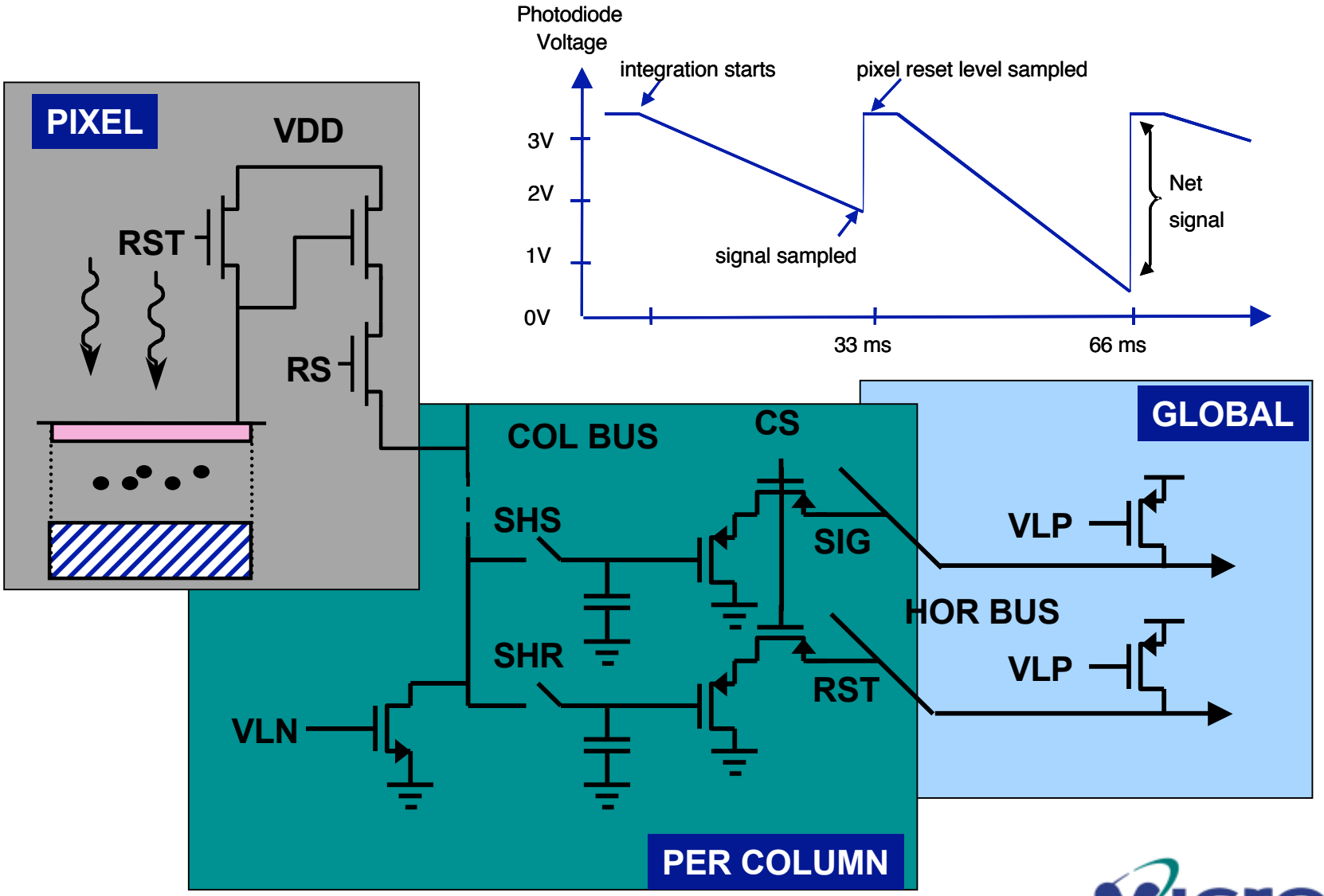


Voltage on 3T Pixel vs. Time



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

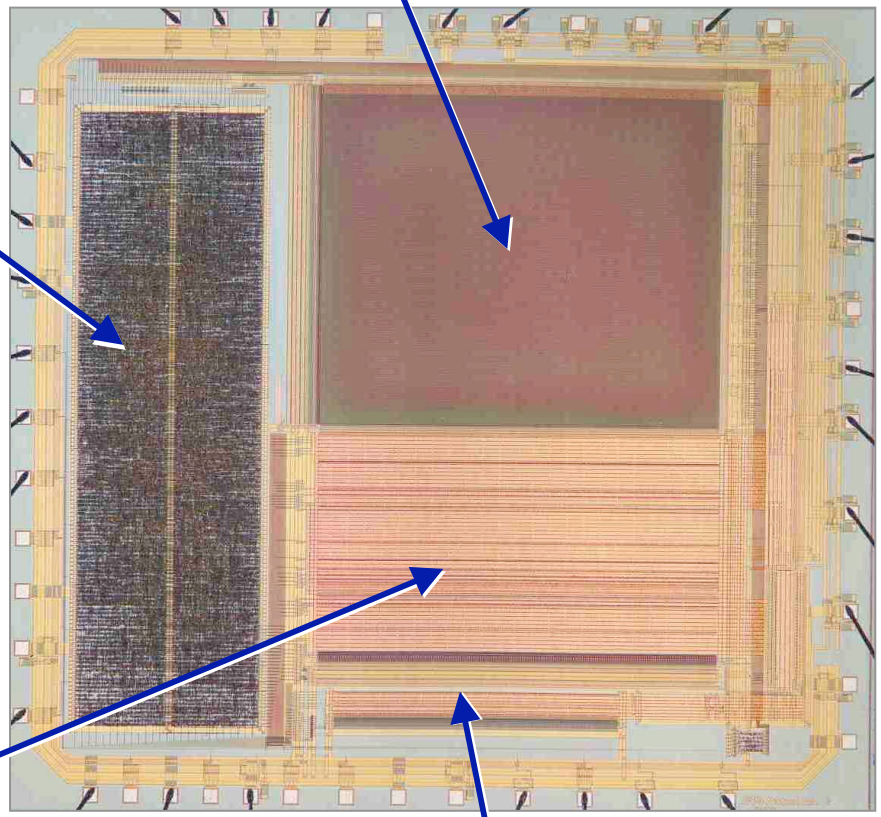
Simplified Signal Chain



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

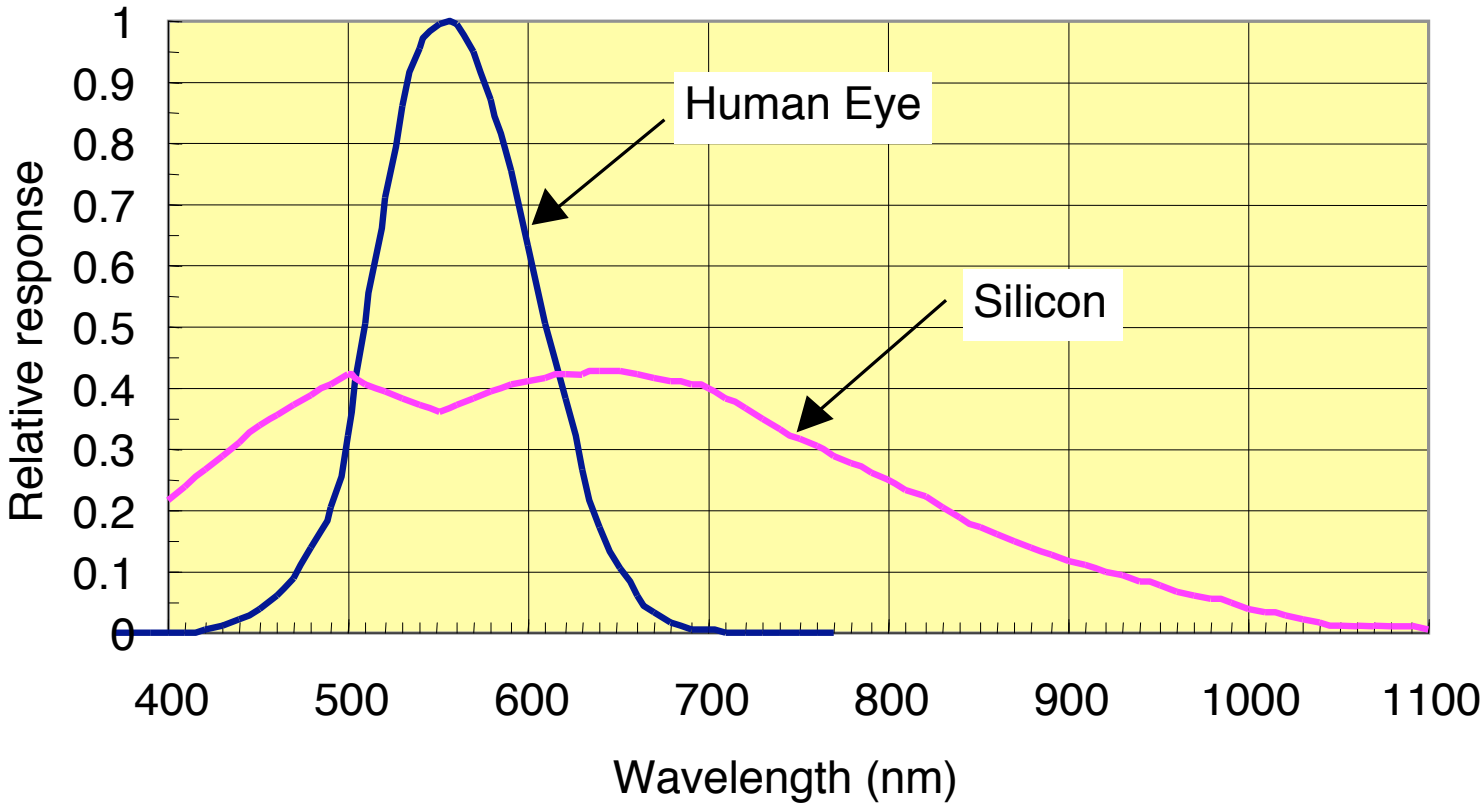
CMOS Active Pixel Color Imaging Array



Analog Signal Processing
- Data Sampling
- Noise Reduction
- Gain

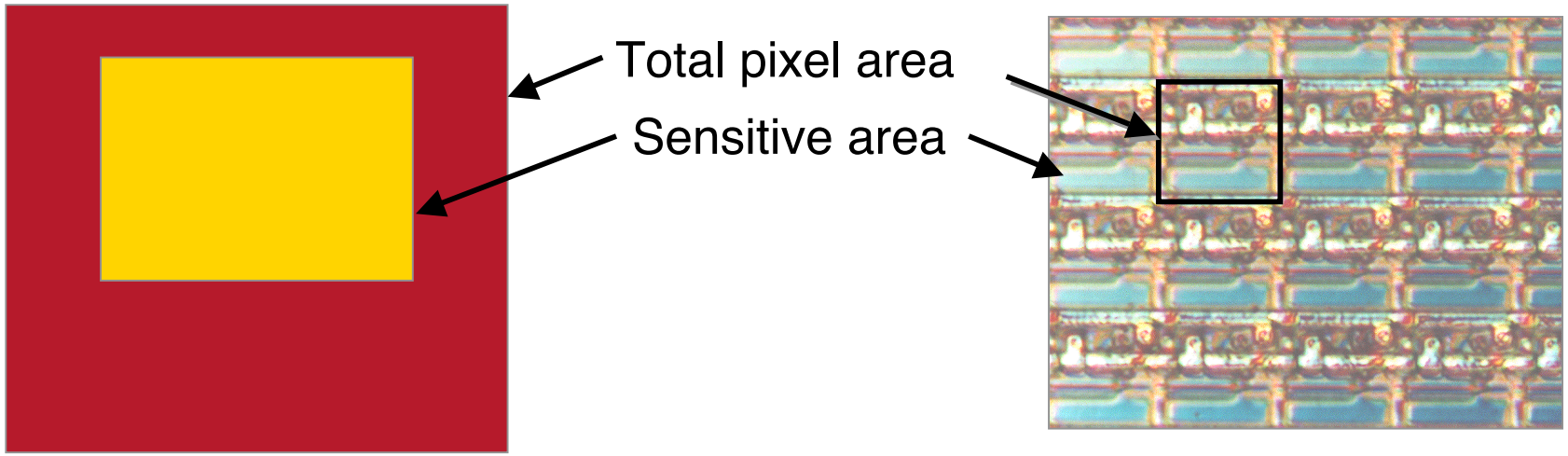
Analog-To-Digital Conversion

Spectral Response of Eye and Silicon

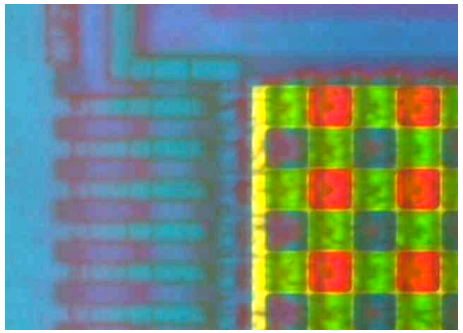


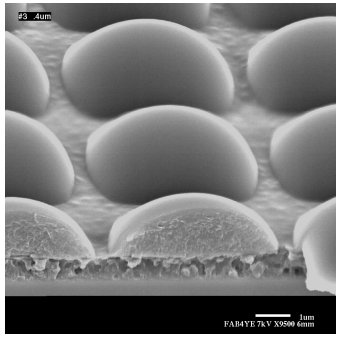
Fill Factor

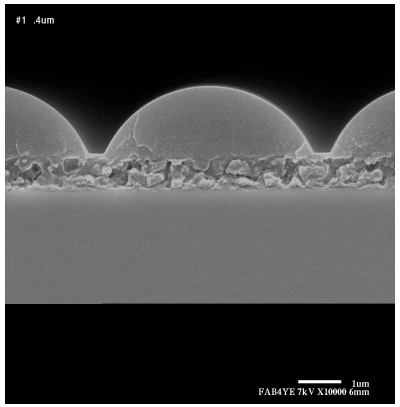
- A pixel is divided into a sensing portion and a readout portion
- Fill factor is the ratio of sensing area to total area and is typically about 20-30%

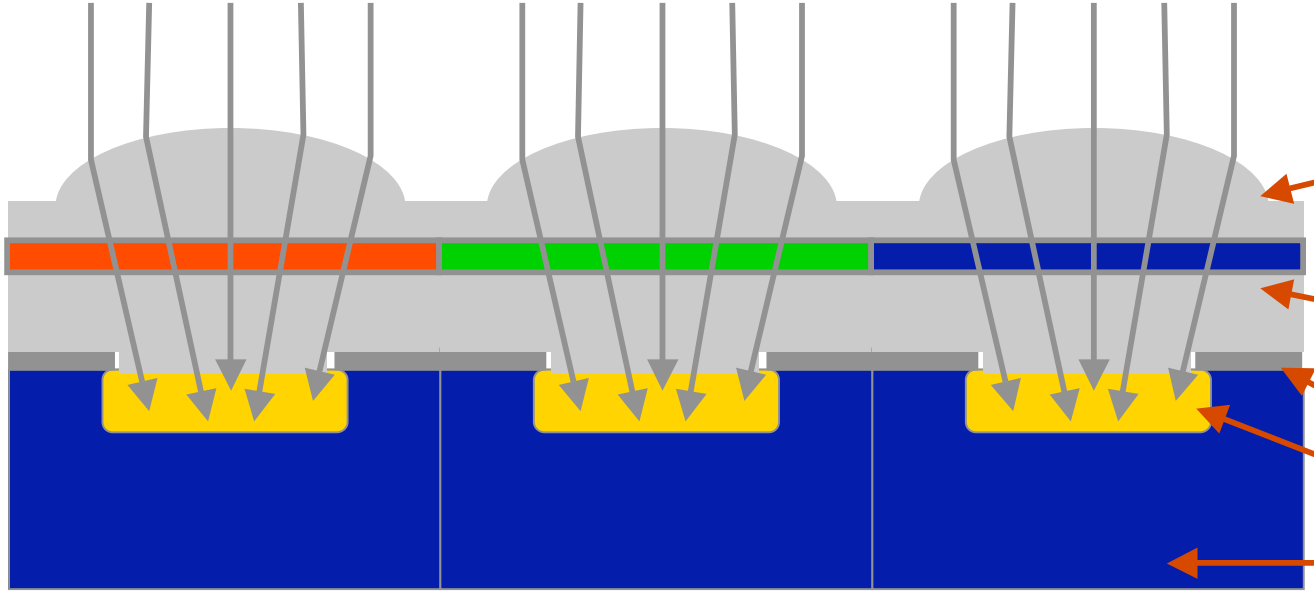


Color Filter Arrays and Microlenses



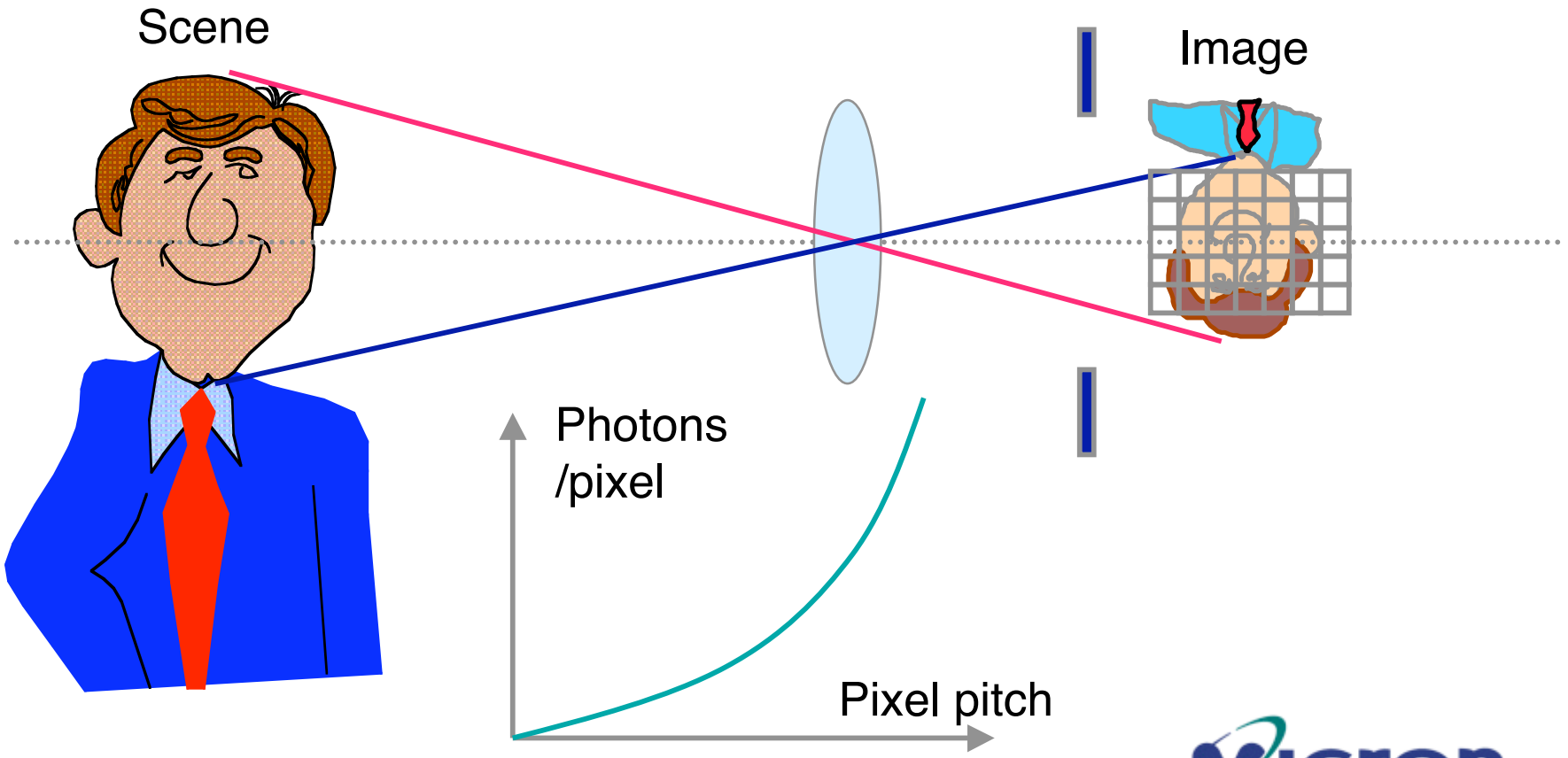




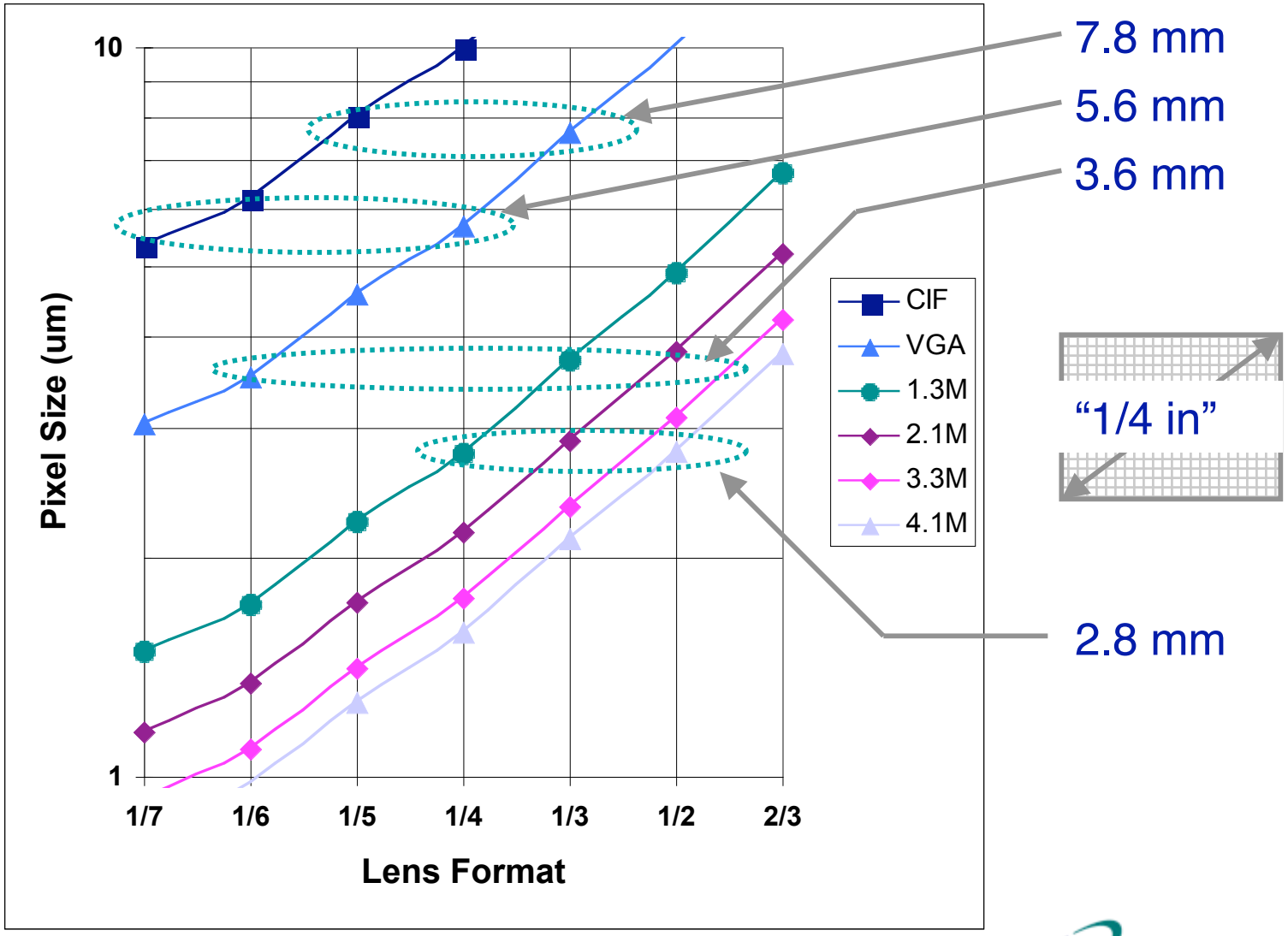


Resolution and Sensitivity

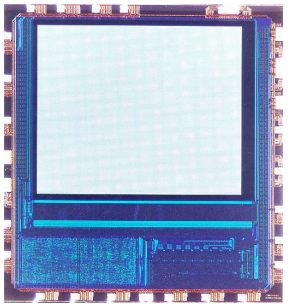
- More pixels = high resolution
- Smaller pixels = less sensitivity



Optical Formats



Pictures from PC Camera Sensors

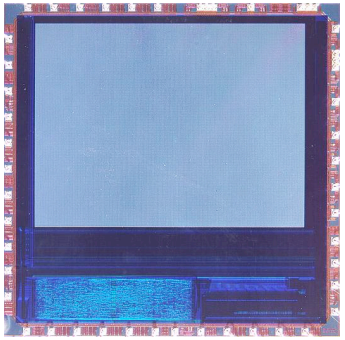


CIF Resolution

(352 x 288)

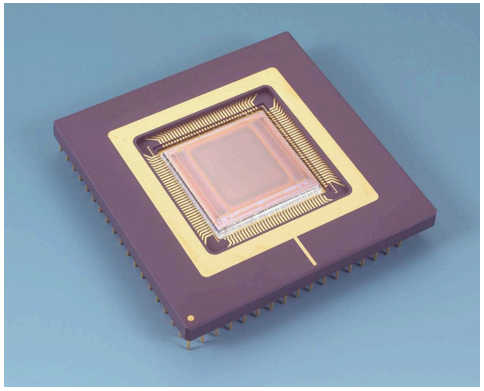
VGA Resolution

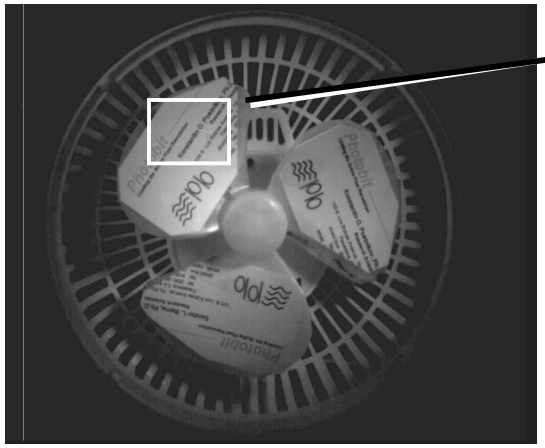
(640 x 480)

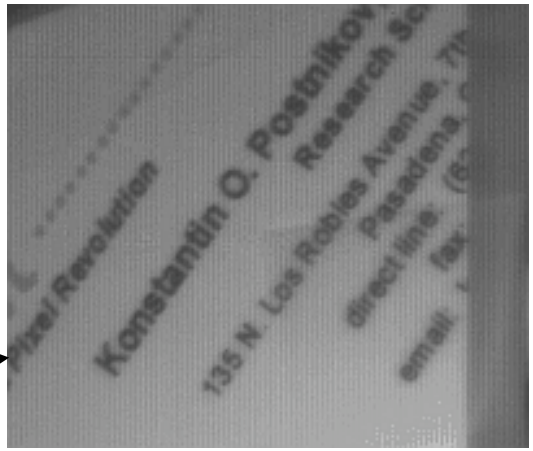


1.3Mpixel High Speed Sensor

- 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 →

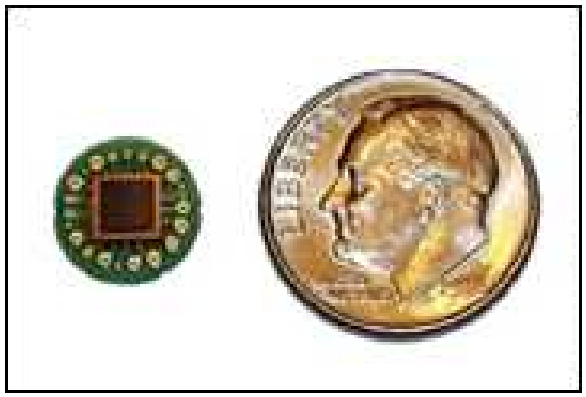






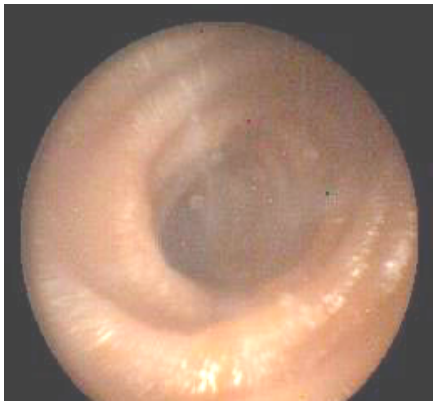
1/33,000 sec = 30 usec
Freeze frame shutter

Pill Camera



Sensor and US$0.10

Pill Camera and US$0.25



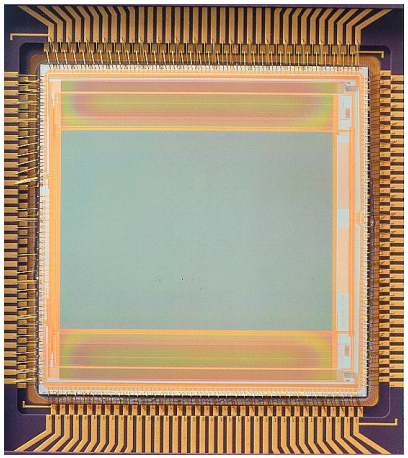
View inside small intestine

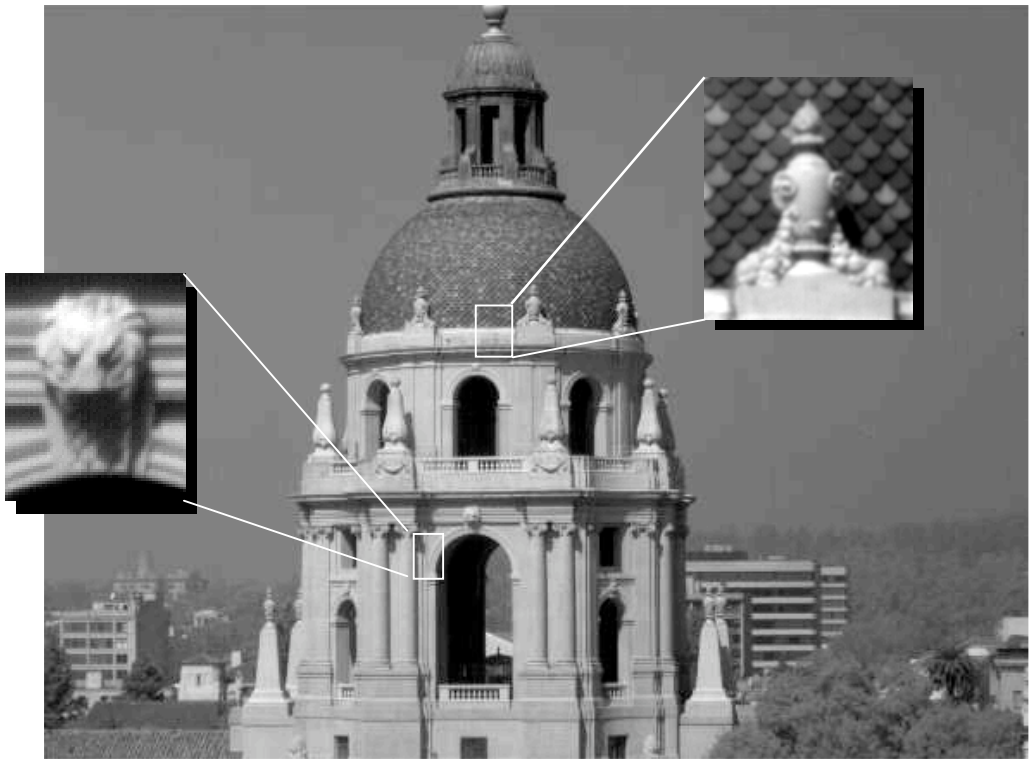
- **Pixel Format: 256 X 256**
- **Pixel Size: 10 μm X 10 μm**
- **Frame Rate: 2 fps**
- **ADC: On-Chip, 8 bits**
- **Power Supply: 2.8 V**
- **Power: 3 mW**

Krymski 1998

Micron

4 Mpixel sensor 240fps ERS





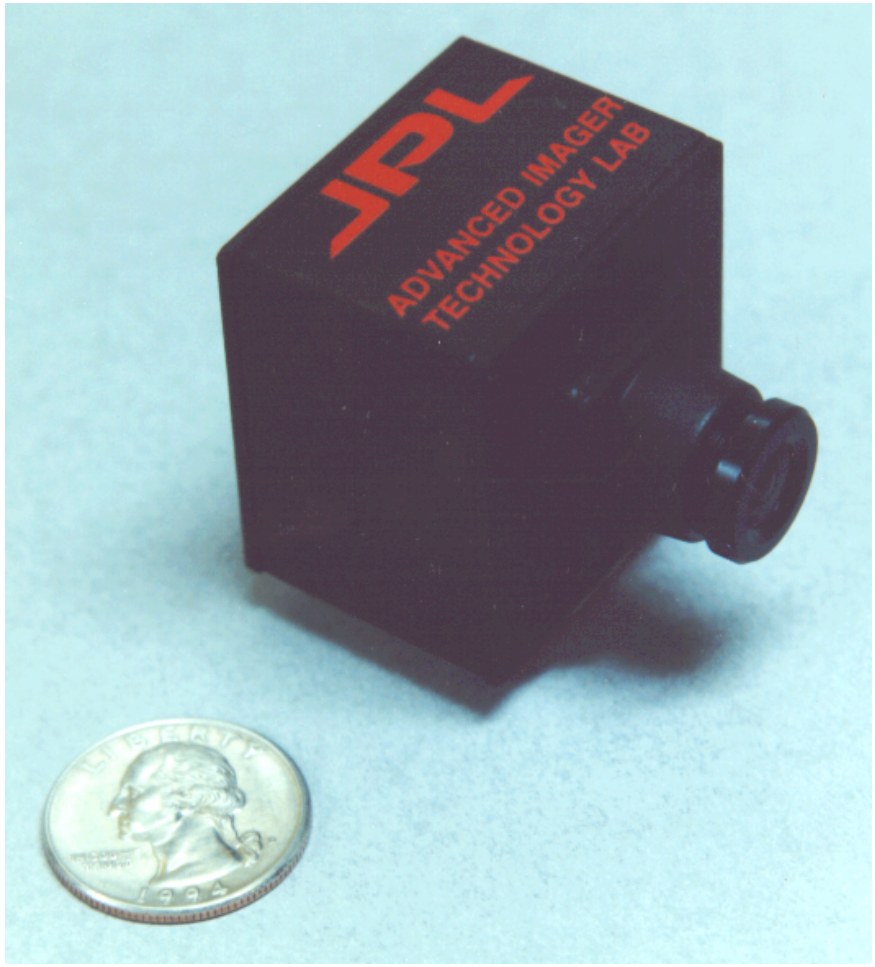
- 2352 x 1728
- 7 □m x 7 □m pixel pitch
- 16x10b digital output
- 240 fps ERS
- 960 Mbytes/sec at 66 MHz
- 4000 bits/lx-sec
- 3.3 volt operation

Customer Drivers

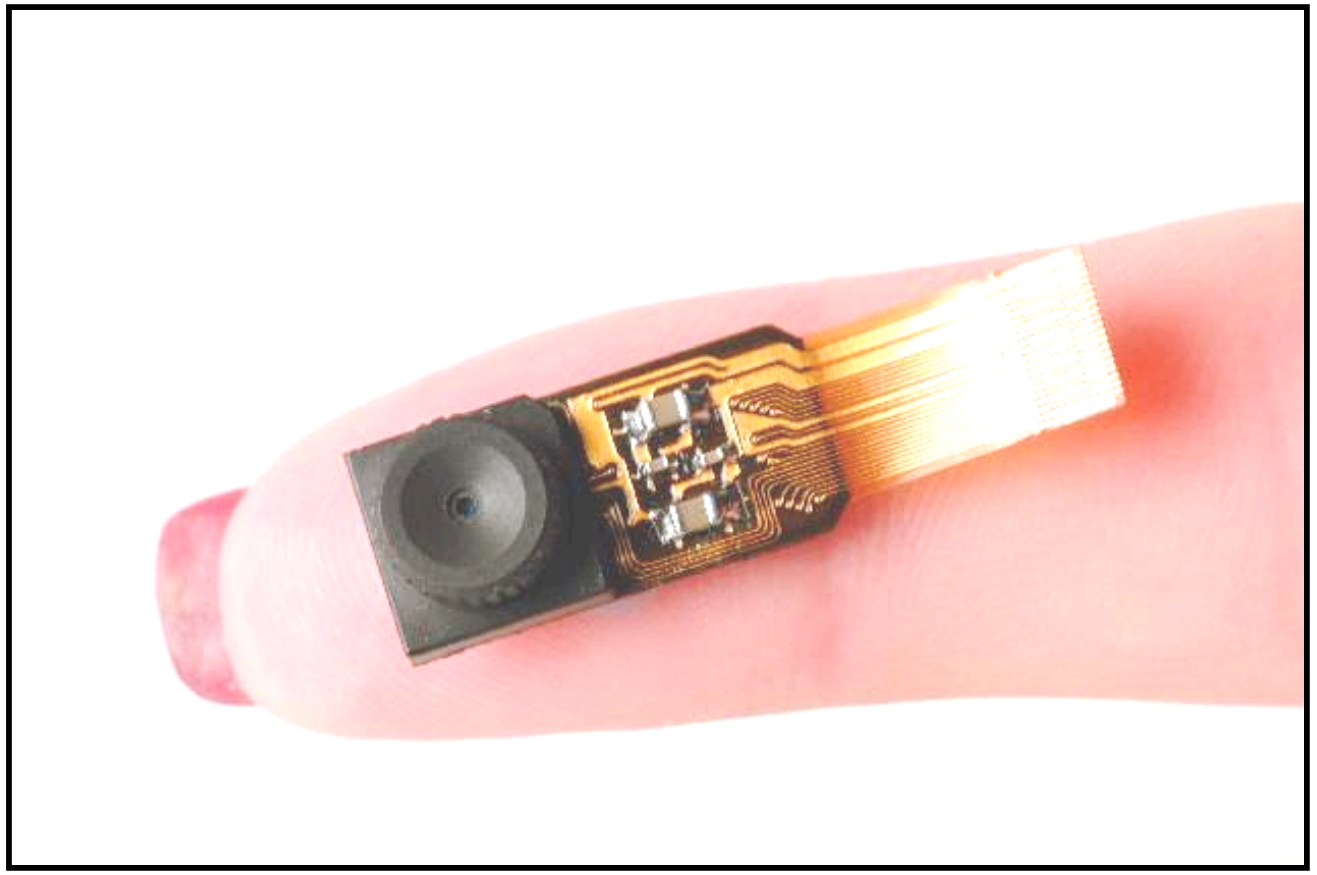
- Incredibly fast price point erosion (2Mpixel CCD now sells for $8 in Japan)
- Voltage scaling required to be compatible with companion chips (3.3V -> 2.8V ->…1.8V)
- Power dissipation <200 mW/megapixel for portable apps
- CCD performance sets benchmark for DSC applications (SNR, dark current, etc.)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



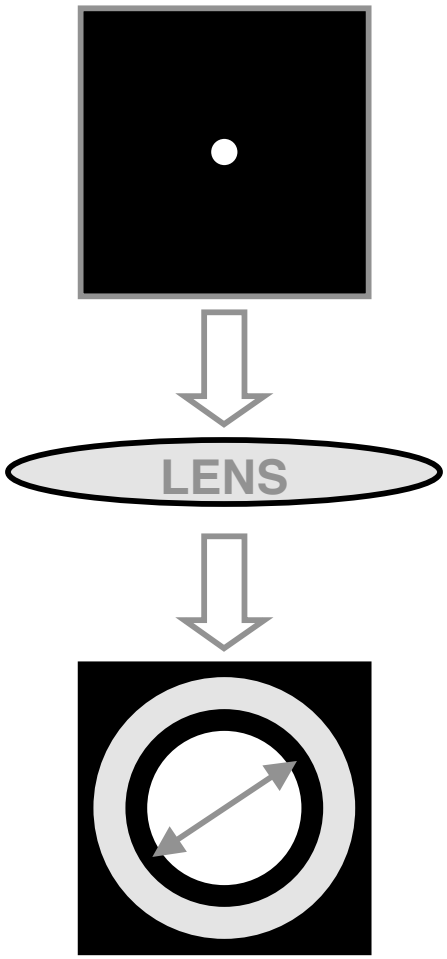
Cell Phone Cameras Are Small

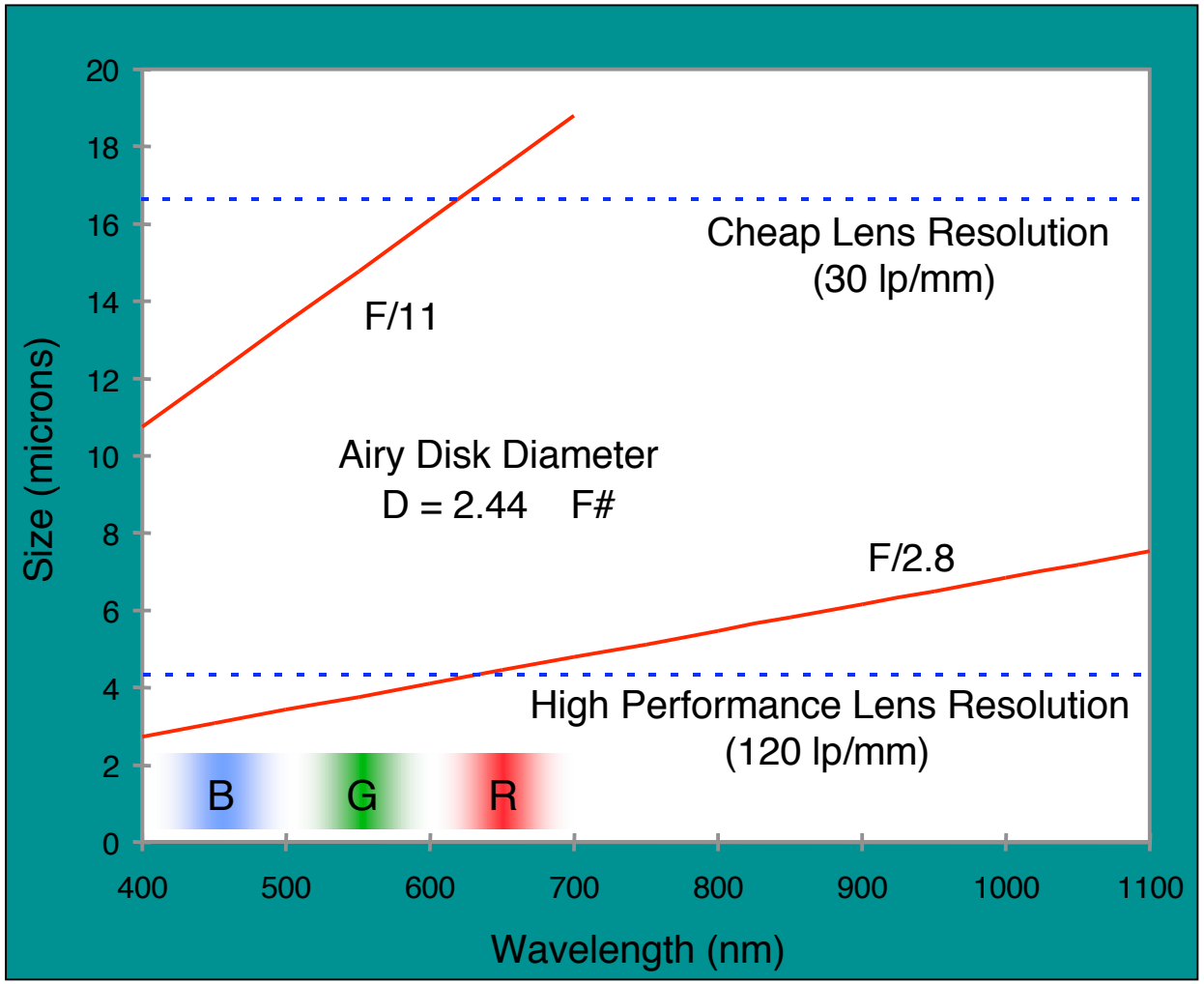


Technology Challenges

- 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

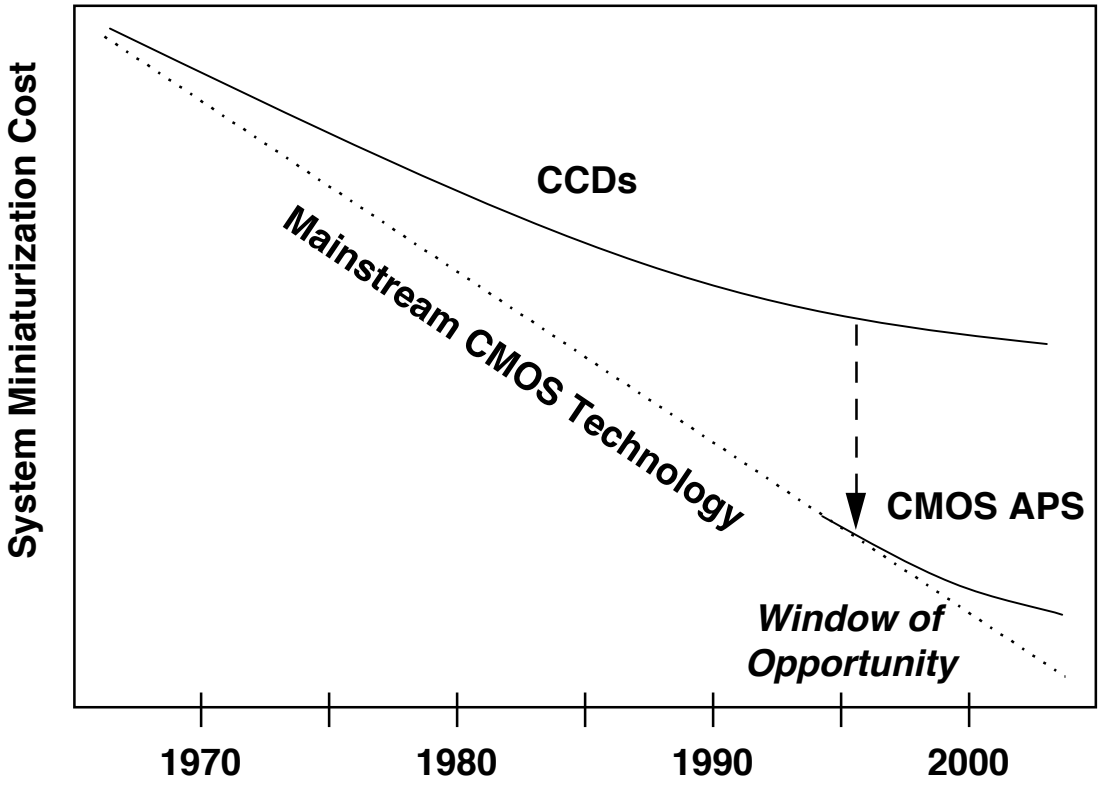
Diffraction Limit





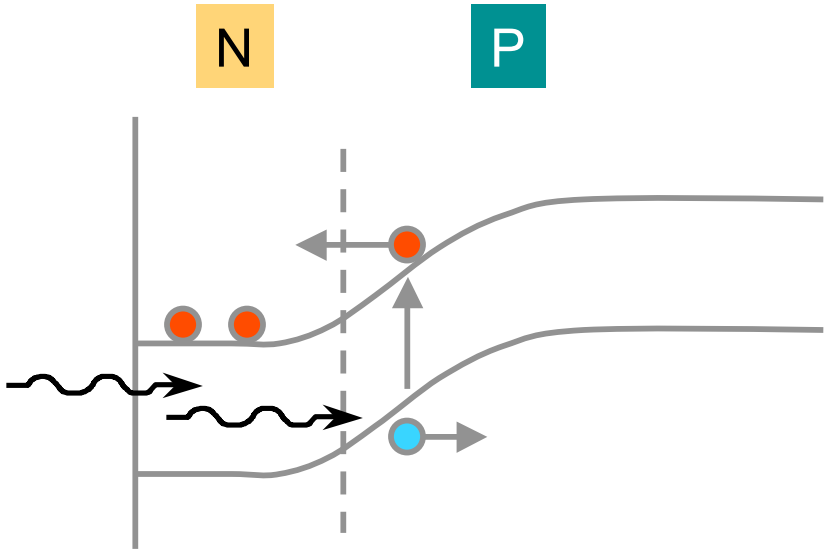
Alignment to Mainstream Technology

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

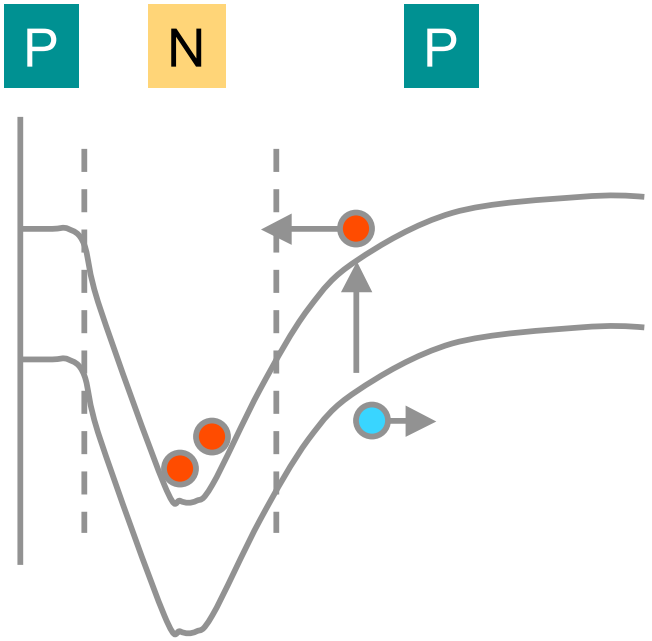


Buried Photodiodes

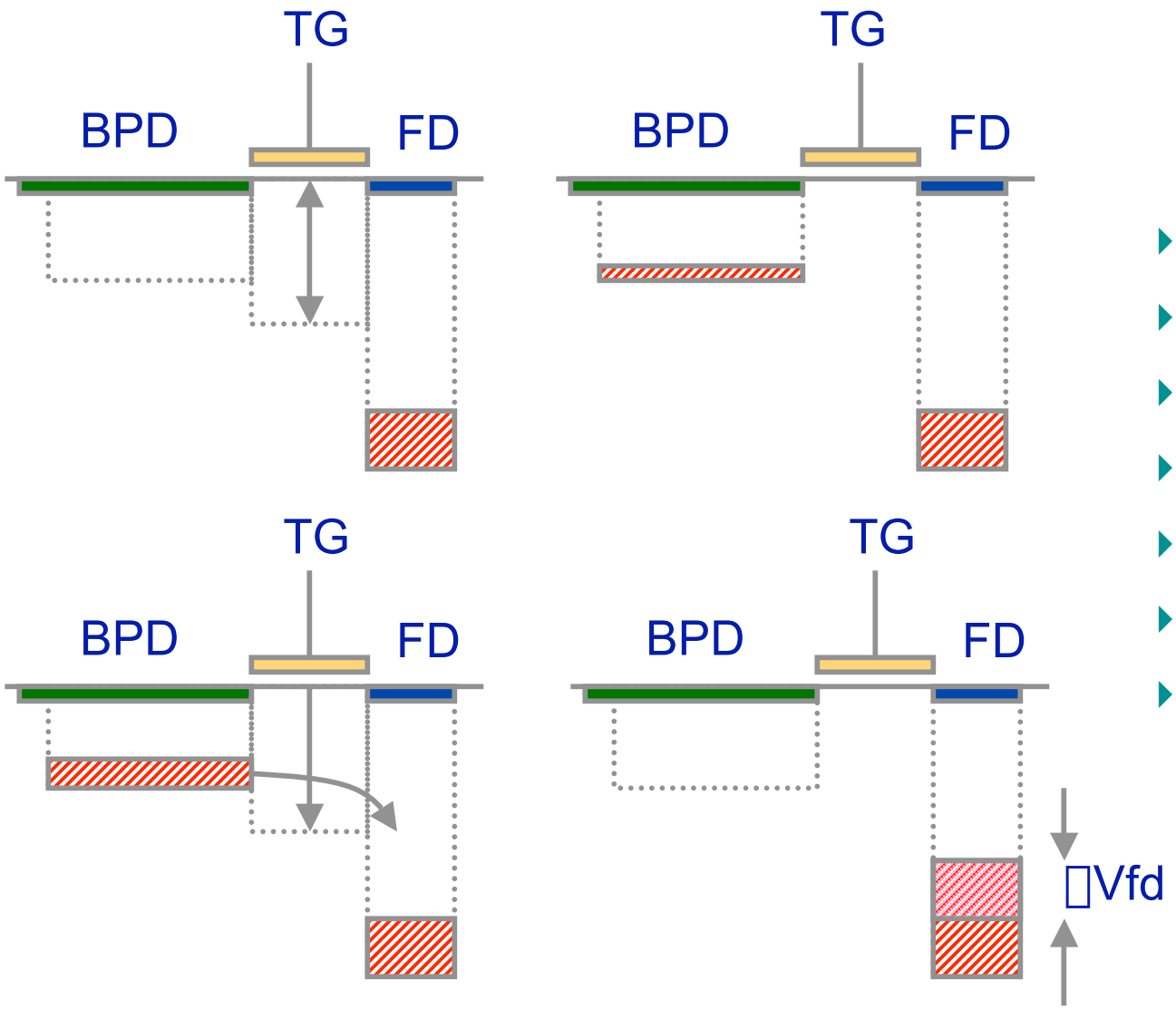
Conventional Photodiode



Buried Photodiode



4T Buried Photodiode



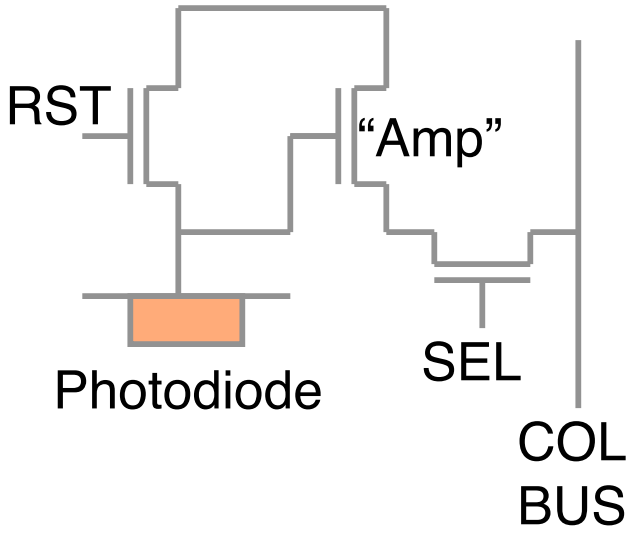
- Reset Pixel
- Integrate
- Readout
  - Reset FD
  - Read FD
  - Transfer Q
  - Read FD

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
- popoorer under good light
+ better under low light

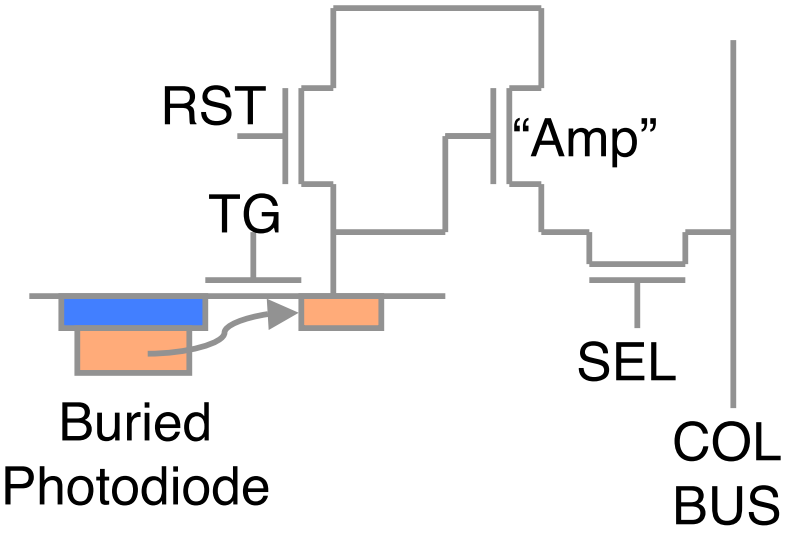
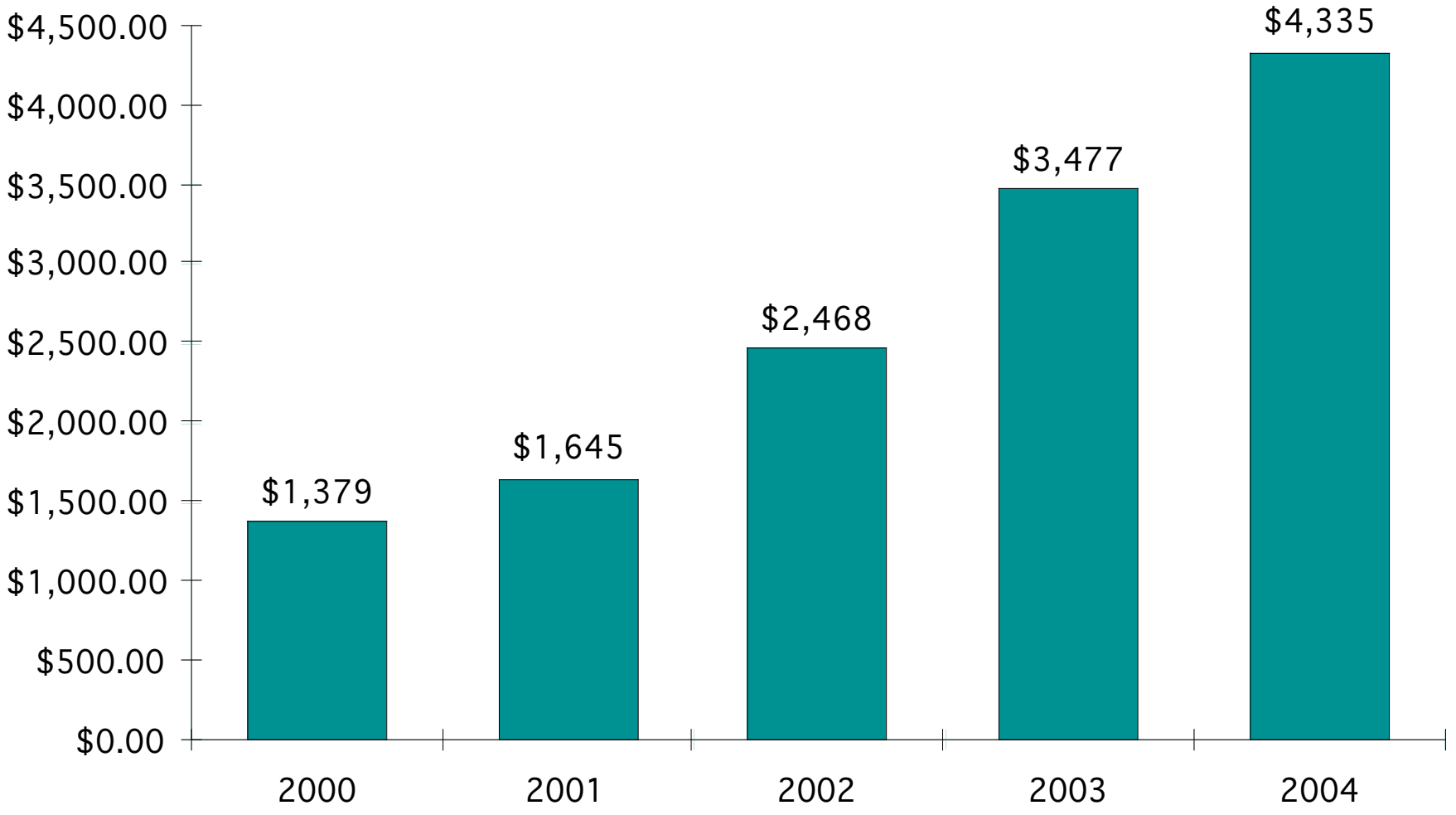
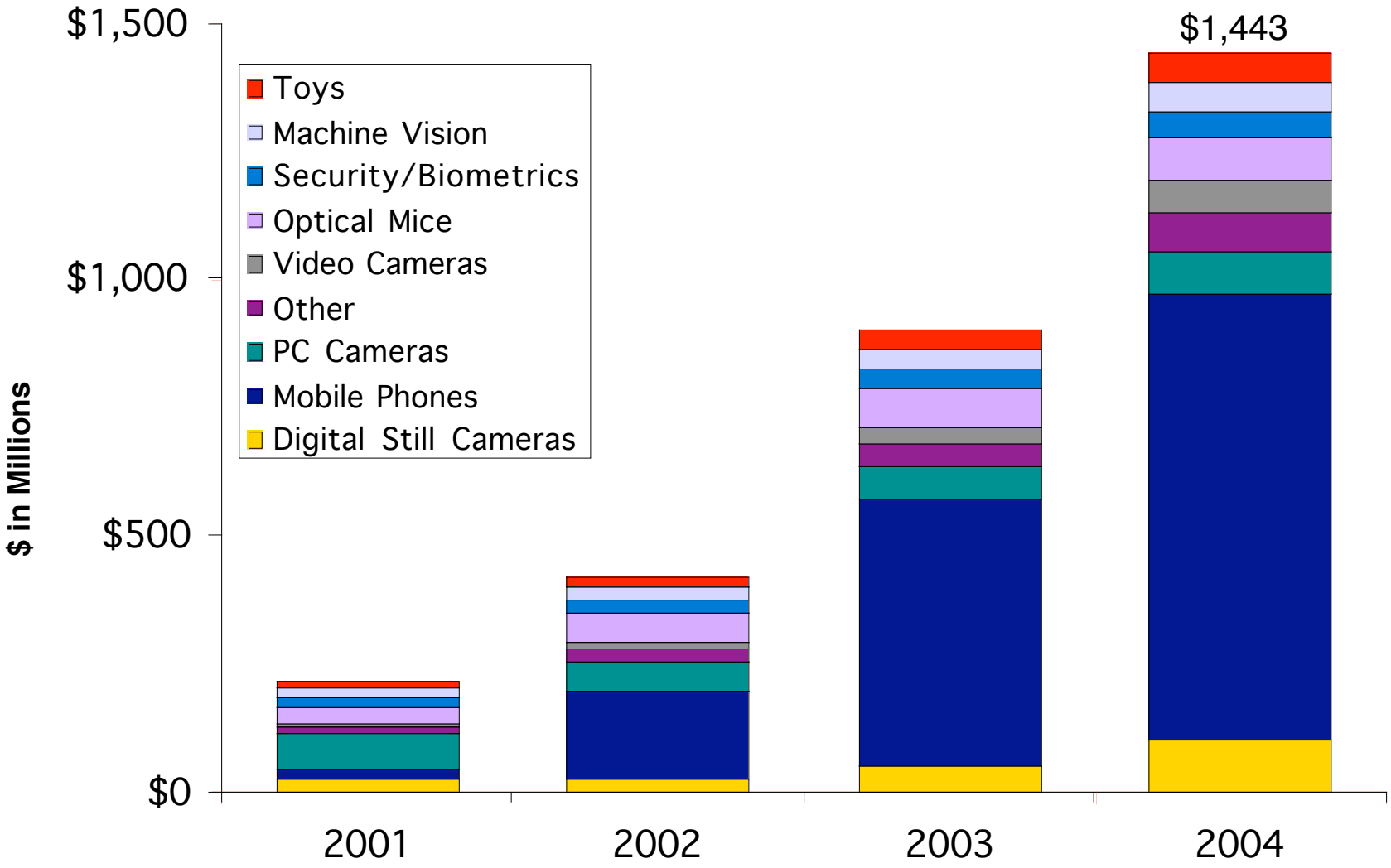


Image Sensor Revenue Projections



Sources: CD analysis based on OEM and industry research reports

CMOS Image Sensor Market Growth



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CMOS Vs. CCD Market Growth