Imperial College London

14 – Technology of Vision

Prof Peter YK Cheung

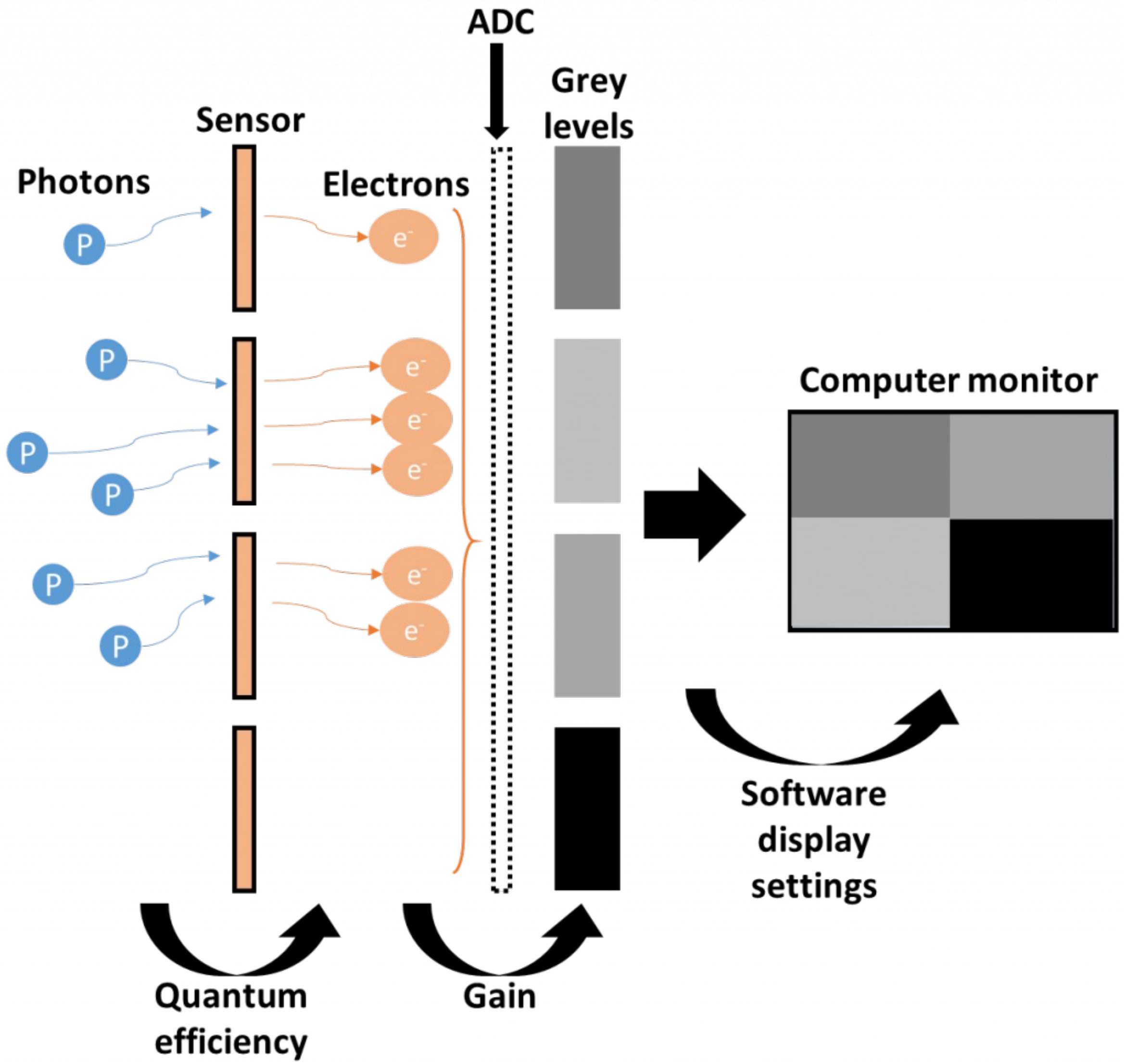
Dyson School of Design Engineering

URL: www.ee.ic.ac.uk/pcheung/teaching/DE4_DVS/
E-mail: p.cheung@imperial.ac.uk

Three Categories of Vision Technology

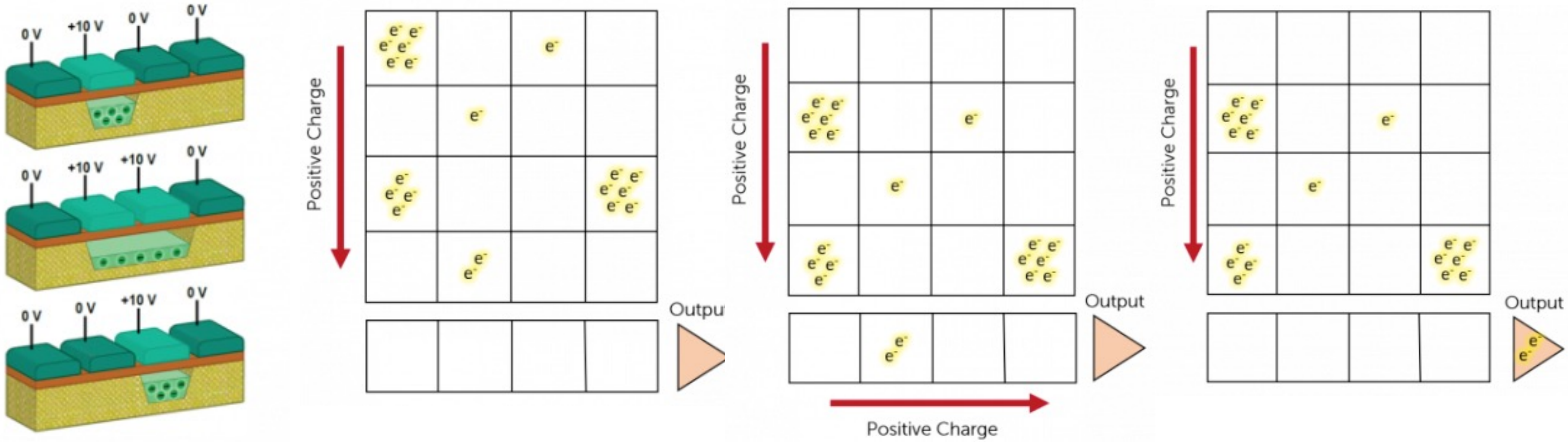
- Sensors for vision
  - Visible light image sensors
  - IR image sensors
  - Time of Flight (ToF) image sensors
- Display Technology
  - Thin-film Transistor (TFT) Liquid Crystal Displays(LCD)
  - In-Plan Switch (IPS) Liquid Crystal Displays (LCD)
  - Organic LED (OLED) Displays
  - Digital Light Processing (DLP) Projectors
- Visual Data Processors
  - Graphics Processing Units (GPU)
  - AI/Neuro Processors

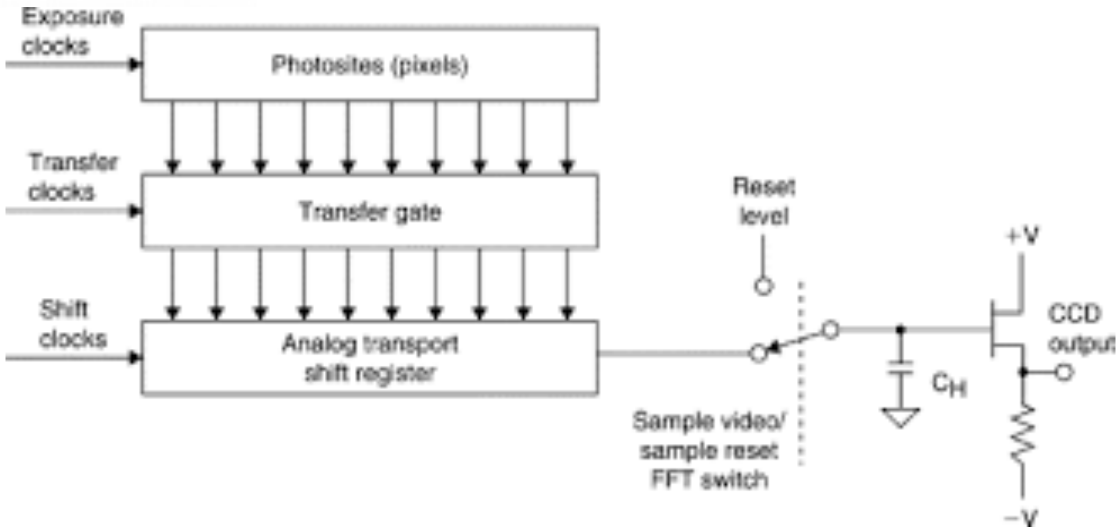
Photons to Electrons



Source: Teledyne

CCD Sensor Technology

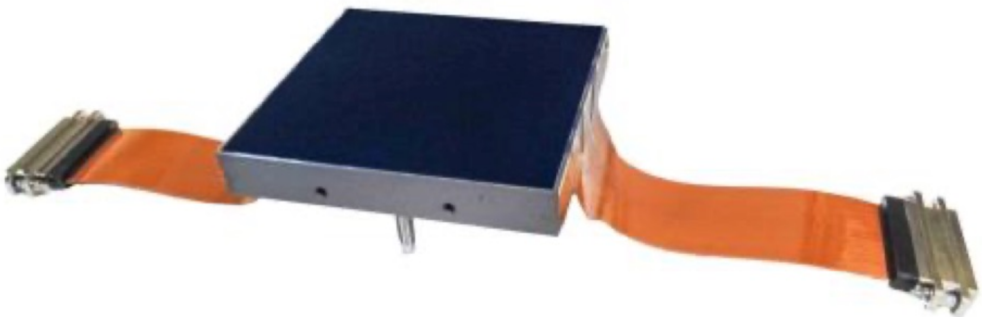


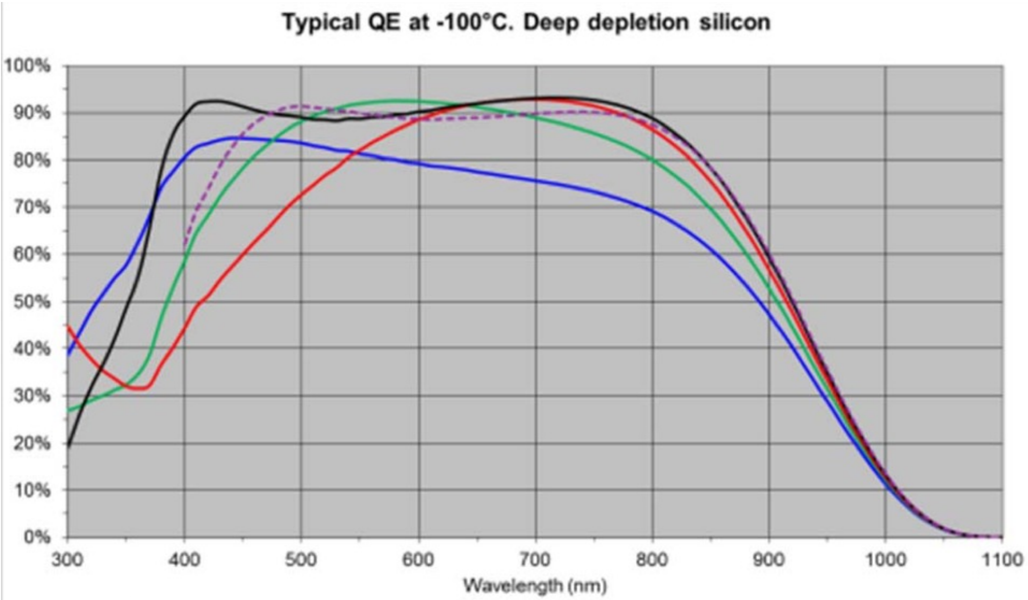


Source: Teledyne

Example of a CCD Sensor

Teledyne CCD290-99 Scientific CCD Sensor, 9216 x 9232 Pixels





Number of pixels	9216 (H) × 9232 (V)
Pixel size	10 μm square
Image area	92.2 mm × 92.4 mm
Outputs	16
Package size	98.5 × 93.7 mm
Package format	Silicon carbide with two flexi connectors
Focal plane height, above base	20.0 mm
Connectors	Two 51-way micro-D
Flatness	20 μm (peak to valley)
Amplifier sensitivity	7.5 μV/e^-
Read-out noise	4 e^- at 0.5 MHz 2.5 e^- at 50 kHz
Maximum pixel data rate	3 MHz
Charge storage (pixel full well)	90,000 e^-
Dark signal	4 e^-/pixel/hour (at –100 °C)

Source: Teledyne

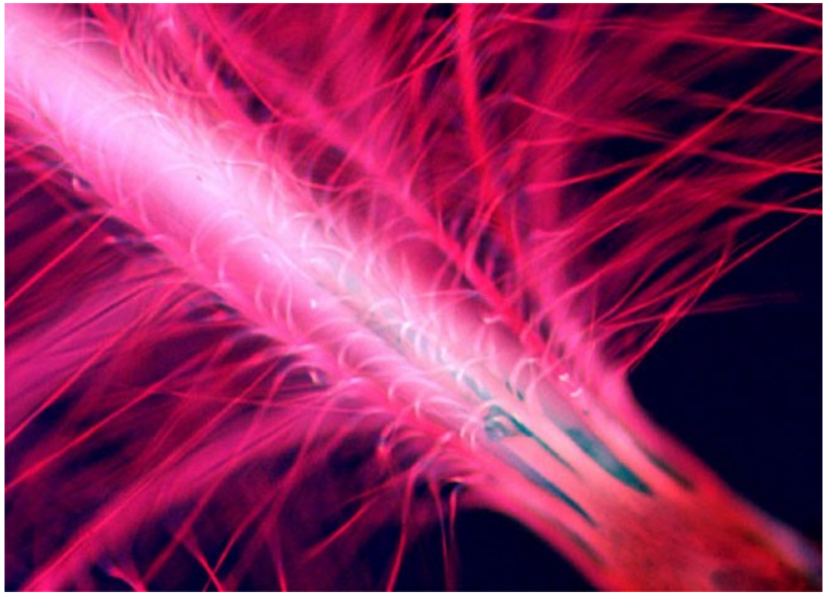
Example of a CCD Camera

Specification	Nikon DXM 1200
Maximum Pixel Output	12 Million
CCD	Sony ICX085AK (Bayer Mosaic Filters)
Pixel Size (Shape)	6.7 Microns (Square)
CCD Chip Size	10.0 (H) x 8.7 (V) (Millimeters)
CCD Cooling	None
Fastest Shutter Speed	1/12000 Seconds
Slowest Shutter Speed	170 Seconds
Sensitivity Setting	3 Levels (Normal, High, Max
Exposure Control	Manual
Signal/Noise	50 dB
Dynamic Range	8 Bits (48 dB)
Dark Current	4 Electrons/Pixel/Second
Read Noise	16 Electrons/Pixel
Well Depth	16,000 Electrons
Resolution	1800 TV Lines
Live Image Display Rate	12 Frames/Second
Maximum Image Size	3840 x 3072 Pixels
Image Storage Format	TIF, BMP, JPG
Lens Mount	C-mount
Computer Interface	PCI BusMaster

Source: Nikon

Sample images from CCD microscope

1



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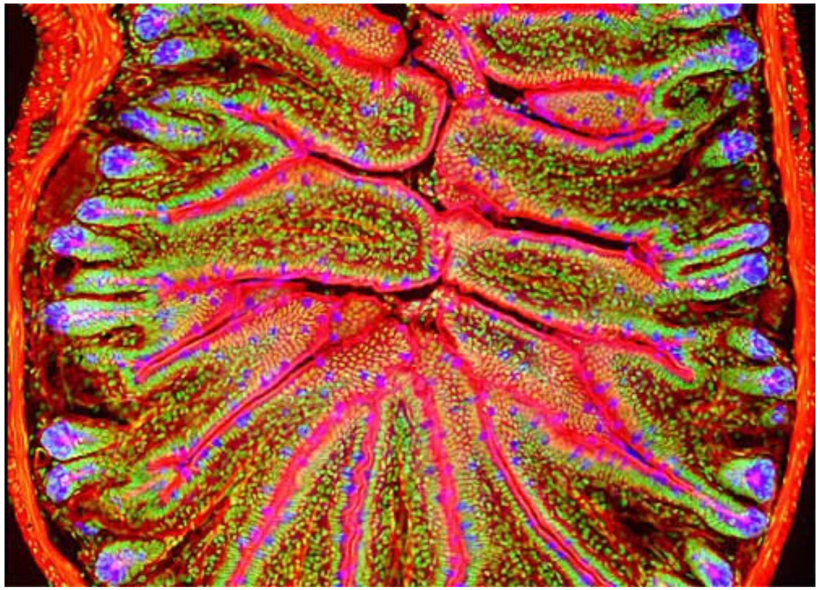
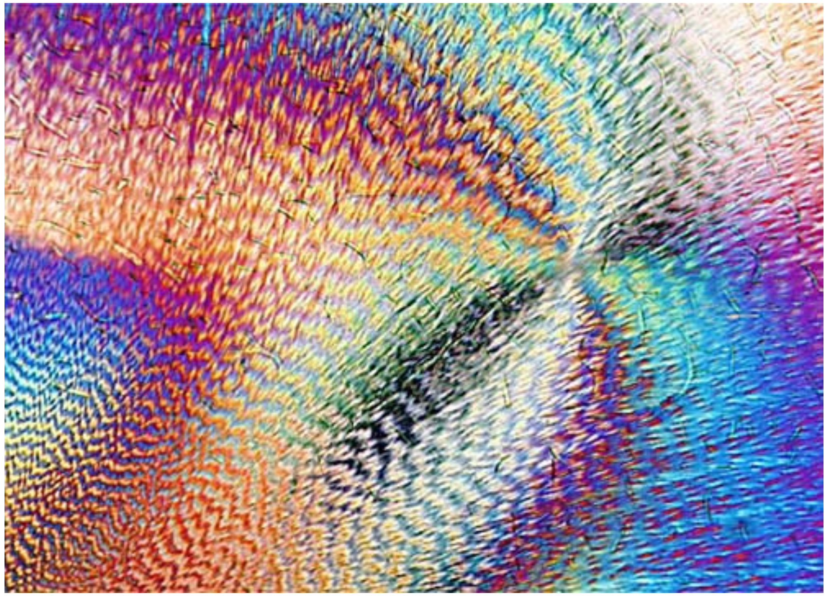
3

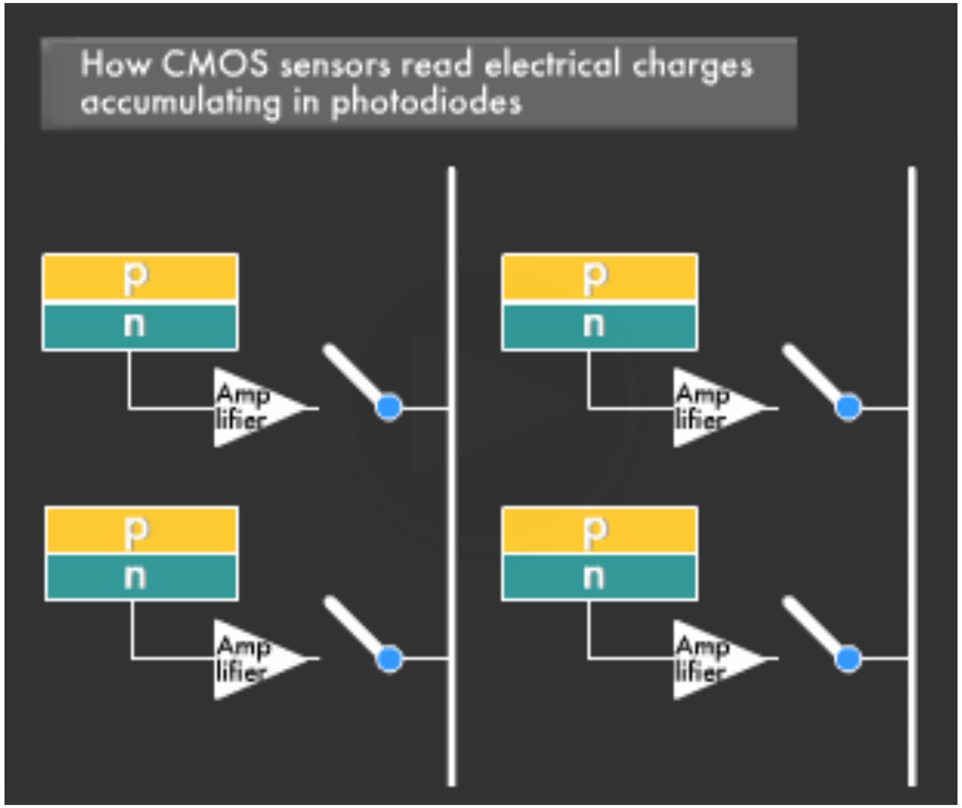


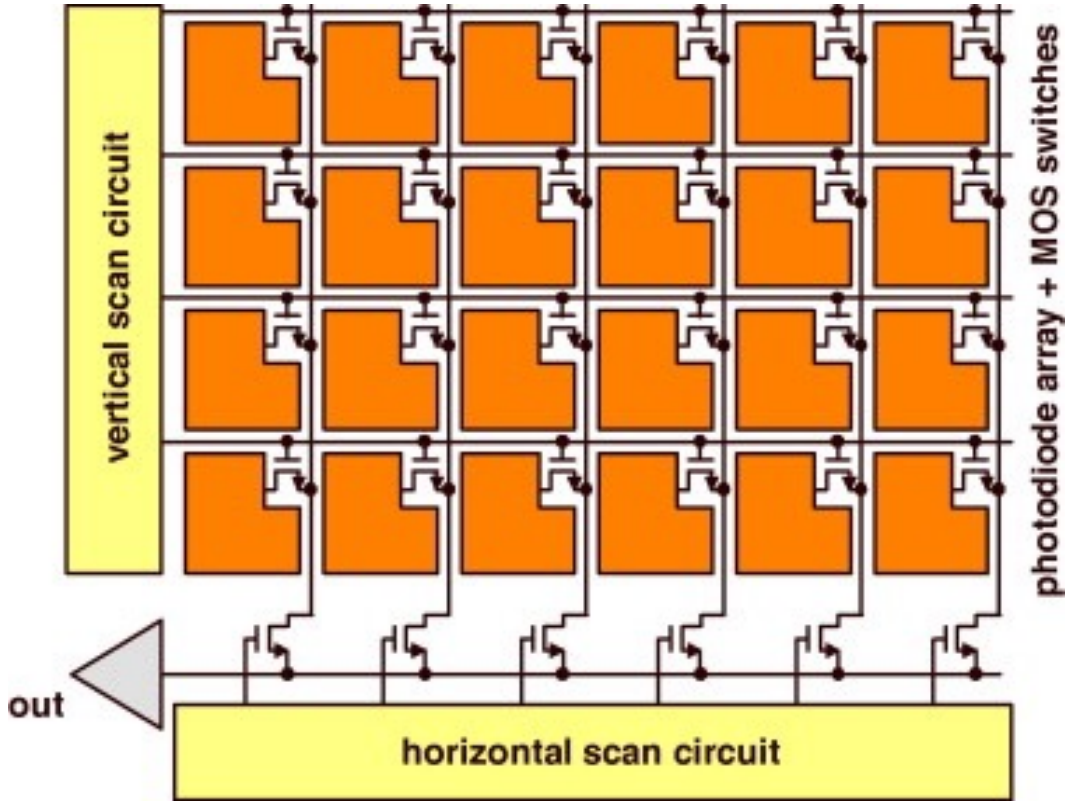


4

Source: Nikon

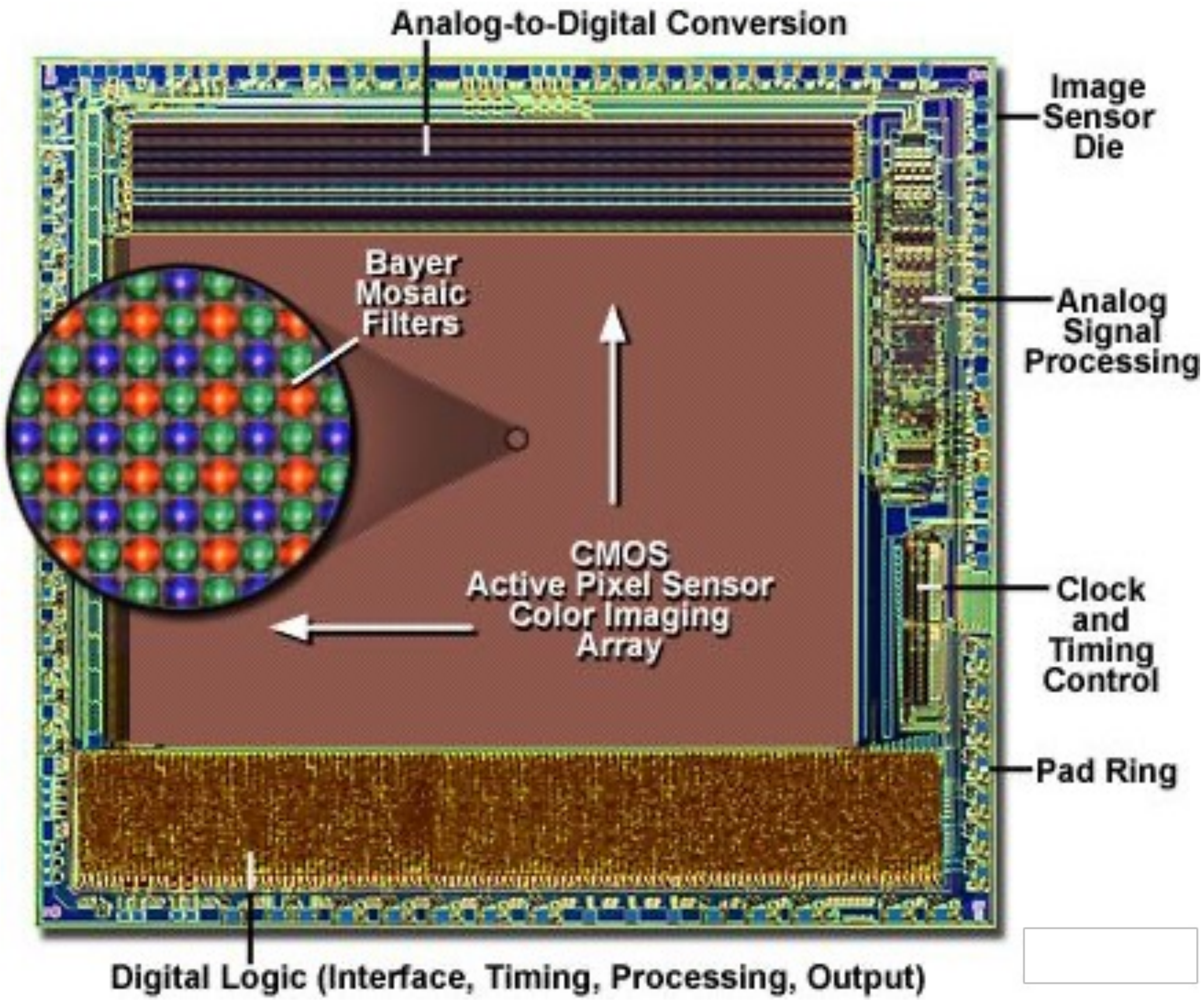
CMOS Sensor – photodiode array





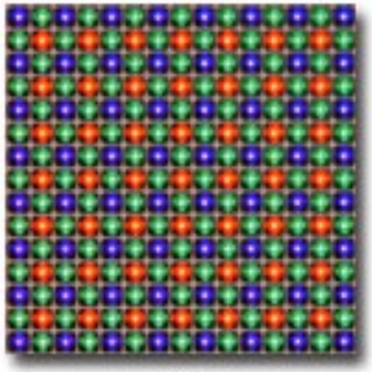
Source: Canon

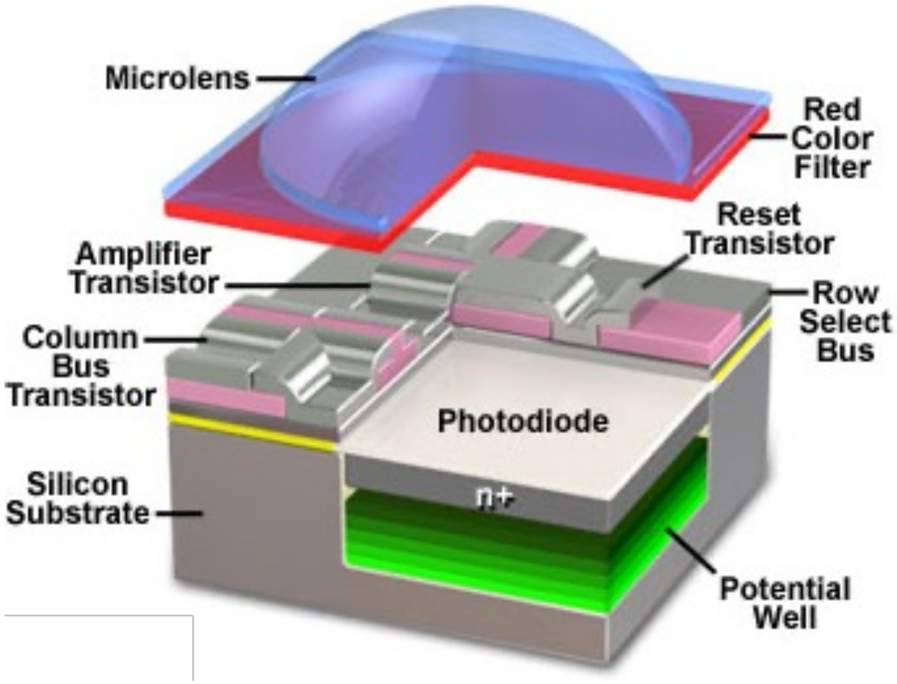
Structure of a CMOS Sensor Device

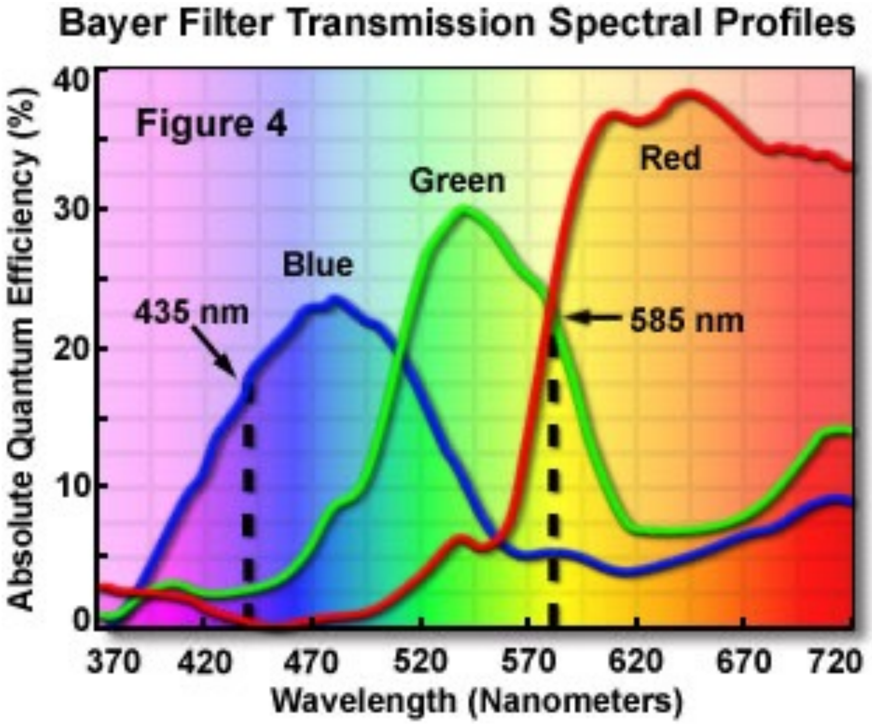


Source: Olympus

Bayer Mosaic Filter arrangement

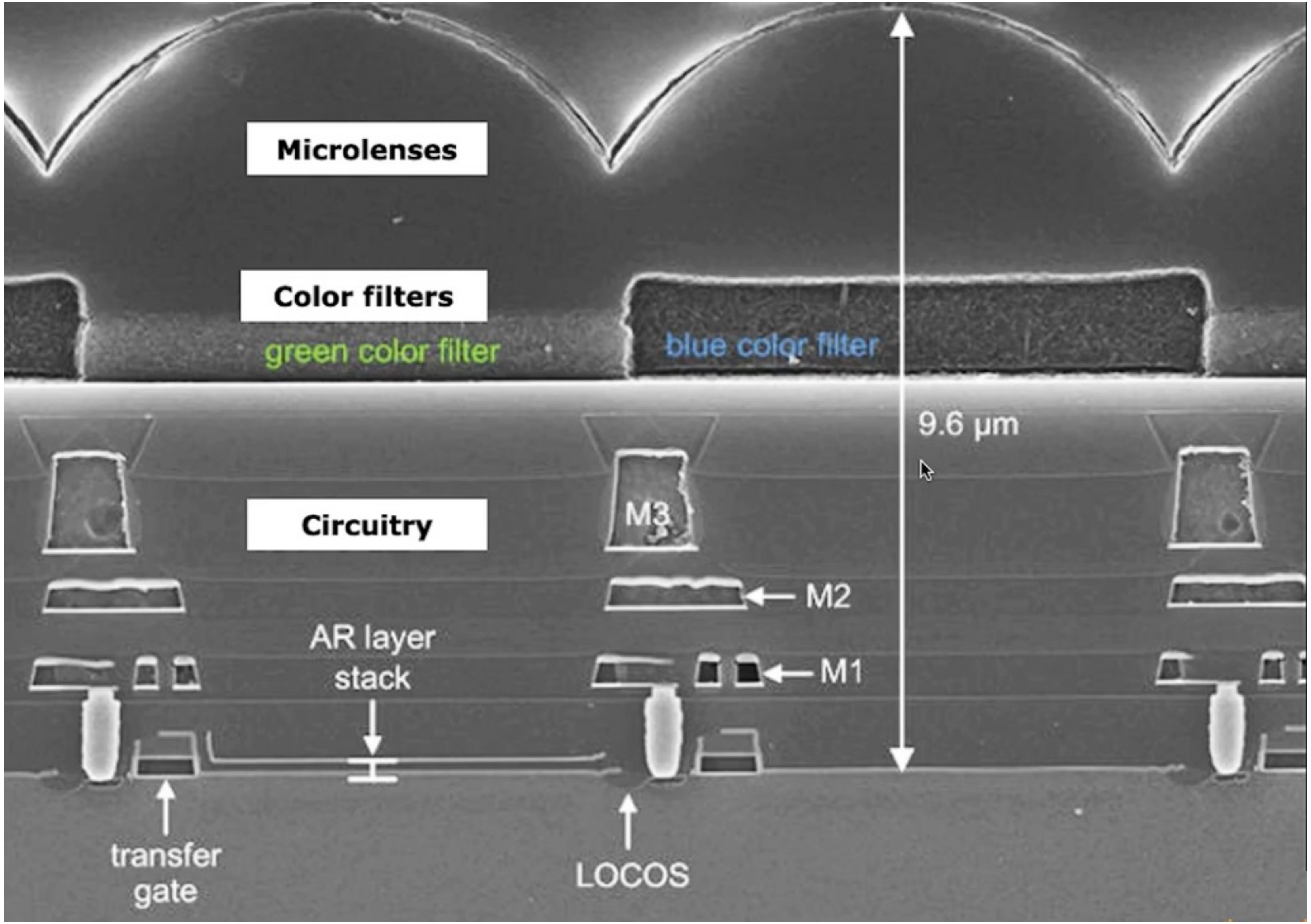






Source: Olympus

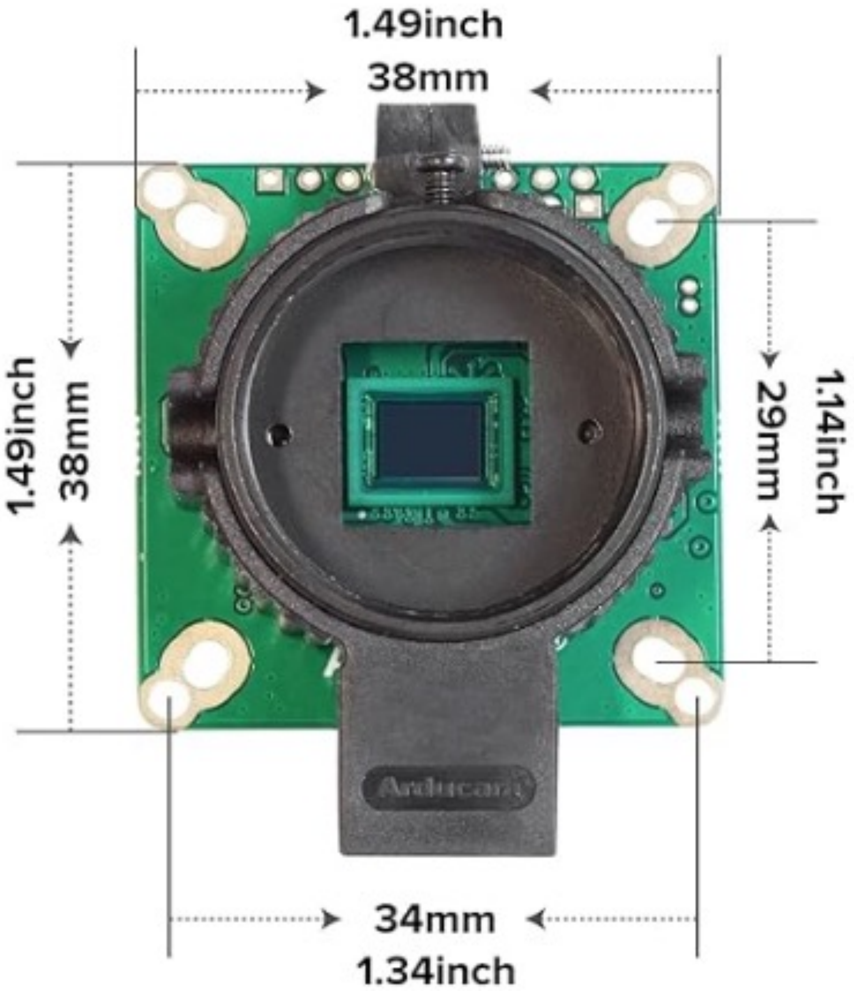
SEM image of Cross Section of a CMOS Sensor



Low Cost Camera - Raspberry Pi

	Camera Module v1	Camera Module v2	Camera Module 3	Camera Module 3 Wide	HQ Camera	GS Camera
Net price	$25	$25	$25	$35	$50	$50
Size	Around 25 × 24 × 9 mm	Around 25 × 24 × 9 mm	Around 25 × 24 × 11.5 mm	Around 25 × 24 × 12.4 mm	38 x 38 x 18.4mm (excluding lens)	38 x 38 x 19.8mm (29.5mm with adaptor and dust cap)
Weight	3g	3g	4g	4g	30.4g	34g (41g with adaptor and dust cap)
Still resolution	5 Megapixels	8 Megapixels	11.9 Megapixels	11.9 Megapixels	12.3 Megapixels	1.58 Megapixels
Video modes	1080p30, 720p60 and 640 × 480p60/90	1080p47, 1640 × 1232p41 and 640 × 480p206	2304 × 1296p56, 2304 × 1296p30 HDR, 1536 × 864p120	2304 × 1296p56, 2304 × 1296p30 HDR, 1536 × 864p120	2028 × 1080p50, 2028 × 1520p40 and 1332 × 990p120	1456 x 1088p60
Sensor	OmniVision OV5647	Sony IMX219	Sony IMX708	Sony IMX708	Sony IMX477	Sony IMX296
Sensor resolution	2592 × 1944 pixels	3280 × 2464 pixels	4608 x 2592 pixels	4608 x 2592 pixels	4056 x 3040 pixels	1456 x 1088 pixels
Sensor image area	3.76 × 2.74 mm	3.68 x 2.76 mm (4.6 mm diagonal)	6.45 x 3.63mm (7.4mm diagonal)	6.45 x 3.63mm (7.4mm diagonal)	6.287mm x 4.712 mm (7.9mm diagonal)	6.3mm diagonal
Pixel size	1.4 µm × 1.4 µm	1.12 µm x 1.12 µm	1.4 µm x 1.4 µm	1.4 µm x 1.4 µm	1.55 µm x 1.55 µm	3.45 µm x 3.45 µm

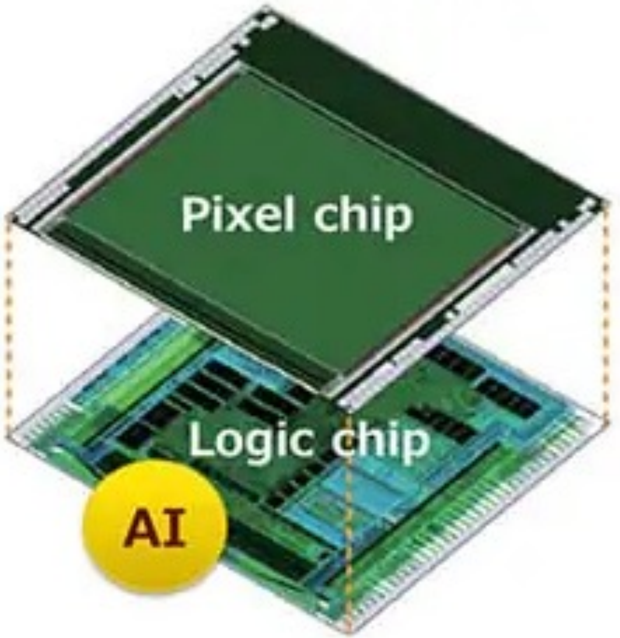
Low Cost Camera - Raspberry Pi



Resolution	4056 (H) x 3040 (V)
Megapixels	12.3MP
Supply Voltage	1.05 V (Digital), 1.8 V (Interface), 2.8 V (Analog)
Chroma	Color, RGB
Shutter Type	Rolling Shutter Only
Frame Rate	15 to 240 fps, depending on the video mode
ADC resolution	10-bit, 12-bit
Pixel Size	1.55 µm (H) x 1.55 µm (V)
Interface	MIPI 2-lane/4-lane, D-PHY V1.2
Data Rate	Max. 2.1Gbps/lane
Clock Frequency	6-27 MHz

Source: Raspberry Pi Foundation

Sony’s Latest Sensor



Intelligent vision sensor stacked configuration

<Main functions on the logic chip>

- ✓ Conventional image sensor operation circuit
- ✓ ISP which processes the image signal
- ✓ Original DSP dedicated to AI signal processing
- ✓ Memory for the AI model

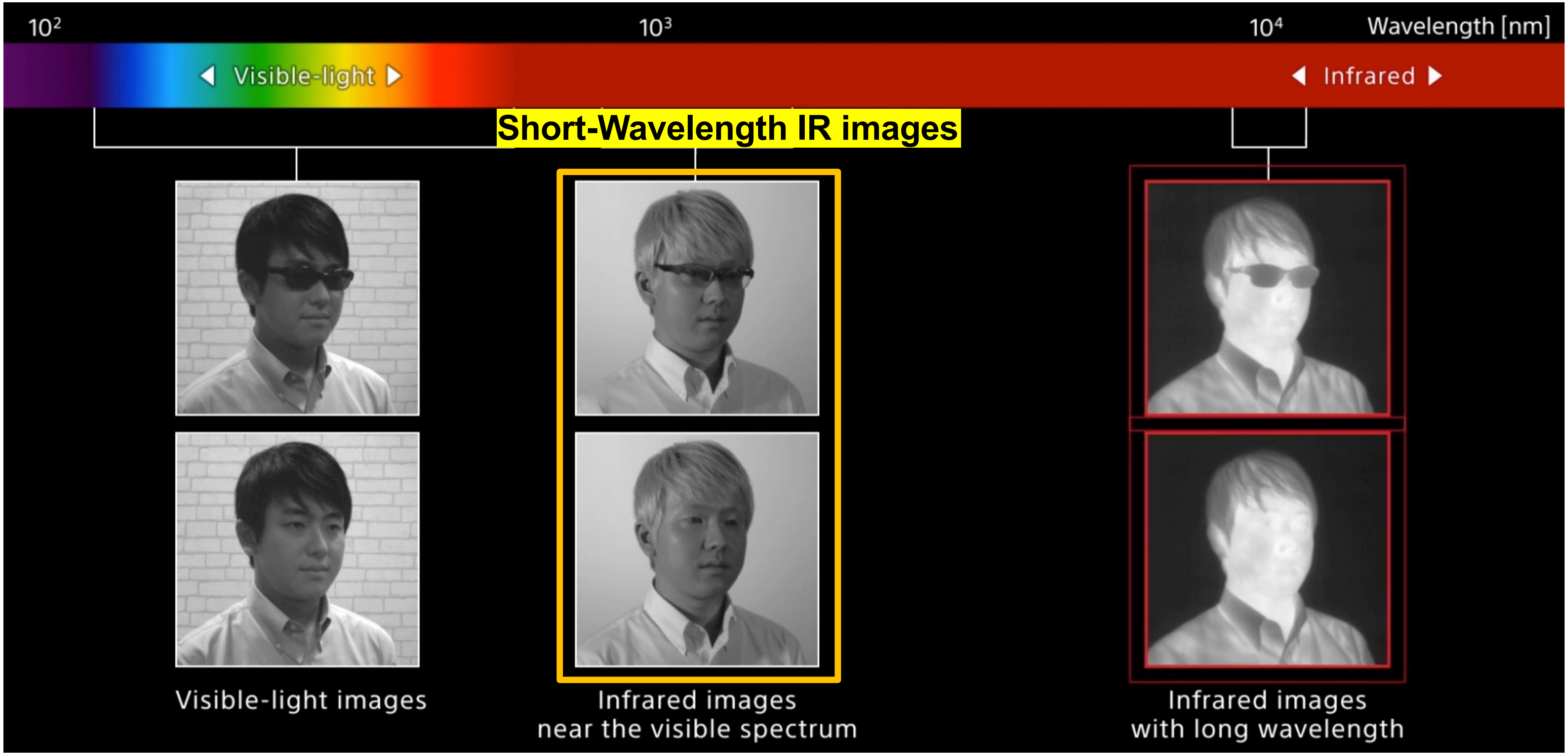
⇒ Eliminates the need for high-performance processor or external memory

Source: Sony

Integration of AI into an Image Sensor

Source: Sony

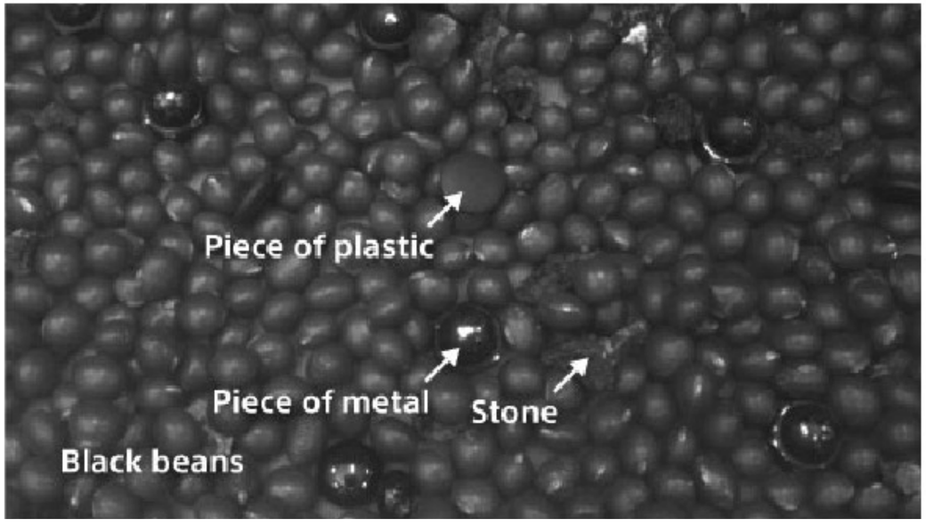
Infrared (IR) and SWIR Images

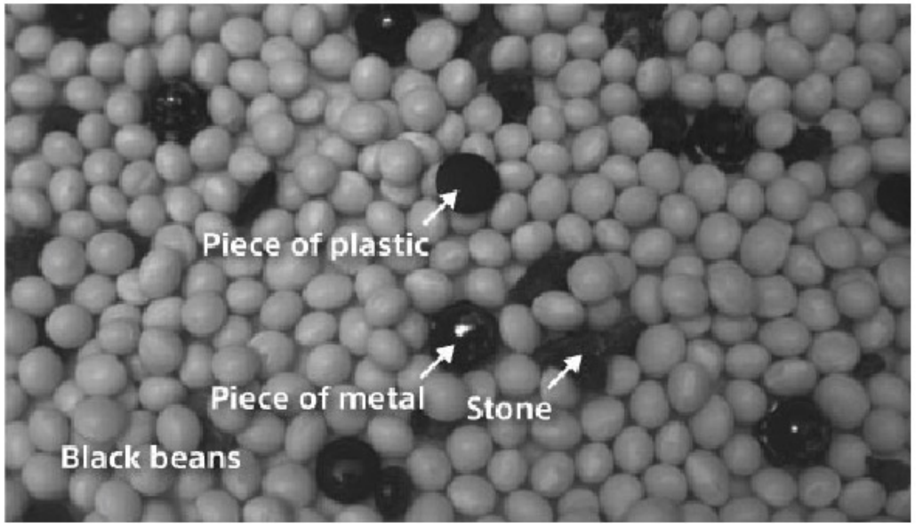


Source: Sony

Infrared (IR) and SWIR Images

Example of detecting contaminants in food





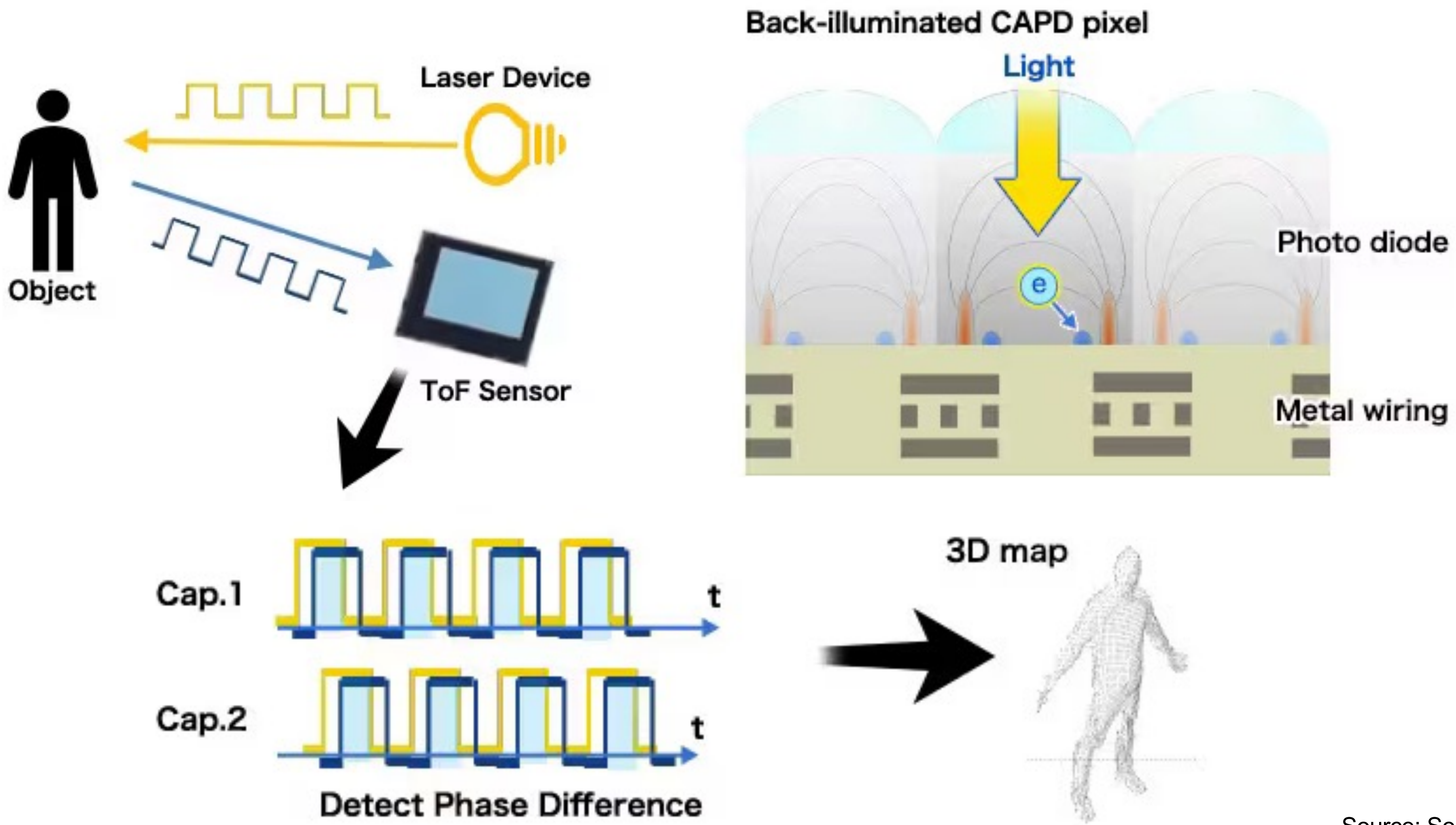
Under visible light

Under SWIR (1,550 nm)

Source: Sony

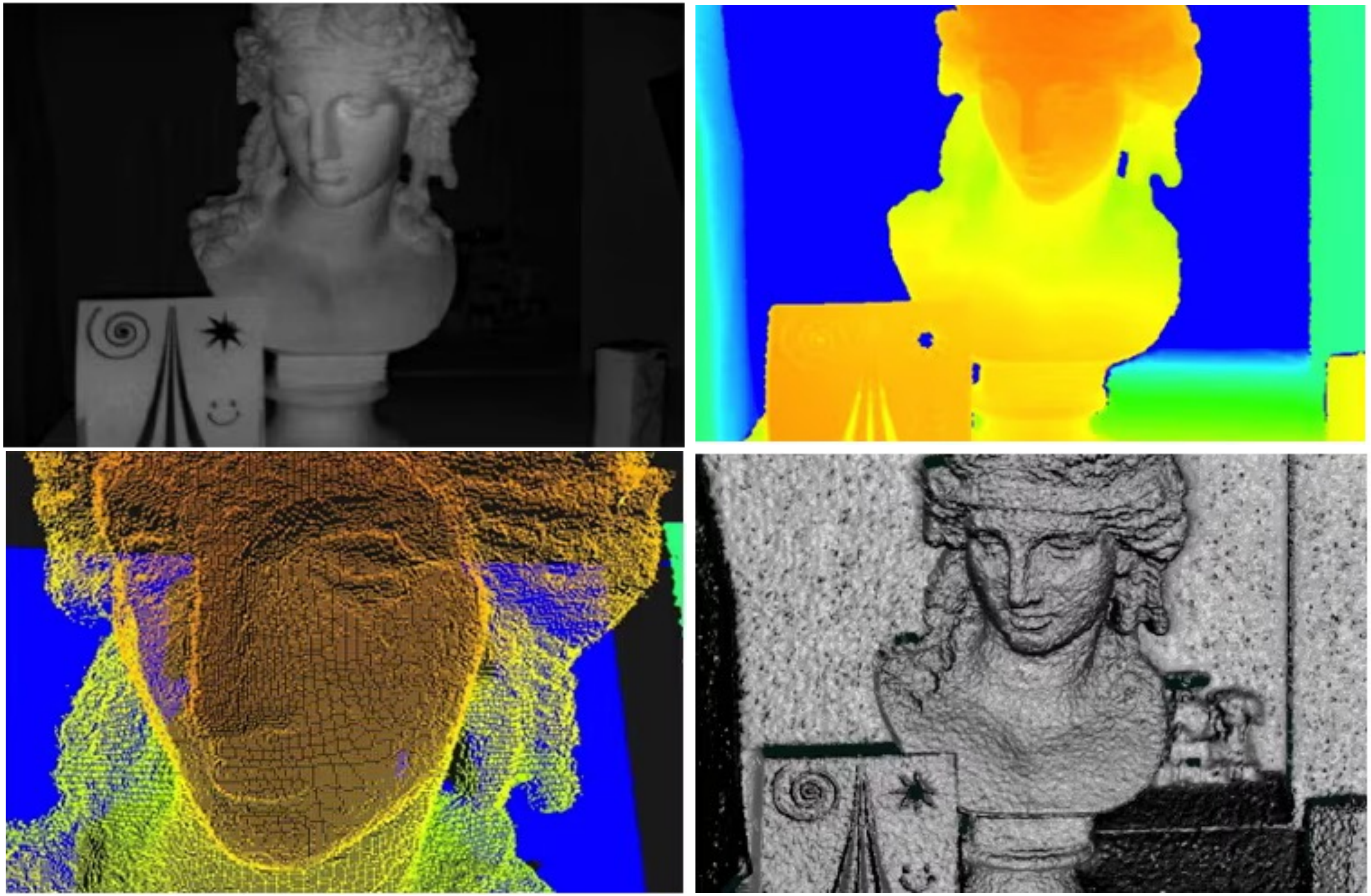
Time of Flight (ToF) Image Sensor

Current Assisted Photonic Demodulator (CAPD)



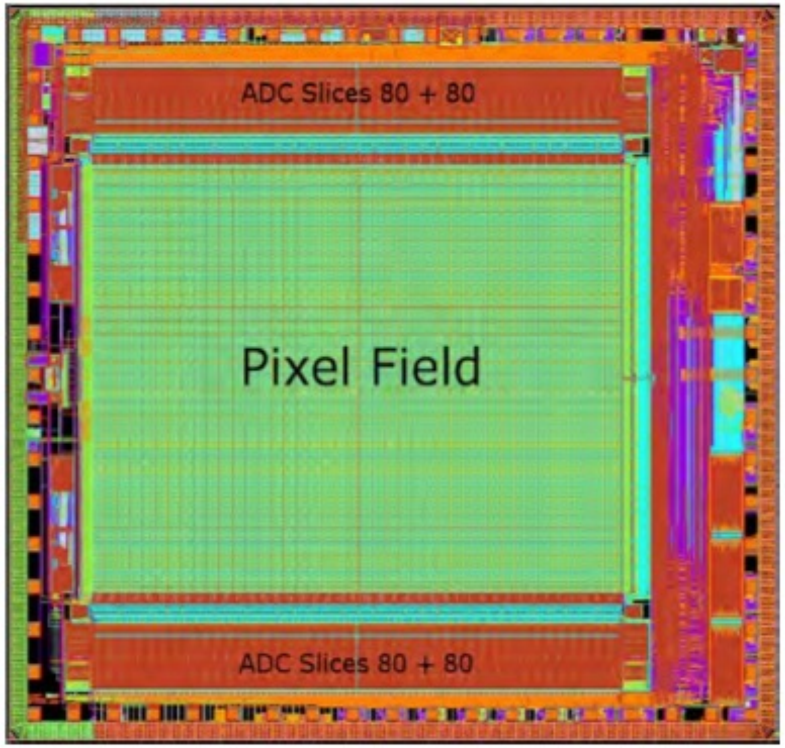
Source: Sony

Time of Flight (ToF) Image Sensor



Source: Sony

Another ToF Sensor – epc660



epc660

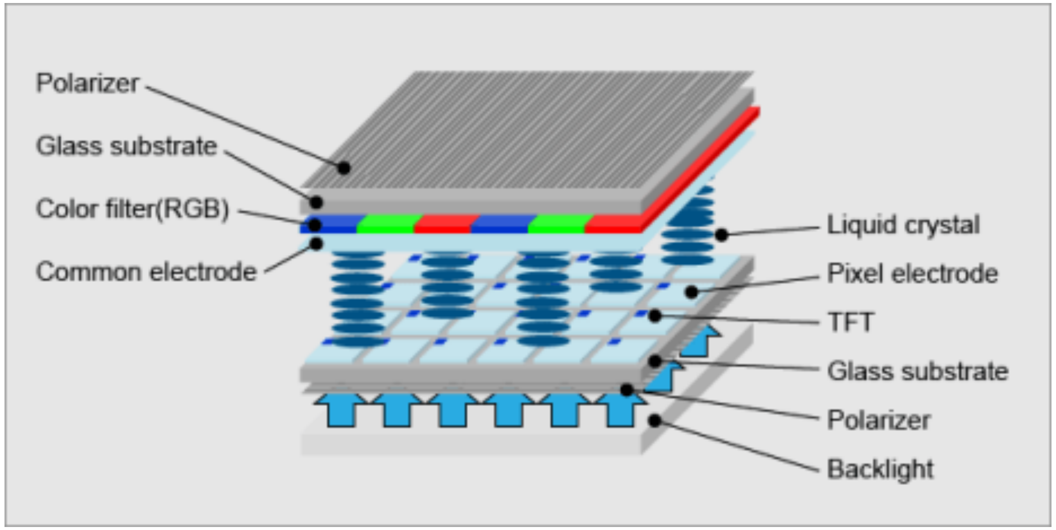
3D TOF imager 320 x 240 pixel

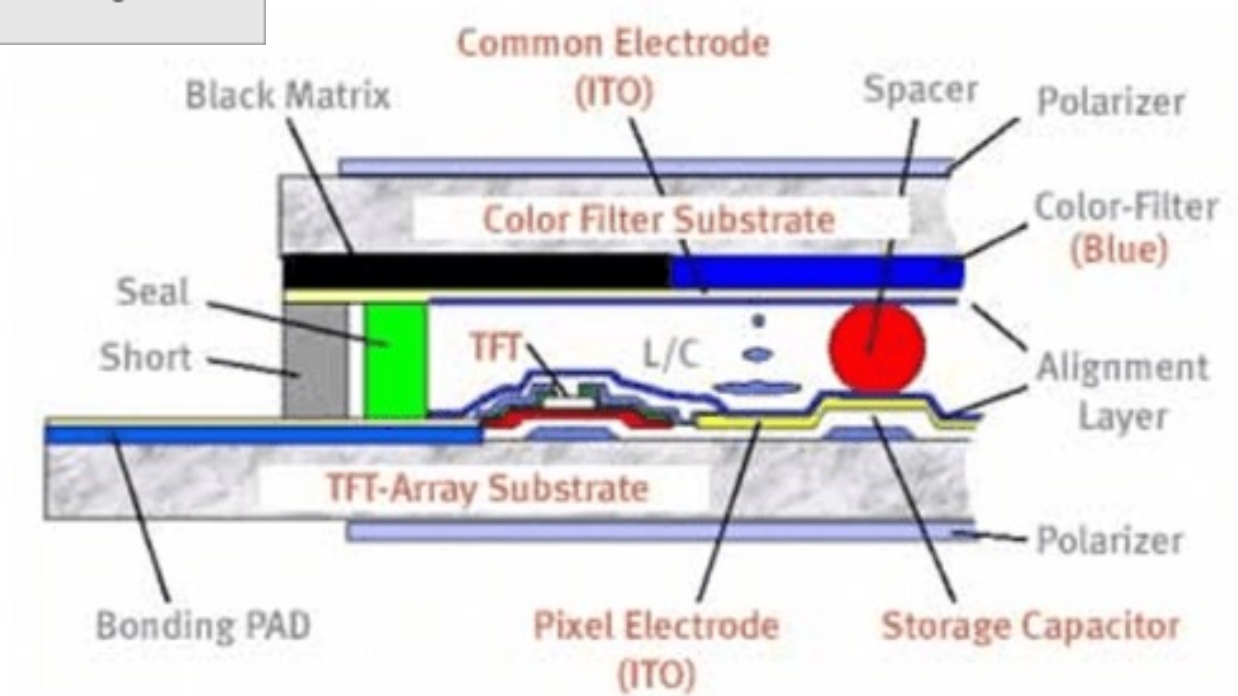
Main Features

- **General**
  - 3D TOF imager in full monolithic design
  - 320 x 240 pixel-field, backside illuminated
  - QE >80% @ 850nm
  - Full well capacity 8'000 ke- (ambient and signal)
  - 39 fps full 3D TOF frame rate, single frame rate up to 158fps
  - Region of interest setting allows up to several kfps
  - 4 integrated temperature sensors
- **Measurement performance**
  - Absolute accuracy in the sub-centimeter range with appropriate setup and calibration
- **Integrated LED (or laser diode) driver**
  - Laser diode (LD) illumination possible
  - Open-drain LED output pad, up to 200mA drive
  - Push-pull LED2 output pad, up to 50mA drive
- **Parallel digital data interface TCMI**
  - 48MS/s max. data rate, 2.5/3.3V compatible
  - 12/8-bit parallel DATA output + XSYNC/SAT flag
  - VSYNC, HSYNC and DCLK outputs
- **I^2C control interface (slave)**
  - 400kHz (FM) / 1MHz (FM+)
- **Integrated EEPROM 128 x 8-bit**
  - Calibration data and user programmable parameters
  - Unique chip ID

Source: EPC

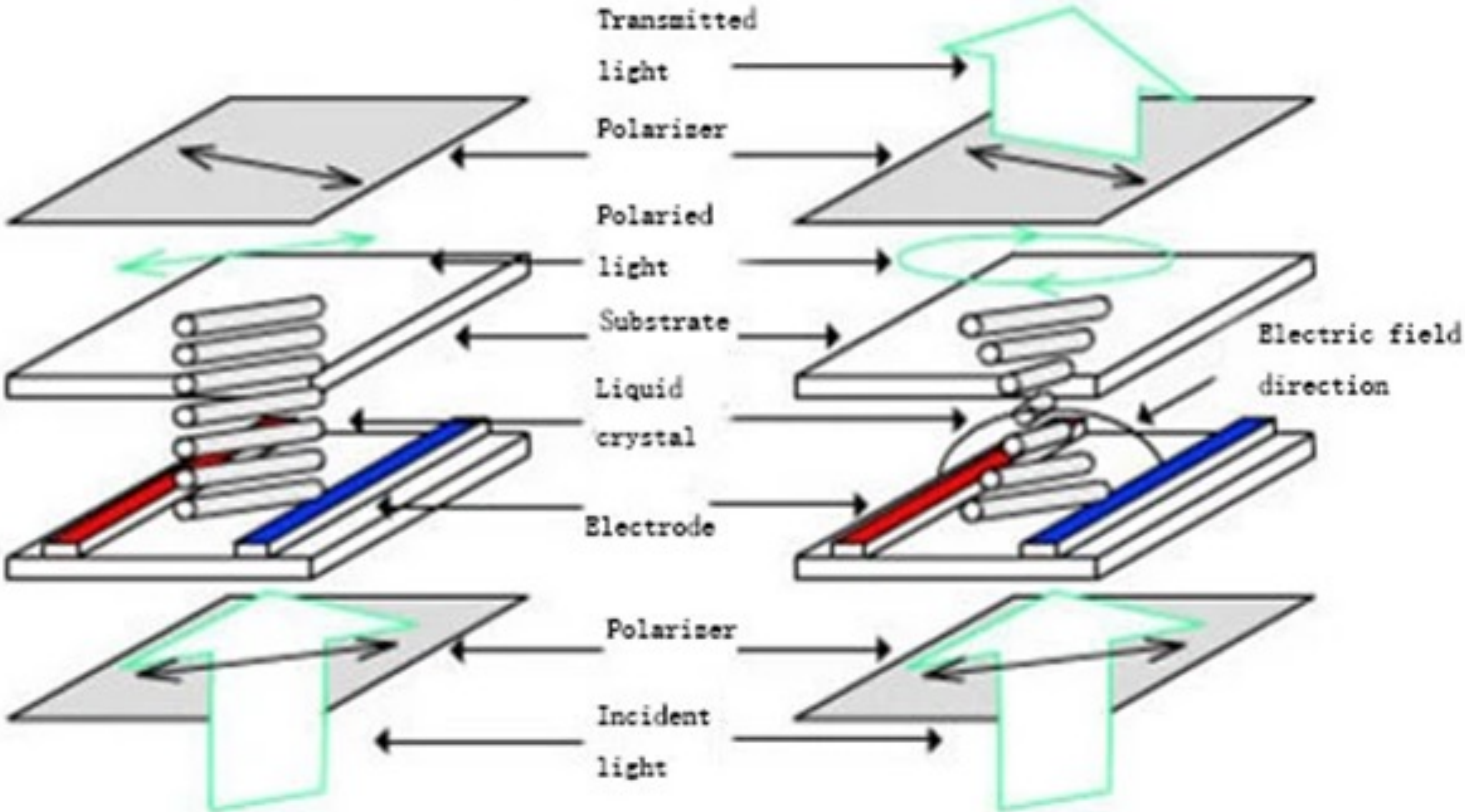
TFT LCD Technology





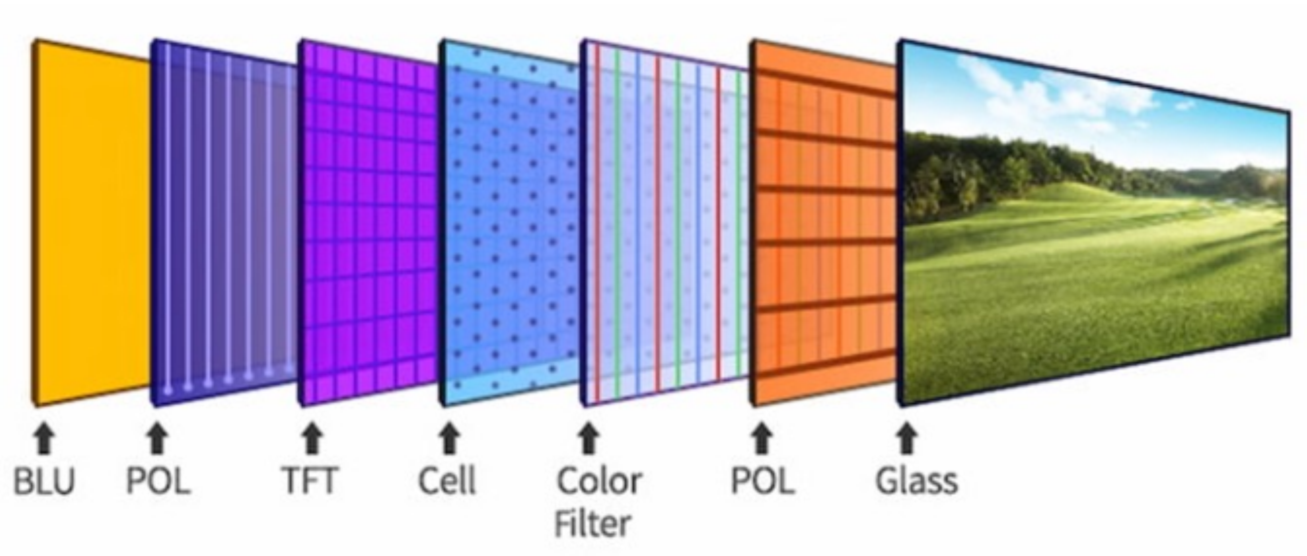
Source: Orient Display

In-plane-switching (IPS) LCD Technology



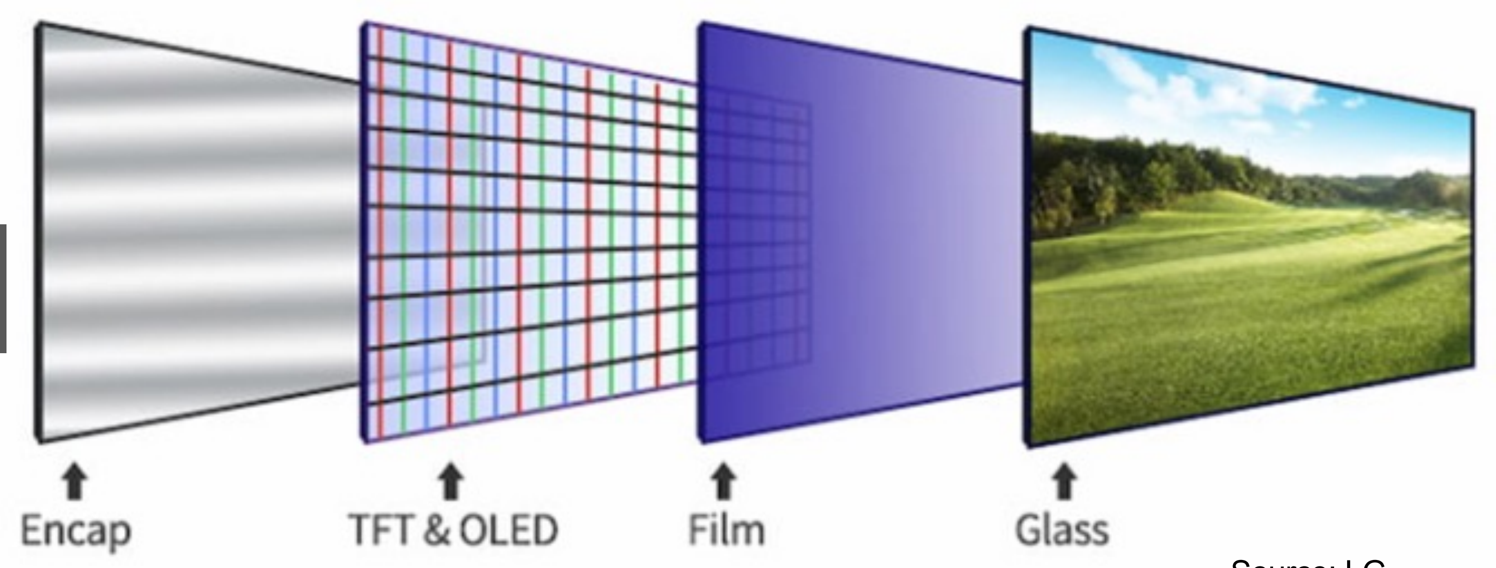
Source: Orient Display

OLED Display Technology



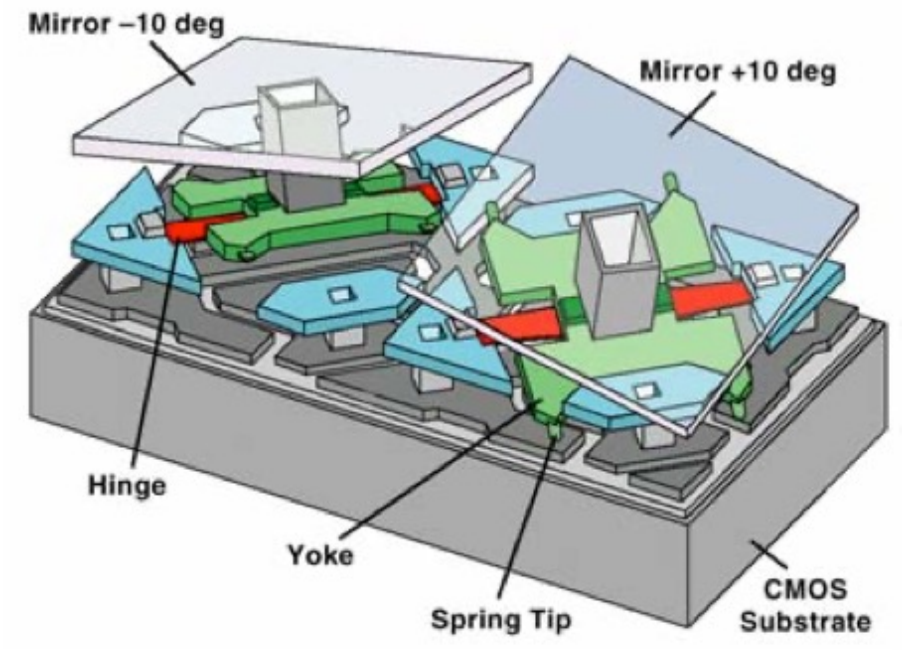
LCD display

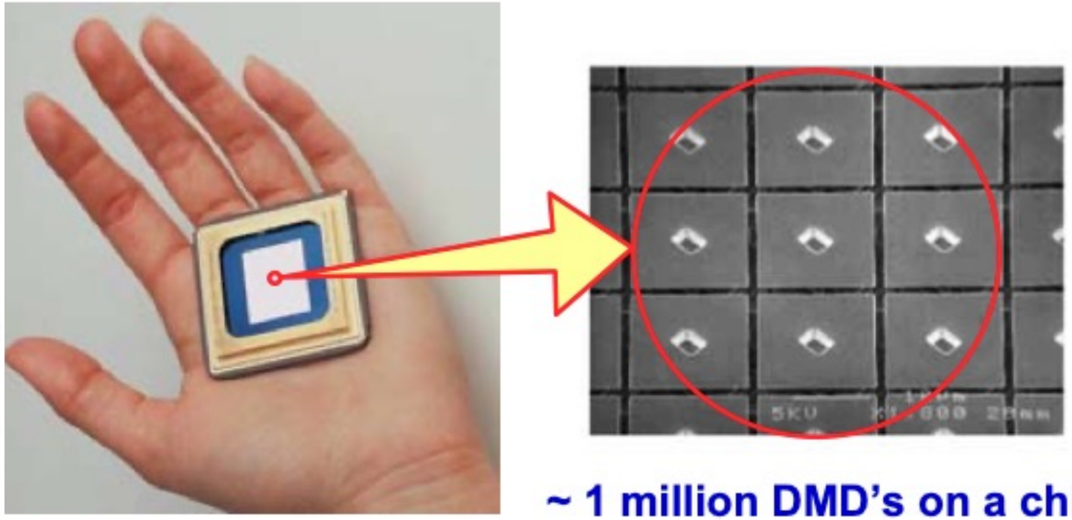
OLED display



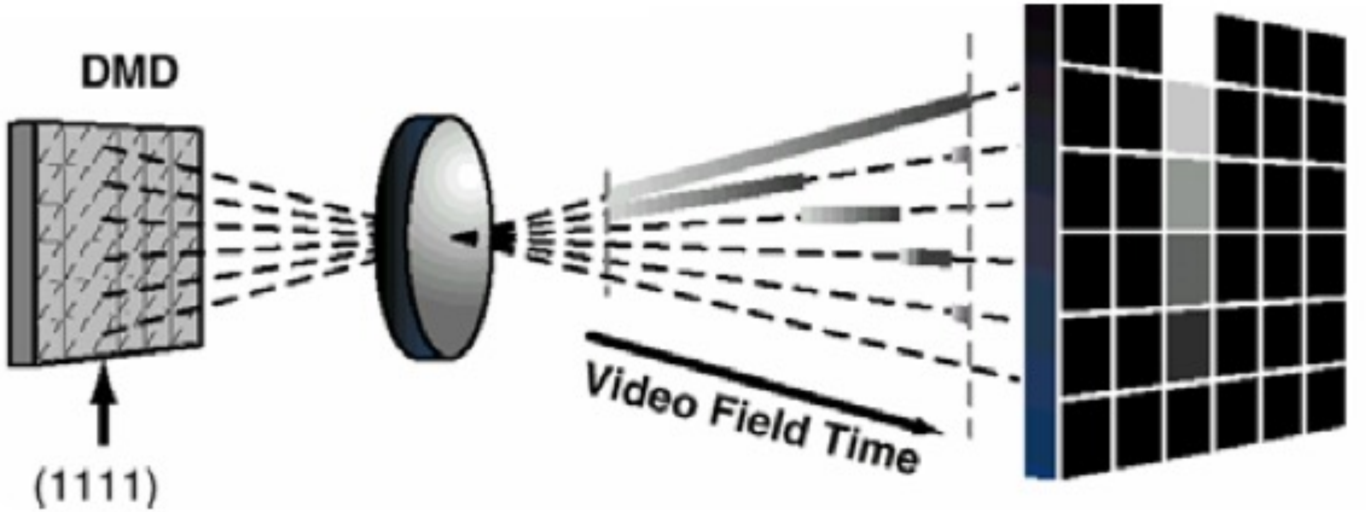
Source: LG

Digital Micromirror Device (DMD) Technology



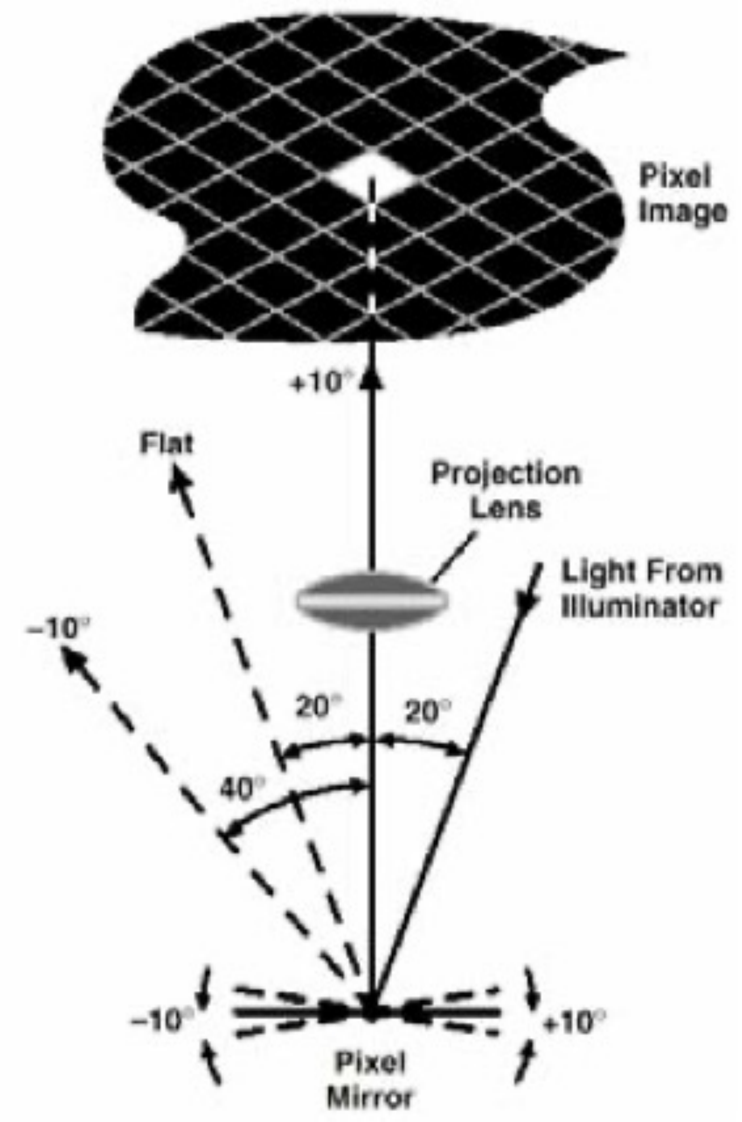


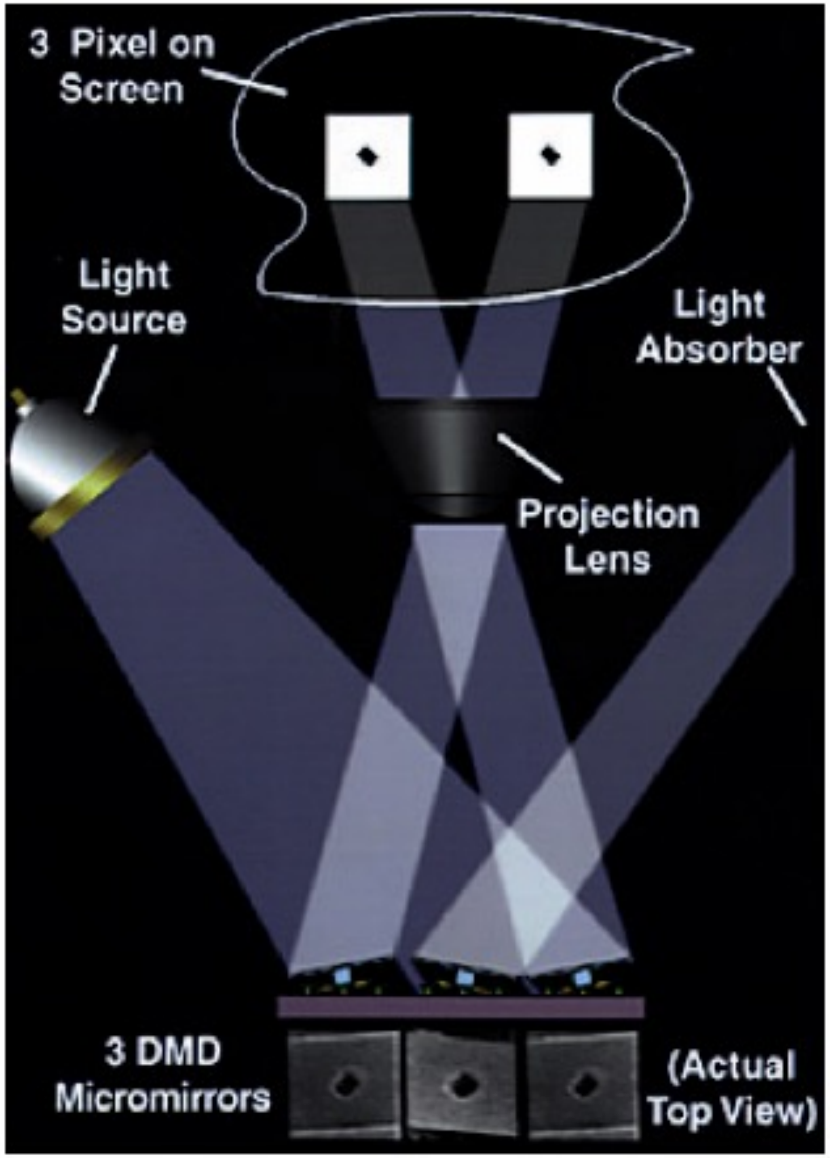
~ 1 million DMD's on a chip



Source: Texas Instruments

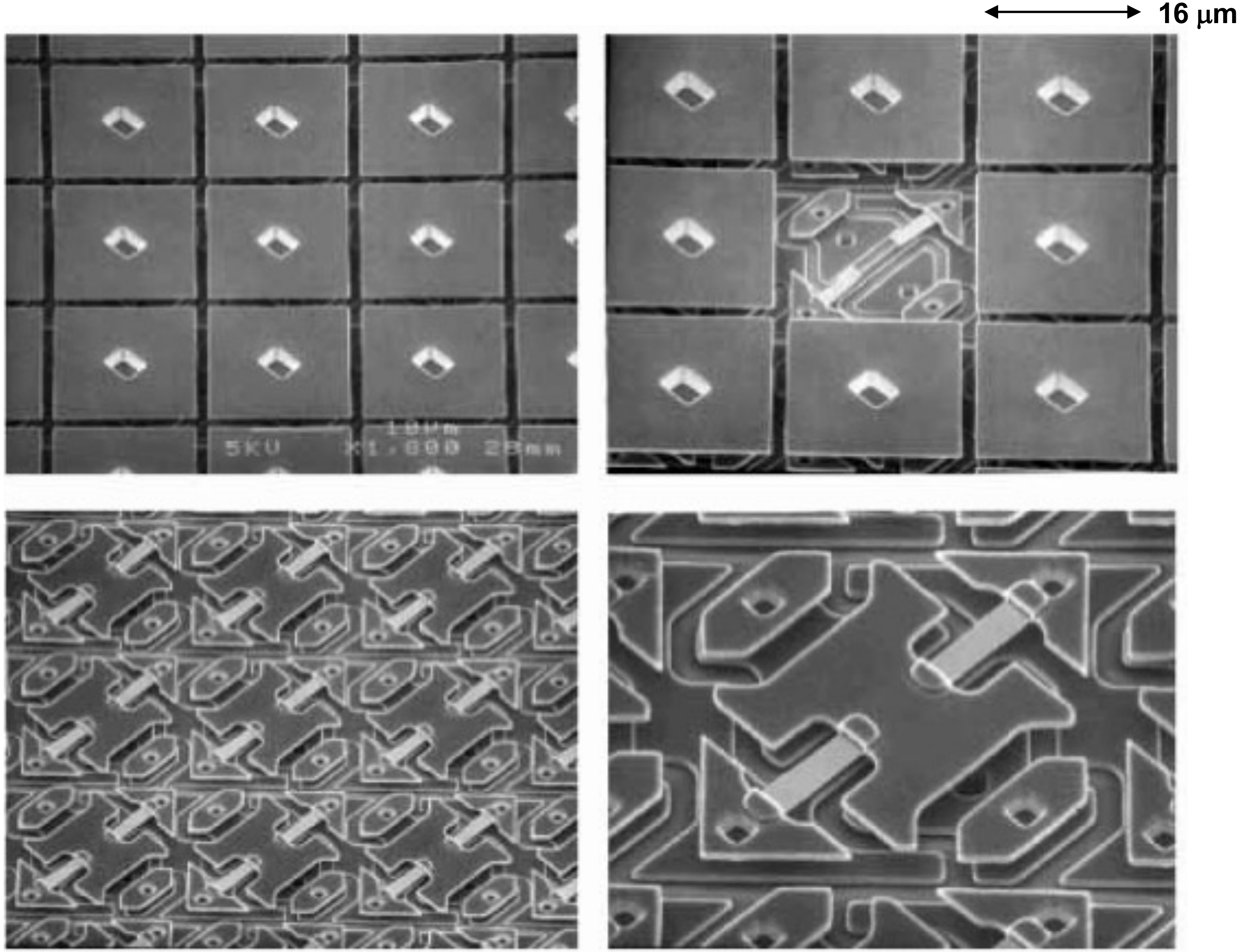
Principle of Projection using DMD





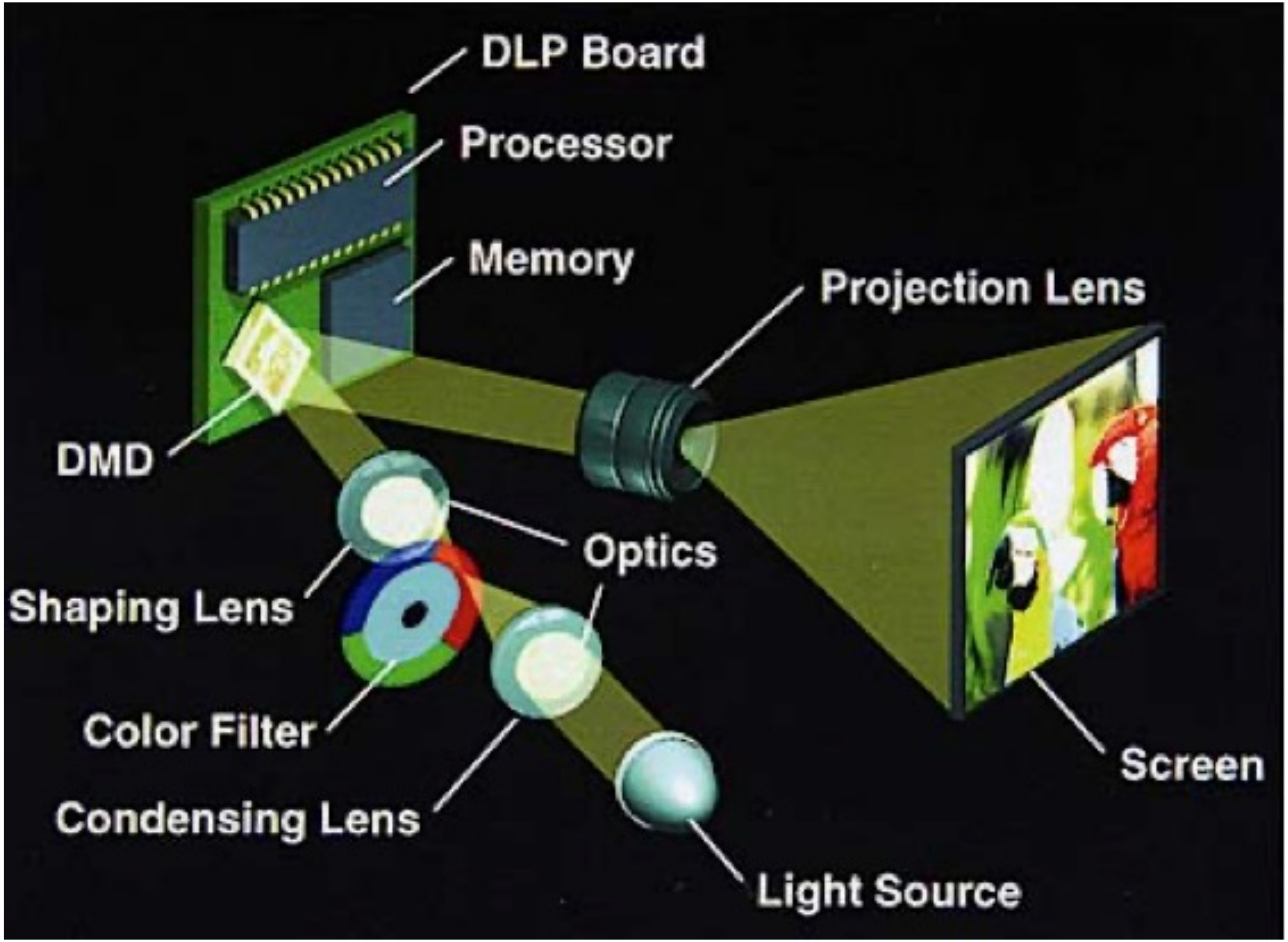
Source: Texas Instruments

SEM images of DMD by TI



Source: Texas Instruments

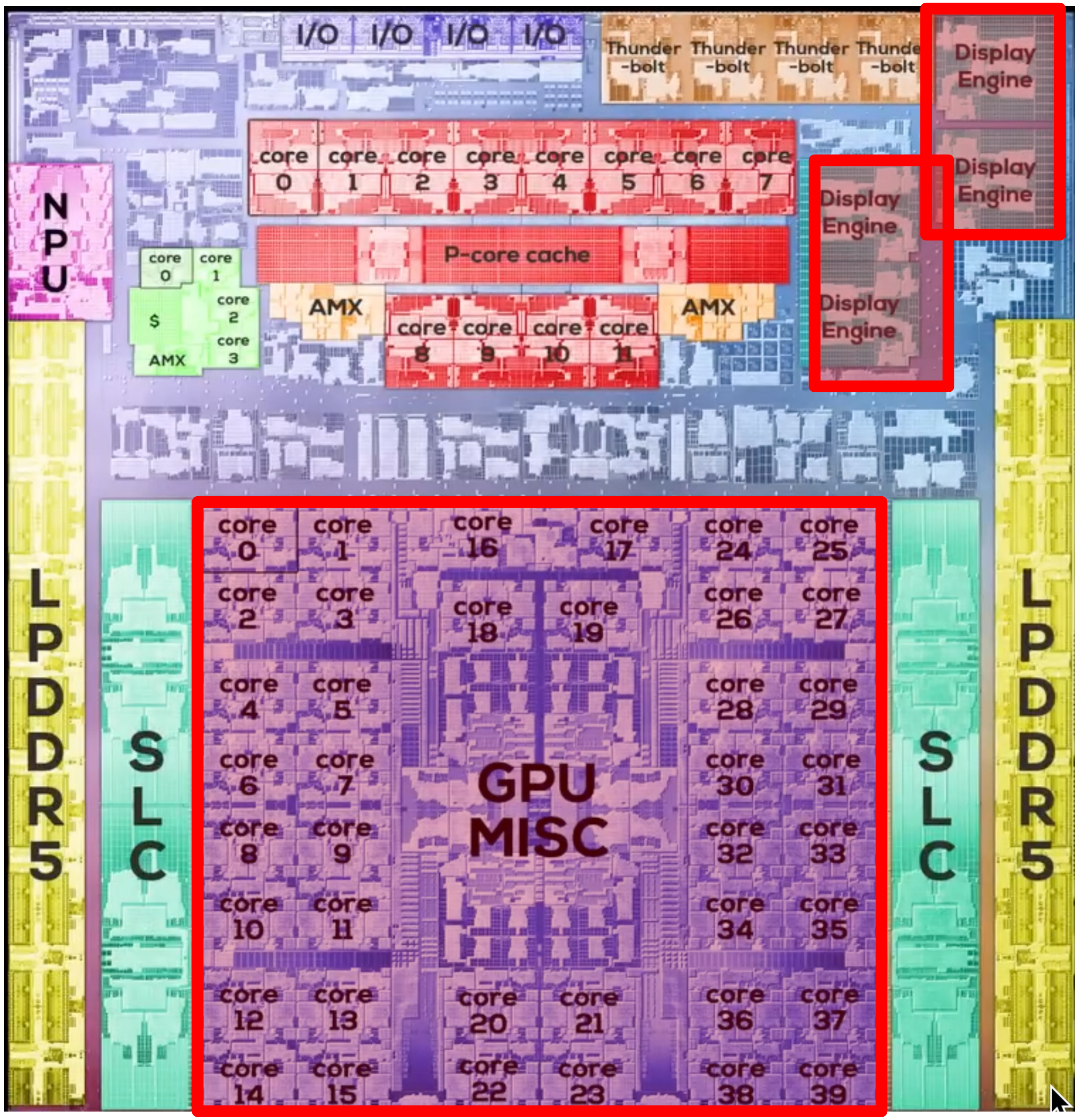
Digital Micromirror Device (DMD) Technology



DLP – Digital Light Processing

Source: Texas Instruments

Apple Silicon M3 Pro Chip Photo

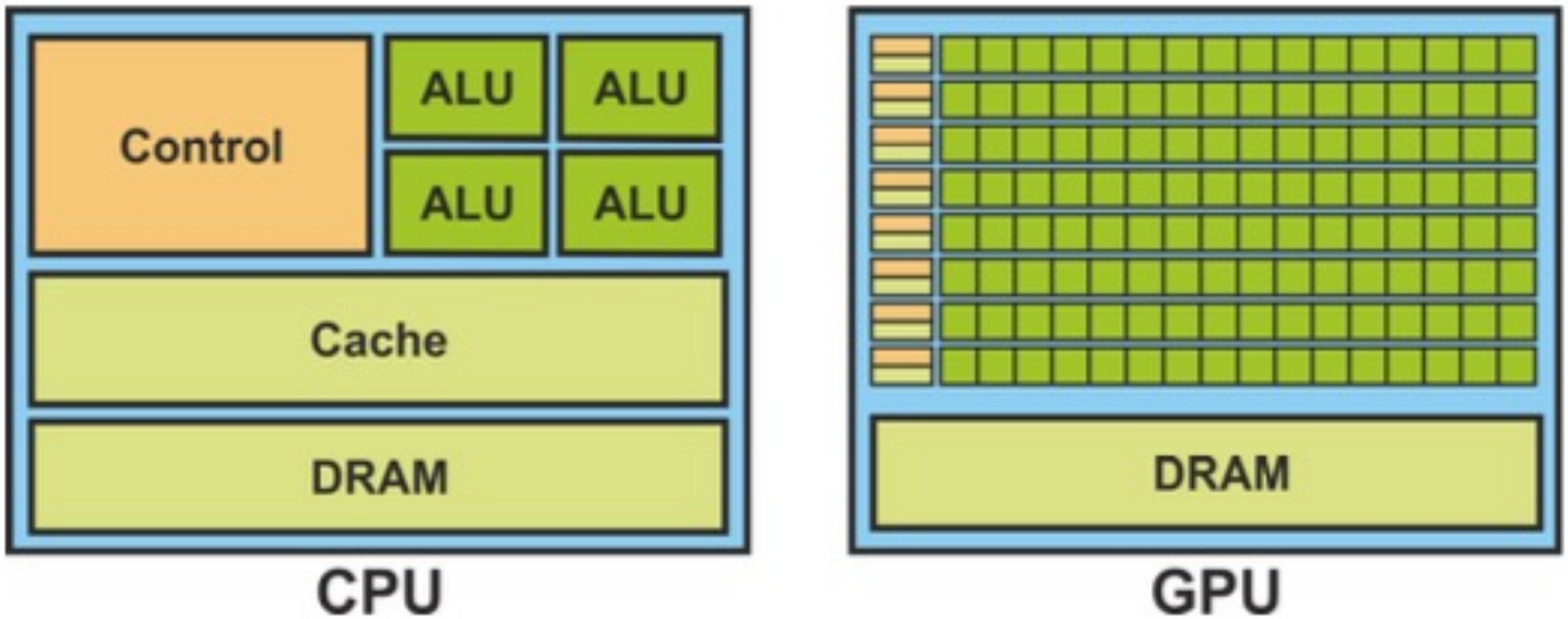


Source: Apple Computers

What is a GPU?

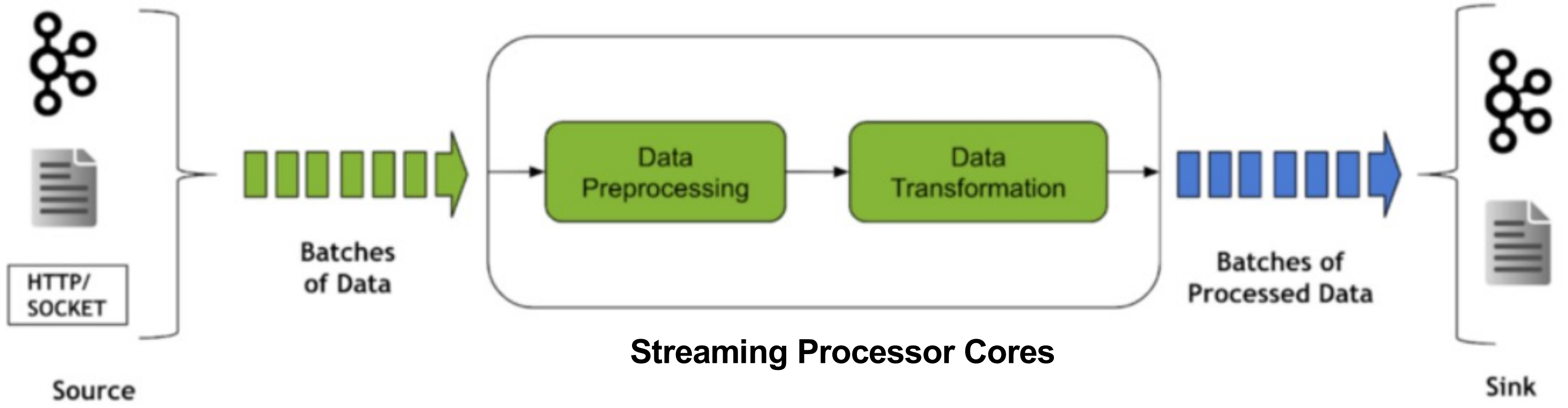
- Based on SIMD architecture – Single Instruction, Multiple Data.
- Exploit data parallelism.
- High compute density due to massive degree of parallel processing.
- Initially developed as graphics accelerators for games.
- Now used for many other scientific processing and particularly for AI training.
- Software based on C/C++, and also on CUDA (Nvidia's own programming language).

MISD

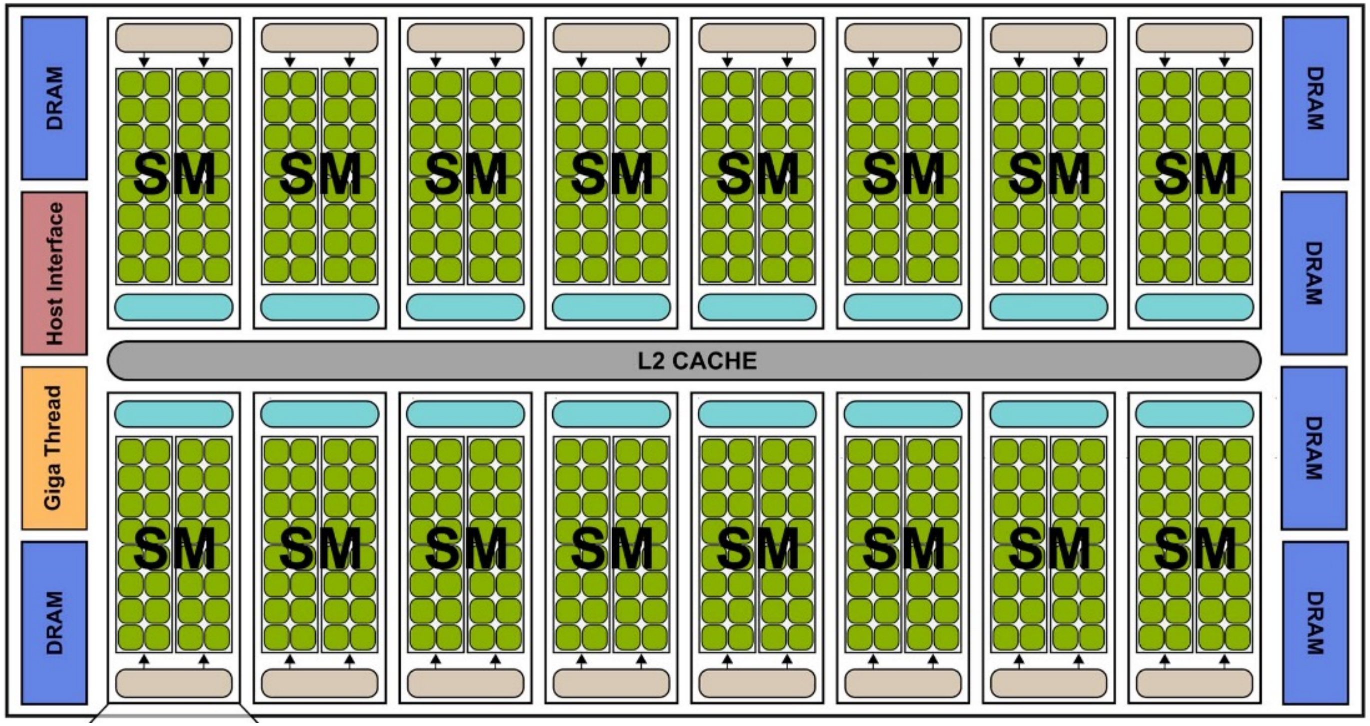


SIMD

Typical Nvidia GPU Architecture

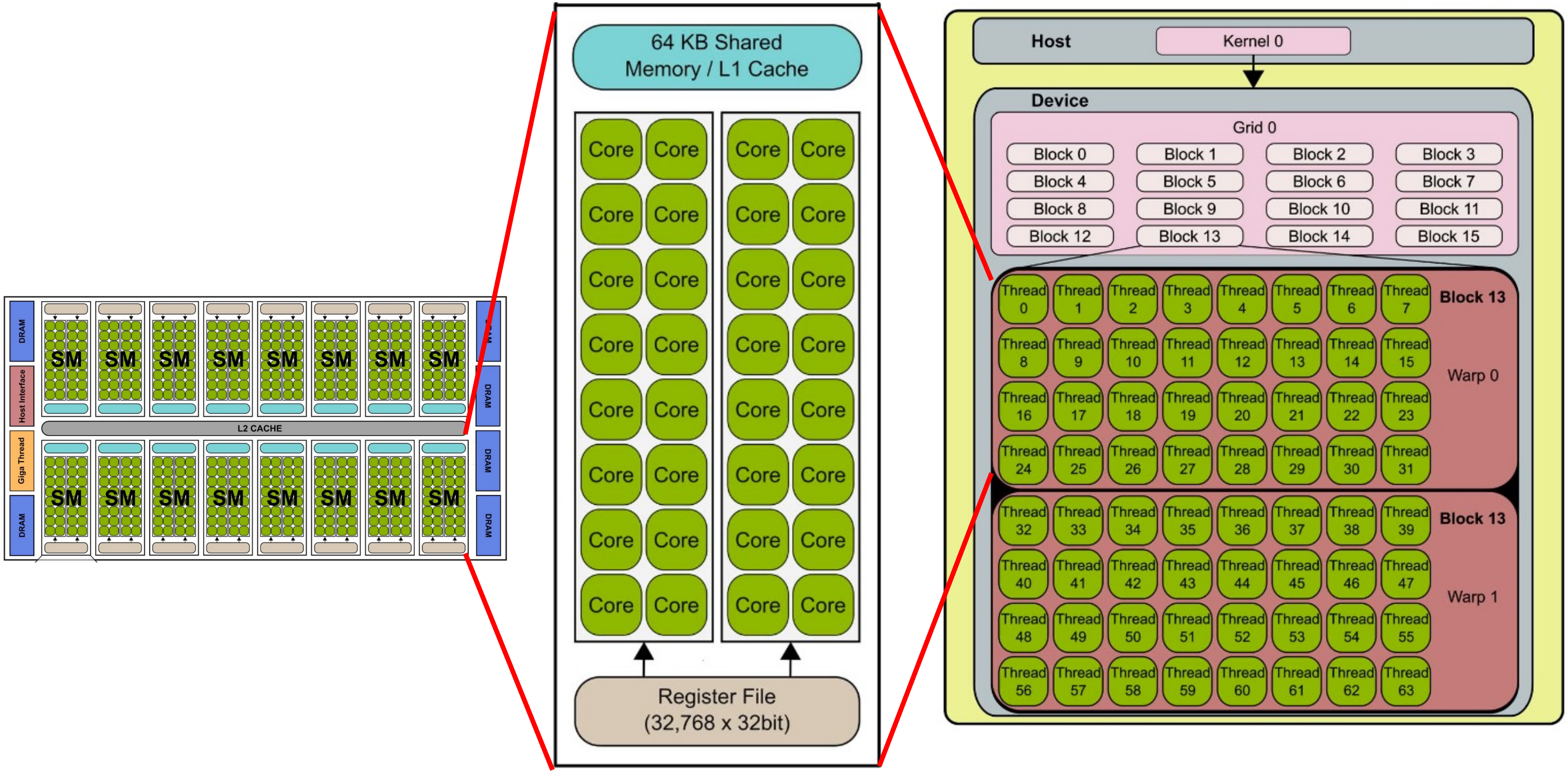


Streaming Processor Cores



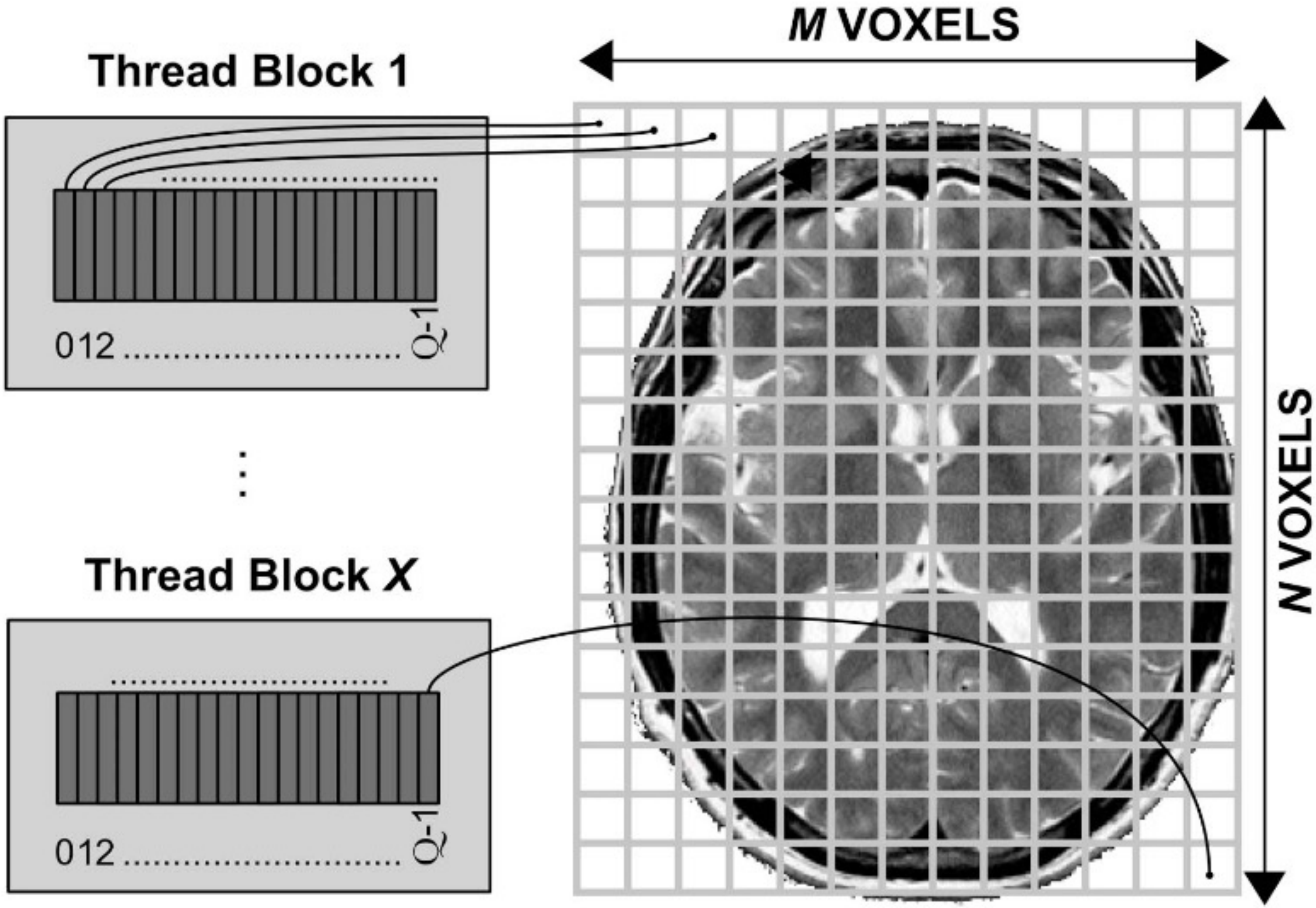
Source: NVIDIA

SM and the CUDA programming model



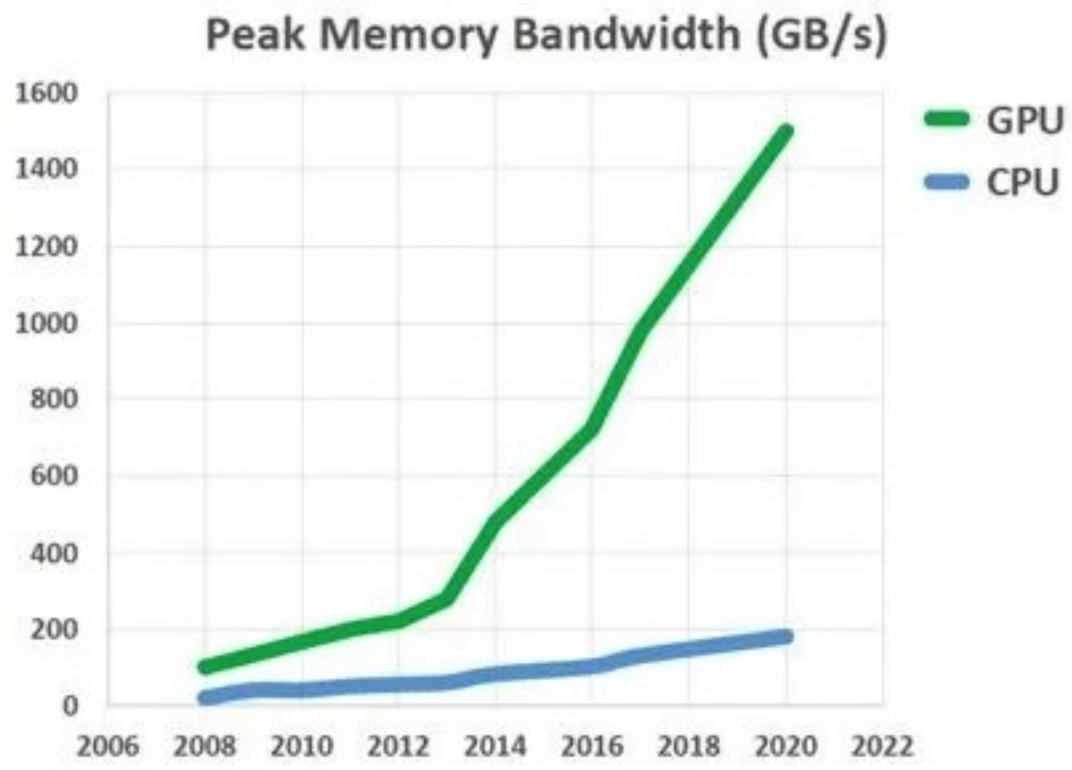
Source: NVIDIA

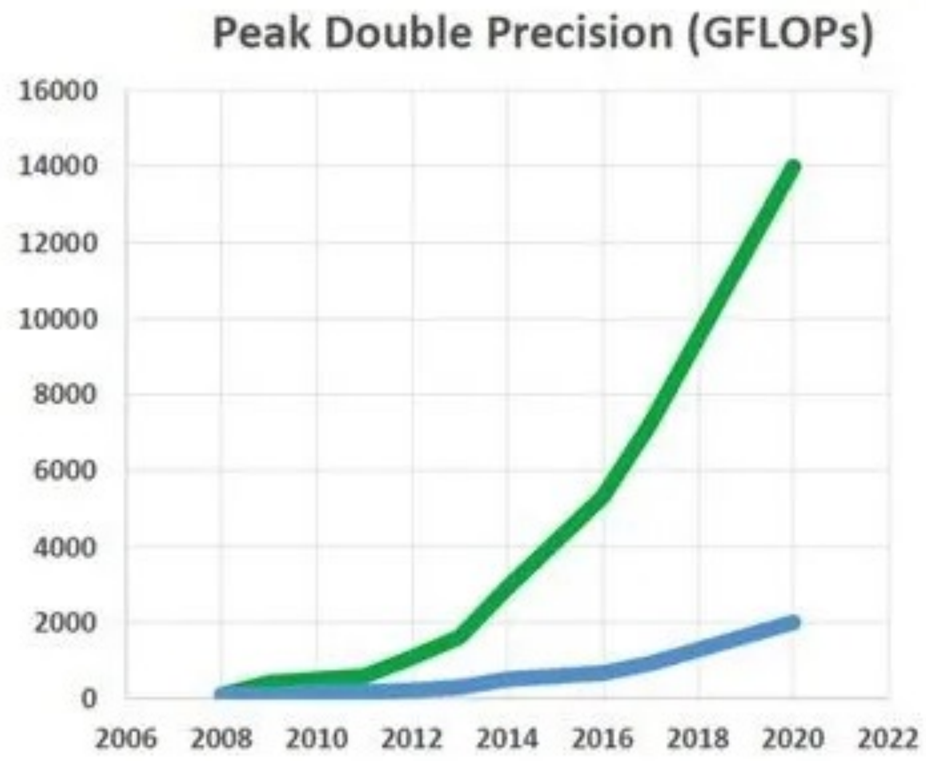
Nvidia CUDA Programming Model



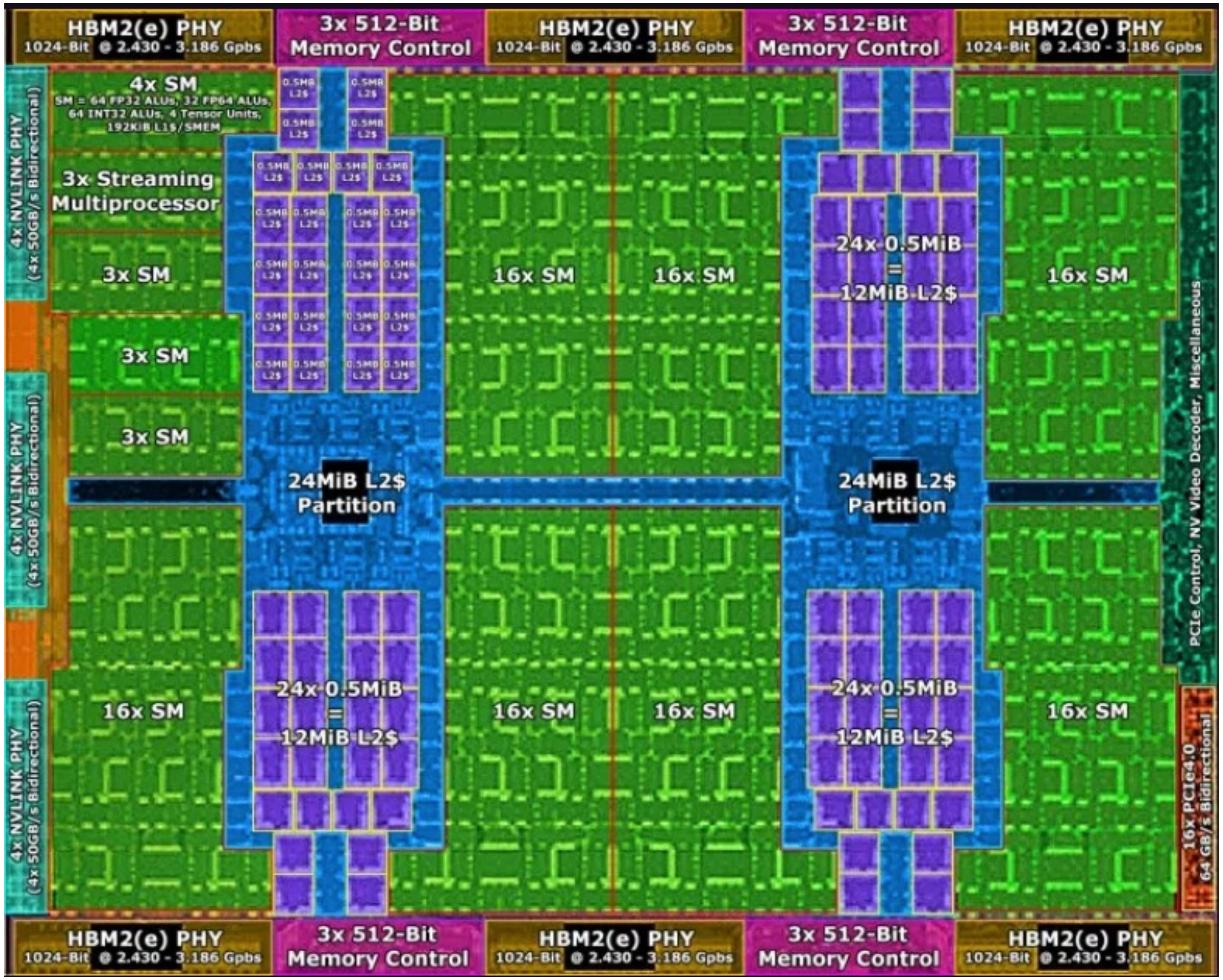
Source: Moises Hernandez

GPU vs CPU on Performance





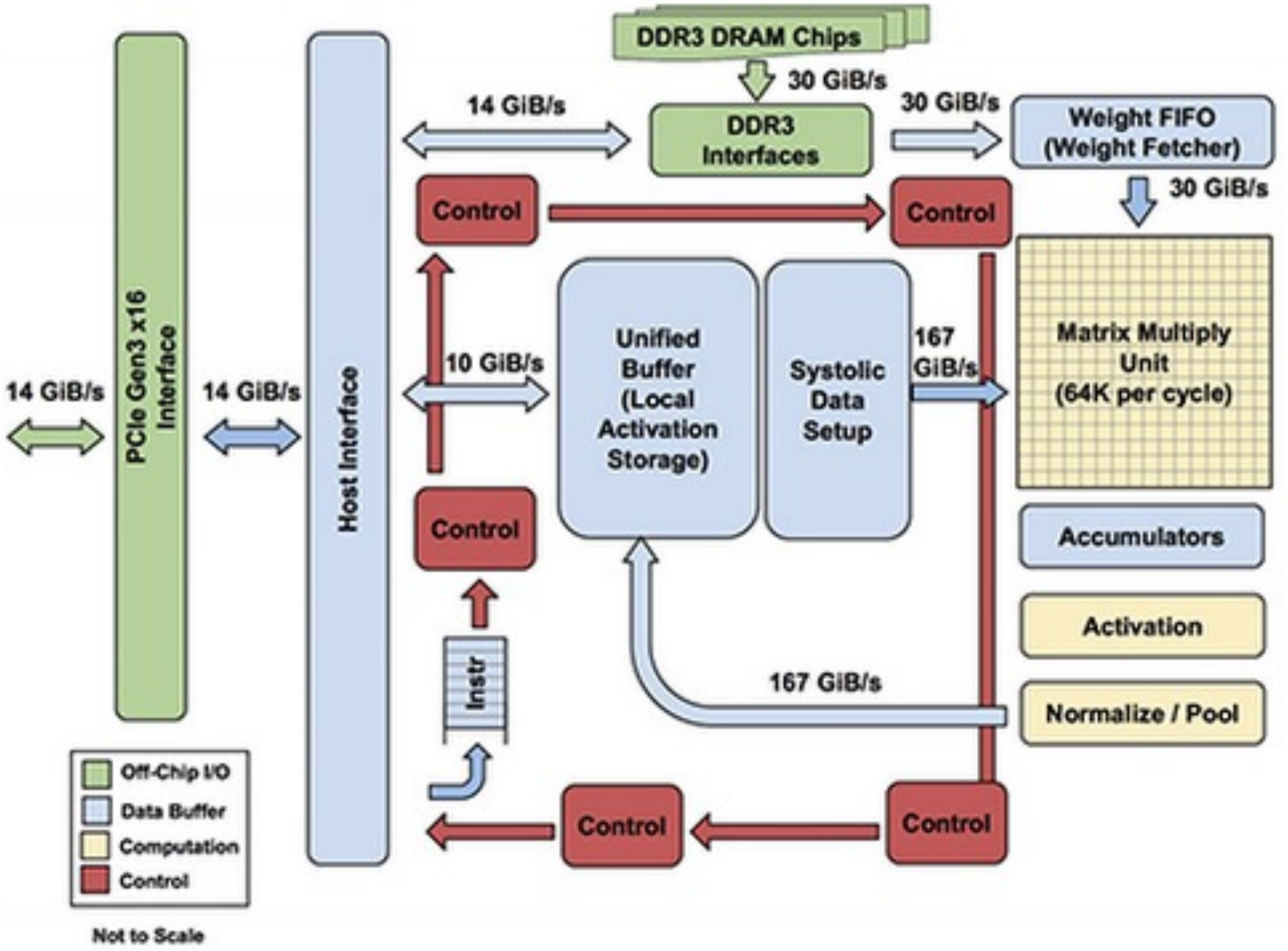
Nvidia Latest – Ada GPU AD102



- 288 FP64 cores in
- 144 Streaming Multiprocessors (SMs)
- 12 Graphics Processing Clusters (GPCs)
- 72 Texture Processing Clusters (TPCs)
- 384-bit memory interface
- 12 32-bit memory controllers.

Source: NVIDIA

Google Tensor Processing Unit (TPU)

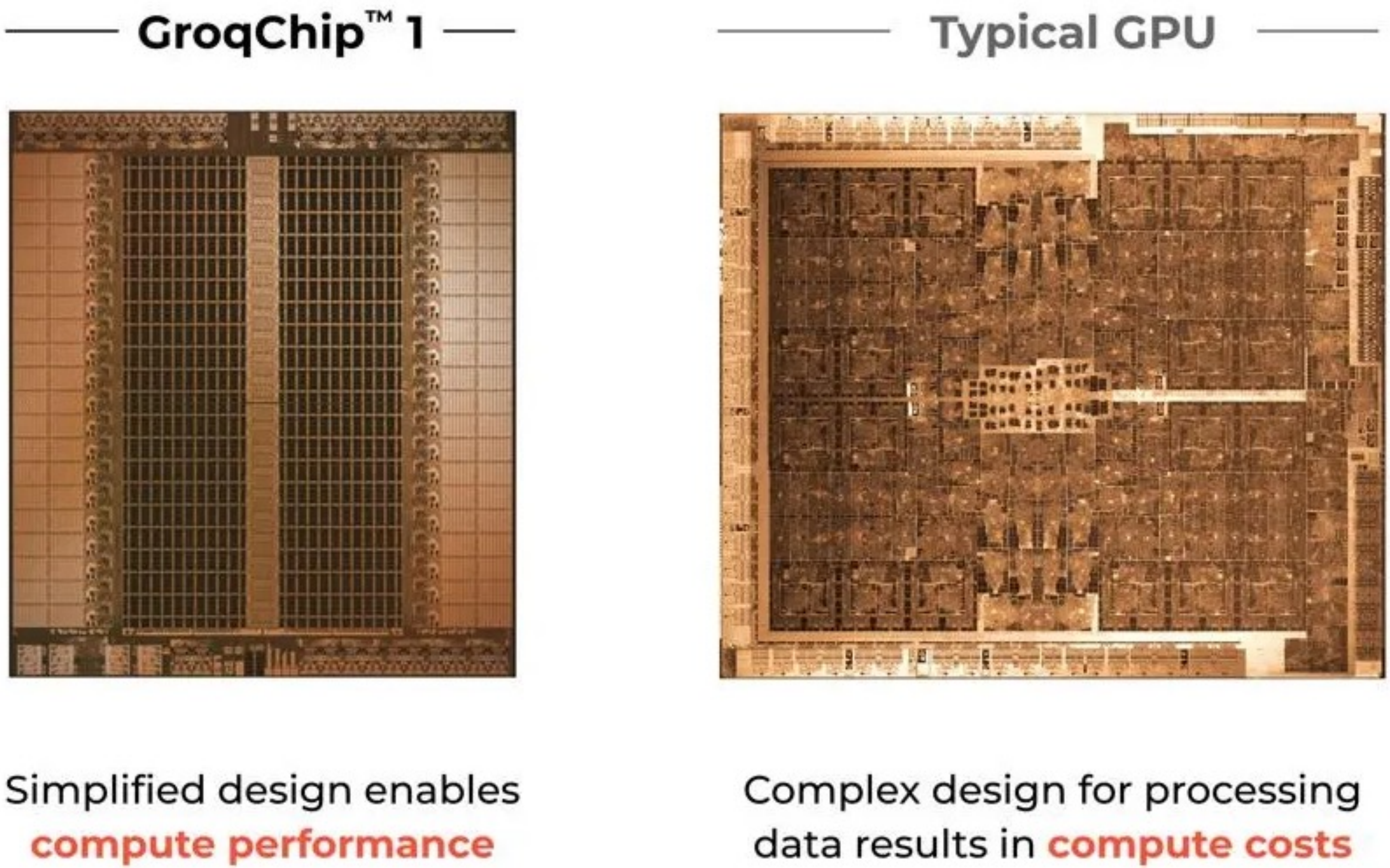


The TPU includes :

- **Matrix Multiplier Unit** (MXU): 65,536 8-bit multiply-and-add units for matrix operations
- **Unified Buffer (**UB): 24MB of SRAM that work as registers
- **Activation Unit** (AU): Hardwired activation functions

Source: Google

GroqChip 1 – Another AI inference engine



Source: Groq

Cerebras 1.2 trillion transistor AI interference engine