INTELLIGENCE TO SHAPE YOUR TOMORROW

The CMOS Image Sensor Industry Technology Trends and Emerging Applications

Edge AI and Vision Alliance Webinar

3 December 2024

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YOLE Intelligence

YOLE GROUP

We provide industrial companies, financial investors and R&D organizations, with market research and marketing analysis, technology, supply chain and cost analysis, as well as performance evaluation, to help our customers in their decision-making about their future business and manufacturing strategy in the semiconductor, photonic and electronic sectors.

3 CORE ACTIVITIES BASED ON DEEP SYNERGIES

Market & Technology

- Market, technology, and strategy consulting

- M&A, Due Diligence and evaluation of companies

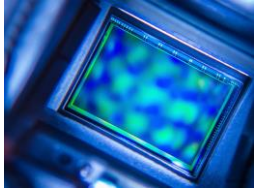### Teardown Reverse engineering and costing

- Technology, process & cost analysis

- Teardown and reverse engineering

- Comparative analysis

Performance analysis

- Test of electric and electro-optical performance of devices

- Comparison of performances and related technical choice

IMAGING: YOLE INTELLIGENCE REPORTS

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Components

Status of the CMOS Image Sensor Industry 2024

Neuromorphic Computing, Memory and Sensing 2024

Optical Metasurfaces 2024

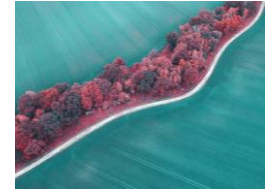## Modules

Status of the Camera Module Industry 2024

3D Imaging and Sensing 2023

Markets

Imaging for Security 2022

Imaging for Industrial – Machine Vision 2024

Imaging for Automotive 2024

Digital X-ray Imaging 2022

VIS-NIR

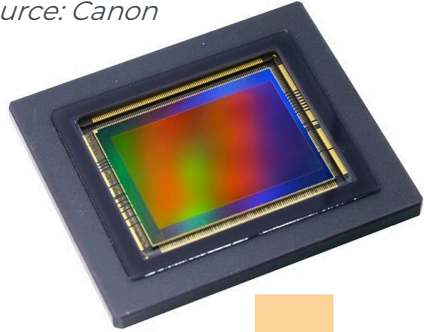SWIR Imaging 2023

Thermal Imaging and Sensing 2024
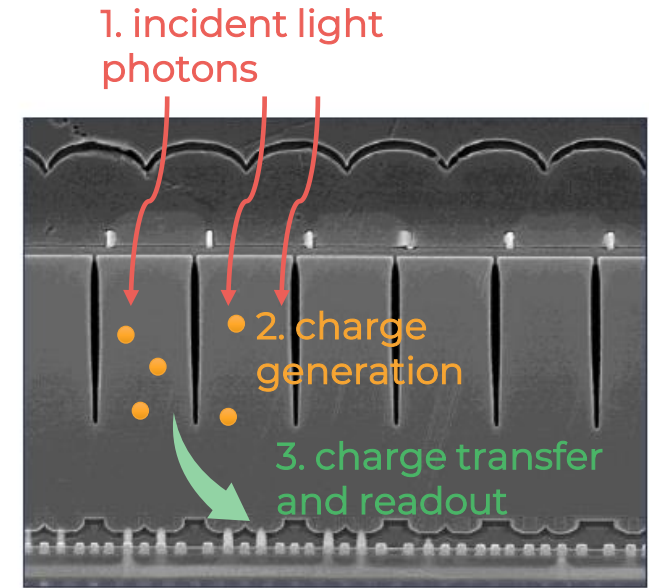
Wavelength

INTRODUCTION

From photons to light and color information

Typical CMOS image sensor
Source: Canon

CMOS image sensor: a pixel array of Silicon-based photodiodes with operating transistors and dedicated signal processing

1. incident light photons

2. charge generation
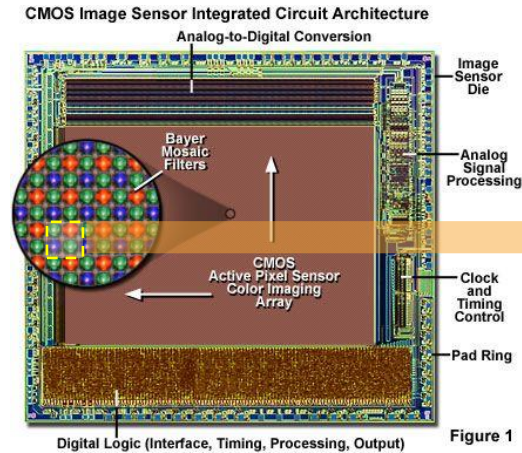
3. charge transfer and readout

Cross Section of the Pixel Array of the Ultra-Wide CIS in the 14 Pro Max - SEM View
©Yole SystemPlus 2024

Source: Yole SystemPlus

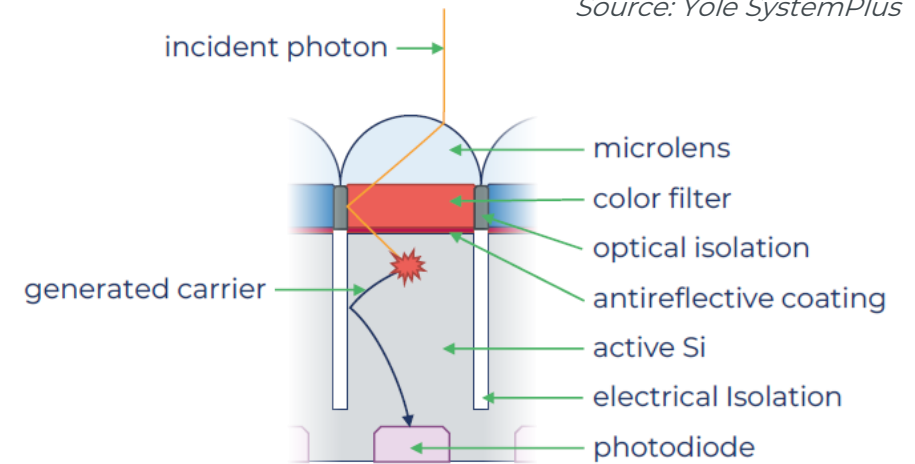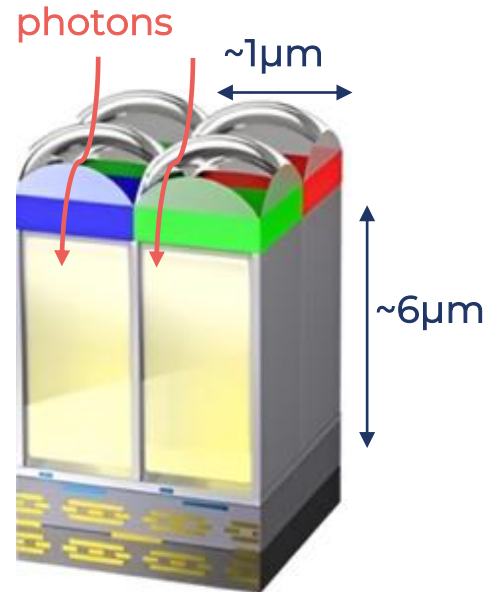*CMOS image sensor schematic top view*
Source: Olympus

CMOS Image Sensor Integrated Circuit Architecture
Analog-to-Digital Conversion

Image Sensor Die

Bayer Mosaic Filters

Analog Signal Processing

CMOS Active Pixel Sensor Color Imaging Array

Clock and Timing Control

Pad Ring

Digital Logic (Interface, Timing, Processing, Output)   Figure 1

3D cross-section of four RGB pixels
Source: Sony

photons

~1μm

~6μm

incident photon

microlens

color filter

optical isolation

antireflective coating

generated carrier

active Si

electrical Isolation

photodiode

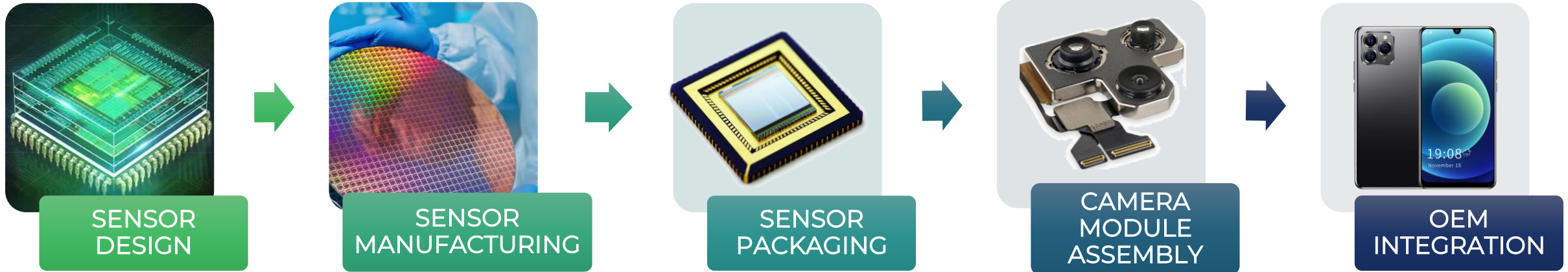*Schematic of the Cross Section of a typical pixel*
©Yole SystemPlus 2024

INTRODUCTION
CMOS image sensor is a semiconductor product

SENSOR DESIGN → **SENSOR MANUFACTURING** → **SENSOR PACKAGING** → **CAMERA MODULE ASSEMBLY** → **OEM INTEGRATION**

- Fabricated in semiconductor fabs, mostly in 8-inch (~8%) and 12-inch (~92%).

- Technology nodes ranging from 180nm to 22nm for the most advanced sensor logic at mass production level.

- Highly sensitive to cross-contamination that can affect their performance and degrade their production yield, so dedicated production line or specific protocols have to be setup by the fabs.
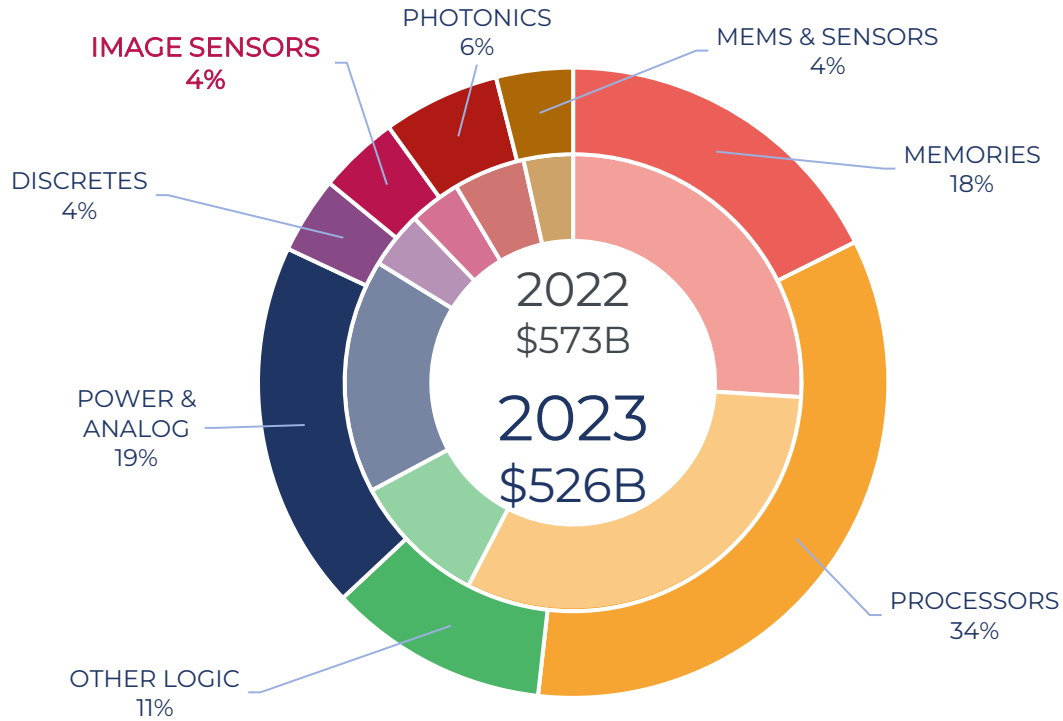
Connector
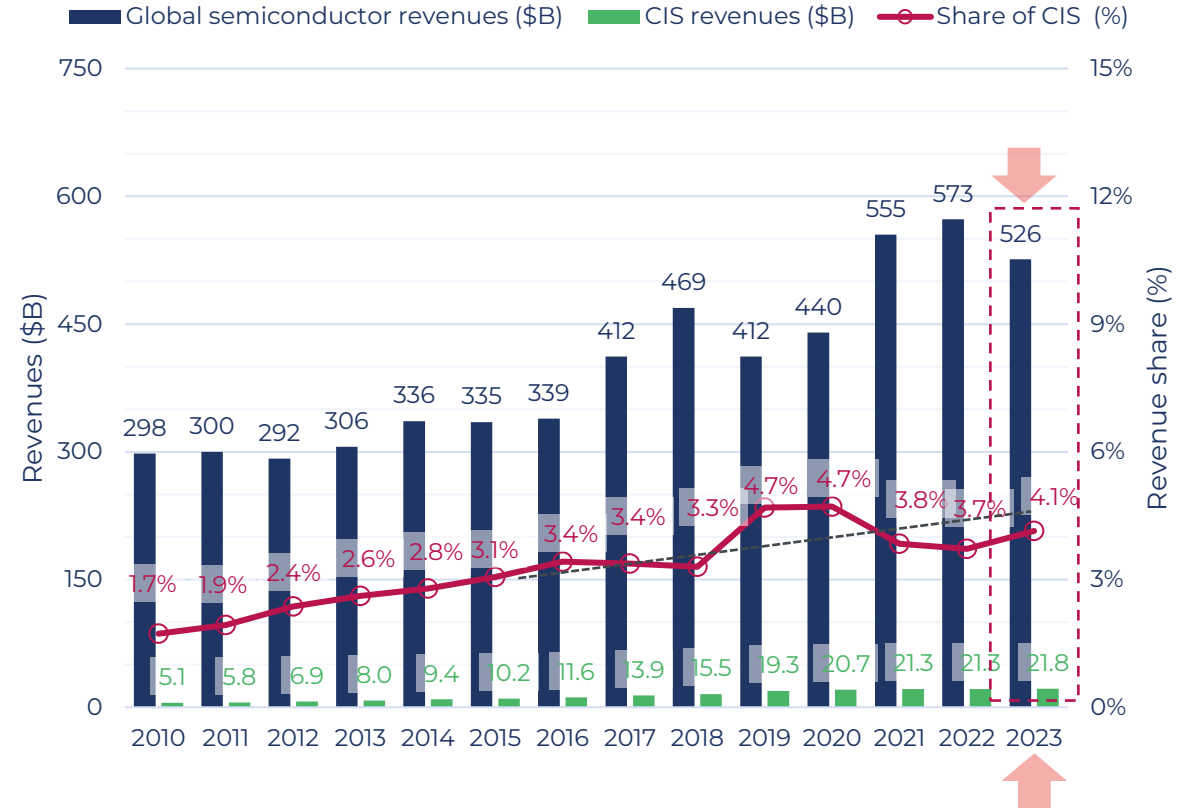Flex-rigid substrate
Image sensor (CIS)
Actuator driver
Metal shield
IR-cut filter
Actuator (AF/OIS)
Lens set
Lens mount

courtesy of Oppo

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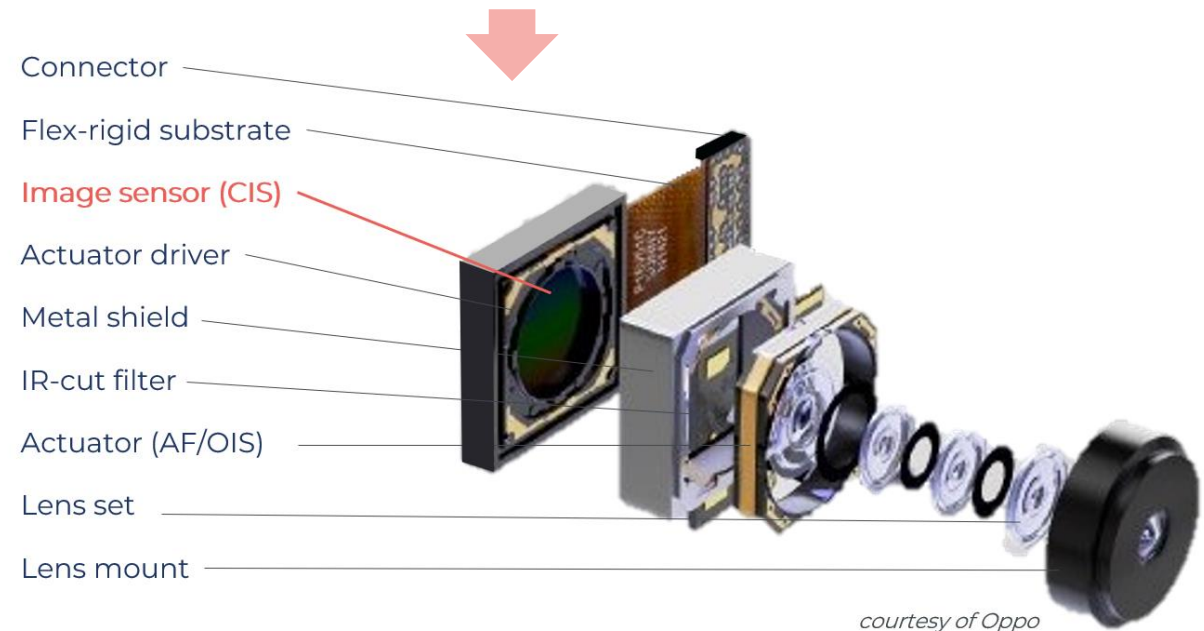
Semiconductor and CMOS image sensors industry revenue

2022-2023 Semiconductor industry
Revenues (in $B)

- PHOTONICS 6%
- MEMS & SENSORS 4%
- IMAGE SENSORS 4%
- MEMORIES 18%
- DISCRETES 4%
- PROCESSORS 34%
- POWER & ANALOG 19%
- OTHER LOGIC 11%

2022 $573B
2023 $526B

2010-2023 Global semiconductor vs. CIS industry
Revenues (in $B)

Legend: Global semiconductor revenues ($B) — CIS revenues ($B) — Share of CIS (%)

Global semiconductor revenues ($B): 298, 300, 292, 306, 336, 335, 339, 412, 469, 412, 440, 555, 573, 526

CIS revenues ($B): 5.1, 5.8, 6.9, 8.0, 9.4, 10.2, 11.6, 13.9, 15.5, 19.3, 20.7, 21.3, 21.3, 21.8

Share of CIS (%): 1.7%, 1.9%, 2.4%, 2.6%, 2.8%, 3.1%, 3.4%, 3.4%, 3.3%, 4.7%, 4.7%, 3.8%, 3.7%, 4.1%

Years: 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023
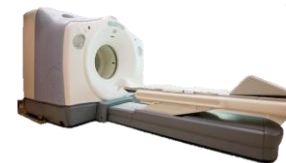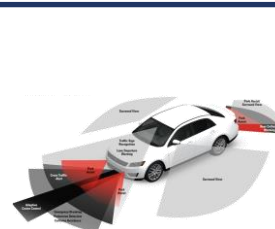
- On a continuous increase since 2019, the semiconductor revenue decreased by -8.2% in 2023. In this context, the CMOS image sensors industry revenue growth outperformed that of the global semiconductors, representing 4.1% of the total.

INTRODUCTION
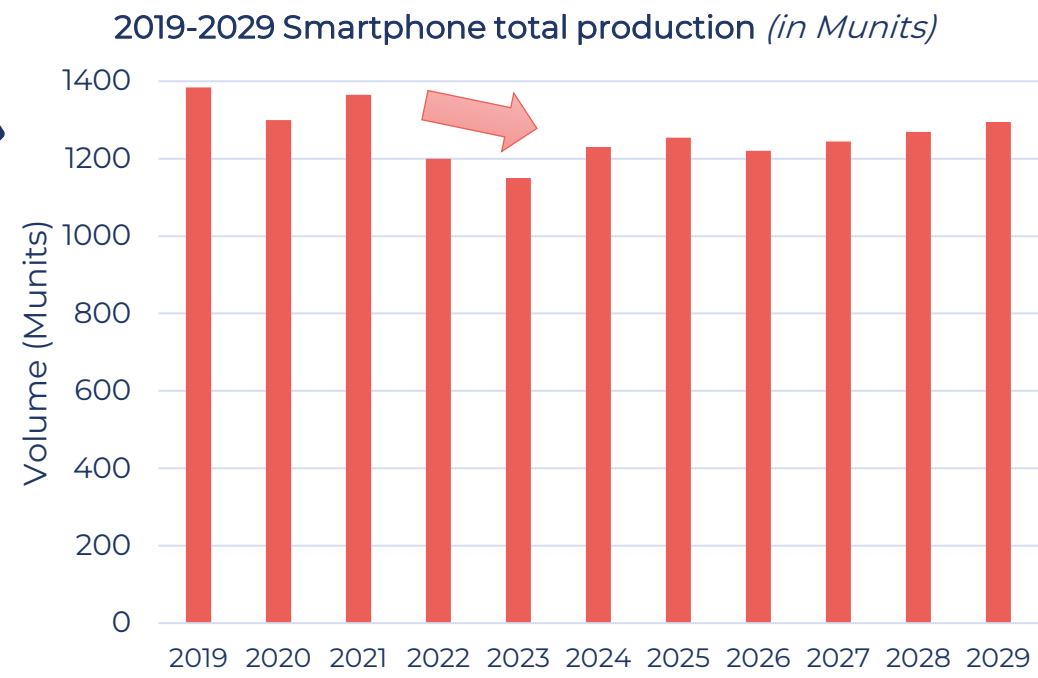## CMOS imaging market segmentation and applications

Market	MOBILE & CONSUMER			AUTOMOTIVE & MOBILITY	MEDICAL	INDUSTRIAL		DEFENSE & AEROSPACE
Segment	Mobile	Other consumer	Productivity	Automotive	Medical	Security	Industrial	Defense and Aerospace

End system Applications	Smartphone	DSLR/ILCs DSC	Mice	Light vehicle	Endoscopy	Security camera	Matrix code	Def. & Aerospace
	➤ Rear photography	Action camera	Tablet	➤ In-cabin	X-ray detector	➤ Home security	Machine vision	Science & Research
	➤ Front selfie	Consumer drone	➤ Rear photography	➤ Viewing	➤ Flat panel	➤ Commercial	Prof. broadcast	
	➤ Authentication	Personal robotics	➤ Front selfie	➤ ADAS	➤ Dental	➤ Infrastructure		
	➤ Rear 3D sensing	AR/VR headset	➤ Authentication	➤ Dash recorder	➤ CT scan	➤ Authentication		
	Feature phone	➤ Tracking cameras	➤ Rear 3D sensing		PET detector			
	➤ Rear photography	➤ RGB cameras	Laptop					
	➤ Front selfie	➤ 3D sensing	➤ Webcam					
		Game station/TV/projector	➤ Authentication					
		Smart speaker/assistant						
		Smartwatch						

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IMAGING MARKET TRENDS

MOBILE MARKET TRENDS
The recent mobile market dynamics

What is the future of mobile imaging and sensing?

2019-2029 Smartphone total production *(in Munits)*

Decrease in 2022 and longer-term expectations for smartphone shipments by about 10%.

2019 - 2029 average number of cameras per smartphone handset

- 2.37
- 2.61
- 2.79
- 2.81
- 2.83
- 2.87
- 2.93
- 2.97
- 3.03
- 3.10

— Smartphones Rear camera   — Smartphones Front camera
- - - Previous forecast

Nokia 9 PureView

Deceleration in the increase of the average number of cameras per smartphone.

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MOBILE MARKET TRENDS
Inside Xiaomi's 14 Ultra periscope camera module


14 Ultra

Front view of the camera module showing the position of the cross-sectional plane
©Yole SystemPlus 2024

Periscope camera cross-section, showing lens stack

spacer

prism module

prism

lens module

glass plate (filter)

CIS

top metal enclosure

Camera Module Cross Section – Optical Overview
©Yole SystemPlus 2024

Module Dim. excl. flex	3217 mm³
OIS/AF	Yes/Yes
Lens Number	5P
Avg. Lens Diameter	5.3 mm
Filter Material	Glass
TTL	21 - 23 mm
Assembler	SEMCO
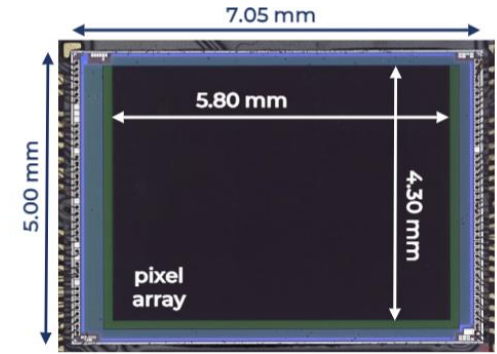
CIS Die Overview
©Yole SystemPlus 2024

CMOS image sensor from Sony

2023

~40 Munits

CAGR₂₃₋₂₉ **16.4%**

2029

~100 Munits

At Yole, we perform extensive comparative analysis of the different smartphone flagship models from leaders such as Apple, Samsung, Xiaomi.

P30 Pro with periscope x5

Reno 10x Zoom series

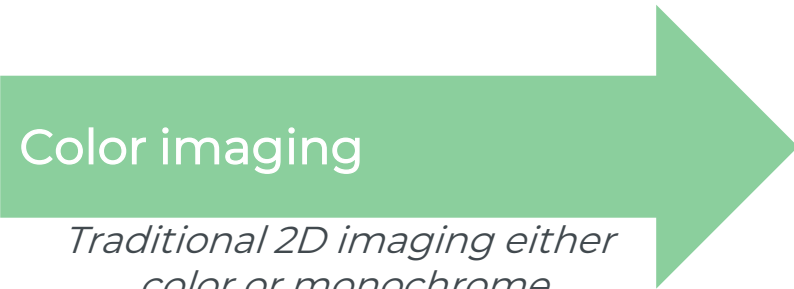Adoption by multiple OEMs

First periscope camera in the iPhone 15

HUAWEI OPPO SAMSUNG HONOR mi SONY vivo Google

Apple realme ONEPLUS MOTOROLA

| 2019 | 2020 | 2021 | 2022 | 2023 | 2024 |

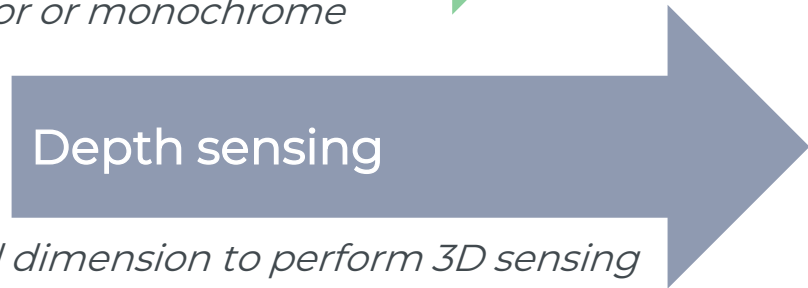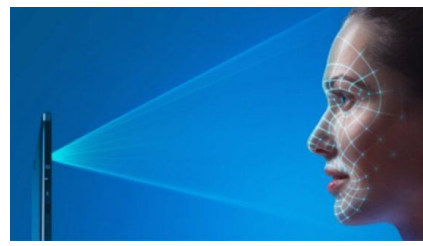## Camera module technology, from imaging to sensing diversity

2D Color imaging

Traditional 2D imaging either color or monochrome

3D Depth sensing
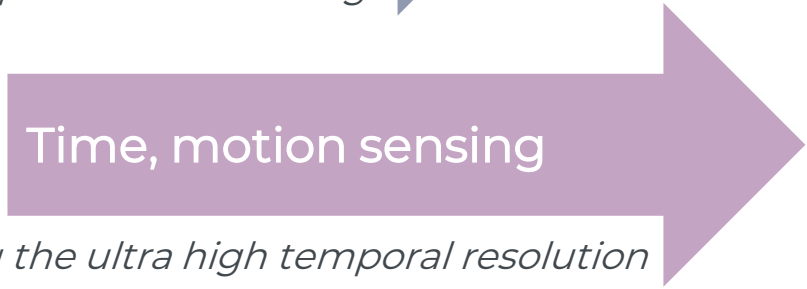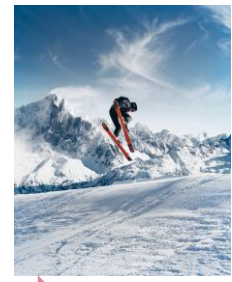
Bringing the 3rd dimension to perform 3D sensing
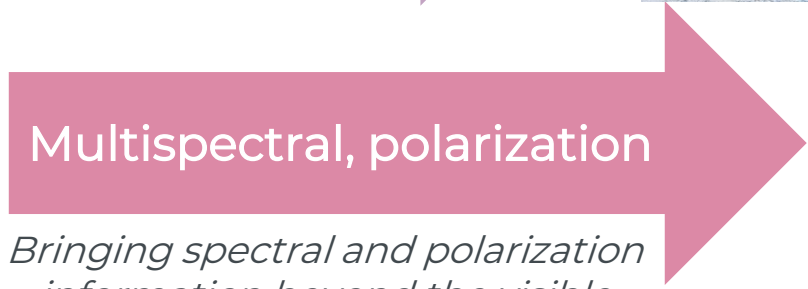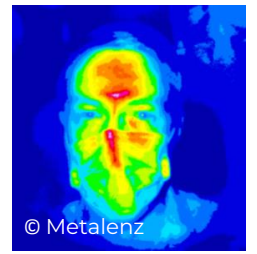
© Velodyne

4D Time, motion sensing

Bringing the ultra high temporal resolution
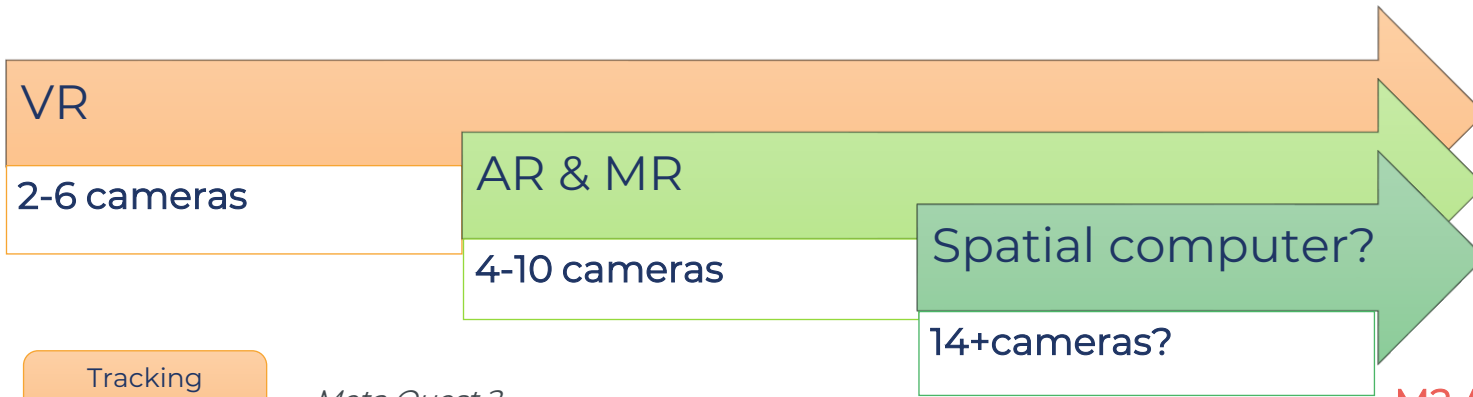
5D Multispectral, polarization

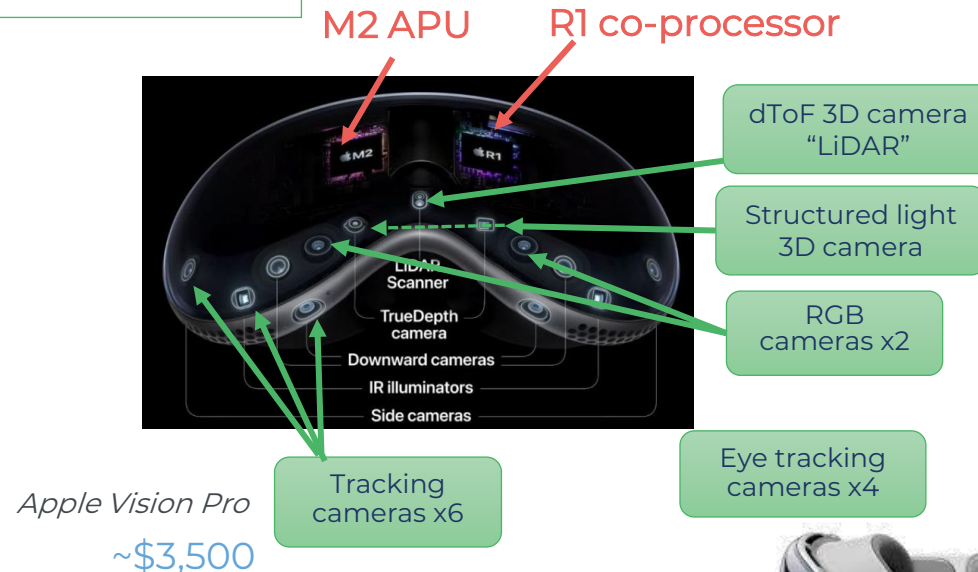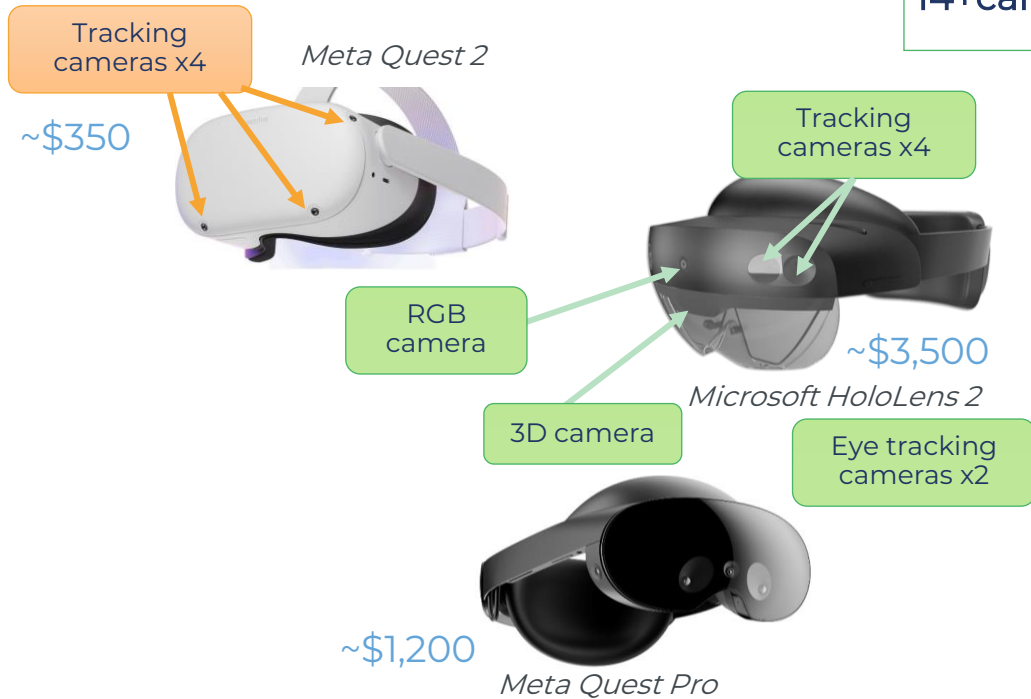*Bringing spectral and polarization information beyond the visible*

© Metalenz

CONSUMER MARKET TRENDS
Proliferation of sensors for XR, including 3D sensing modules

VR

2-6 cameras

AR & MR

4-10 cameras

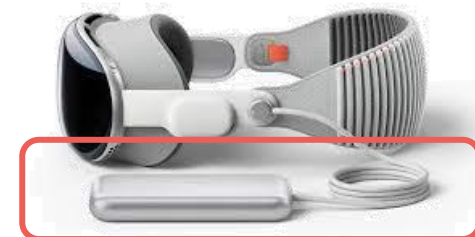**Spatial computer?**

14+cameras?

Users definitely do not desire the use of a bulky external battery.

New imaging paradigm to unlock lower power and latency sensing approaches?

Tracking cameras x4

Meta Quest 2

~$350

RGB camera

Tracking cameras x4

3D camera

Microsoft HoloLens 2

~$3,500

Eye tracking cameras x2

~$1,200

Meta Quest Pro

M2 APU

R1 co-processor

dToF 3D camera "LiDAR"

Structured light 3D camera

RGB cameras x2

LiDAR Scanner

TrueDepth camera

Downward cameras

IR illuminators

Side cameras

Tracking cameras x6

Eye tracking cameras x4

Apple Vision Pro

~$3,500

Battery

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AUTOMOTIVE MARKET TRENDS
More cameras and more resolution

2019 - 2029 Automotive camera module volume forecast
Cameras per car (in units)

6.4% CAGR 2023-2029

Number of cameras per car (units)

1.9 · 2.2 · 2.4 · 2.7 · 2.7 · 2.8 · 3.0 · 3.3 · 3.5 · 3.7 · 3.9

2019 · 2020 · 2021 · 2022 · 2023 · 2024e · 2025e · 2026e · 2027e · 2028e · 2029e

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Resolution

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12MP

8MP

5MP — Between 5 and 8MP

2.4MP

1.2MP — Between 1.2 and 2.4MP

VGA

12MP?

For further object recognition

Current front ADAS resolution trend

2021 · 2023 · 2029?   Time

Lidar

3x Camera 3MP

2x Camera 8MP

Camera 3MP

Camera 3MP

Radar

Camera 3MP

Radar

3x Camera 3MP

Xiaomi's SU7 electric car

Higher autonomy level applications

Pedestrian detection / avoidance

Automatic Emergency Breaking

Park Assist / Highway Assist

AUTOMOTIVE MARKET TRENDS
Imaging applications by sub-segment

In-cabin

Driver monitoring system

Occupant monitoring system

Gesture recognition

Face authentication

Dash recorder

System

2D or 3D camera
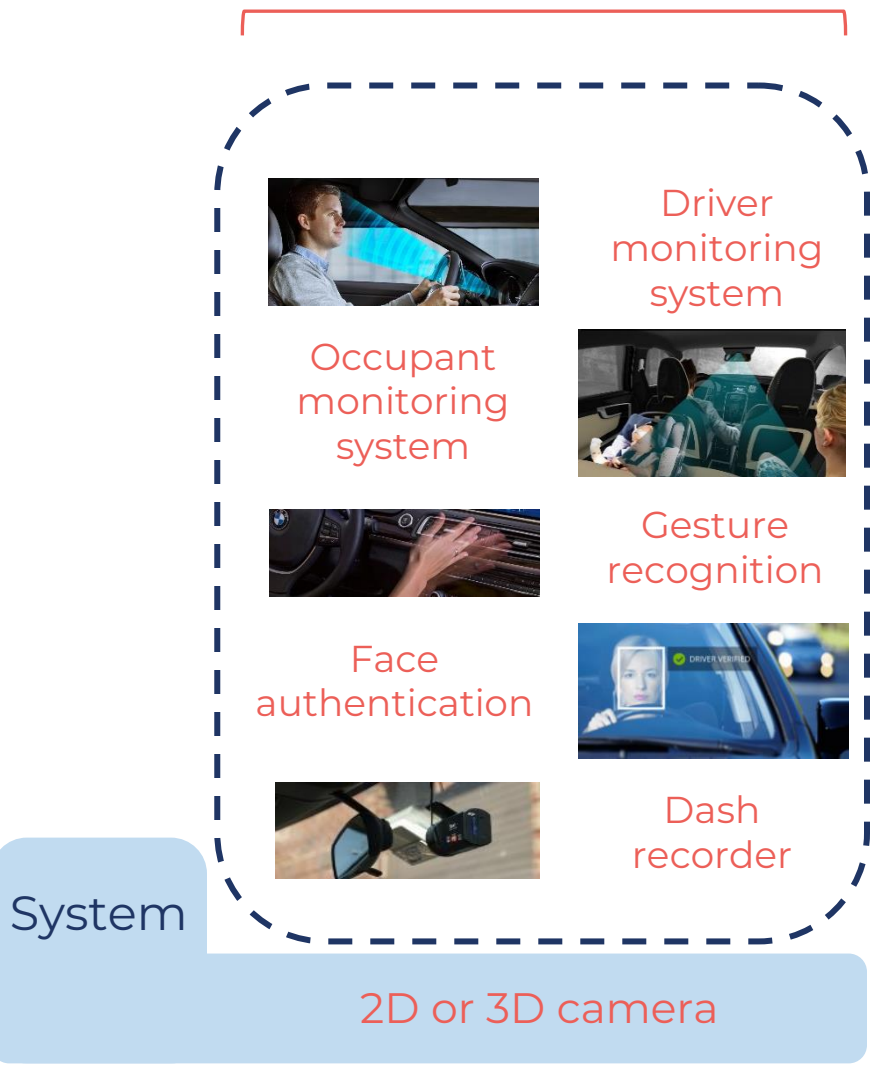
Source: Valeo

Human entertainment

C-NCAP

C-NCAP will include DMS for the first time in the rating from 2024

European Commission | EURO NCAP
FOR SAFER CARS
www.euroncap.com

DMS mandatory in Europe from 2026

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Inside a forward ADAS camera: Continental front ADAS camera

Type	Tier 1	OEM	Image sensor supplier	Image sensor name	Description CIS	Computing supplier	Lens module*	Estimated Cost
Monocular	Continental	Changan	Omnivision	OX08B40	8.3 MP / 2.1 μm	Horizon Robotics	7G	~$72

*G: Glass

Lens module
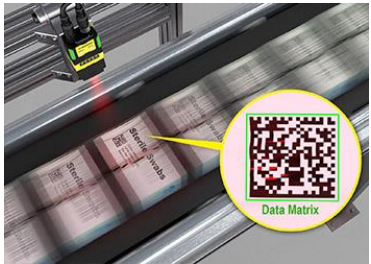
CIS sensor

MCU

Horizon Robotics processor

Flash memory

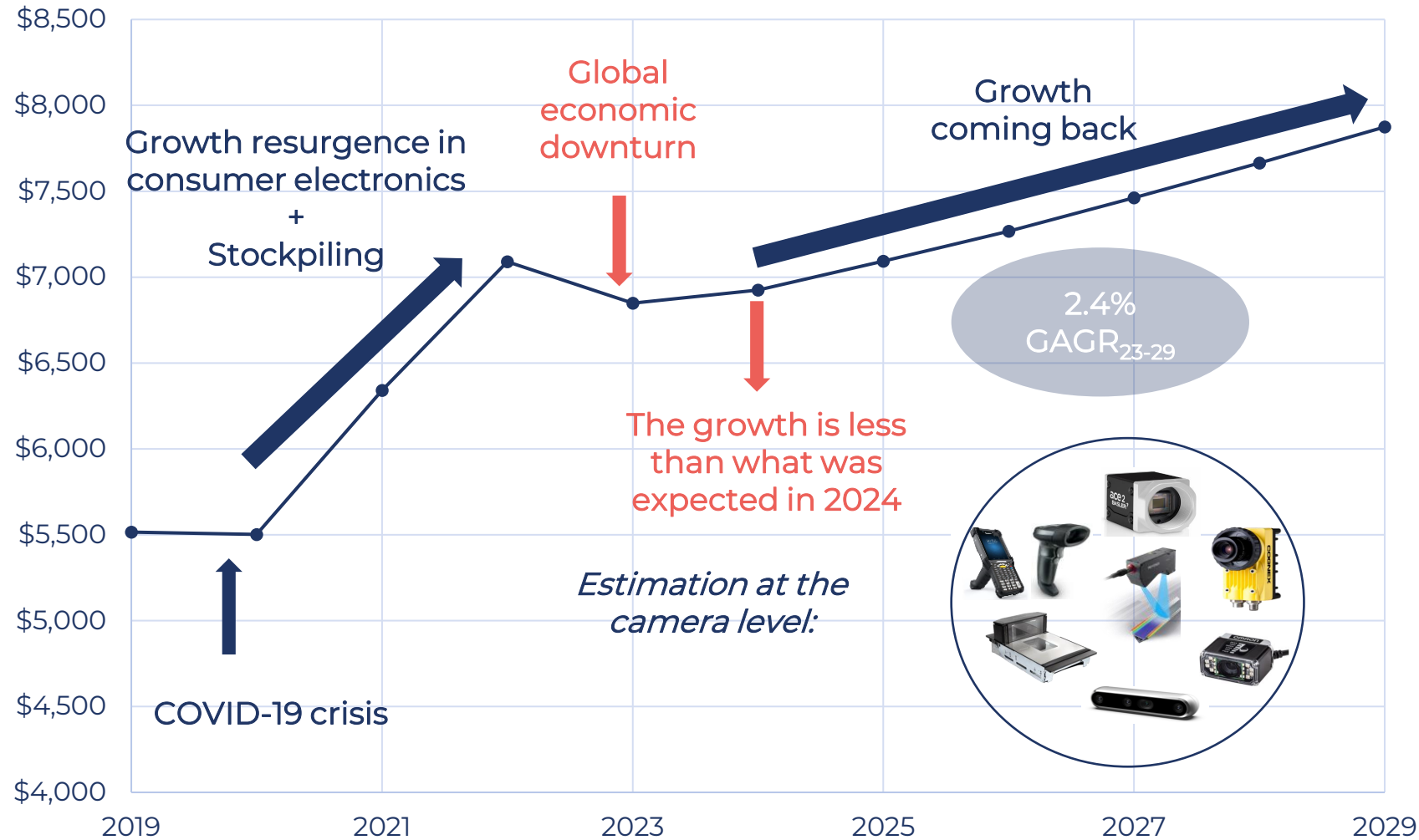Memory PMIC

INDUSTRIAL MARKET TRENDS
2019-2029 market forecast

Factory and warehouse automation

Retail

Growth resurgence in consumer electronics
+
Stockpiling

COVID-19 crisis

Global economic downturn

The growth is less than what was expected in 2024

Estimation at the camera level:

Growth coming back

2.4% GAGR$_{23-29}$

$8,500
$8,000
$7,500
$7,000
$6,500
$6,000
$5,500
$5,000
$4,500
$4,000

2019   2021   2023   2025   2027   2029

2023 & 2024 has been a challenging years for the machine vision industry, after two years of intensive growth.

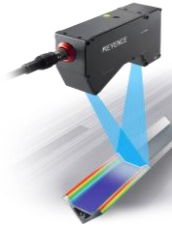YOLE Intelligence

INDUSTRIAL MARKET TRENDS
A wide range of cameras and systems

High-end CMOS image sensors | Low-end CMOS image sensors

High-end CMOS image sensors:
- PC-based cameras
- 3D laser profilers
- Smart cameras
- Fixed-mount industrial barcode scanner

Low-end CMOS image sensors:
- 3D camera module for robots
- Fixed barcode scanner for retail
- Handheld barcode scanner

Camera market evaluation for 2023:

High-end:
- Market Value: ~$5 billion
- Volumes: ~7 million units

Low-end:
- Market Value: ~$1.8 billion
- Volumes: ~21 million units
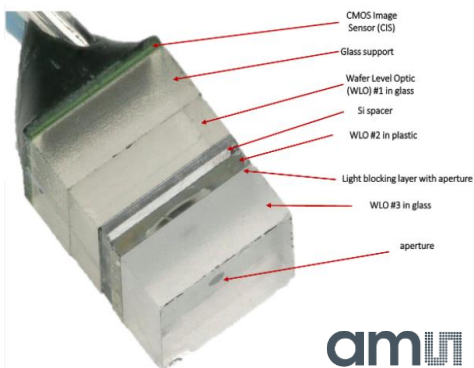
Legend:
- Market Value
- Volumes

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MEDICAL MARKET TRENDS
An insight into endoscope camera modules and image sensors

ams OSRAM NanEye camera

CIS top view
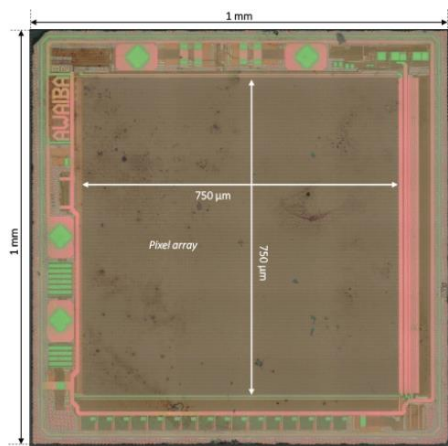
Omnivision OVM6948 camera
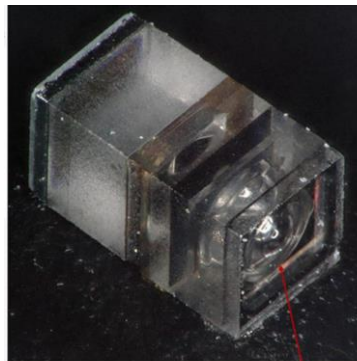
Wafer optics stacked lens
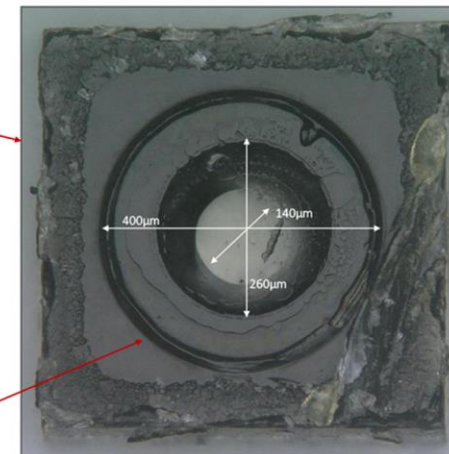
Model	Resolution	Package dimensions
ams OSRAM NanEye	200 x 200	$1 \times 1 \times 1.43 mm^3$
ams OSRAM NanEyeC	320 x 320	$1 \times 1 \times 2.3 mm^3$
Omnivision OVM6848	250 x 250	$0.66 \times 0.66 \times 1.16 mm^3$
Omnivision OCH2B	1,500 x 1,500	$2.5 \times 2.5 \times 3.6 mm^3$

IMAGING TECHNOLOGY TRENDS

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TECHNOLOGY TRENDS
Silicon is sensitive to visible and near-infrared light

IMAGING — RADAR

X-ray | UV | VIS | NIR | SWIR | MWIR | LWIR | Terahertz

1nm — 10nm — 100nm — 1µm — 10µm — 100µm — 1mm — 1cm
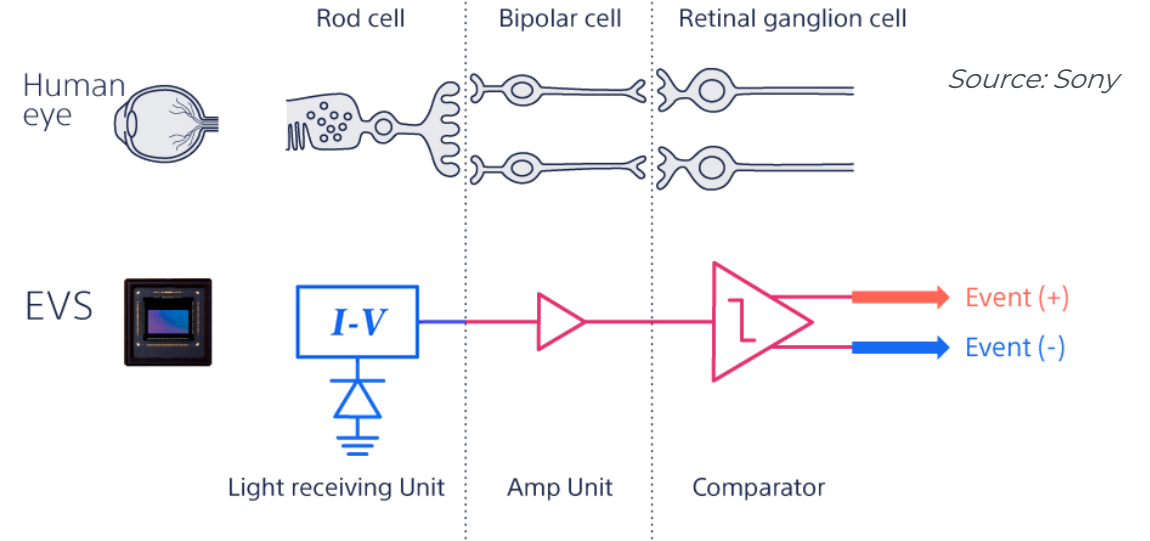
wavelength

Visible | NIR

400nm — 800nm — 1.1µm
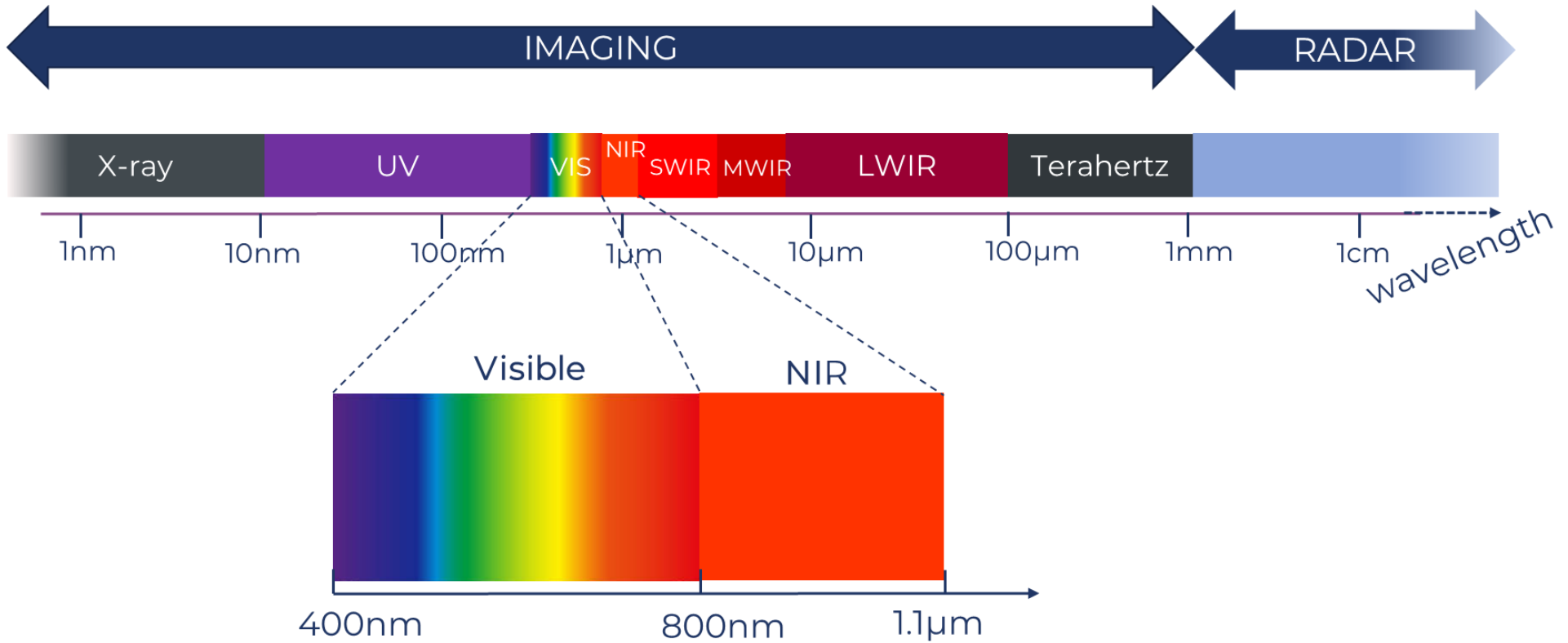
- Silicon, the semiconductor most popular material, is sensitive in visible and near-infrared domain.

- Beyond in the infrared, specific materials: quantum dots, Germanium, InGaAs, InSb, MCT, etc. or other devices: microbolometers… have to be used.

TECHNOLOGY TRENDS
Event-based neuromorphic sensors can target < 1mW applications

Mimicking the human retina:

Input Events | Input Image | Refocus Results

From: Boxin Shi, Peking University, CVPR 2023

Rod cell | Bipolar cell | Retinal ganglion cell

Source: Sony

Human eye

EVS

I-V

Event (+)
Event (-)

Light receiving Unit | Amp Unit | Comparator

- Minimal data loading
- Lower power
- Lower latency
- Higher sensitivity

and intra-scene dynamics

Neuromorphic sensing ecosystem:

| The CIS « big 3 »	Dedicated companies			
	Broad range of apps.	Focus on industrial and defense apps.	Focus on 3D sensing for XR & robotics	Differentiated in processing
SONY	PROPHESEE	SCD	VoxelSensors	oculi
SAMSUNG	AlpsenTek 锐思智芯	BAE SYSTEMS		
OMNIVISION	inivation *acquisition* SynSense		SUMMER ROBOTICS	AISTORM

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TECHNOLOGY TRENDS
Going beyond smartphone photography

- The next opportunity coming for neuromorphic sensing is motion deblur for smartphone photography applications.

Neuromorphic image sensor will allow unprecedented HDR photography and video, motion deblur and image refocus capabilities.
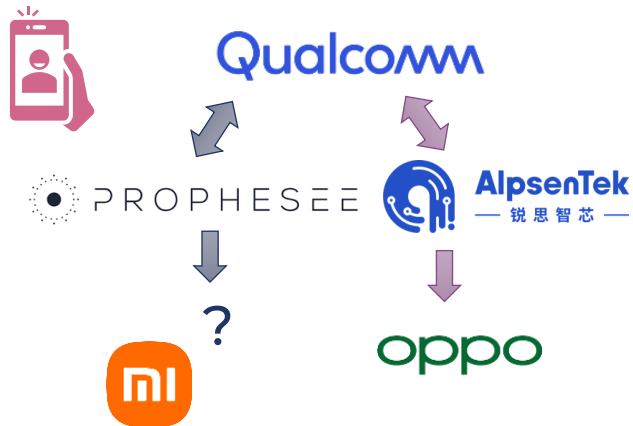
>2028

Tablets

>2027

Action cams

>2026

Drones

>2024

Smartphones

Qualcomm

PROPHESEE

AlpsenTek 锐思智芯

?

mi

oppo

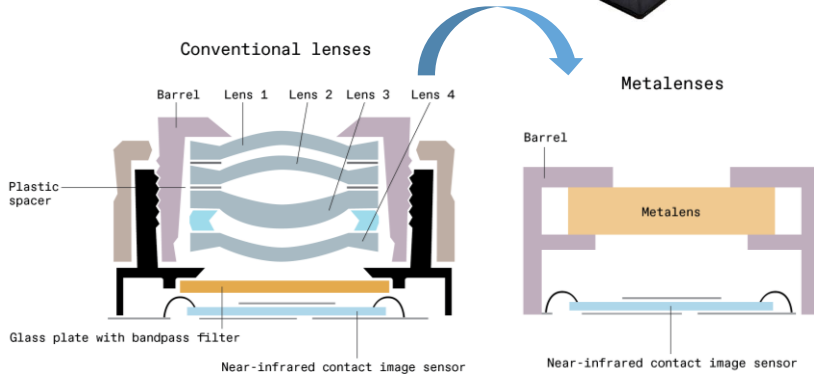Yole report: Neuromorphic Computing, Memory and Sensing 2024

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TECHNOLOGY TRENDS
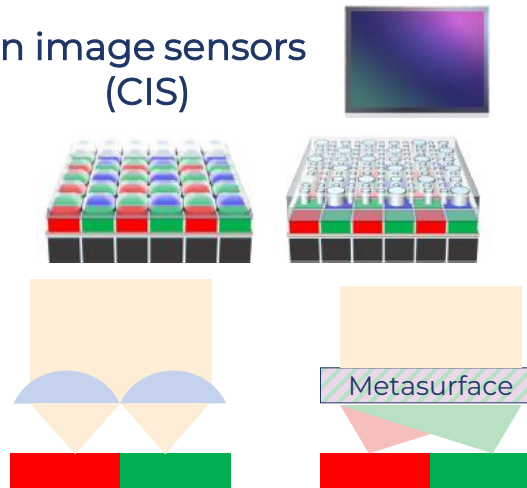## Optical metasurfaces coming to real products

Metalenses are diffractive components made of nanoplots and the final devices are perfectly flat. They are supposed to offer a higher degree of freedom in the design, allowing replication or combination of the qualities of several refractive lenses.
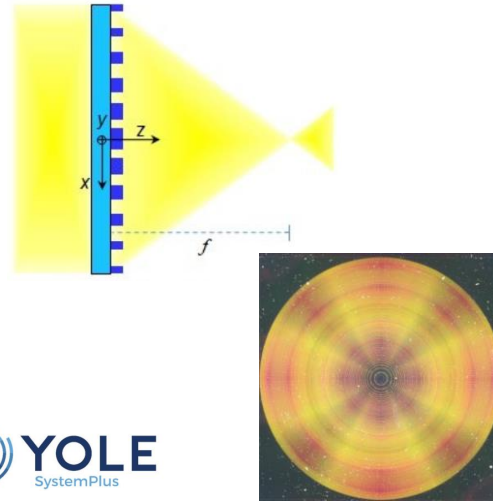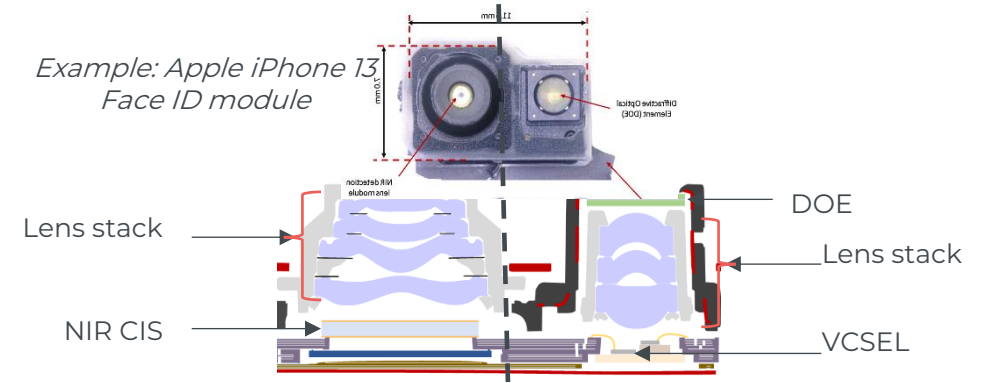

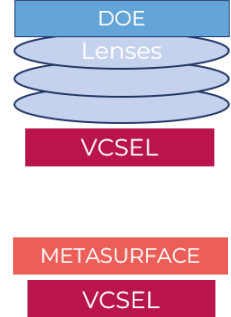
In camera module (CCM)

In image sensors (CIS)

Metasurface

THINNER, CHEAPER MODULE

Example: Apple iPhone 13 Face ID module

Lens stack

NIR CIS

DOE

Lens stack

VCSEL

Camera module

Lenses

NIR CIS

METASURFACE
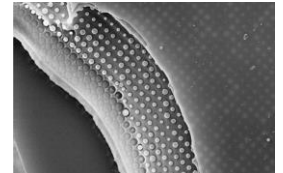
NIR CIS

Dot projector
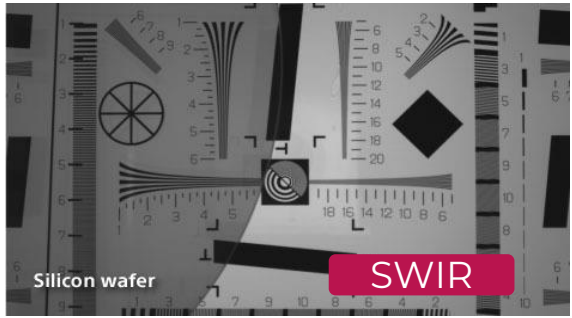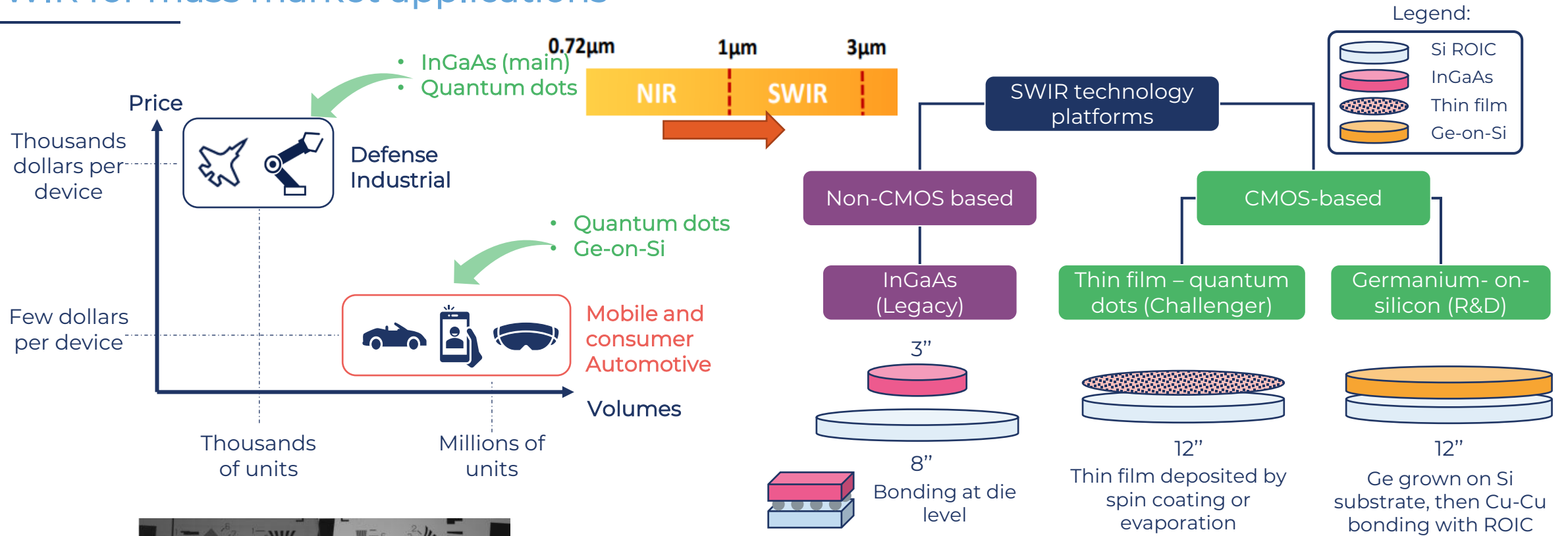
DOE

Lenses

VCSEL

METASURFACE

VCSEL
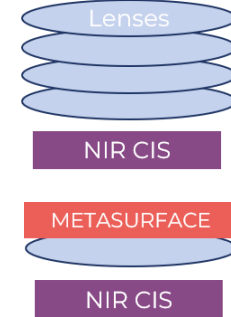
Apple iPad Pro 11

*Top view
Source: Yole System Plus*

Yole report: Optical Metasurfaces 2024

TECHNOLOGY TRENDS
SWIR for mass market applications

Price

Thousands dollars per device — Defense Industrial

- InGaAs (main)
- Quantum dots

0.72μm   1μm   3μm

NIR   SWIR

SWIR technology platforms

Legend:
- Si ROIC
- InGaAs
- Thin film
- Ge-on-Si

- Quantum dots
  Ge-on-Si

Few dollars per device

Mobile and consumer Automotive

Volumes

Thousands of units   Millions of units

Non-CMOS based   CMOS-based

InGaAs (Legacy)   Thin film – quantum dots (Challenger)   Germanium- on-silicon (R&D)

3"

8"
Bonding at die level

12"
Thin film deposited by spin coating or evaporation

12"
Ge grown on Si substrate, then Cu-Cu bonding with ROIC
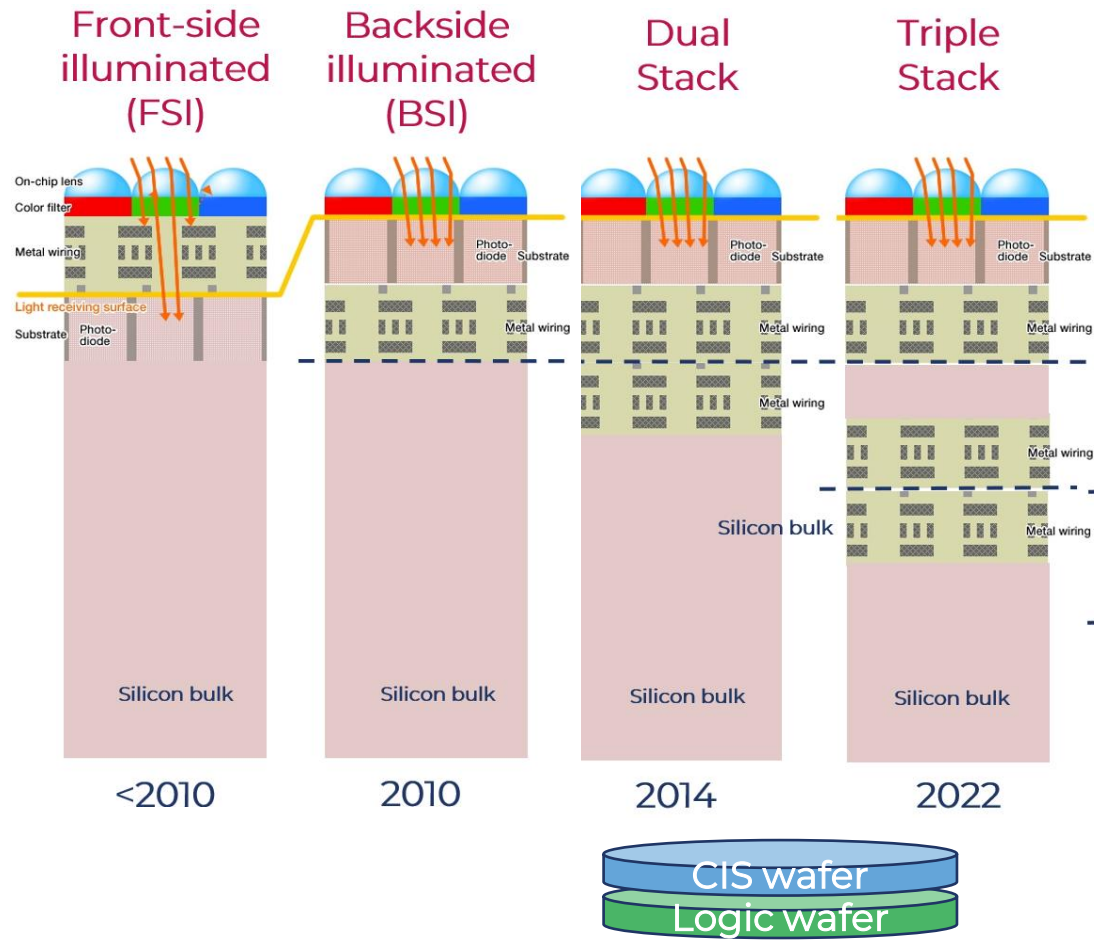
Silicon wafer   SWIR

Wafer inspection

SWIR imaging has gained interest for consumer and automotive applications, but not yet commercialized.
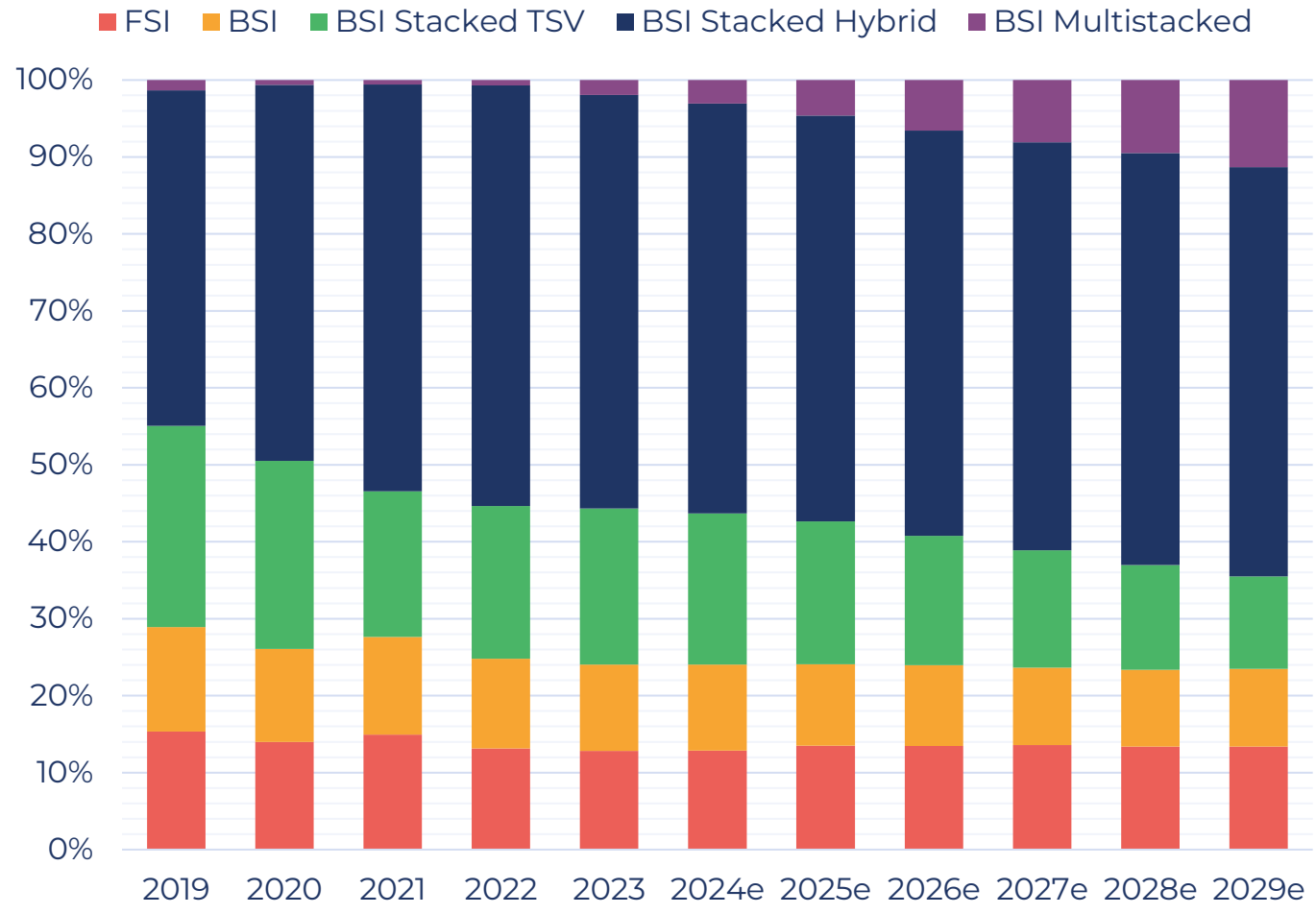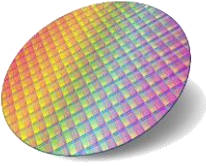
TECHNOLOGY TRENDS
Evolution towards 3D stacking

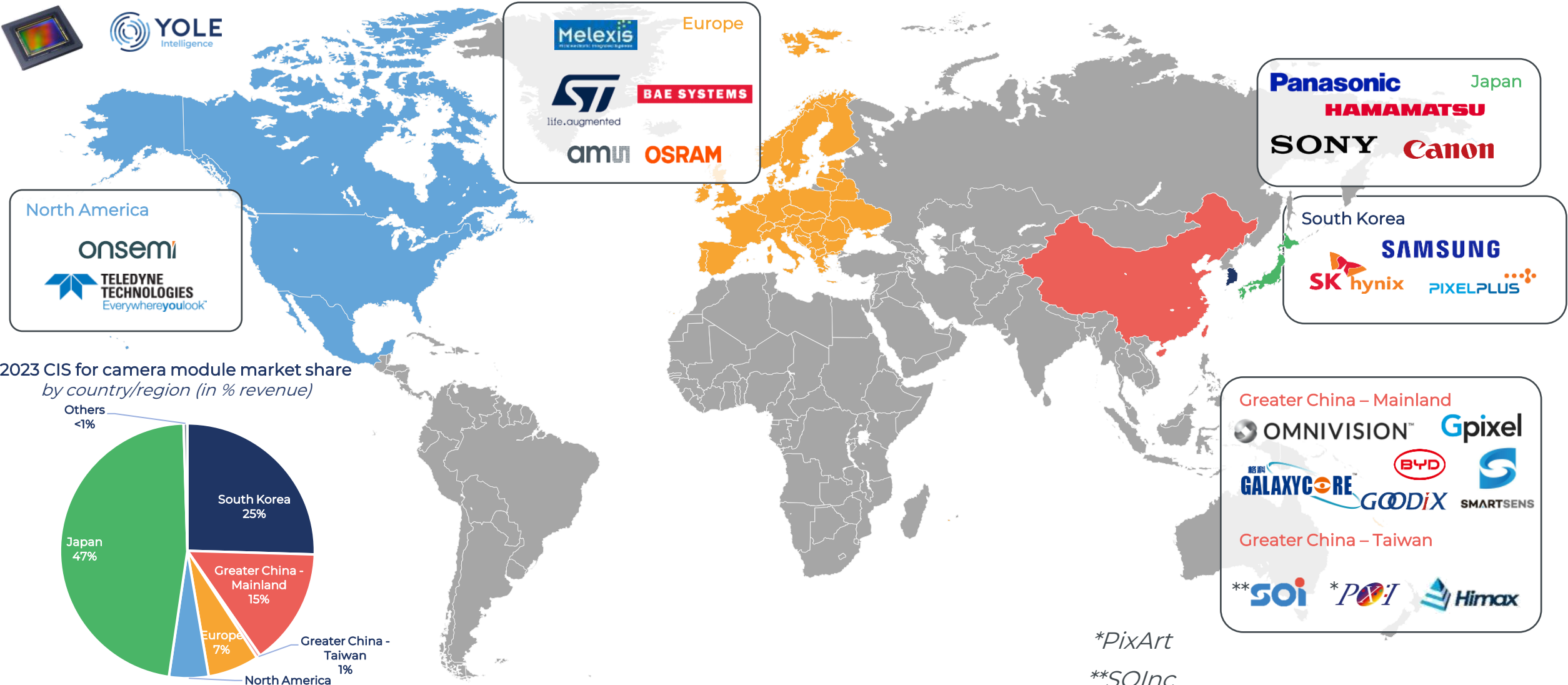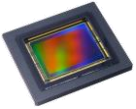- 76% of 2023 production is stacked, with a stable FSI and BSI production share.

2019 - 2029 CIS wafer production forecast *by technology (in % 12" eq.)*

ECOSYSTEM AND MARKET FORECAST

CMOS IMAGE SENSOR MARKET SHARES
2023 competitive map of the top 22 CIS players

YOLE Intelligence

Europe
Melexis
ST life.augmented
BAE SYSTEMS
amu
OSRAM

Japan
Panasonic
HAMAMATSU
SONY
Canon

North America
onsemi
TELEDYNE TECHNOLOGIES
Everywhereyoulook

South Korea
SAMSUNG
SK hynix
PIXELPLUS

Greater China – Mainland
OMNIVISION
Gpixel
GALAXYCORE
BYD
GOODIX
SMARTSENS

Greater China – Taiwan
**SOI
*PXI
Himax

*PixArt
**SOInc

2023 CIS for camera module market share
by country/region (in % revenue)

- Others <1%
- South Korea 25%
- Japan 47%
- Greater China - Mainland 15%
- Europe 7%
- Greater China - Taiwan 1%
- North America 5%
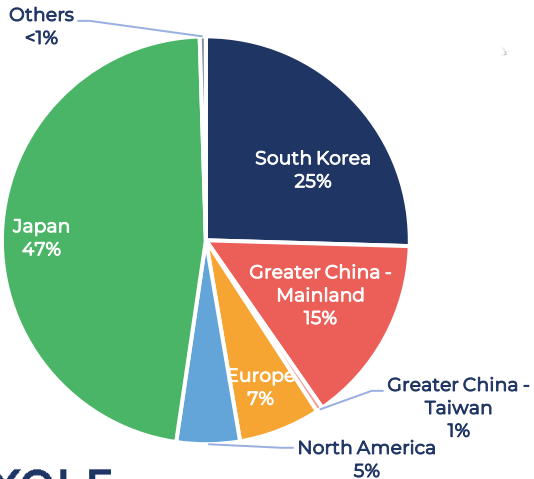
Limited space and map resolution may not display all territories of a country.

YOLE Intelligence

AUTOMOTIVE ECOSYSTEM & SUPPLY CHAIN
A strong Chinese supply chain is in the making

The Chinese automotive camera ecosystem is becoming more vertical, with component suppliers providing the entire camera module.

OEM — Original Equipment Manufacturer

TIER 1 — System / Module Suppliers

TIER 2 — Components Suppliers

TIER 3 — Parts Suppliers

DJI — Drone maker

HASCO

Zong Mu

SenseTime 商汤

经纬恒润 JINGWEI HIRAIN

MINIEYE

DESAY SV

舜宇光学科技 SUNNY OPTICAL TECHNOLOGY — lens set market leader

OFILM 欧菲光

HIKVISION — Leader in security and machine vision markets
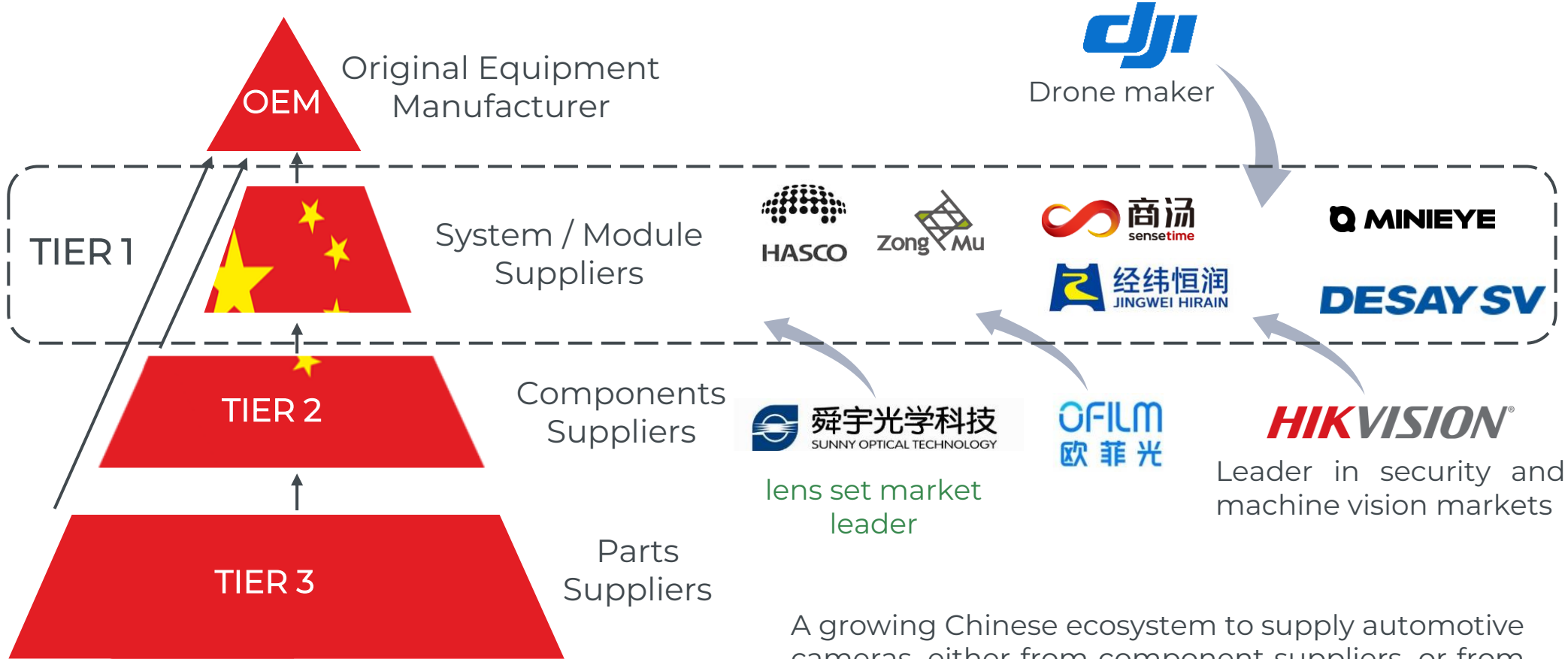
A growing Chinese ecosystem to supply automotive cameras, either from component suppliers, or from camera manufacturers from another market.

YOLE Intelligence
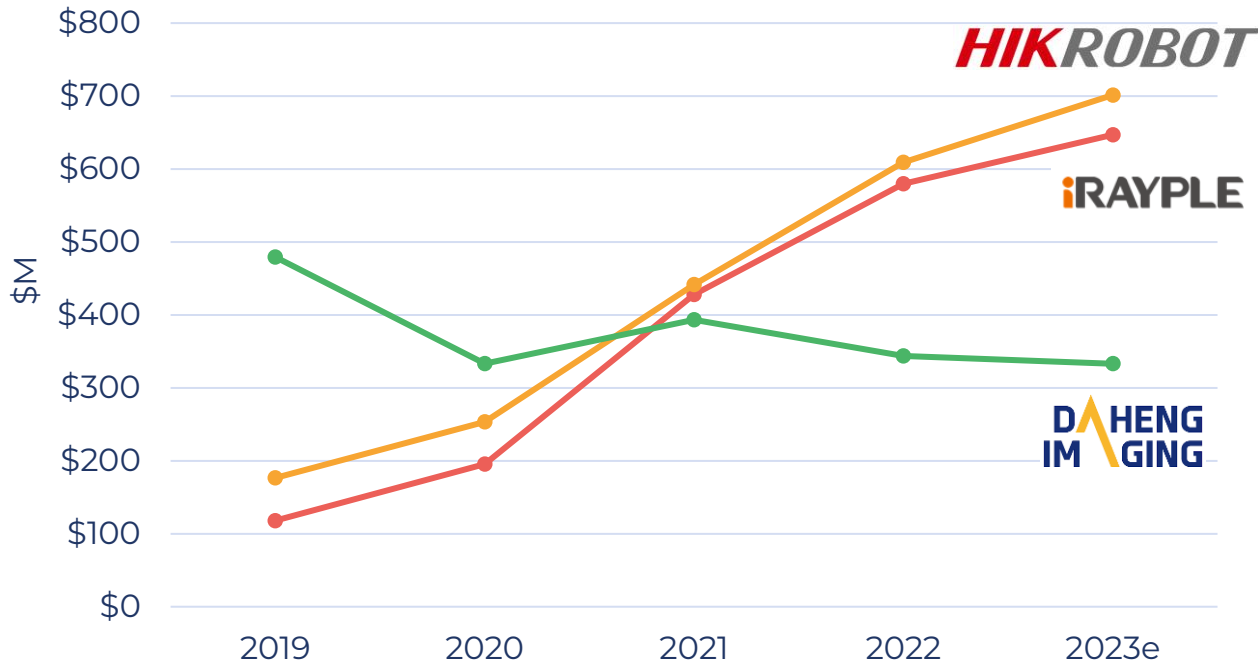
INDUSTRIAL ECOSYSTEM & SUPPLY CHAIN
The rise of the Chinese ecosystem

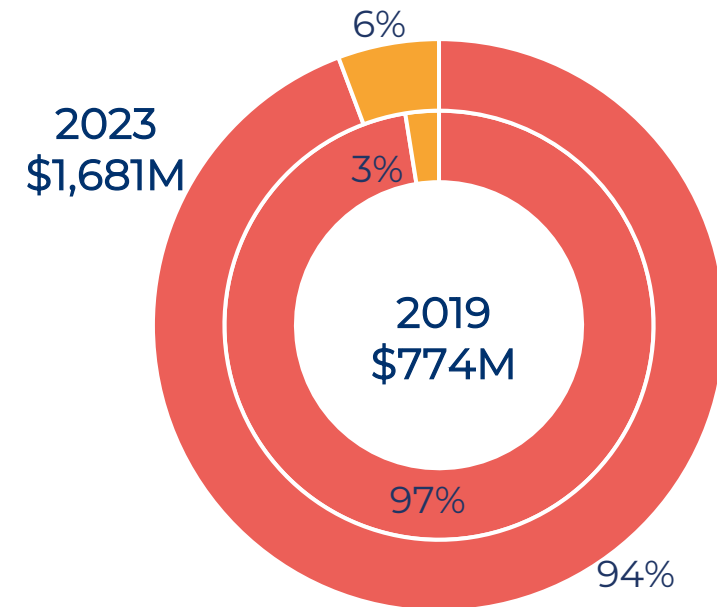The three Chinese leaders are now among the **Top 6 companies** in PC-based cameras

2019-2023: Chinese top player revenues
(in $M)

HIKROBOT

iRAYPLE

DAHENG IMAGING

They are driven by a strong local demand and become more and more present overseas.
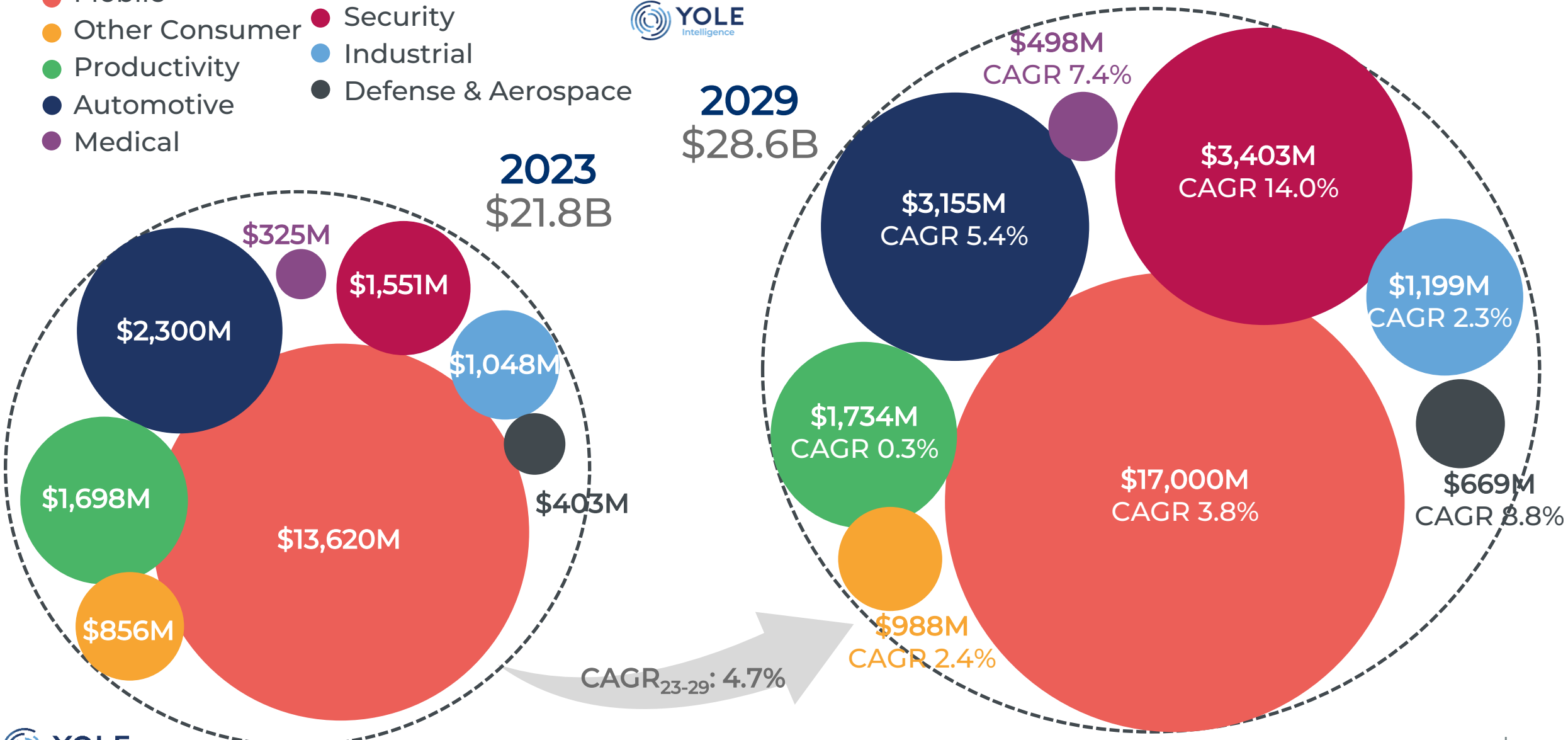
Top 3 Chinese players revenues:
geographical breakdown

2023
$1,681M

2019
$774M

6%

3%

97%

94%

■ Domestic ■ Overseas

YOLE Intelligence

2023-2029 CMOS IMAGE SENSOR MARKET REVENUE FORECAST

Legend:
- Mobile
- Other Consumer
- Productivity
- Automotive
- Medical
- Security
- Industrial
- Defense & Aerospace

YOLE Intelligence

2023
$21.8B

- $325M
- $1,551M
- $2,300M
- $1,048M
- $1,698M
- $13,620M
- $856M
- $403M

2029
$28.6B

- $498M CAGR 7.4%
- $3,403M CAGR 14.0%
- $3,155M CAGR 5.4%
- $1,199M CAGR 2.3%
- $1,734M CAGR 0.3%
- $17,000M CAGR 3.8%
- $669M CAGR 8.8%
- $988M CAGR 2.4%

CAGR$_{23-29}$: 4.7%

The Edge AI and Vision Alliance is a partnership of ~100 leading edge AI and vision technology and services suppliers, and solutions providers

The Alliance provides high-quality technical educational resources for product developers

Register for updates at www.edge-ai-vision.com

The Alliance enables edge AI and vision technology providers to grow their businesses through leads, partnerships, and insights

For membership, email us: membership@edge-ai-vision.com

The only industry event focused on practical techniques and technologies for system and application creators

- *"Awesome! I was very inspired!"*
- *"Fantastic. Learned a lot and met great people."*
- *"Wonderful speakers and informative exhibits!"*

Summit highlights:

- **Inspiring keynotes** by leading innovators
- High-quality, practical **technical, business and product talks**
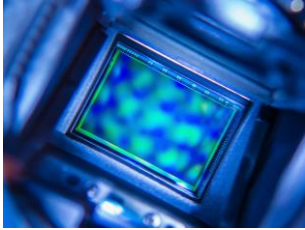- Exciting **demos**, **tutorials** and **expert bars** of the latest applications and technologies

Visit www.embeddedvisionsummit.com for updates

YOLE GROUP RELATED PRODUCTS

Reports

Contact our Sales Team for more information

Status of the CMOS Image Sensor Industry 2024

Status of the Camera Module Industry 2024

Imaging for Automotive 2024

Imaging for Industrial - Machine Vision 2024

Optical Metasurfaces 2024

Neuromorphic Computing Memory and Sensing 2024

SWIR Imaging 2023

3D Imaging and Sensing 2023