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Using VCSELs in 3D Sensing Applications

Power & Compound Semiconductor International Forum
SEMICON China
Shanghai – March 21, 2019

3D Depth Camera Becomes Pervasive

- 3D camera and depth-sensing systems are rapidly evolving with advances in image sensor and laser ‘illuminator’ technology
- Face ID, photo-enhancement and Augmented Reality driving adoption in high-volume consumer mobile
- Automotive industry rapidly adopting same technologies for in-cabin driver and passenger monitoring

BIOMETRIC SENSING

GESTURE RECOGNITION

3D IMAGE CAPTURE

MACHINE VISION

MIXED REALITY

HUMAN MACHINE INTERACTION

RANGING

Industrial 3D camera

Microsoft Kinect (2010)

Today’s Mobile 3D Camera

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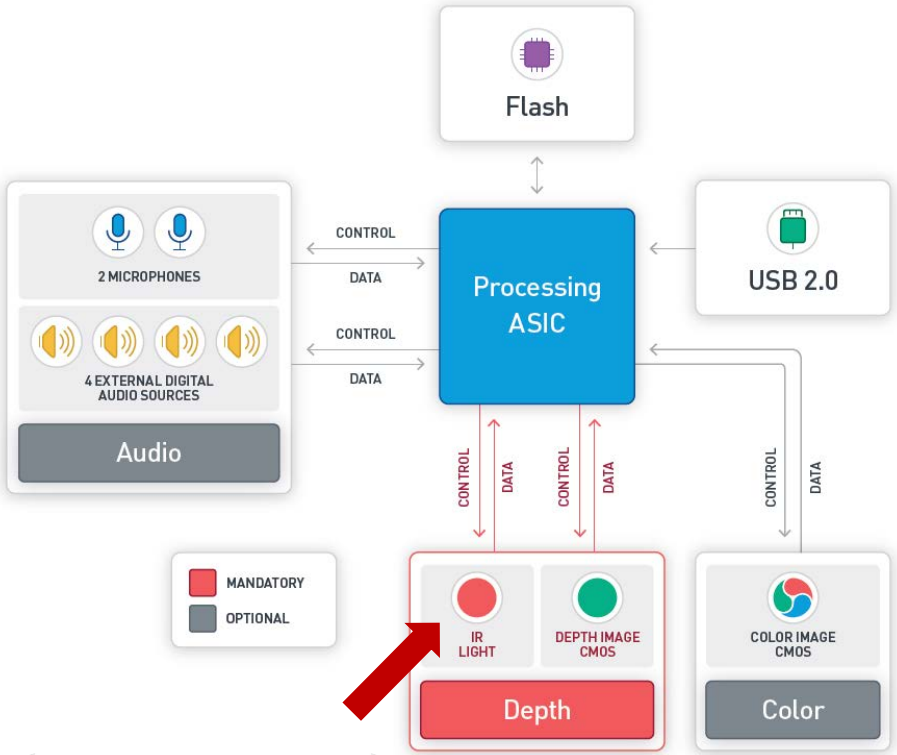
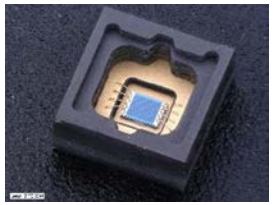
Typical Laser-based 3D Sensing System

- 3D camera/sensing systems augment standard 2D image data with ‘depth’ data
- Best approaches use **laser-based** infrared light (IR) to generate the ‘depth’ data
  - **Structured Light**
  - **Time-of-Flight (ToF)**
- Implementations rely on algorithms running on processors to interpret data
- Superior to ‘stereoscopic’ and IR cameras using LEDs





Finisar VCSEL provides the IR light source

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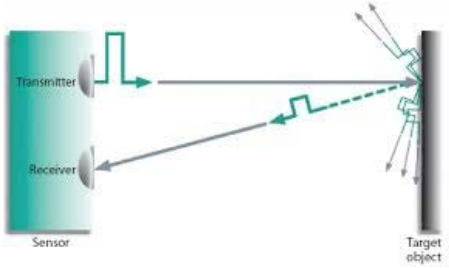
Primer on Structured Light vs. ToF

Structured Light

- Uses optical techniques to project a specific pattern.
- Advantages:
  - Highly accurate within working distances
  - Known image (relatively) immune to interference from other sensors
- Disadvantages:
  - Complex image processing
  - Larger form factor driven by baseline
  - Sensitive to double reflection (e.g. glass tabletops)



Time-of-Flight

- Source lighting is pulsed and the timing of the return pulse is converted to distance.
- Advantages:
  - Accurate over a broader working distances
  - Pulsed light allows higher optical intensity while staying under the eye-safety limit
  - (Typically) Lower power consumption for the light source
  - Simple, compact
  - Fast distance algorithm
  - Single frame contains all the information
- Disadvantages:
  - Interference from other ToF sensors
  - Background light / multiple reflections
  - Not as accurate for low dynamic range applications

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Finisar is a Pioneer in VCSEL Technology

- **>$250M invested capital since 2007**
- **Over 300M communications VCSELs shipped**

1993	VCSEL Research begins at Honeywell Technology Center in Minnesota, USA
1996	First commercial VCSEL sold (by Honeywell to Finisar)
2004	**Finisar acquires Honeywell's VCSEL division**
2005	Finisar relocates its operations to Allen
2006	50 millionth VCSEL sold
2010	100 millionth VCSEL sold
2011	First $3M+ Aixtron reactor purchased
2012	Development work on 28Gb/s VCSEL ongoing
2014	28Gb/s VCSEL production qualified
2016	56Gb/s VCSELs demonstrated
2018	Finisar breaks ground on new Sherman Manufacturing Location in December.
2018	Leading supplier of VCSELs to 3D Camera suppliers. Sherman fab expected to be in full production this year.

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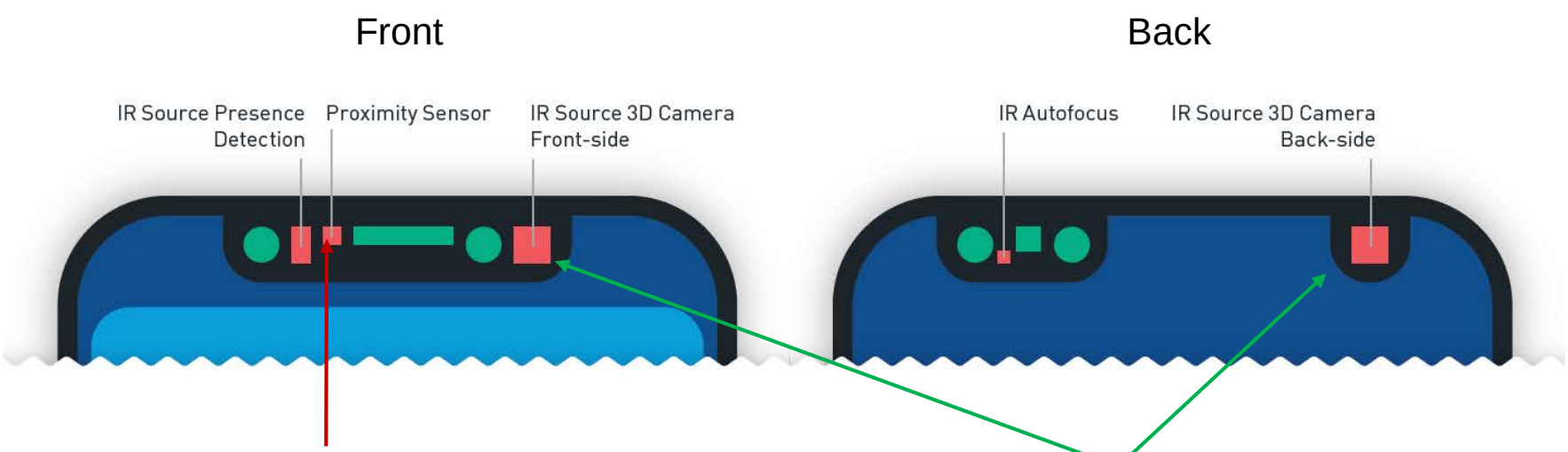
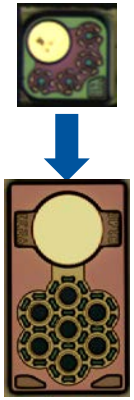
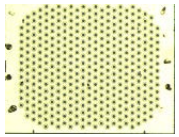
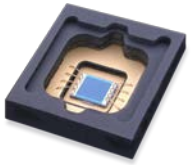
Several VCSELs in a Smart Phone





- **Lower-power die** for shorter-range ToF applications
- Packaged with highly integrated CMOS sensor ICs
- Dozens of phones and many 100Ms units today
- Migration to higher-power (longer-range) or single-mode (higher precision), tighter spacing, improved specs - allows further innovation





- **Higher-power die** for Structured Light and long-range ToF applications
- Front and back 3D Cameras in next-gen models
- Higher-end models to start, migrating to mid and low over time

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Apple and Huawei Leading 3D Camera ‘Push’ – Others Following

- Apps for front-facing growing slowly: Unlock, Secure Payments, 3D Selfies, 3D Video Conference, and Avatar/Gaming
- Apple expanding use of front-facing 3D camera
  - Selfie portrait mode uses 3D camera for improved definition of subject
  - Expanded use of Animoji
  - Memoji - you can now create and animate your own Avatar using 3D camera
  - Memoji support in 32-way FaceTime
- Huawei Mate 20 Pro marketing multiple uses for 3D camera:
  - 3D Face Unlock
  - Animated Emojis
  - 3D Mapping of objects with video and stills – ‘AI Live Model’
- Others: Oppo R17 Pro, Vivo NEX, Xiaomi Mi8 Explorer, Samsung Galaxy S10 5G, LG G8

“Scan a toy with the 3D Depth Sensing Camera to create an AI live model. Not only can you take photos, but also record it moving and dancing on your desk. Enjoy the fun of interaction and share with your friends.”

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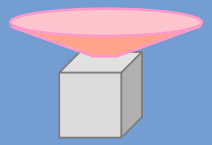
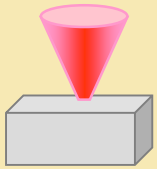
VCSELs vs. LEDs, Edge Emitters

LED

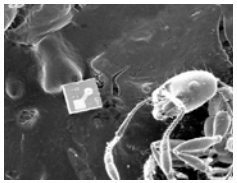


- Incoherent
- Lambertian emission from all facets

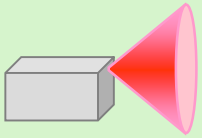
VCSEL



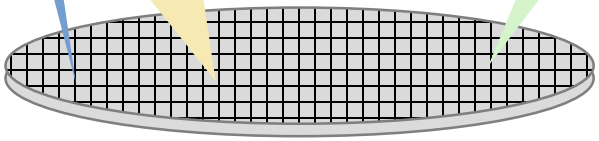
- Coherent
- Symmetrical
- Low divergence optical beam
- No astigmatism
- Mirrors formed vertically during epi growth

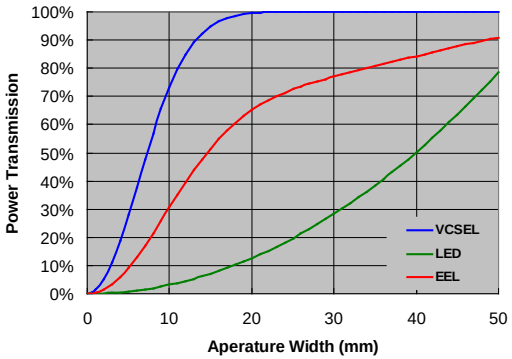


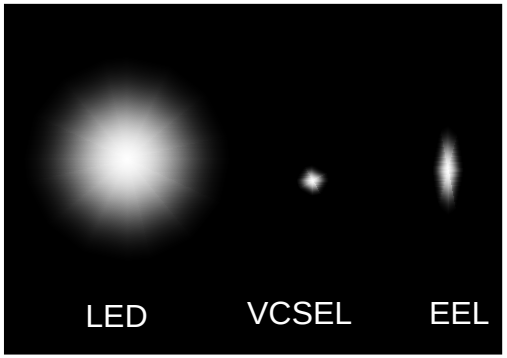
EEL



- Coherent
-Elliptical, astigmatic optical emission
- Mirrors formed by cleaving and coating







All sources are grown by either MOCVD or MBE

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VCSELs are a Superior IR Source

- Scalable output power
- High quality optical beam
- Stable over temperature and lifetime
- High Wall-Plug Efficiency (>35%)
- Fast: allows precise, high power optical pulses in synchronization with high-res, high frame-rate image sensors
- Easy to package
- No single emitter failure point
- Multi-emitter increases robustness and lifetime

	LED	Edge Emitter	VCSEL
Output Power	Up to 1W CW typical	100mWs CW	>3W CW >30W pulsed
Wall-Plug Efficiency	~25%	>45%	>35%
Beam Divergence & Quality	180 degrees Circular No speckle	11x40 degrees Elliptical Speckle	~17 degrees Circular No speckle
Wavelength Stability	Broadband 0.3nm/C	0.3nm/C	0.07nm/C
Pulse Speed	10s or 100s Nanoseconds	Nanoseconds	Nanoseconds
Packaging	Lowest cost, mature, surface-mount	Complex, larger, But low Z-height	Lower cost, Surface Mount

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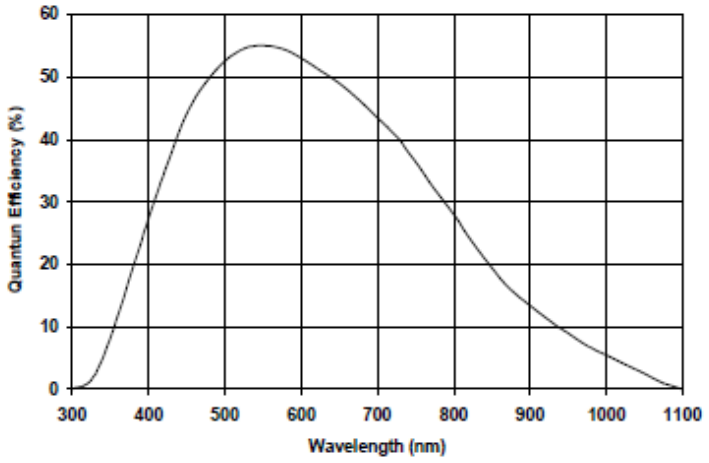
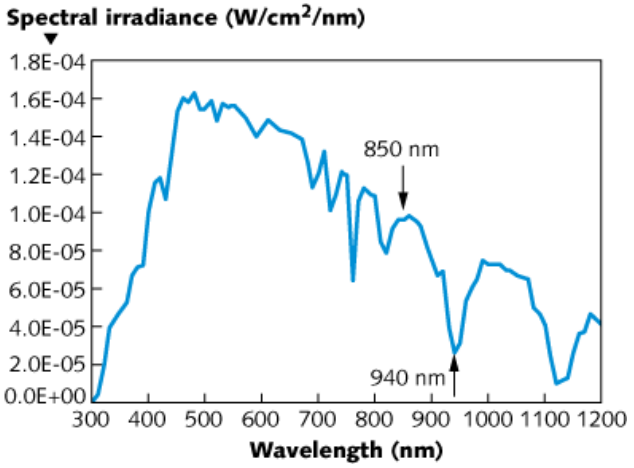
Why is 940nm the Most Requested Wavelength?

- 940nm is preferred for mobile devices
  - Better noise immunity in direct sunlight
- Responsivity of CMOS imagers is lower at 940nm (almost 10%); however, due to lower noise emissions at 940nm, it is still the wavelength of choice
- Spectral irradiance of white light (sunlight) is shown below

CMOS Imager Response



White Light Spectrum



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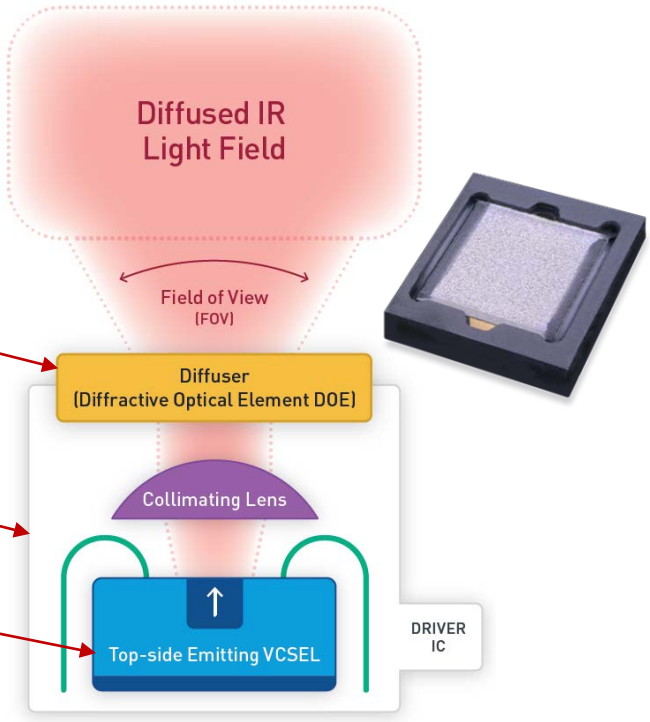
What is an ‘Illuminator’?

Time-of-Flight

‘Diffuser’ DOE to generate a well defined, even plane of IR light

Illuminator Package

VCSEL

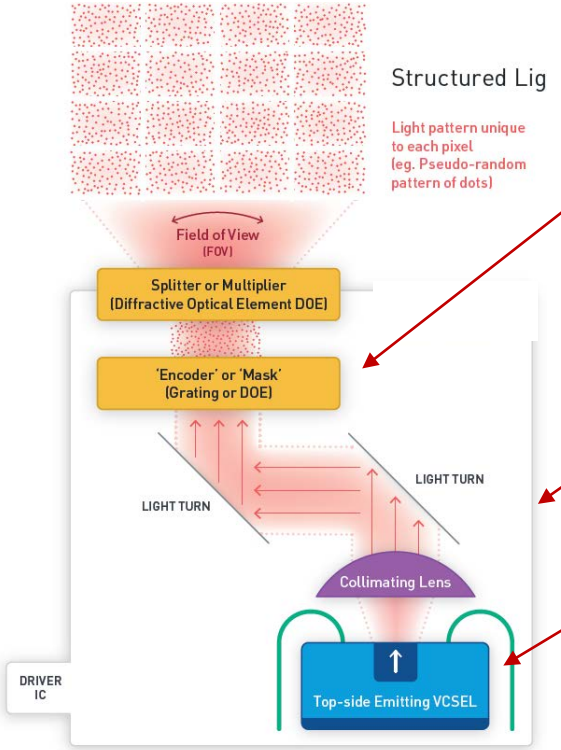


Structured Light

‘Encoder’ DOE to generate a structured light pattern

Illuminator Package

VCSEL



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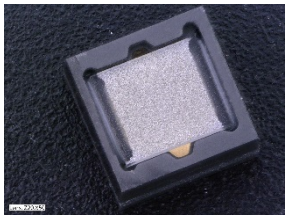
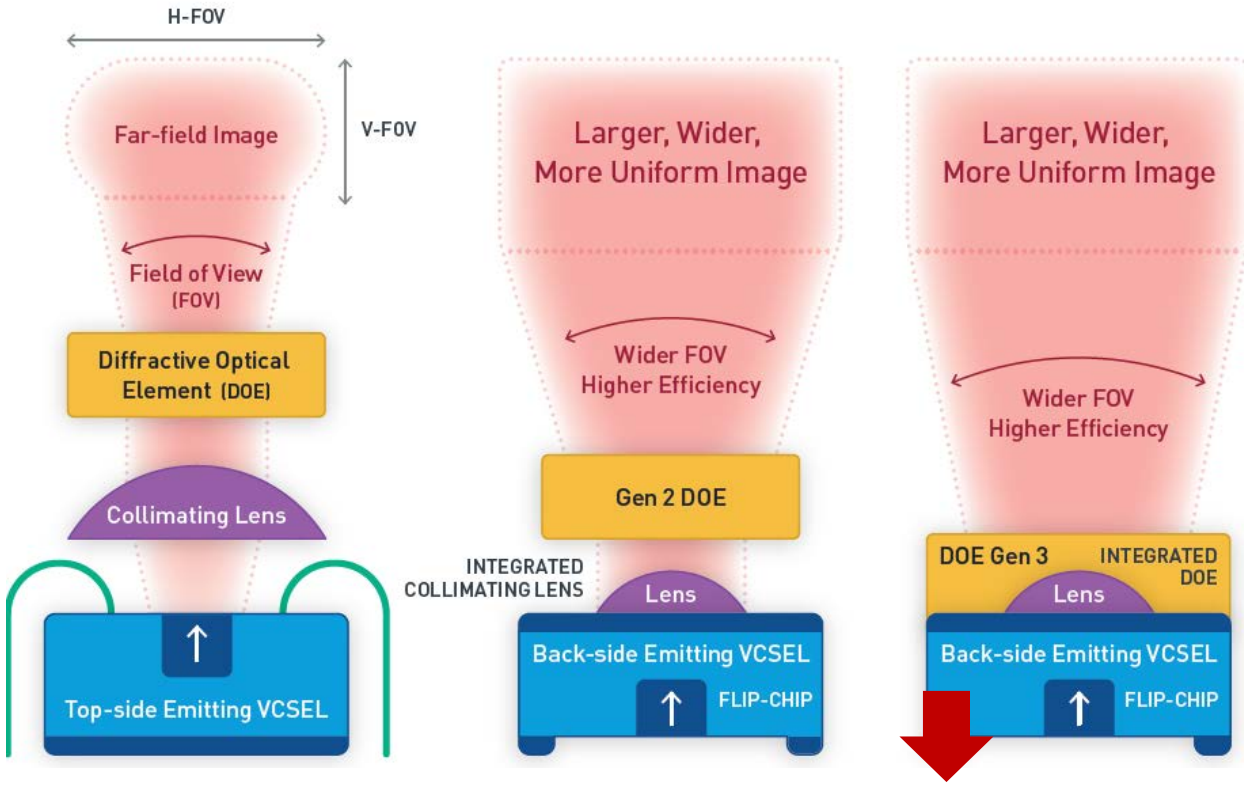
Evolution of VCSEL & 'Illuminator' Package

Co-design of VCSEL, lens and DOE provides higher performance, lower power & smaller package





- Wafer-scale packaging
- Lower cost
- Smaller package size

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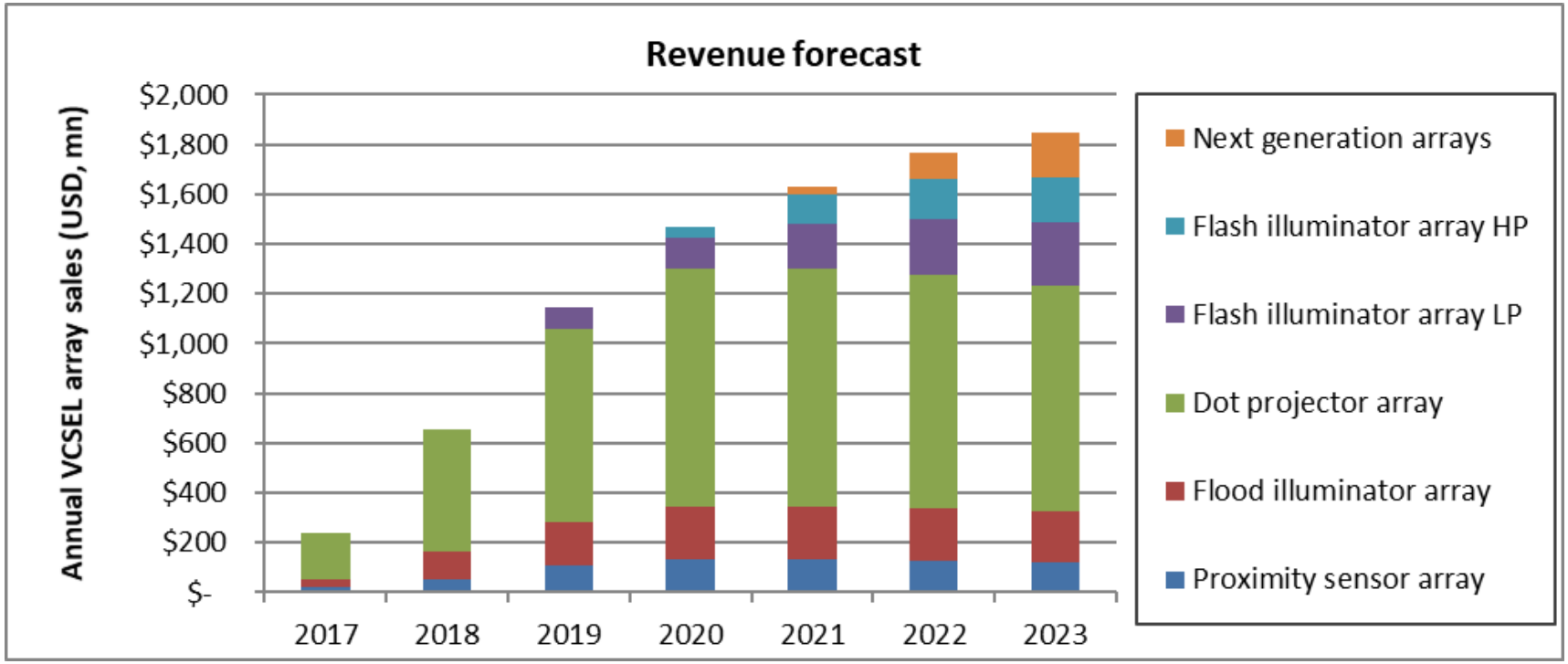
3D Sensing Mobile Market for VCSELs



Source: LightCounting, October 2018

- TAM revenue expected to exceed $600M in 2018 and grow to more than $1.8B by 2023.

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Back-side Smartphone 3D Cameras for AR/3D is the Next Wave

- Backside or ‘World Facing’ 3D camera for real-time 3D mapping and imaging in development now
- Driven by promise of AR, photo enhancement, 3D object mapping and content creation in apps and gaming
- Oppo R17 Pro the 1st phone to ship with world-facing ToF 3D camera
- Mainstream adoption of technology expected starting in 2021

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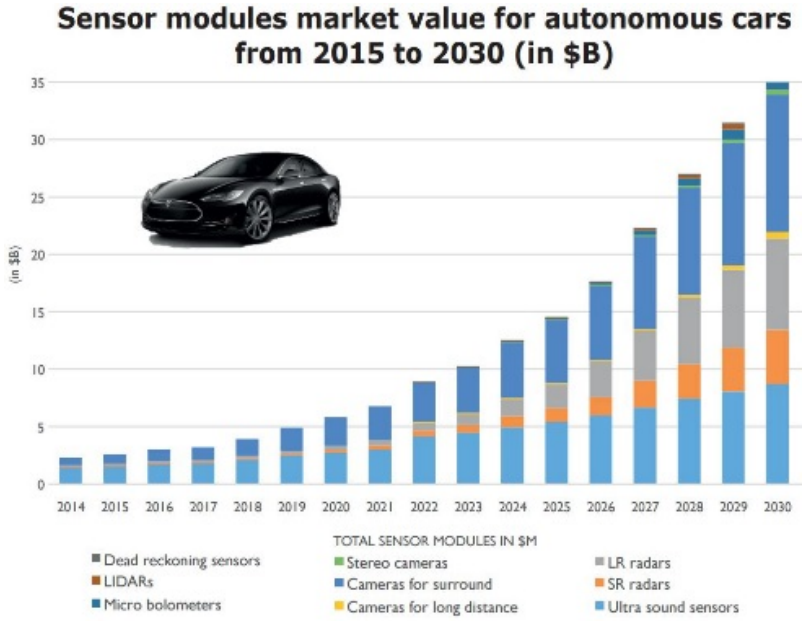
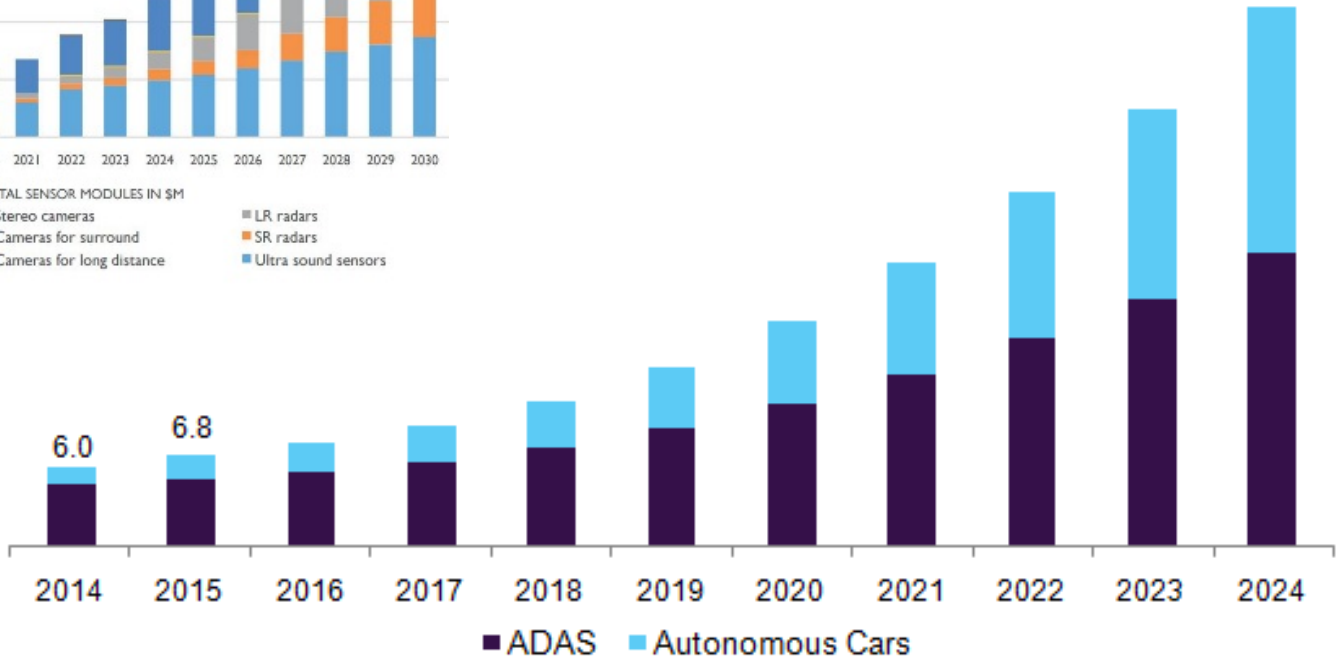
Automotive LIDAR Marketplace



(Yole Développement, October 2015)

$223M



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Two Types of Automotive LIDAR Markets to Develop

- The VCSEL LIDAR system is a key short-range (<50m) technology for providing:
  - Pedestrian avoidance
  - Lane change
  - Adaptive Cruise Control (ACC) real time speed monitoring
  - Automated/adaptive braking

- For autonomous high-speed driving, long-range LIDAR (300m) is required:
  - Ideally with simultaneous range and speed (Doppler), higher accuracy
  - Beyond VCSEL LIDAR's capabilities
  - 1550nm and coherent detection may provide ideal solution if costs can be achieved

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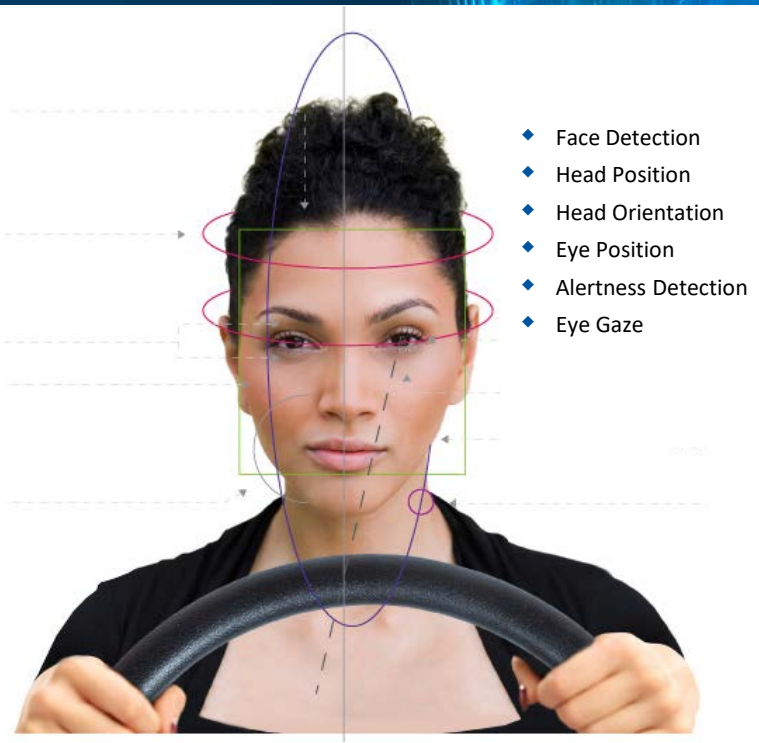
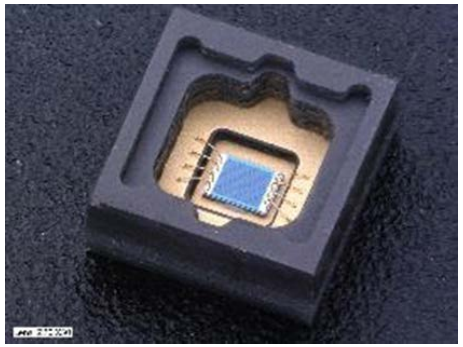
VCSEL Adoption in In-Cabin 3D Cameras for Automotive

- First 3D camera systems in cars will be ‘In-Cabin’ driver monitoring systems, starting in 2019
- More robust versions of consumer mobile 3D cameras
- Head position + distance to dashboard, eyelids analysis, gaze direction, driver identification





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Summary

- Consumer mobile will continue to drive VCSEL deployments in the 3D Sensing market for the next few years.
- ‘Face ID’ has been the enabling application that drives high volume.
- 3D cameras for AR/VR in consumer mobile, and in-cabin monitoring in automotive appears to be the next attractive application for VCSELs.
- VCSEL LIDAR may also be interesting in the longer term.

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Thank You

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