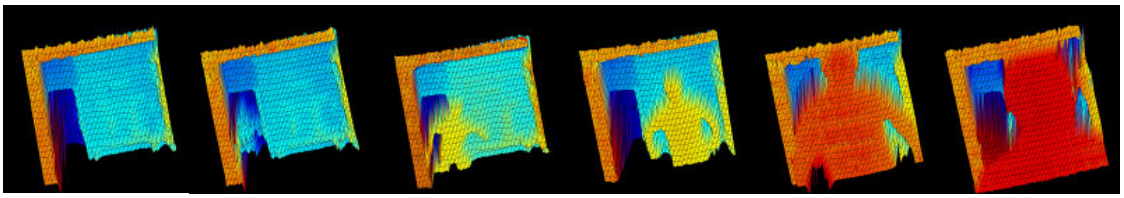
MESA IMAGING

Image Sensor Technologies for 3D Time-of-flight Range Imaging

Thierry Oggier

Bergen, 2009



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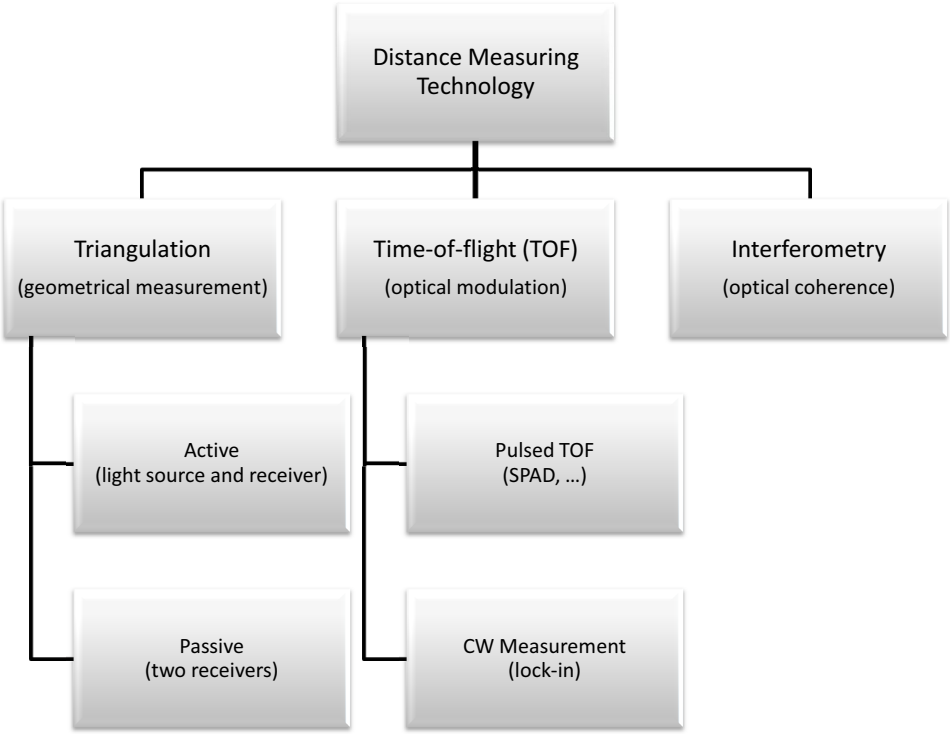
TOF Technologies
Content

- Overview 3D Technologies
- How does a 3D TOF demodulation pixel work?
- Why is a 3D TOF pixel 100 times bigger than state-of-the art CCD / CMOS pixel?
- Why does a 3D TOF pixel require extremely high-speed electron transfer?
- Overview of state-of-the-art 3D TOF pixel implementations
- Summary / Outlook

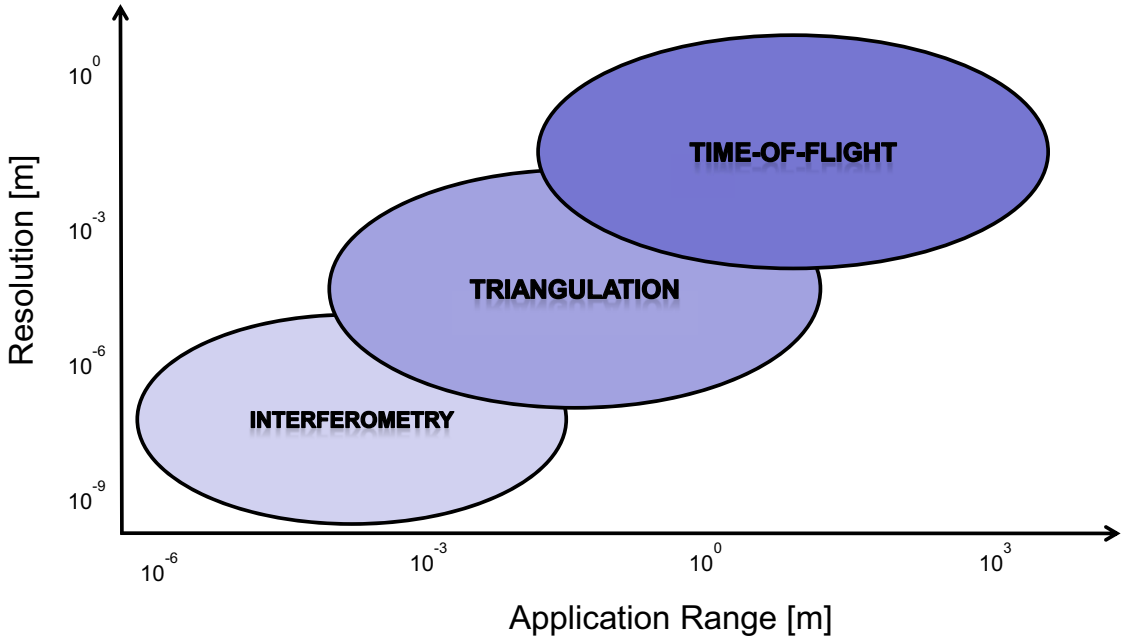
Overview 3D Technologies
Comparison



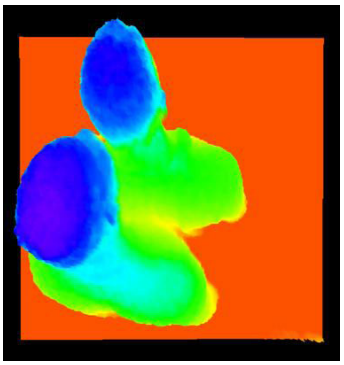
Overview 3D Technologies
Comparison

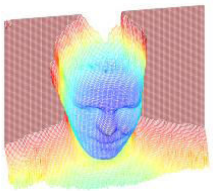
	Triangulation (geometrical measurement)	Time-of-flight (TOF) (optical modulation)	Interferometry (optical coherence)
Range R_0	Basis dependent → mm to a few m	$R_0 \infty c/F$ → cm to 100m	$R_0 \infty \lambda$ → µm
Depth noise σ	$\sigma \infty R^2$	$\sigma \infty R$	$\sigma \infty \lambda$
Required computing power	-	+	+
Miniaturization potential	-	+	-
Economic potential	-	+	-
Other	Passive: Texture required		

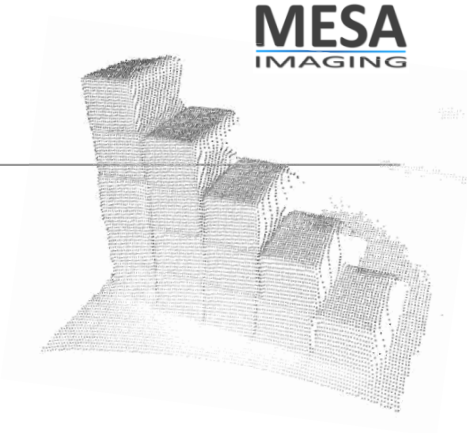
Overview 3D Technologies
Comparison

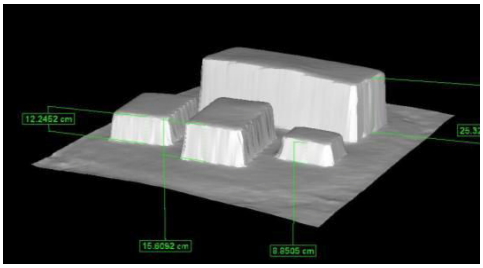


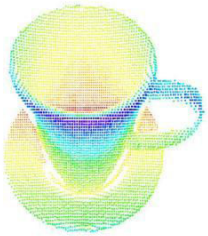
3D TOF Imaging
Acquisition Samples

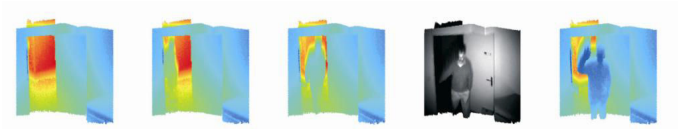


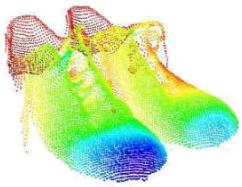






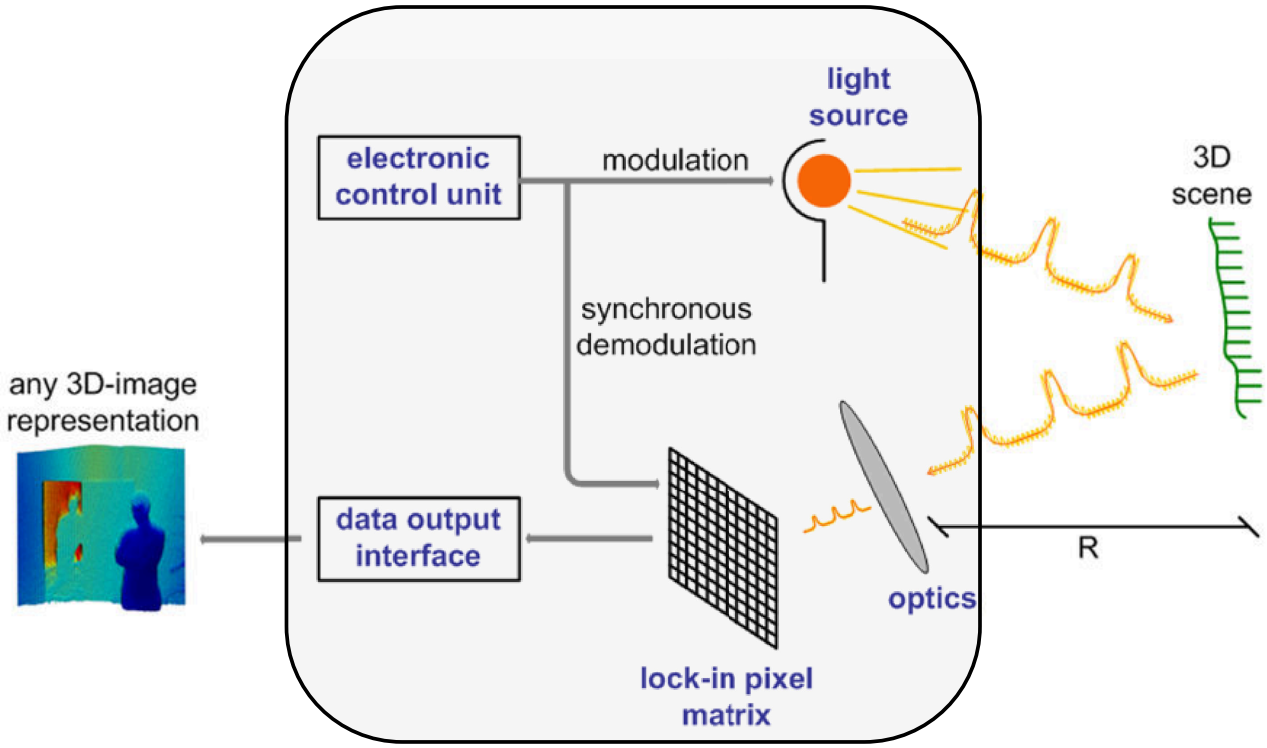






TOF Technologies

How does a 3D TOF pixel work?



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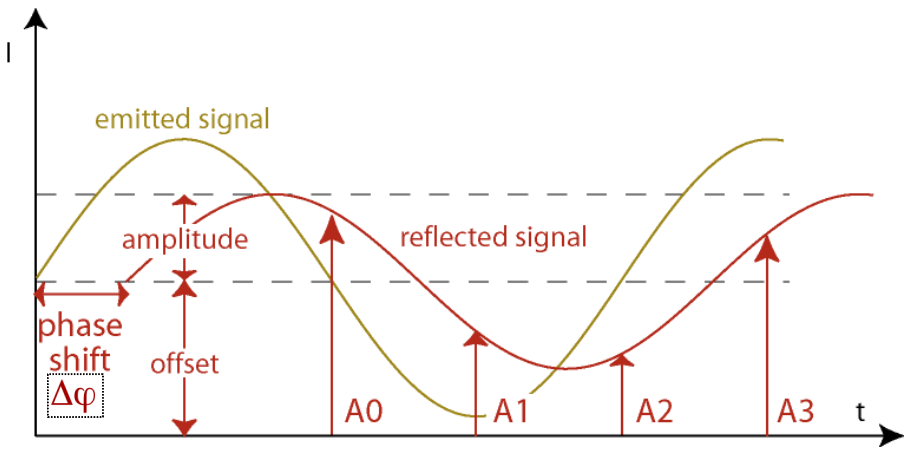


$$A = \frac{\sqrt{[A_3 - A_1]^2 + [A_0 - A_2]^2}}{2}$$

→ Amplitude / Quality

$$B = \frac{A_0 + A_1 + A_2 + A_3}{4}$$

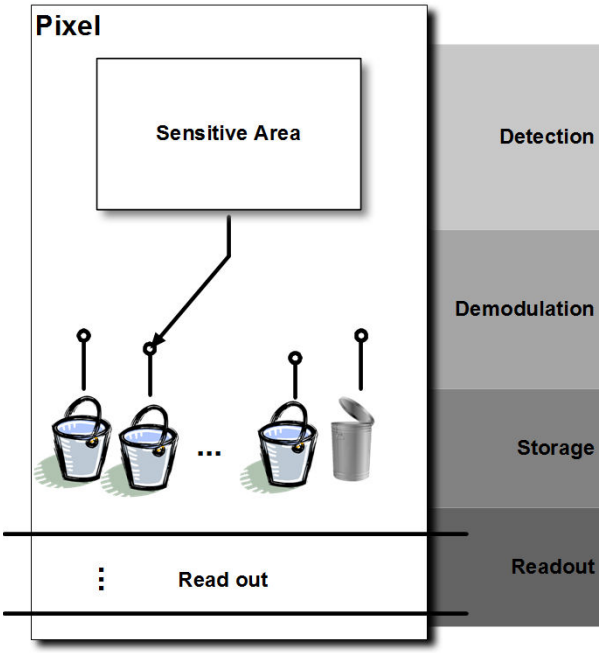
→ Intensity / BW

$$\varphi = \operatorname{atan}\left(\frac{A_3 - A_1}{A_0 - A_2}\right)$$

→ Phase / Distance

TOF Technologies

How does a 3D TOF pixel work?



Main challenges for 3D TOF pixels

TOF Technologies

Why a 3D TOF pixel requires high-speed?

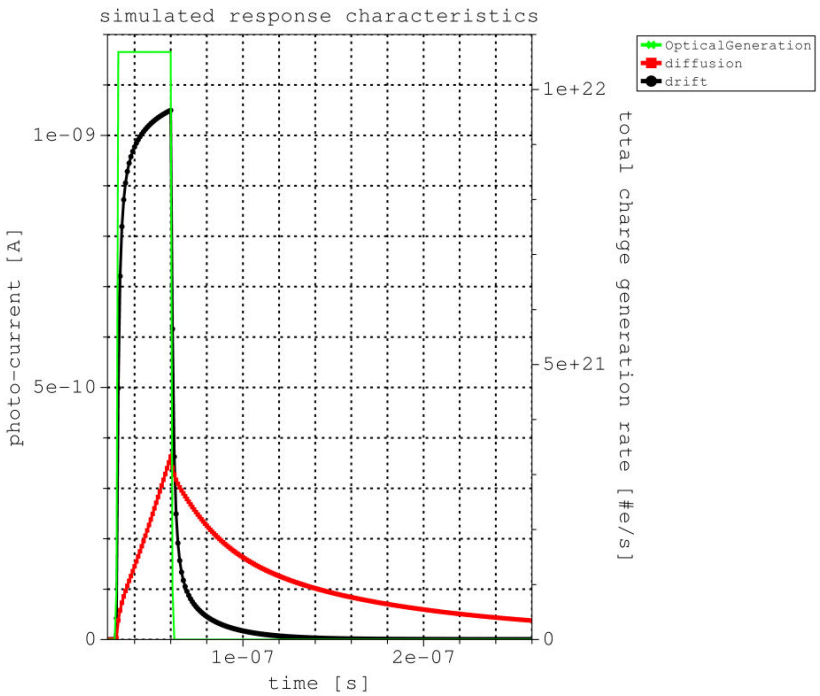
Electron Transfer Time:

$$\Delta t_{diffusion} = x^2 / D_n$$

$$\Delta t_{drift} = \frac{x^2}{-u_n \cdot E} = \frac{x^2}{u_n \cdot dU / dx}$$

Device Simulation:

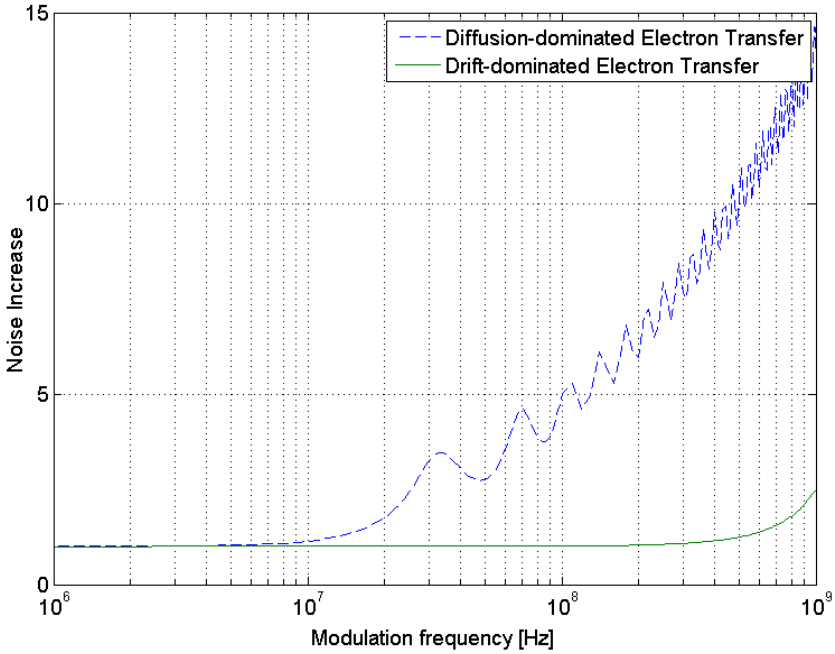
$$x = 7\,\mu m$$
$$\Delta U_{drift} = 2\,V$$



TOF Technologies

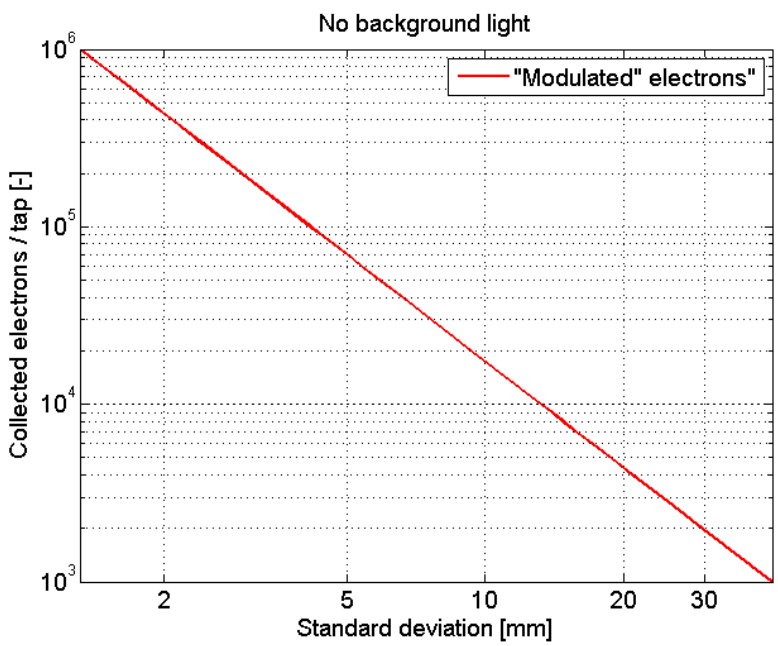
Why a 3D TOF pixel requires high-speed?

System Simulation



TOF Technologies

Why are 3D TOF Pixels that big?

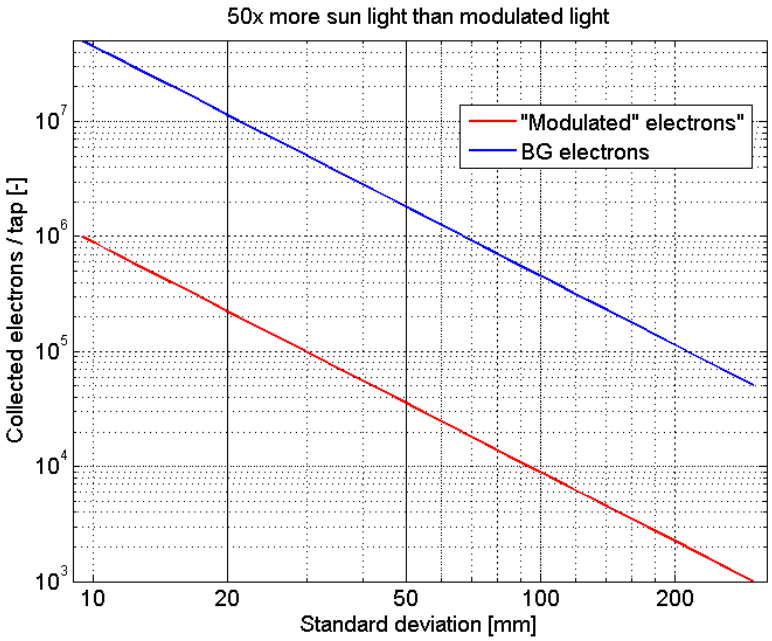


Note:

- Modulation at 20MHz
- Ideal imager (perfect demodulation, no saturation, no noise)
- No background light
- Phyiscal limitation (photon shot noise limit)
- 10mm standard deviation requires ~ **20ke- / sample**

TOF Technologies

Why are 3D TOF Pixels that big?



Assumption:

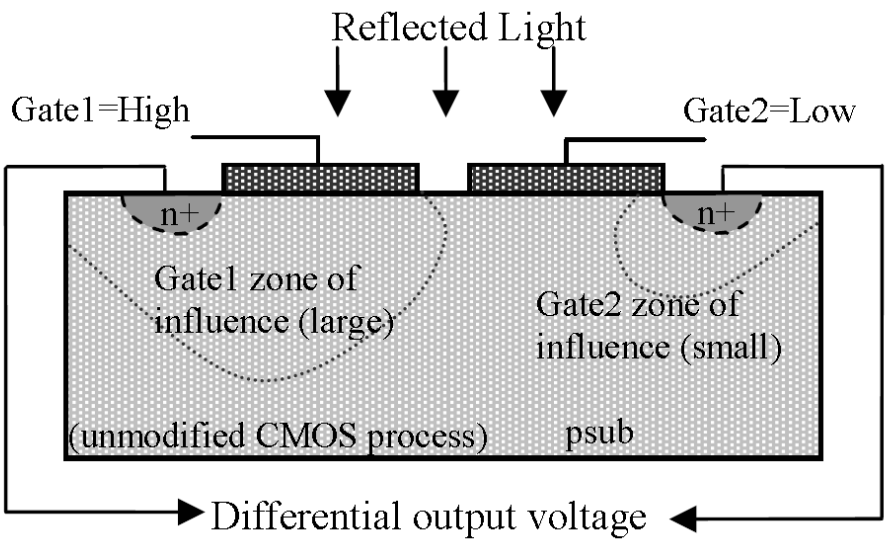
- Camera with 1W/m^2 on target (typical for a target at 1m)
- Sun light ~50W/m^2

Note:

- Modulation at 20 MHz
- Ideal imager (perfect demodulation, no saturation, no noise)
- Physical limitation (photon shot noise limit)
- 10mm standard deviation requires close to 1Me / tap modulated and dealing with 30Me- background

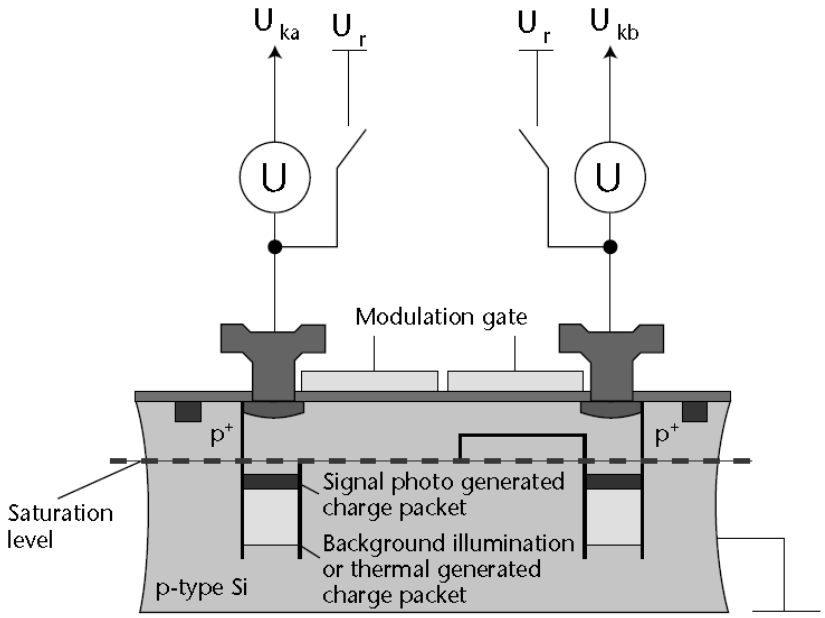
TOF Technologies

Implementations (Canesta)



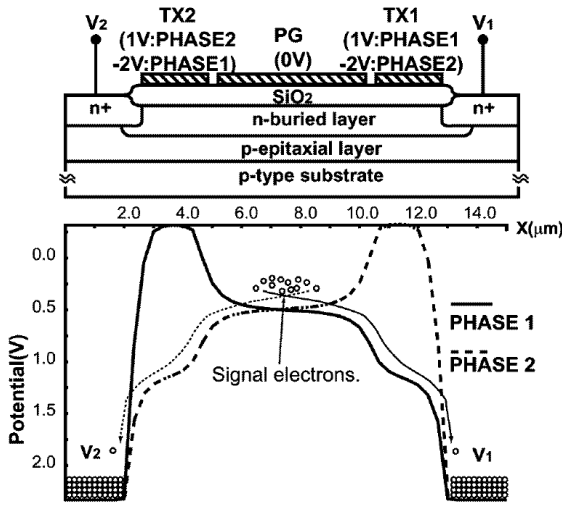
*Gokturk et al, "A Time-Of-Flight Depth Sensor - System Description, Issues and Solutions", CVPR 04, Vol.3, p.35

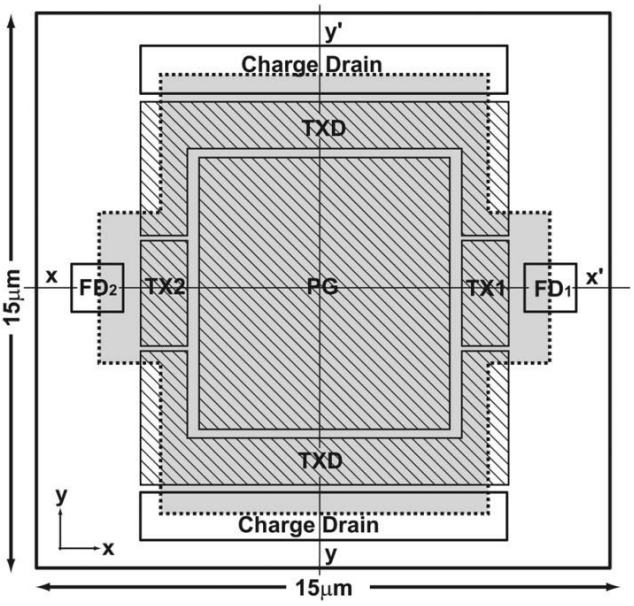
TOF Technologies
Implementations (PMD Technology)



*Hagebeuker, „Mehrdimensionale Objekterfassung mittels PMD Sensorik“, Optik & Photonik, March 08

TOF Technologies
Implementations (University Shizuoka)

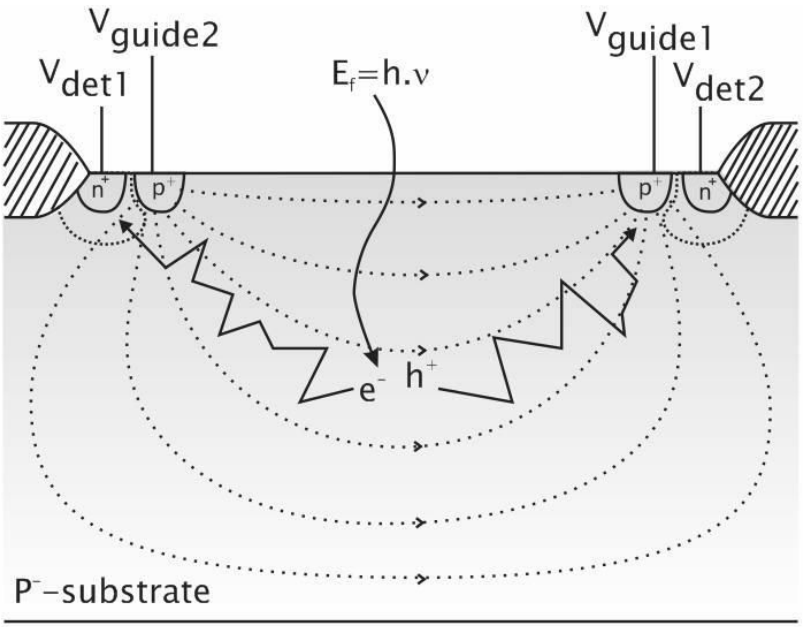




*Kawahito et al, „A CMOS time-of-flight range image sensor with gates-on-field-oxide structure“; IEEE Sensors Journal, Vol. 7, No. 12, Dec 2007

TOF Technologies

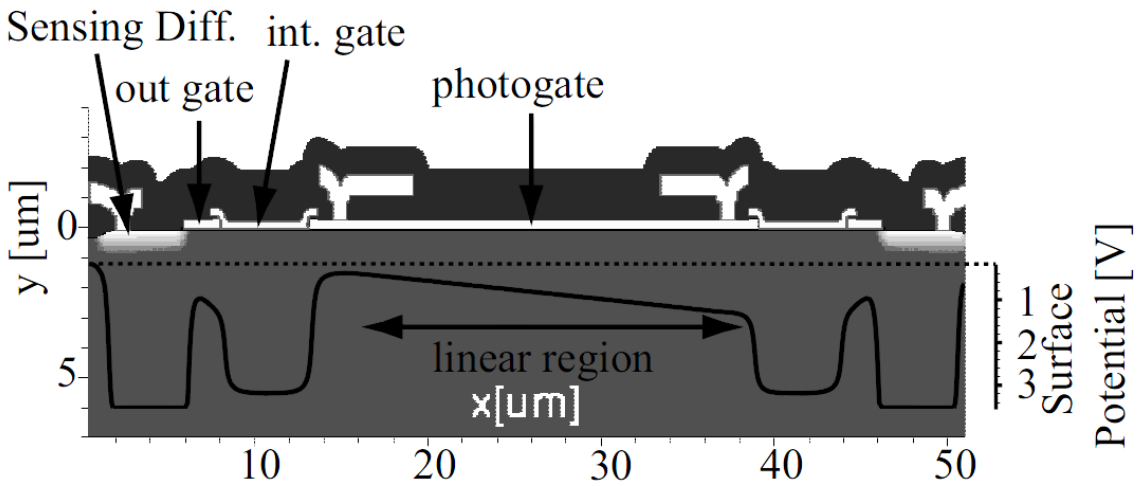
Implementations (Vrejie University Brussels)



*D. Van Nieuwenhove et al, "Novel Standard CMOS Detector using Majority Current for guiding Photo-Generated Electrons towards Detecting Junctions", Proceedings Symposium IEEE/LEOS Benelux Chapter, 2005, Mons

TOF Technologies

Implementations (MESA / CSEM)



*B. Büttgen et al, "Demonstration of a Novel Drift Field Pixel Structure for the Demodulation of Modulated Light Waves with Application in Three-Dimensional Image Capture", SPIE Proc. Vol. 5302 (2004)

TOF Technologies
Summary / Outlook

- Interferometry, triangulation and TOF technologies offer approaches for different ranges and resolutions.
- Biggest challenges for TOF Pixel:
  - the high-speed demodulation
  - the required high dynamic range
- Compared to standard pixels, TOF pixel are much larger and have a lower fill factor.
- First industrial-grade TOF camera on the market in 2009.
- High volume applications represent interesting opportunity for TOF cameras.

Thank you for your attention!

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