SiPM and SPAD Arrays for Next Generation LiDAR

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Senior LiDAR Engineer

International SPAD-Sensor Workshop
SensL Quick Facts

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<th>Business</th>
<th>Low Light Sensors</th>
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<td>Markets</td>
<td>Medical Imaging</td>
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<td>Radiation Detection</td>
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<td>LiDAR</td>
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<tr>
<td>Model</td>
<td>Fabless Semiconductor</td>
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- Established 2004
- ISO9001:2008 Certified
LiDAR Product & Demonstrator Roadmap

**Products**

- **RA-Series SiPM**
- **1x16 SiPM Array**
- **3D ToF SPAD Array**

**Demonstration Platforms**

- **Gen 1 – Single Point**
  - 30m indoors
  - February 2016

- **Gen 2 – Single Point**
  - 100m outdoors
  - Low reflective targets
  - September 2016

- **Gen 3 – 3D ToF Imaging**
  - 100m+ outdoors
  - Low reflective targets
  - June 2017
Agenda

- Anatomy of a LiDAR system
  - Tx: eye safe laser beam
  - Rx: high sensitivity SiPM/SPAD sensors
- Challenges for long distance outdoor LiDAR systems
- Current LiDAR systems solutions based on SiPM sensors
- Future LiDAR sensors based on SiPM/SPAD array sensors
- SensL Gen3 demonstrator
Anatomy of a LiDAR System

Point Cloud Image
100s Megabit / s

Tx
- Transmission Lens
- Laser Diode
- Laser Driver
- Timer (TDC)

Rx
- Receiver Lens
- SiPM/SPAD
- Amplification
- Comparator / ADC

Memory
Micro controller
Image Processor
Start
Stop

Timer (TDC)
Direct ToF LiDAR Measurement Techniques

- **Single shot**: one laser pulse per measurement (SiPM)
  - A single returned pulse is time stamped and the range determined
  - High optical SNR required

- **Multishot**: multiple laser pulses per measurement (SiPM or SPAD)
  - Laser pulses are time stamped & histogrammed
  - Range is determined from the histogram data
  - Increases SNR extending range
Challenges for Long-distance LiDAR Systems

- **Tx: Laser diodes / Scanning method**
  - High and eye safe laser peak power required for long distance
  - High repetition rate for high frame rate systems
  - Short laser pulses for power optimization
  - Wavelength drift over temperature
    - Allows for narrower bandpass filters to be used and improve ambient rejection
  - Solid-state scanning methods
    - MEMS
    - OPA

- **Rx: SiPM/SPAD**
  - High responsivity at 905 nm and 940 nm for long range
  - High dynamic range for ambient light rejection
  - Compact size – cost effective
  - High pixelization
    - For high angular resolution
    - For best SNR performance
  - High data rate
  - Fast read out
Anatomy of a LiDAR System

Point Cloud Image 100s Megabits / s

Memory

Micro controller

Image Processor

Timer (TDC)

Laser Diode

Laser Driver

Transmission Lens

Receiver Lens

SiPM/SPAD

Amplification

Comparator / ADC

Start

Stop

100s Megabits / s
Laser Eye Safety and LiDAR Systems

- Long range LiDAR requires high peak power lasers
- Laser power is spread over a wide angle of view (AoV)
- Aperture of the human eye has a limited AoV
- Important factors to meet eye safety limits from IEC 68025
  - Shorten the laser pulse to reduce energy per pulse
  - Increase the laser aperture for light leaving the LiDAR system
Laser Eye Safety

Maximum Permissible Exposure (MPE) IEC 68025-1 (2014)

\[ AoV_x = 0.1^\circ, \text{ assumes viewer is 10 cm (4'') from laser aperture} \]

Key to laser eye safety
- Short laser pulses
- Large laser aperture

Increasing optics aperture
Decreasing pulse width

Maximum scanning system laser power at 905 nm
Anatomy of a LiDAR System

Point Cloud Image 100s Megabits / s

Tx
- Transmission Lens
- Laser Diode
- Laser Driver
- Image Processor
- Timer (TDC)
- Memory

Rx
- Receiver Lens
- SiPM/SPAD
- Amplification
- Comparator / ADC
- Microcontroller
- Memory
- Image Processor

Start
Stop
Nomenclature: SPAD and SiPM

Single microcell/SPAD
- Cathode
- SPAD
- Anode
- \( V_{bias} \)
- \( R_{quench} \)

Time or count single photons

Example of 12 microcell/SPAD SiPM
- Cathode
- Fast Output
- \( V_{bias} \)
- \( R_{quench} \)
- Quench Resistor

Time or count multiple photons
LiDAR Sensor Technology Evolution

Yesterday

Single Point LiDAR

Electromechanical Imaging LiDAR

Solid-State Imaging LiDAR V1

Today

SiPM (C-Series)

SiPM (R-Series)

SiPM Array (R-Series)

SPAD Imager

Tomorrow

Digital

High gain

Low gain

APD

PIN

Solid-State Imaging LiDAR V2
Long-distance LiDAR Systems Evolution

- **Today:** Electromechanical scanning TX \ RX (coaxial)
  - Single point (2D scan)
    - Single SiPM
  - Vertical/Horizontal line (1D Scan)
    - SiPM array

- **Future:** Solid-state scanning TX \ Staring RX
  - Single point (2D scan)
    - MEMS mirrors for TX
    - SiPM/SPAD array for RX
  - Vertical/Horizontal line (1D Scan)
    - MEMS mirrors/array for TX
    - SiPM/SPAD array for RX
LiDAR Design with SiPM
Practical Solutions for Today's LiDAR Modules

- Beam Steering
  - 1D or 2D
    - Electromechanical or MEMS

- Laser Diode
  - High peak power (1000s W)
    - 905 nm commercially available
    - 940 nm solar minimum advantage
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)

- Optics
  - Small AoV per pixel
  - Optical bandpass filter (10 to 50 nm)
    - Driven by laser technology
  - Small aperture size
    - For optimal SNR and system size

- SiPM Sensor or SiPM Array
  - High responsivity @ 905 & 940 nm (100kA/W+)
  - High dynamic range
  - Highly uniform (+- 10% output)
  - Low voltage (<50V)
How to Range >200m With SiPM Technology

- **Ranging Solution**
  - 40° x 30° Long range
  - 120° x 30° Short range

- **Sensor Specification**
  - 1x16 SiPM
  - R-Series

- **Resolution**
  - AoVx = 0.1°
  - AoVy = 1.9°

- **Laser Specification**
  - 905 nm or 940 nm
  - 1ns laser pulse
  - 500 kHz repetition rate
  - Maintains eye-safety for both systems
Challenges with Today’s LiDAR Systems?

1. Poor angular resolution in the y-direction
2. Steering the received light onto the sensor
Future LiDAR Design with SPAD or SiPM Arrays

- Beam Steering
  - TX scanner
    - MEMS, optical phase array, other
    - Ultra compact LiDAR solution
    - No RX beam steering required
- Laser Diode
  - High peak power (1000s W)
  - High pulse rep. rate (100s kHz)
  - Short pulse width (1ns or less)
- Optics
  - TX can be miniaturized
  - RX optimized for SPAD or SiPM array
    - Small AoV per pixel

Target

Laser Diode

Beam Steering

Optics

Staring Rx

LiDAR Module

Filter

Optics

SiPM array

Pandion: SPAD array

or
SensL Pandion SPAD Array for Next Generation LiDAR System

- 400×100 SPAD array
- High dynamic range
- High raw data output rate
- Optimised for vertical line scanning

- 0.1° x-y angular resolution
- Suitable for >100m ranging at 10% reflectivity in full sunlight

Pandion pixels

Sampling Q2 2019
Gen 3 Imaging LiDAR Demonstrator
Anatomy of the Gen 3 Imaging LiDAR System

Specifications Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>AoV</td>
<td>80° x 5.53°</td>
</tr>
<tr>
<td>Pixel AoVx</td>
<td>0.1°</td>
</tr>
<tr>
<td>Pixel AoVy</td>
<td>0.325°</td>
</tr>
<tr>
<td>Aperture Rx</td>
<td>22 mm</td>
</tr>
<tr>
<td>Image Size</td>
<td>800 x 16 pixels</td>
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<tr>
<td>Data Rate</td>
<td>6 Mbits / s</td>
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<tr>
<td>Num. Laser Diodes</td>
<td>16</td>
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<tr>
<td>Pulse Width</td>
<td>1 ns</td>
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<tr>
<td>System Peak Power</td>
<td>400 W (Internal)</td>
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<tr>
<td>System Size</td>
<td>22cm x 18cm x 13cm</td>
</tr>
</tbody>
</table>
3D ToF Imaging LiDAR with SiPM
Gen3 Demonstration Video

- Demo Objectives:
  - Demonstrate SiPM advantages
  - Long distance low reflective target ranging
  - Imaging

- 1x16 SiPM Array
  - Monolithic SiPM array
  - Compact Rx

- System overview
  - 80° x 5° AoV
  - 16 channels acquired simultaneously
  - Imaging and depth displayed simultaneously

Full Video Link
https://www.youtube.com/watch?v=Lg2L7v5vb7M
Thank You

More information can be found at www.sensl.com
Contact us at sales@sensl.com