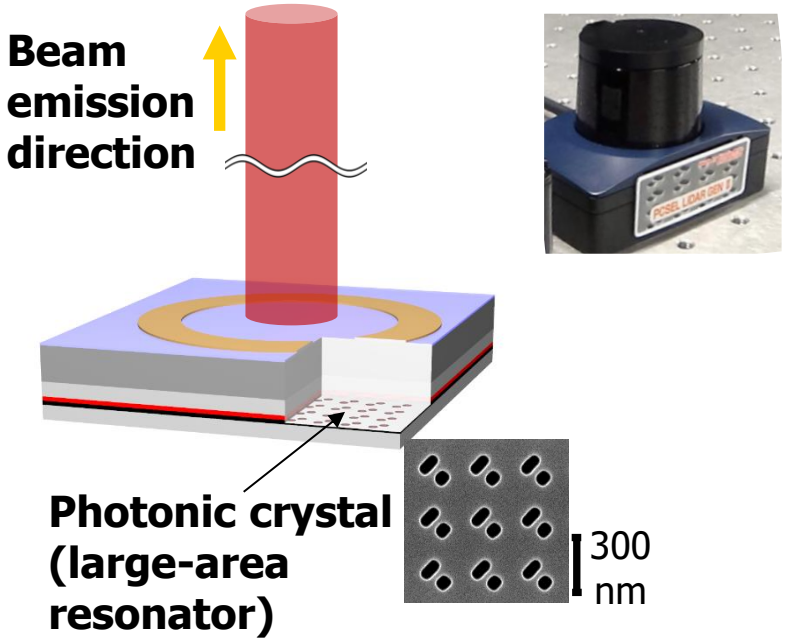
March 2025

「Cross-ministerial Strategic Innovation Promotion Program (SIP) Phase 3 / Construction of smart mobility platform / Development of infrastructure and onboard sensor systems that utilize compact LiDAR technology to understand the actual situations of streets in living areas and busy districts」



Commissionees: Kanazawa University, Kyoto University

金沢大学 京都大学 KYOTO UNIVERSITY

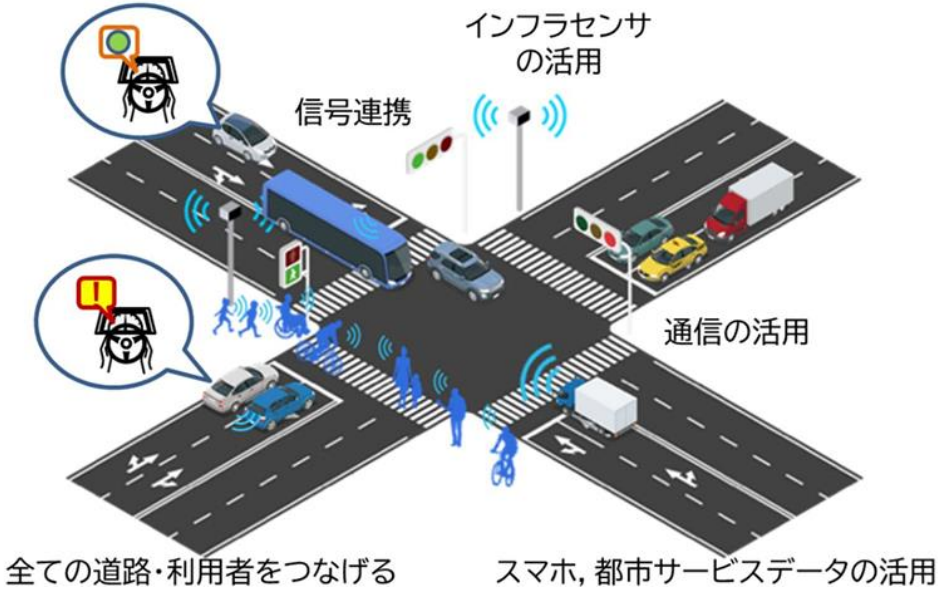
Table of Contents

Research Background (p.4~p.5)

Research Background

- Sensing of infrastructure
  - Monitoring the flow of people and traffic, sensing approaching cars, etc.
  - Cooperate with autonomous driving systems
    - RoAD to the L4 Project, etc.
- Importance of LiDAR*-based sensing
  - Application to infrastructure sensors
    - Effective from perspectives of privacy and resolution
  - Application to on-board sensors
    - Application to driver-assistance and autonomous driving systems
- Current state of LiDAR
  - Mostly foreign-made and large in size
    - Domestic production is desirable from the perspective of economic security
  - Reducing the size and cost are expected to have a ripple effect on the automotive industry

https://www.road-to-the-l4.go.jp/activity/theme04/



https://www.road-to-the-l4.go.jp/activity/theme04/pdf/theme04_01.pdf

Taken from the home page of the RoAD to the L4 Project

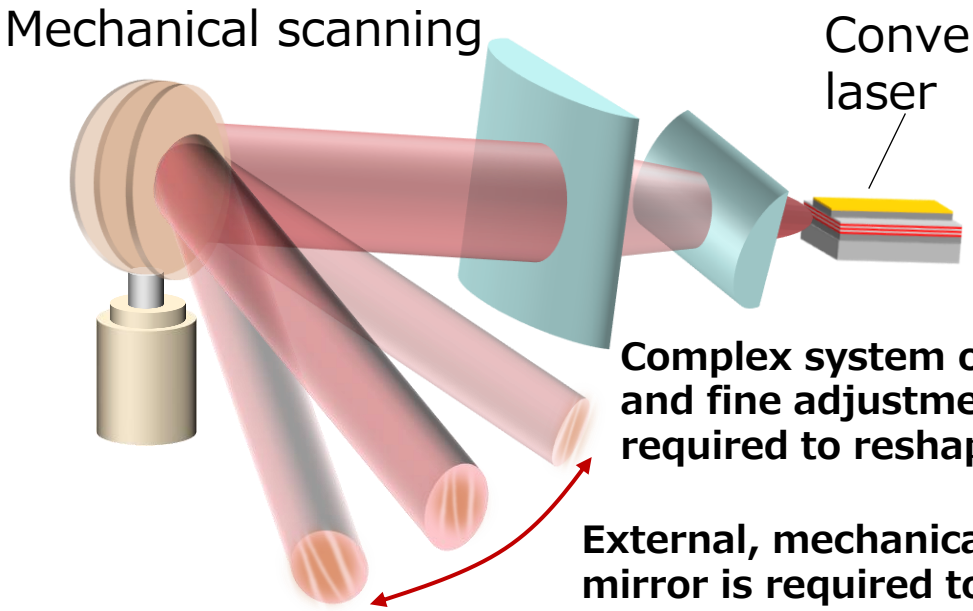
*Light Detection and Ranging

Research Background

Comparison of conventional semiconductor laser and PCSEL* for LiDAR

Conventional laser

Low brightness: Poor beam quality, wide divergence angle
Poor functionality: No native beam scanning



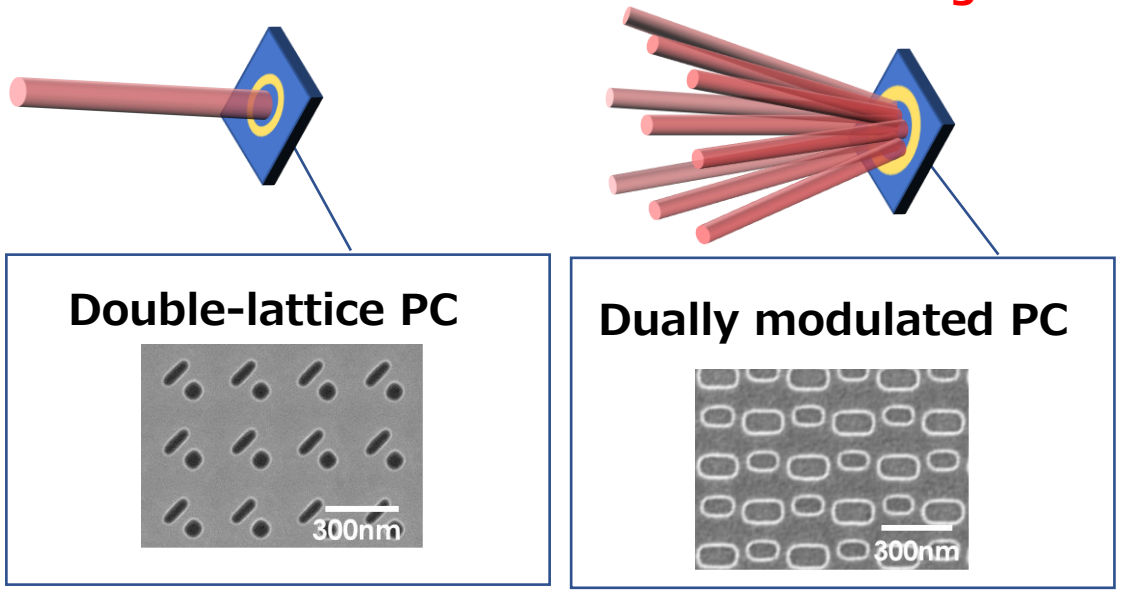
Complex system of lenses and fine adjustments are required to reshape the beam

External, mechanically rotating mirror is required to scan the beam

Bulky, costly LiDAR system: Bottleneck

Photonic crystal laser (PCSEL)

High brightness: High beam quality, narrow divergence angle (lens-free)
High functionality: Capable of multi-dot emission and native beam scanning



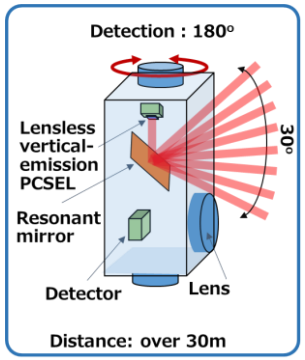
(*PCSEL: Photonic Crystal Surface Emitting Laser)

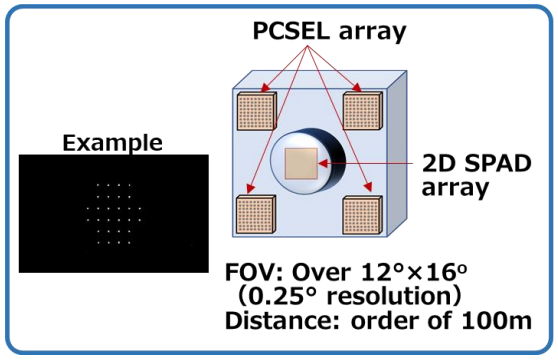
Overview of R&D (p.7~p.9)

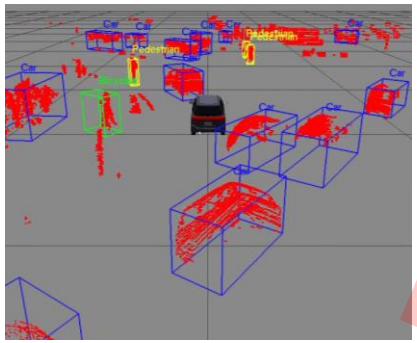
Overview of R&D

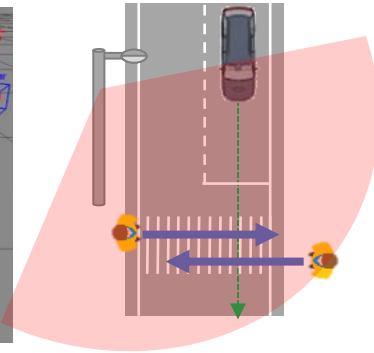
*Photonic Crystal Surface Emitting Laser

- **① Development of 3D PCSEL*-LiDAR system (Kyoto Univ.)**
  - Development of wide-FOV 3D PCSEL-LiDAR (mechanical-type)
    - Use as an infrastructure sensor
    - Use as a sensor for monitoring vehicle blind spots
  - Prototyping & development of non-mechanical PCSEL-LiDAR system
    - Development of low-cost electronically scanned LiDAR
- **② Development of recognition technology and conducting field-operational test (Kanazawa Univ.)**
  - Development of recognition technology using LiDAR
    - Analysis of point cloud obtained by PCSEL-LiDAR
    - Development of technology for precise detection of vehicles, pedestrians etc.
  - Field-operational test (FOT) using LiDAR
    - Demonstration and verification of use as an infrastructure sensor
      - Expansion to and collaboration with other projects are under consideration
    - Demonstration of autonomous driving using PCSEL-LiDAR
      - Demonstration of L4-equivalent autonomous driving in conjunction with infrastructure sensing







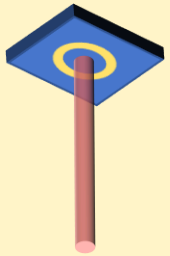


R&D Goals : ① 3D PCSEL-LiDAR System

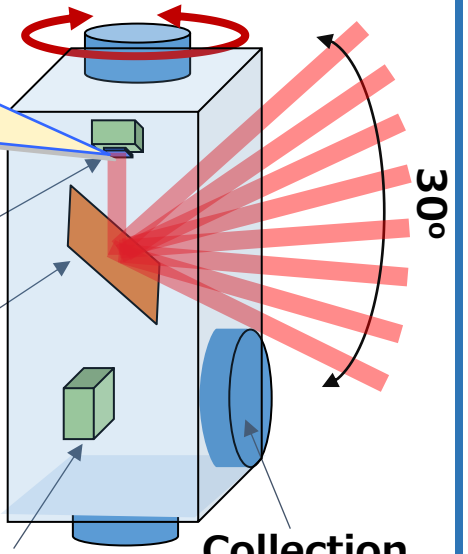
*SPAD: Single Photon Avalanche Diode

STEP1: Wide-FOV 3D PCSEL-LiDAR

Vertical-emission-type PCSEL



Wide-range detection : 180°

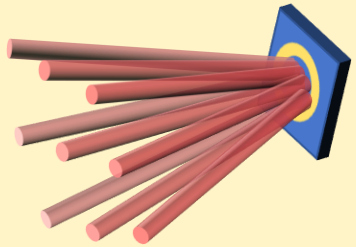


Distance: over 30m

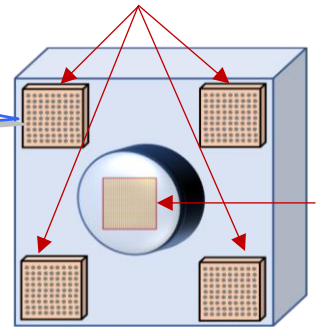
For use as an infrastructure sensor and a sensor that measures distances in a vehicle's blind spots

STEP2: Nonmechanical 3D PCSEL-LiDAR

Multi-dot PCSEL

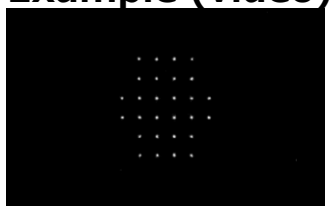


PCSEL array : Over 3,072 dots by multiple chips



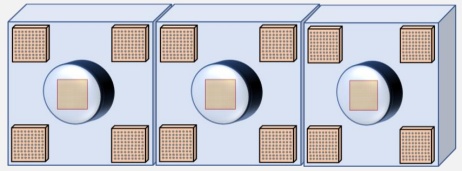
Detects at once with a 2D SPAD* array (3072 pixels in total, single pixel : 2x2 SPADs)

Example (video)



FOV: Over 12°×16° (0.25° resolution)
Distance: order of 100m

(Note 1) Can widen the FOV by stacking multiple systems



(Note 2) In the future, by using pixels consisting of more than 3×3 SPAD arrays and by increasing the peak output power, ranging of 200 to 300 m will be possible. Furthermore, the number of SPAD pixels and the PCSEL irradiation area (number of points) can be expanded to achieve a wider FOV.

For realizing all-semiconductor chips, which are expected to be smaller and less expensive, and for use as a general sensor for vehicles

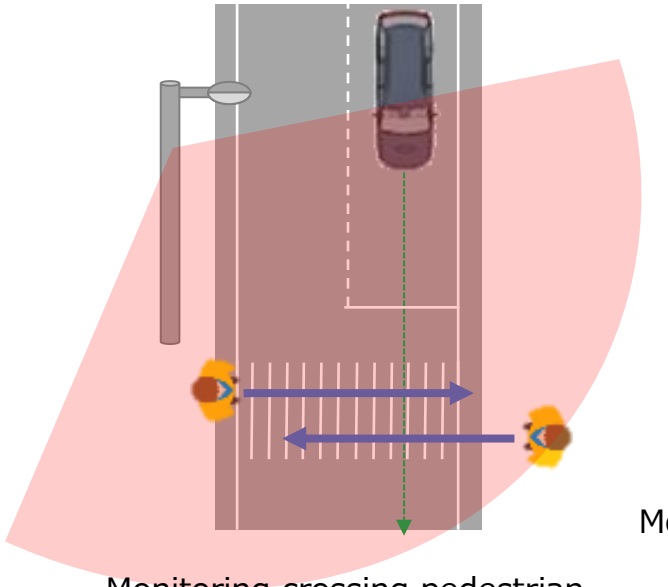
R&D Goal : ② Development of Recognition Technology and Conducting Field-operational Test

Mid-term goal :
Conducting FOT using infrastructure sensing

Development of recognition algorithms using wide-FOV 3D PCSEL-LiDAR, and conducting field operational test

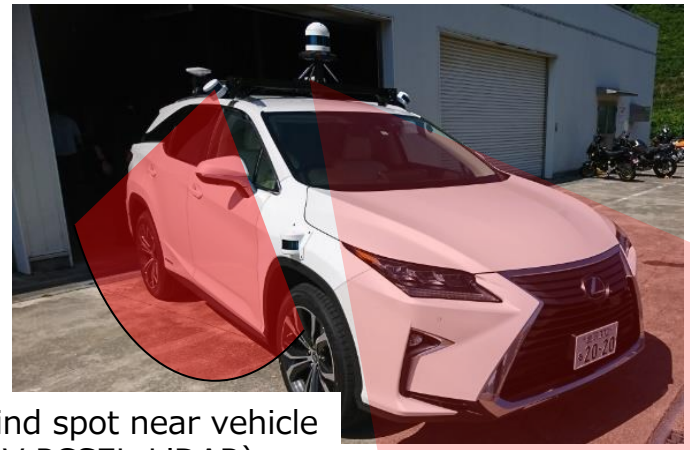
Final goal :
Conducting FOT of level4 equivalent autonomous driving

Development of recognition algorithms using multi PCSEL-LiDAR, and conducting field operational test with cooperating infrastructure and on-board sensors.

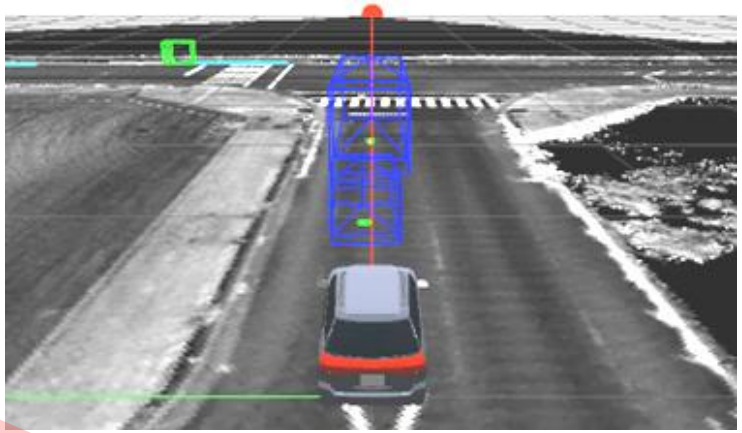


Monitoring crossing pedestrian
(Wide-FOV PCSEL-LiDAR)

Cooperating infrastructure and on-board sensors



Monitoring blind spot near vehicle
(Wide-FOV PCSEL-LiDAR)



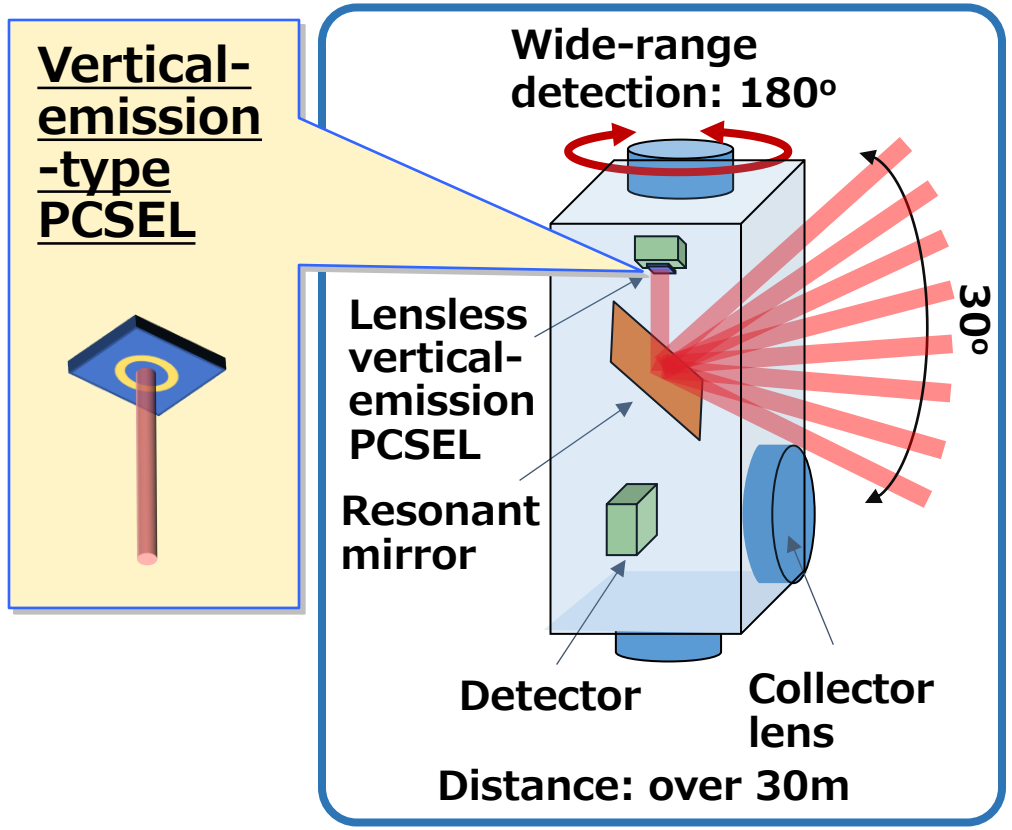
Recognition using on-board sensors

Monitoring in front of vehicle
(Nonmechanical PCSEL-LiDAR)

R&D Results (p.11~p.36)

Result of Current FY: Development of Wide-FOV 3D PCSEL-LiDAR

STEP1 : Wide-FOV 3D PCSEL-LiDAR



For use as an infrastructure sensor and a sensor that measures distances in a vehicle's blind spots

Development items

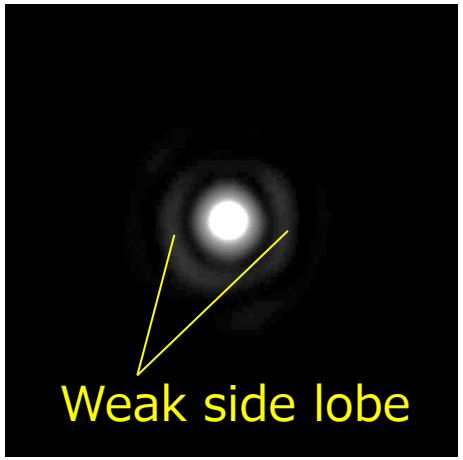
(red text is progress in the current FY)

- **Improvements of vertical-emission-type PCSEL (realizing an ideal Gaussian beam)**
- **Design and fabrication of a narrow bandpass filter compatible with PCSEL to reduce background light influence**
- **3D PCSEL-LiDAR specification and prototyping status**
- **(Additional item) Prototyping and evaluation of card-type PCSEL-LiDAR incorporating improved PCSEL and narrow bandpass filter**

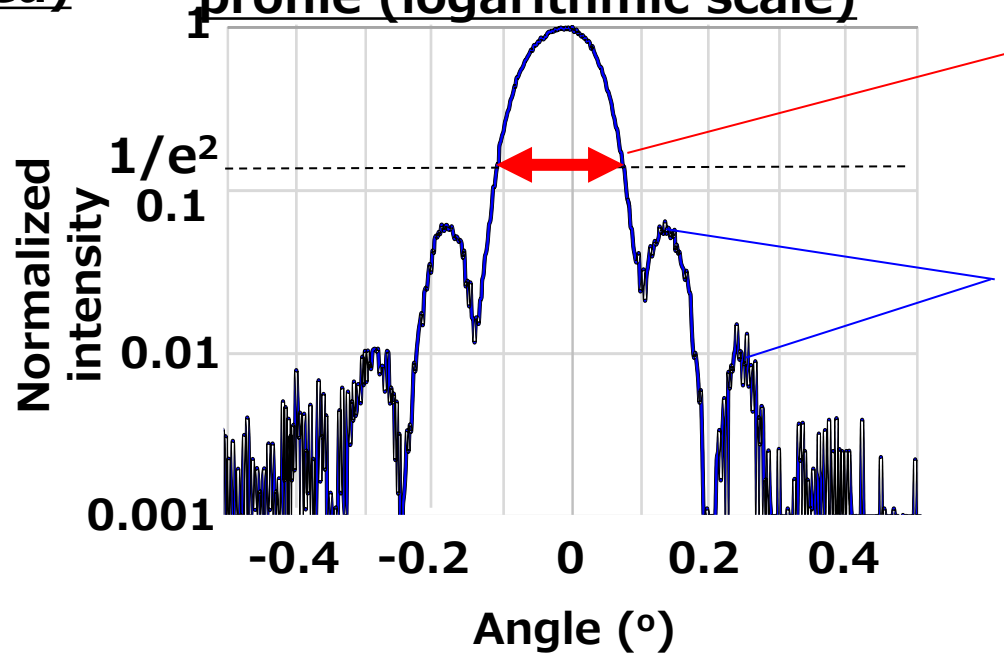
Realizing an Ideal Gaussian Beam with a vertical-emission-type PCSEL (review)

Device used in 2D PCSEL-LiDAR up until now

Emitted beam pattern (brightness enhanced)



Cross-sectional intensity profile (logarithmic scale)



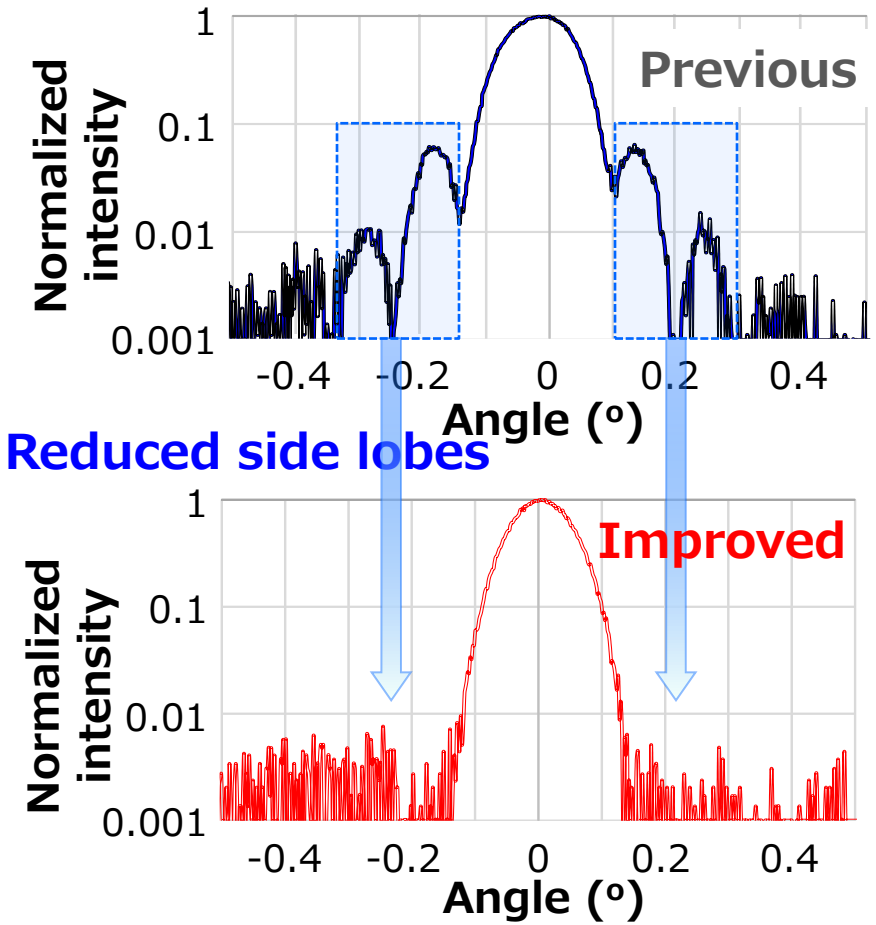
Narrow divergence angle (<0.2°) already achieved

Presence of outlying side lobes, whose intensity is around 1/30 of that of the main lobe
May cause erroneous detection of obstacles in directions other than the one to be measured, and must be suppressed

Goal: Reduce intensity to under 1/1000 that of the main lobe

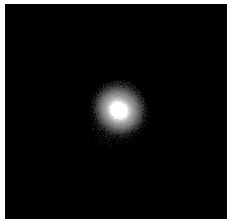
Measured Lasing Characteristics of Fabricated PCSEL (review)

Intensity profile of the emitted beam

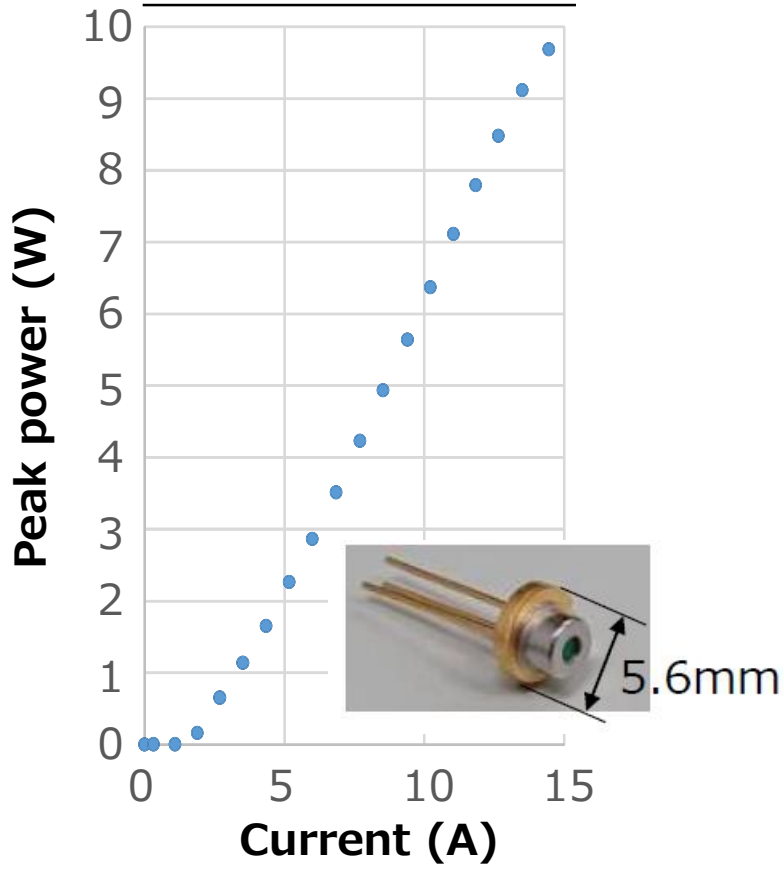


Beam pattern (brightness enhanced)

Beam pattern (brightness enhanced)



I-L characteristic



Successfully realized side-lobe reduction + high-power operation

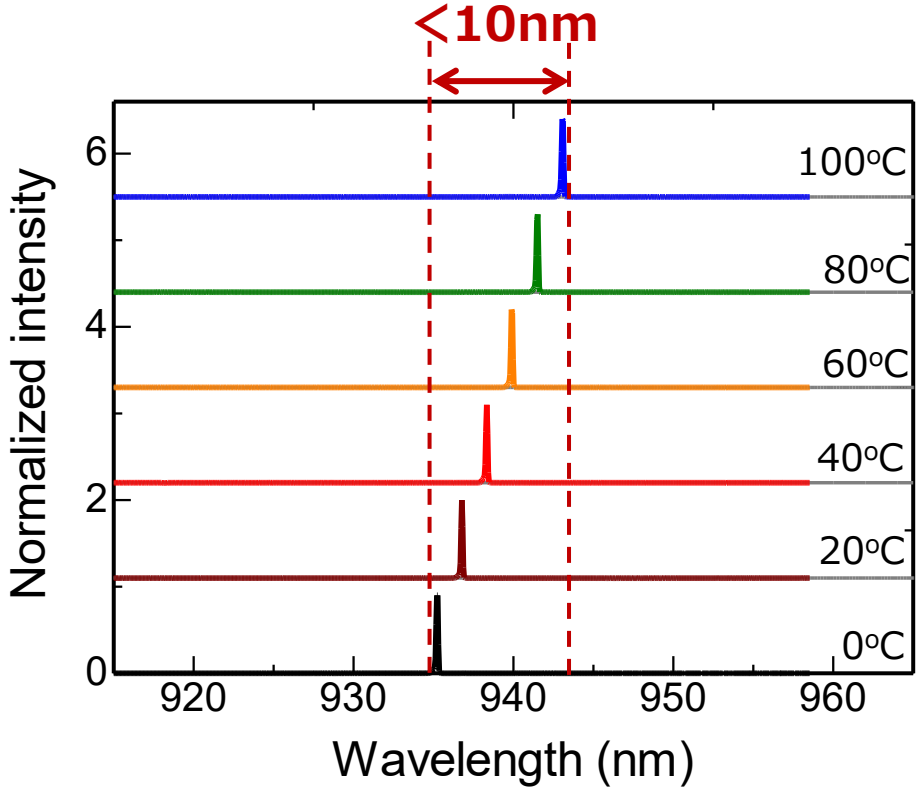
Provided to Hokuyo Automatic (subcontractor) and applied to PCSEL-LiDAR

Narrow Bandpass Filter for PCSELs

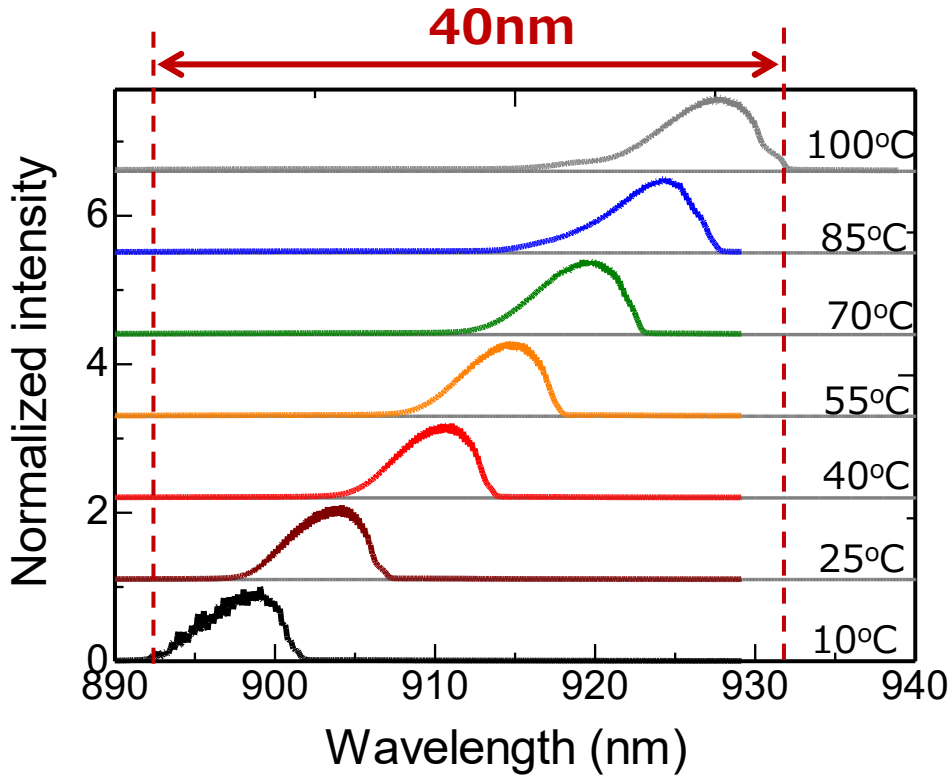
For card-type and STEP1 PCSEL-LiDAR

Comparison of emission spectra of PCSEL and convectional laser

Temperature dependance of PCSEL



Temperature dependance of conventional laser*

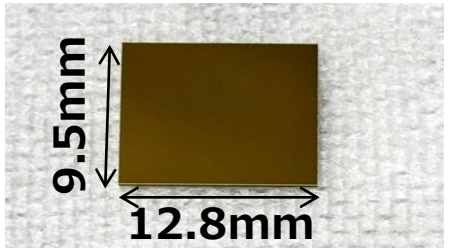


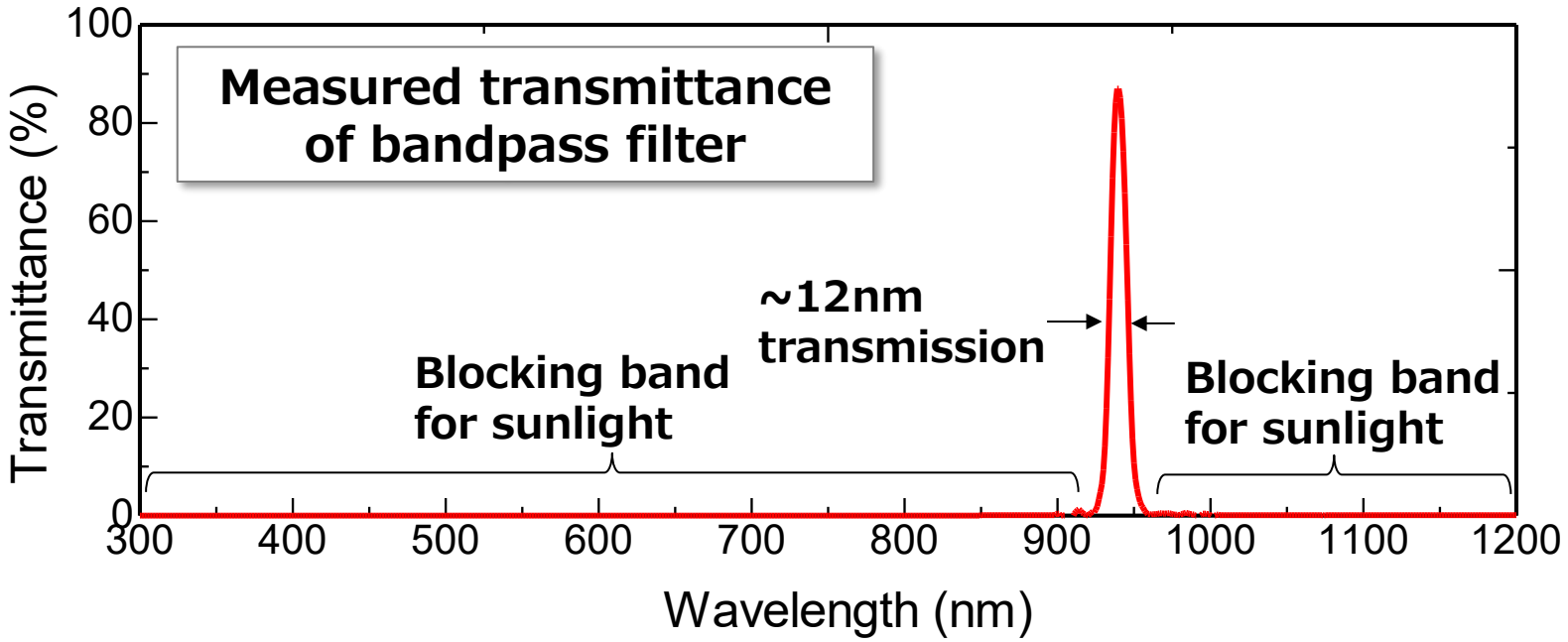
＊Coherent, Inc. semiconductor laser

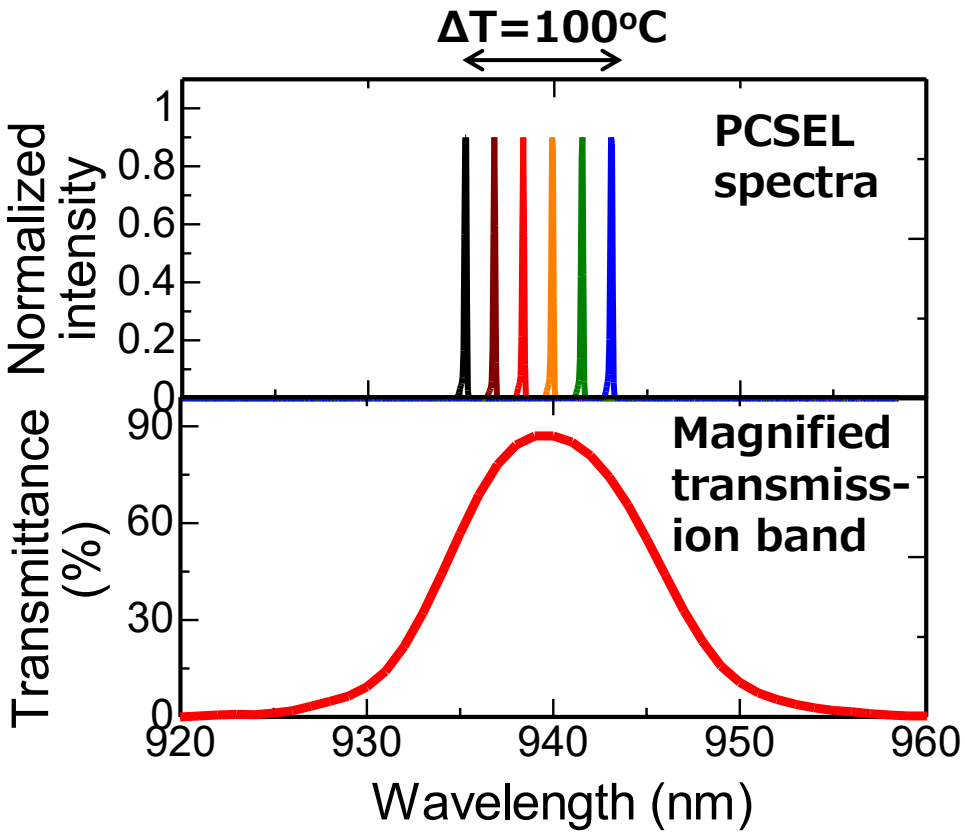
By utilizing a PCSEL, the bandpass filter can be narrowed to less than 1/4

Fabrication of Narrow Bandpass Filter

For card-type PCSEL LiDAR
Size: 12.8mm×9.5mm×0.5mm





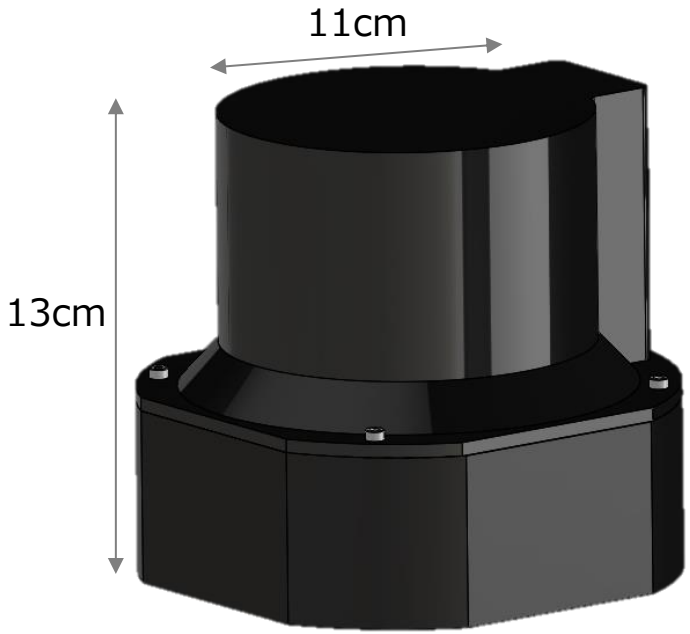


Narrow bandpass filter suitable for PCSEL is successfully fabricated

⇒ **Installed bandpass filter in card-type LiDAR**

STEP1 3D PCSEL-LiDAR Specification and Prototyping Status

Appearance of STEP1 wide-FOV 3D PCSEL-LiDAR



Note (brief explanation) :

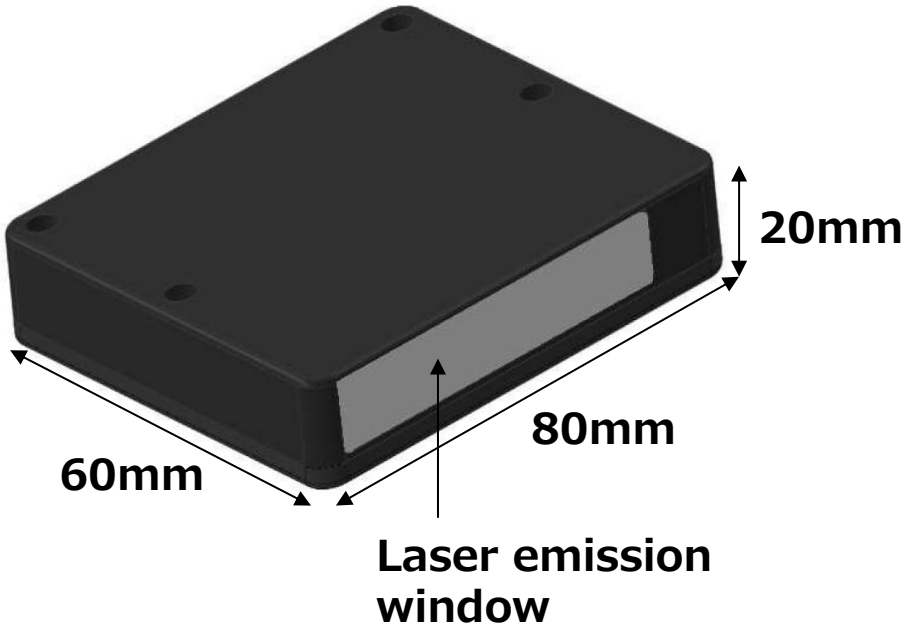
- Laser scans up and down ±15° (total 30°) by a resonant mirror (not visible) in the center
- Light receiver consists of receiving lens and APD array
- Whole unit rotates to achieve wide FOV of over 180°

Specification parameters	Values
PCSEL wavelength	940nm
Bandpass filter	10nm（1/4th of conventional)
Horizontal FOV	>180°
Vertical FOV	30°
Distance（R=90%)	35m
Resolution	0.6°
Distance accuracy	±5cm
Frame rate (max)	20fps
Supply voltage	24V
Interface	Ethernet

Prototyping wide-FOV 3D PCSEL-LiDAR :
By the end of Sept. 2025

(Additional item) Specifications of Card-type PCSEL-LiDAR

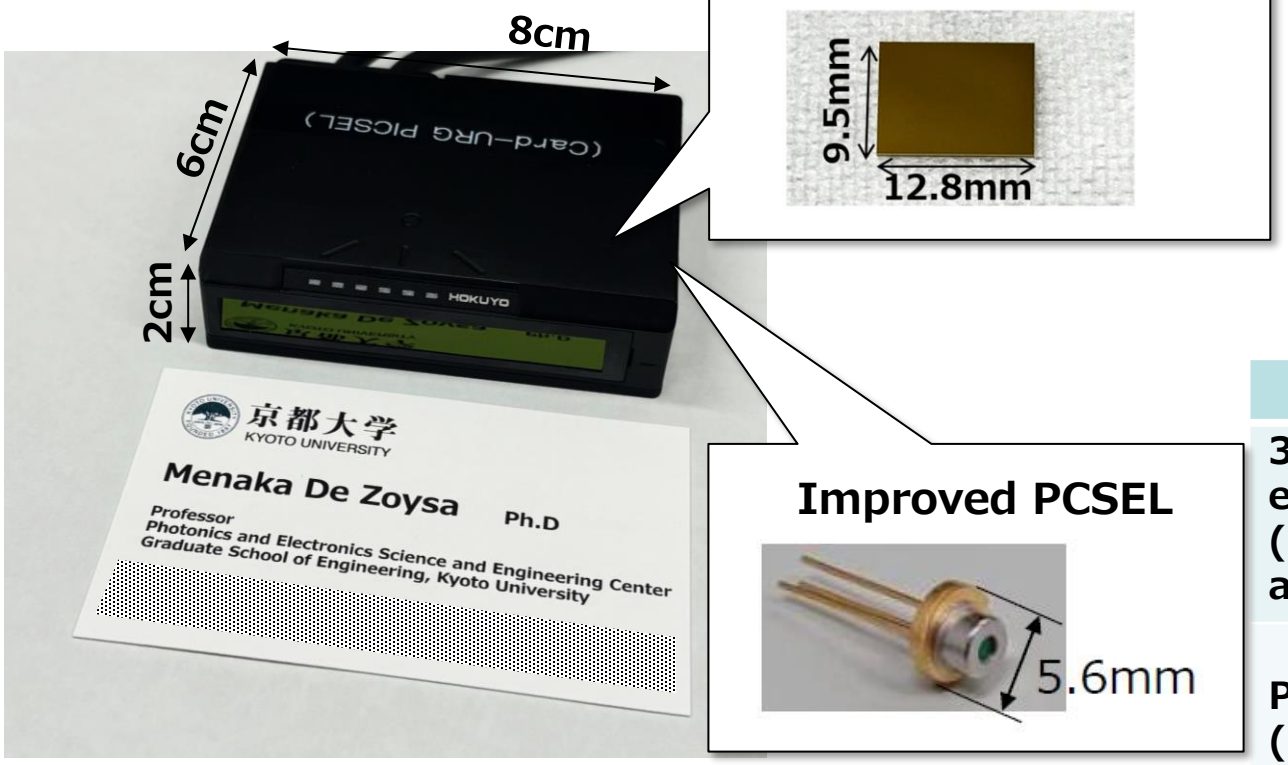
Appearance of the card-type PCSEL-LiDAR



Specification parameters	Values
PCSEL wavelength	940nm
Bandpass filter	10nm（1/4th of conventional)
Horizontal FOV	90°
Vertical FOV	3 layers（-2°, 0°, +1°)
Resolution	0.125°
Distance（R=90%)	10m
Distance accuracy	±4cm
Scan speed	60fps
Data points	172.8k per second
Interface	Ethernet 100BASE-TX
Size	20mm x 60mm x 80mm
Supply voltage	10-30V
Power consumption	<2.7W
Operating temperate	-10～+50℃
Shockproof	20G X,Y,Z, 10 times each
Weight	<100g (excluding cable)

Prototyping Card-type PCSEL-LiDAR

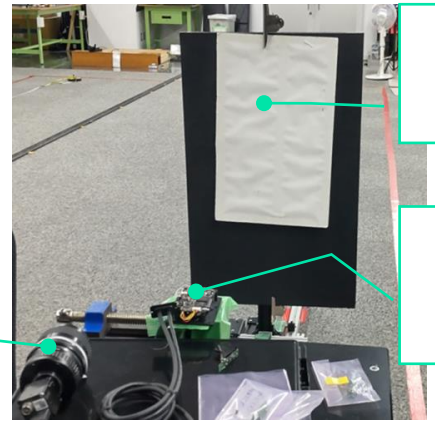
Beam pattern evaluation

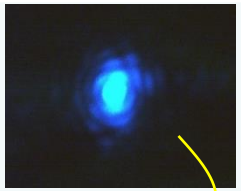
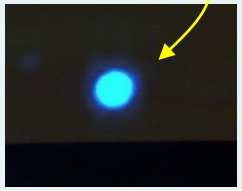


Narrow bandpass filter

Improved PCSEL

Footprint: Smaller than a business card



	Beam at 2m distance	
3-stack edge-emitting laser (lens + complex adjustments)		X : 52.0mm Y : 11.6mm
Previous PCSEL (Lens-free)		X : 23.9mm Y : 30.5mm **Improved flare**
New PCSEL ⇒ Gauss beam (Lens-free)		X : 23.2mm Y : 23.2mm

Even when lenses are used, the beam is horizontally deformed

Perfectly circular beam, very easy to use with Lidar (comment from Hokuyo Automatic)

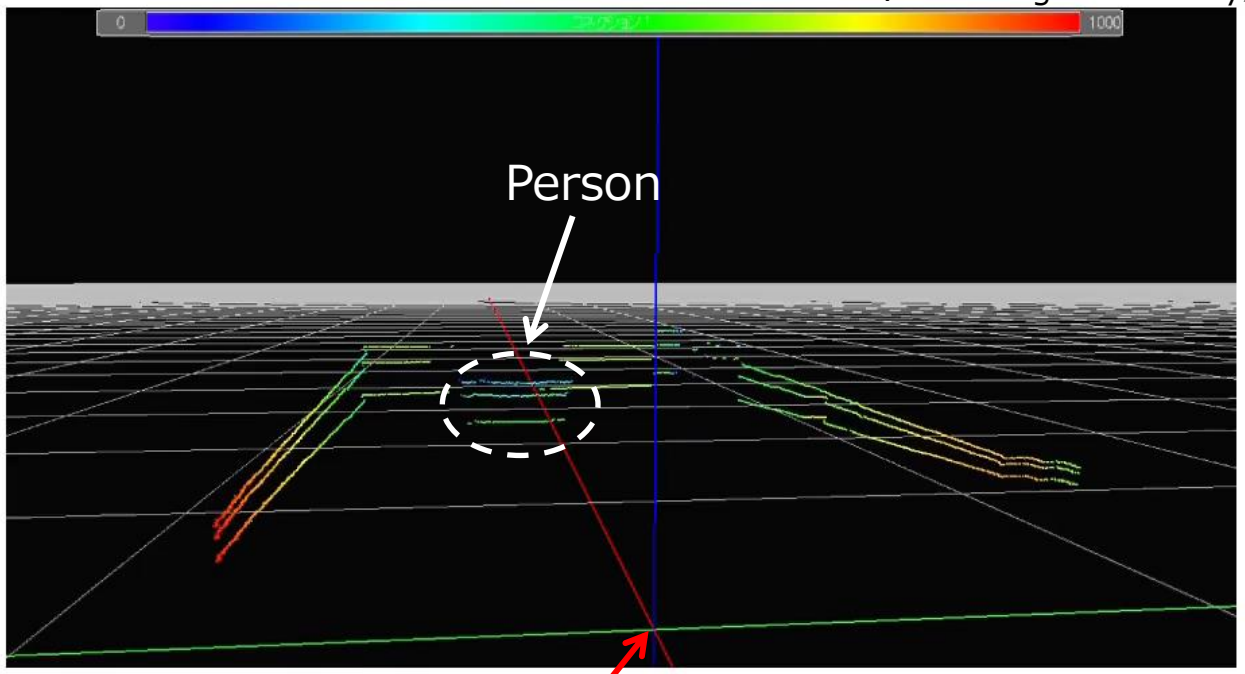
Distance Measurement of Card-type PCSEL-LiDAR

Camera video

Card-type PCSEL-LiDAR

Ranging video (3 layers)

(Color : Signal intensity)



Card-type PCSEL-LiDAR（Origin）

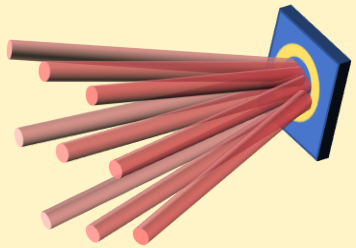
Successful distance measurement is achieved by using the ultra-compact card-type PCSEL-LiDAR

Providing card-type PCSEL-LiDAR to other projects to implement in wheelchairs

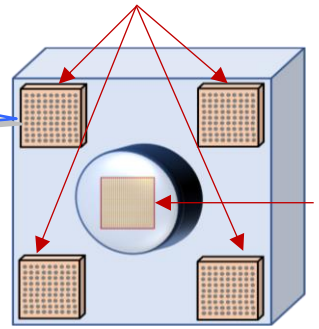
Result of Current FY: Development of Non-mechanical 3D PCSEL-LiDAR

STEP2: Non-mechanical 3D PCSEL-LiDAR

Multi-dot PCSEL

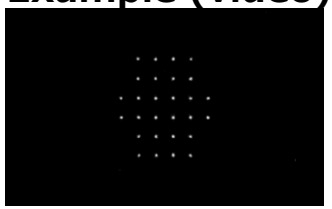


PCSEL array :
Over 3,072 dots by multiple chips



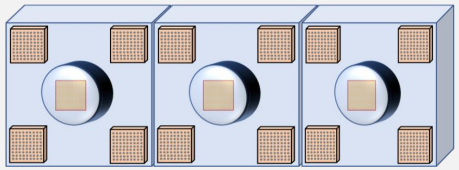
Detects at once with a 2D SPAD array (3072 pixels in total, single pixel : 2x2 SPADs)

Example (video)



FOV: Over 12°×16°
(0.25° resolution)
Distance: order of 100m

(Note 1) Can widen the FOV by stacking multiple systems



(Note 2) In the future, by using pixels consisting of more than 3×3 SPAD arrays and by increasing the peak output power, ranging of 200 to 300 m will be possible. Furthermore, the number of SPAD pixels and the PCSEL irradiation area (number of points) can be expanded to achieve a wider FOV.

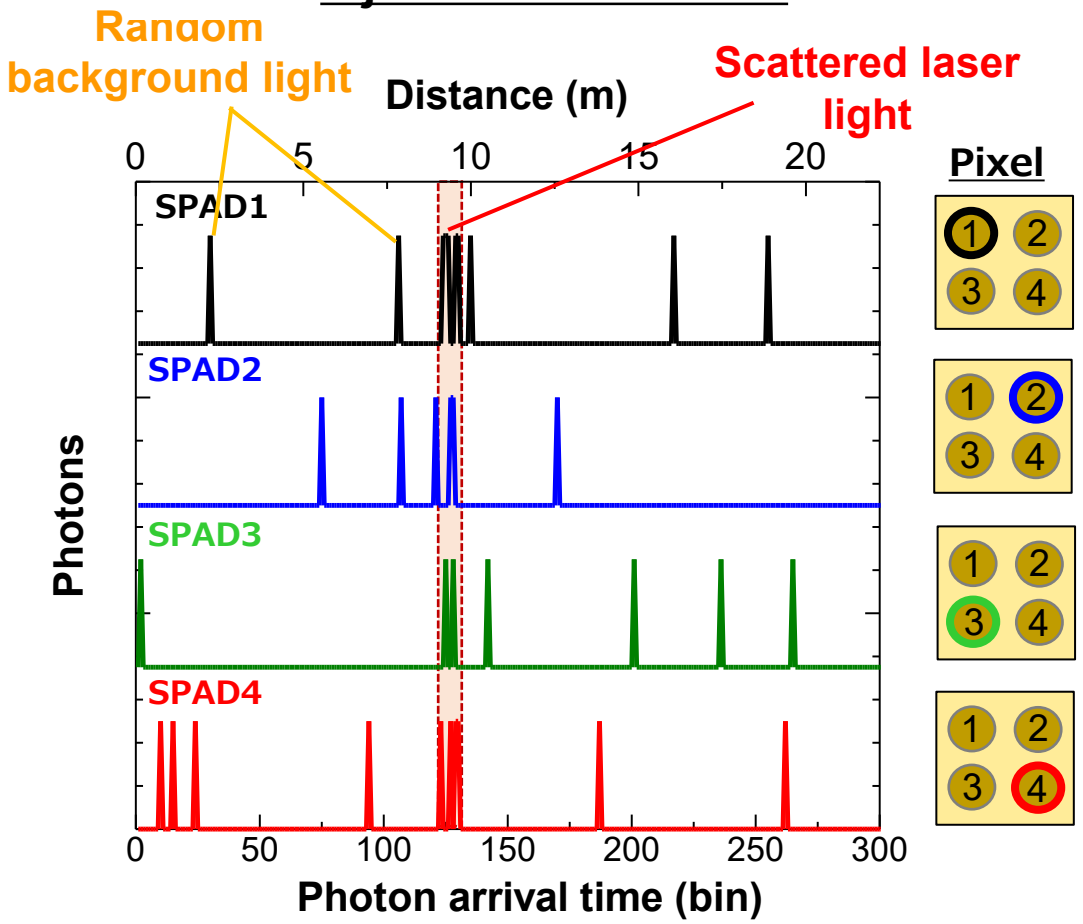
For realizing all-semiconductor chips, which are expected to be smaller and less expensive, and for use as a general sensor for vehicles

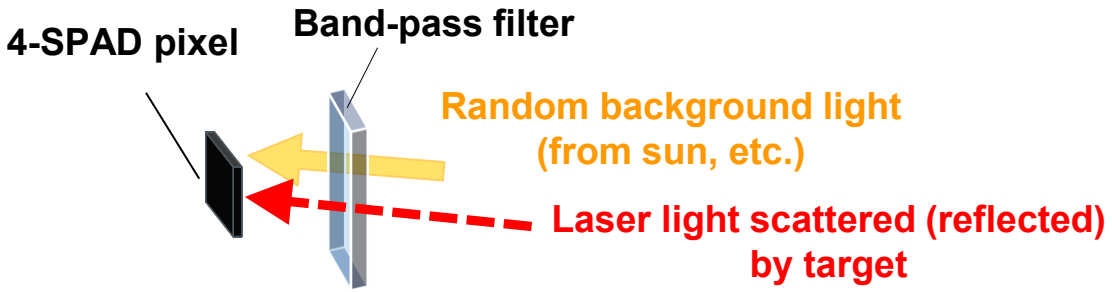
Development items (red text is progress in the current FY)

- **Basic evaluation of 2D SPAD array and PCSEL (utilizing mirrors)**
- **Fabrication and evaluation of PCSEL array and initial demonstration of non-mechanical LiDAR using PCSEL array and SPAD**
- **Prototyping of non-mechanical 3D PCSEL-LiDAR**
- **Theoretical verification of 200-300m ranging**

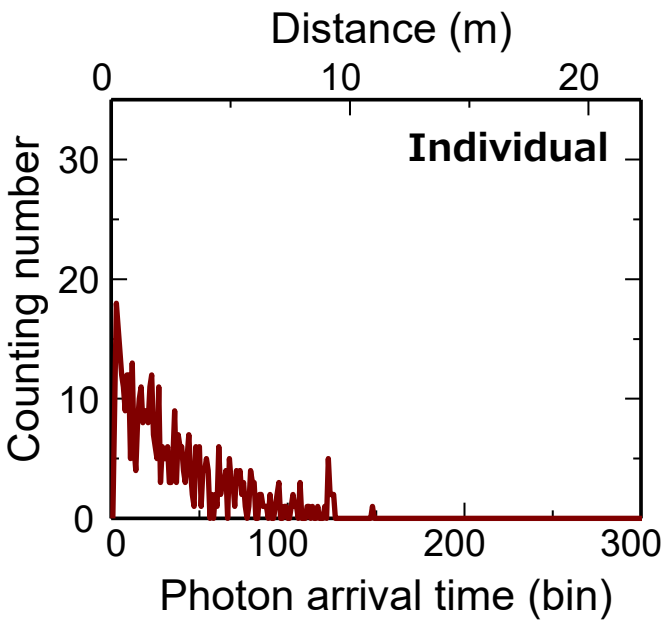
Elimination of Background Light* with SPADs

Example calculation of photons injected into a SPAD

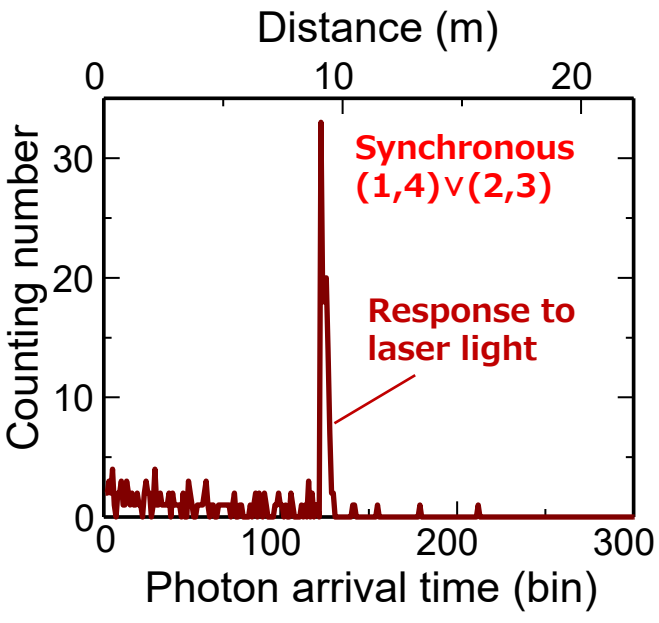




Histogram measurement



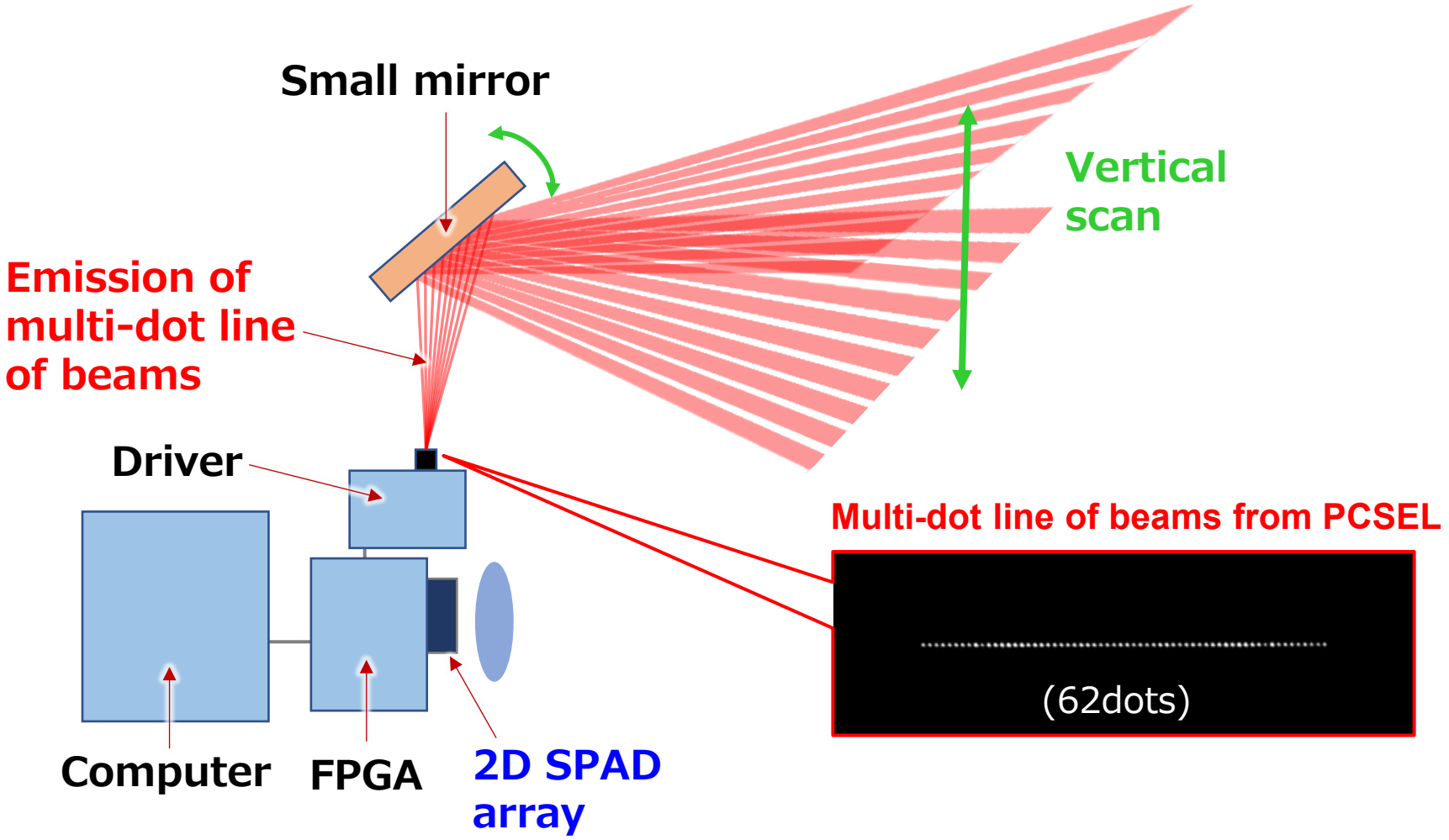
Histogram measurement



*Because SPADs are highly sensitive, they can even respond to weak background light (a single photon) that passes through the bandpass filter. To suppress the effects of such background light, a coincidence detection method that focuses on the temporal randomness of background light is employed. (By utilizing a narrow-band bandpass filter that takes advantage of the characteristics of the PCSEL, even more effective suppression can be achieved)

Initial Demonstration of 3D Ranging by SPAD and PCSEL*

(* As a first step, a line of beams is emitted by the PCSEL and is scanned by a small mirror)



Initial Demonstration of 3D Ranging by SPAD and PCSEL*

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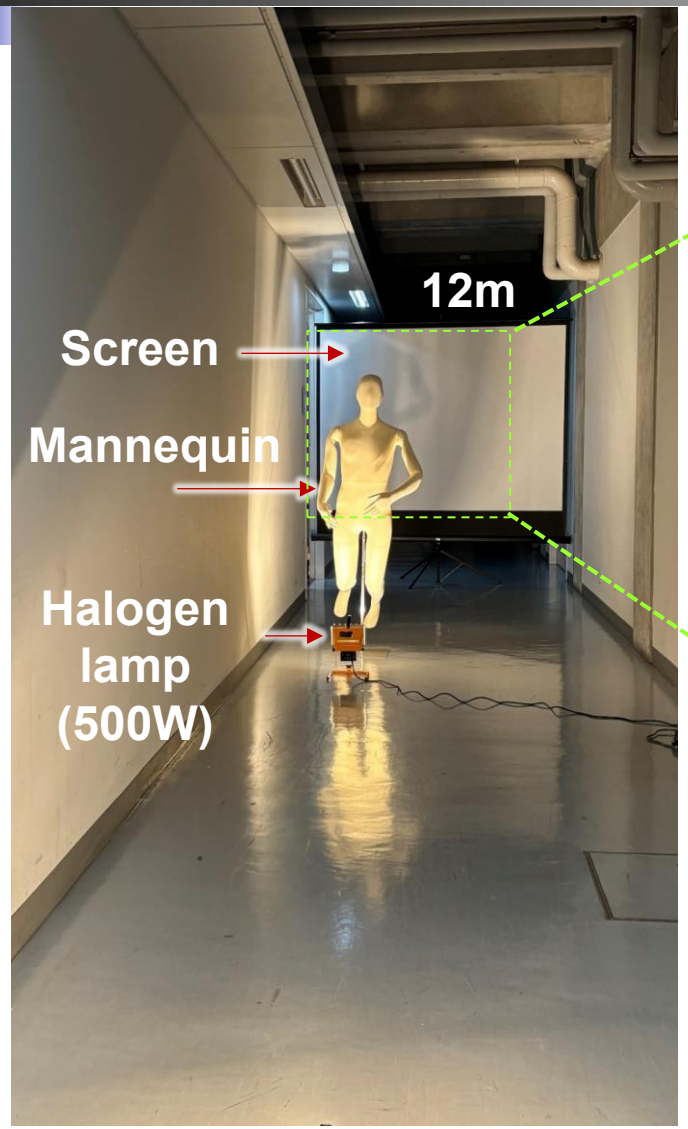
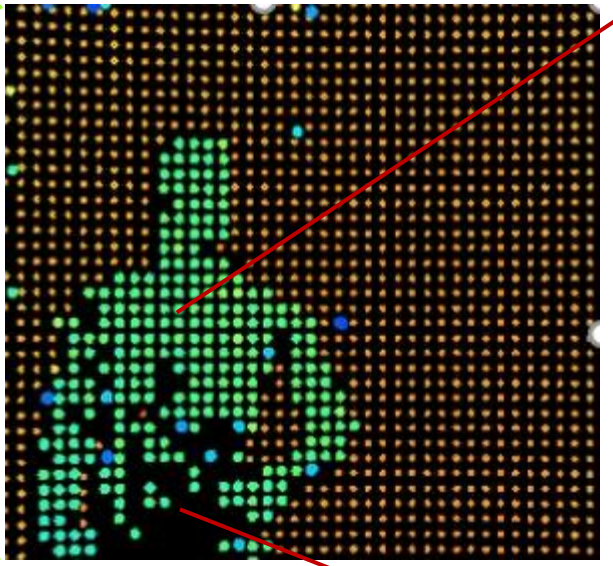
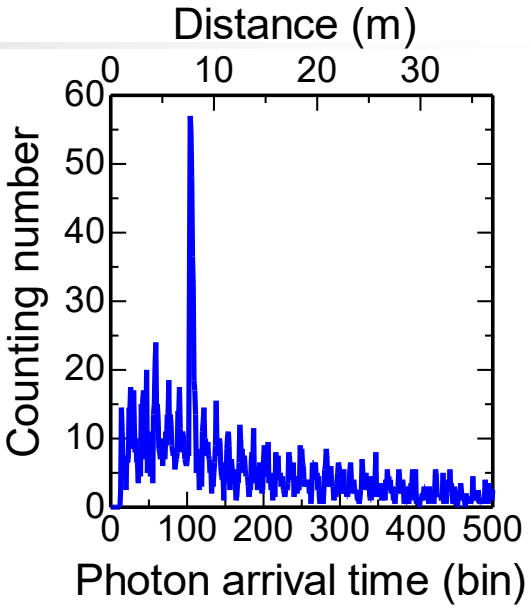
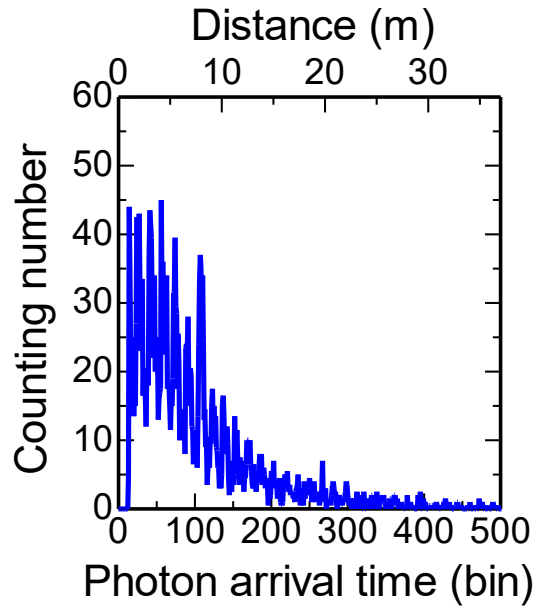


LiDAR (facing forward)

Individual SPAD measurements

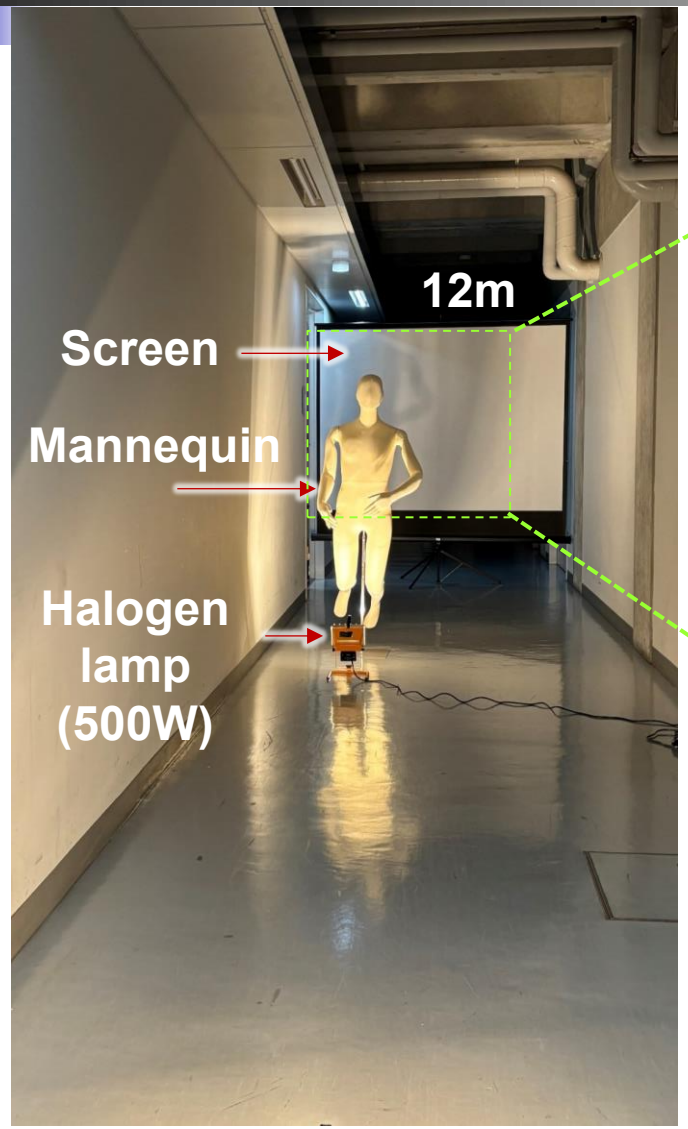






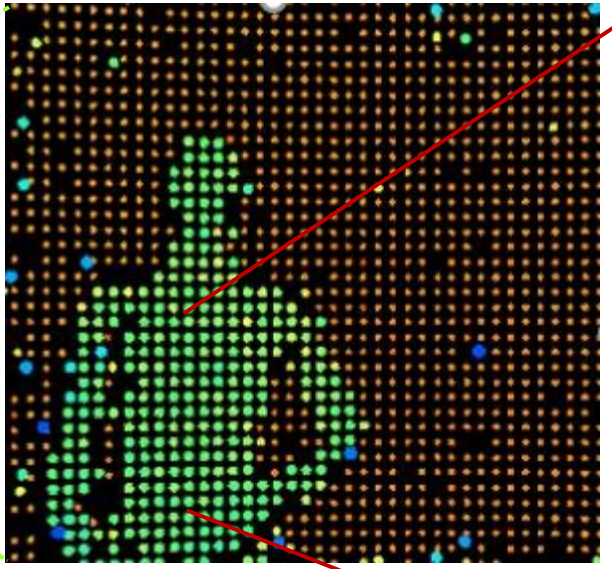
Initial Demonstration of 3D Ranging by SPAD and PCSEL*

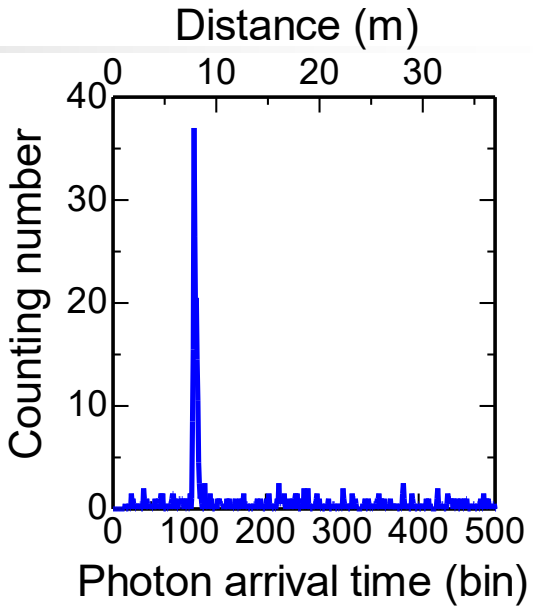
(* As a first step, a line of beams is emitted by the PCSEL and is scanned by a small mirror)

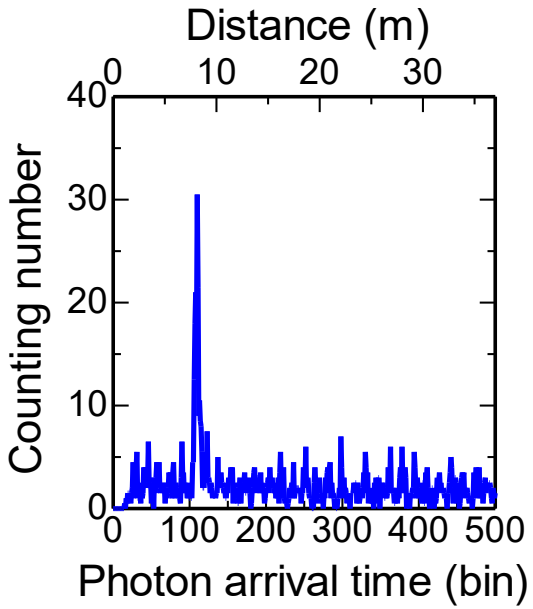


LiDAR (facing forward)

Synchronous SPAD measurements



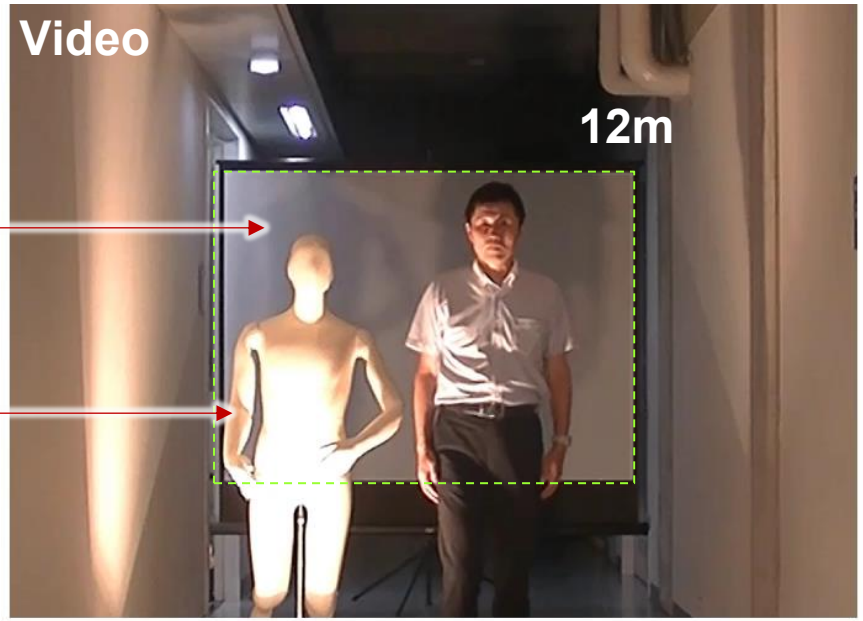


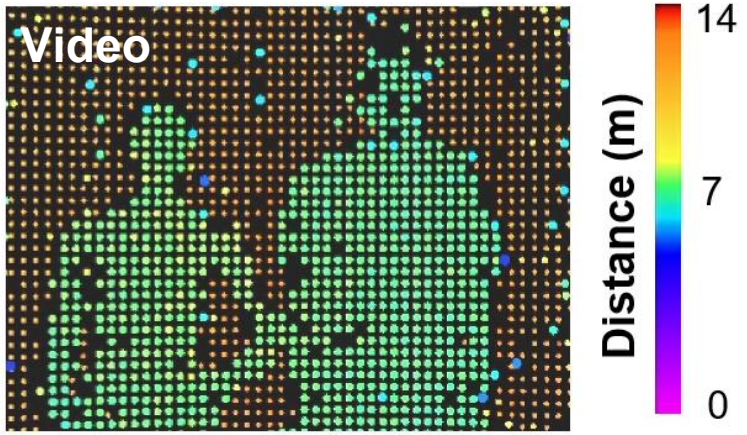


Synchronous measurements eliminate background light ⇒ Accurate ranging becomes possible

Initial Demonstration of 3D Ranging by SPAD and PCSEL*

(* As a first step, a line of beams is emitted by the PCSEL and is scanned by a small mirror)





Initial demonstration of 3D ranging by 2D SPAD array and PCSEL is successful

(Detection of poorly reflective black objects is also possible)

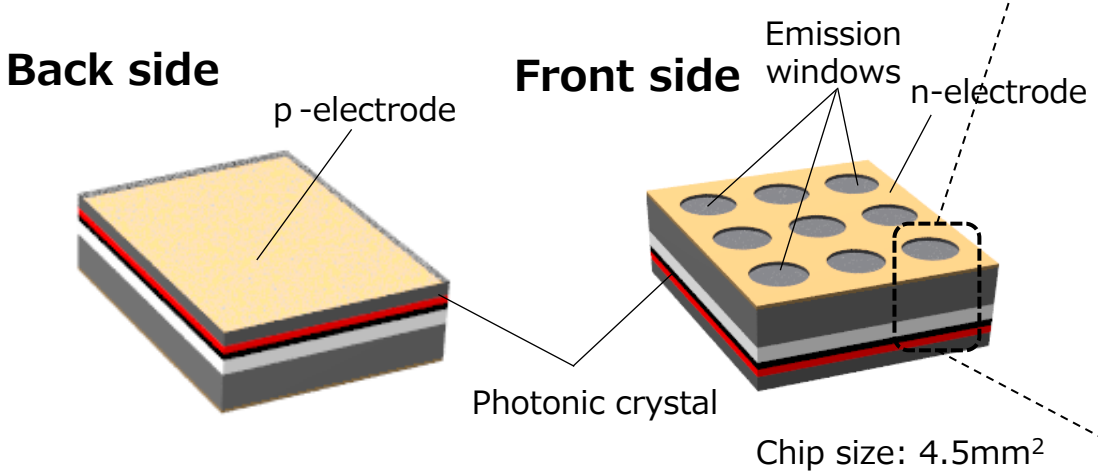
Next step: Expansion to all-semiconductor-chip 3D PCSEL-SPAD LiDAR

Design of PCSEL Array for All-semiconductor-chip LiDAR

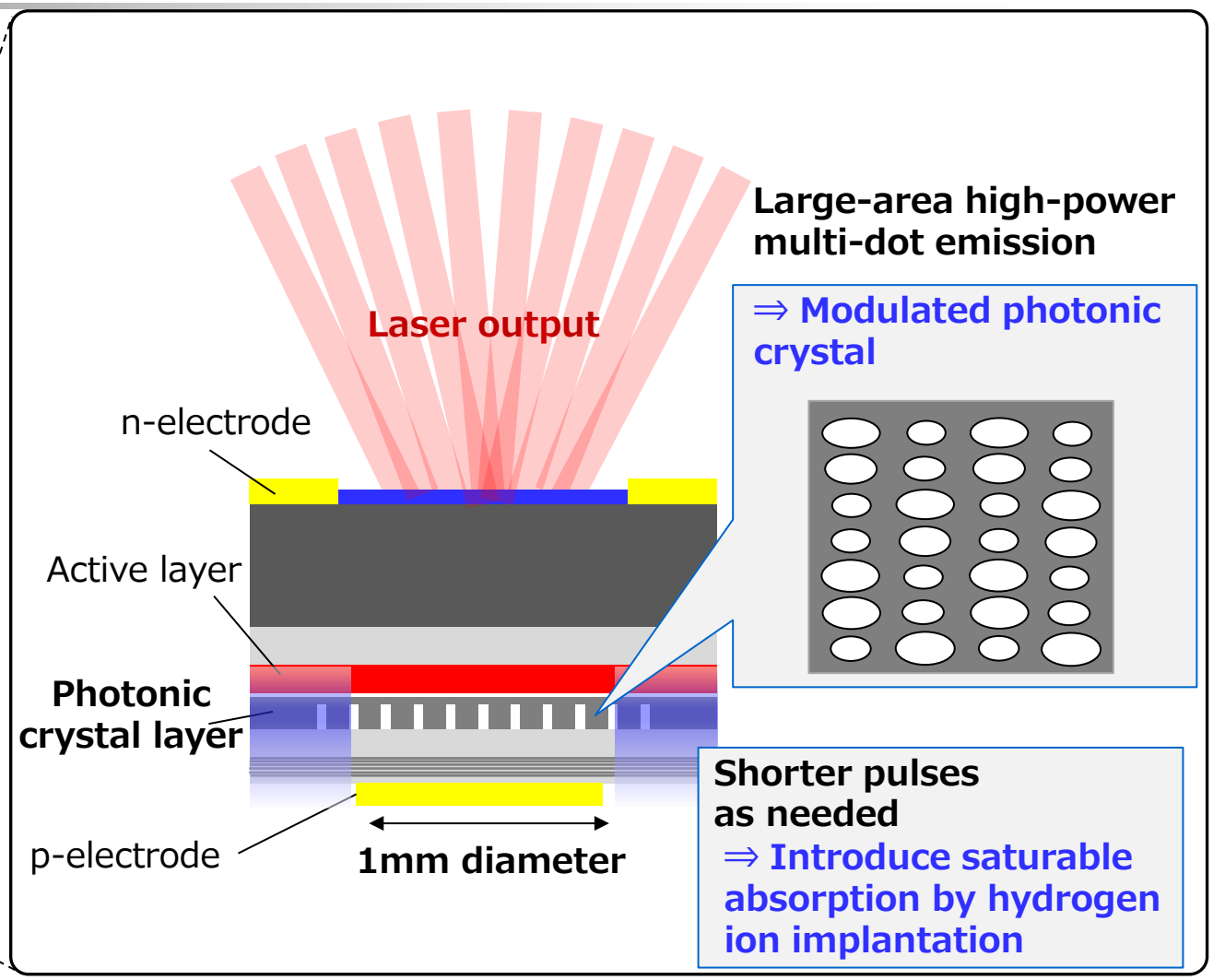
Goals

- Emission of over 3072 beams by multi-chip PCSELs
- Emission of ultra-short pulses for application to high-speed SPADs

One chip : 3×3 PCSEL array

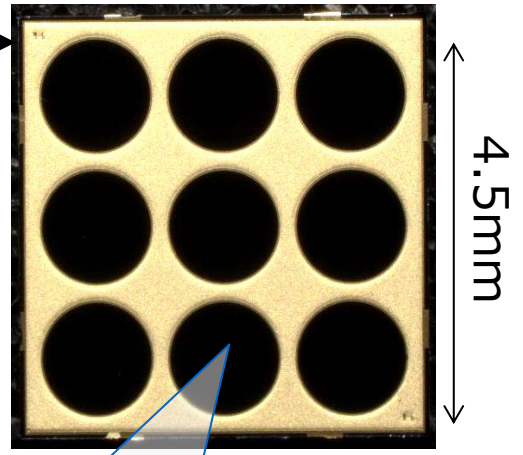


・Use a 3x3 array per chip to reduce electrode inductance
・Use a driving circuit to electrically scan beams of multiple chips

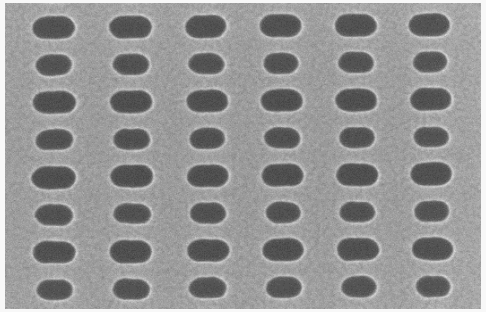


Fabrication of PCSEL and Driving Circuit

3x3 1-mm PCSELs per chip to achieve 400-dot belt-shaped beam pattern

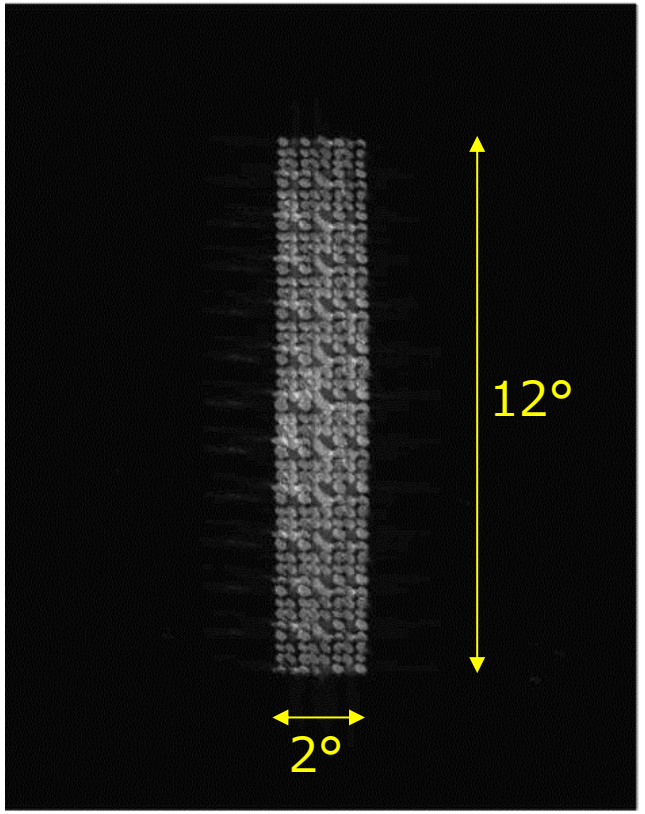


Modulated photonic crystal SEM image



Beam pattern

(emitted by a single array, at a far distance)

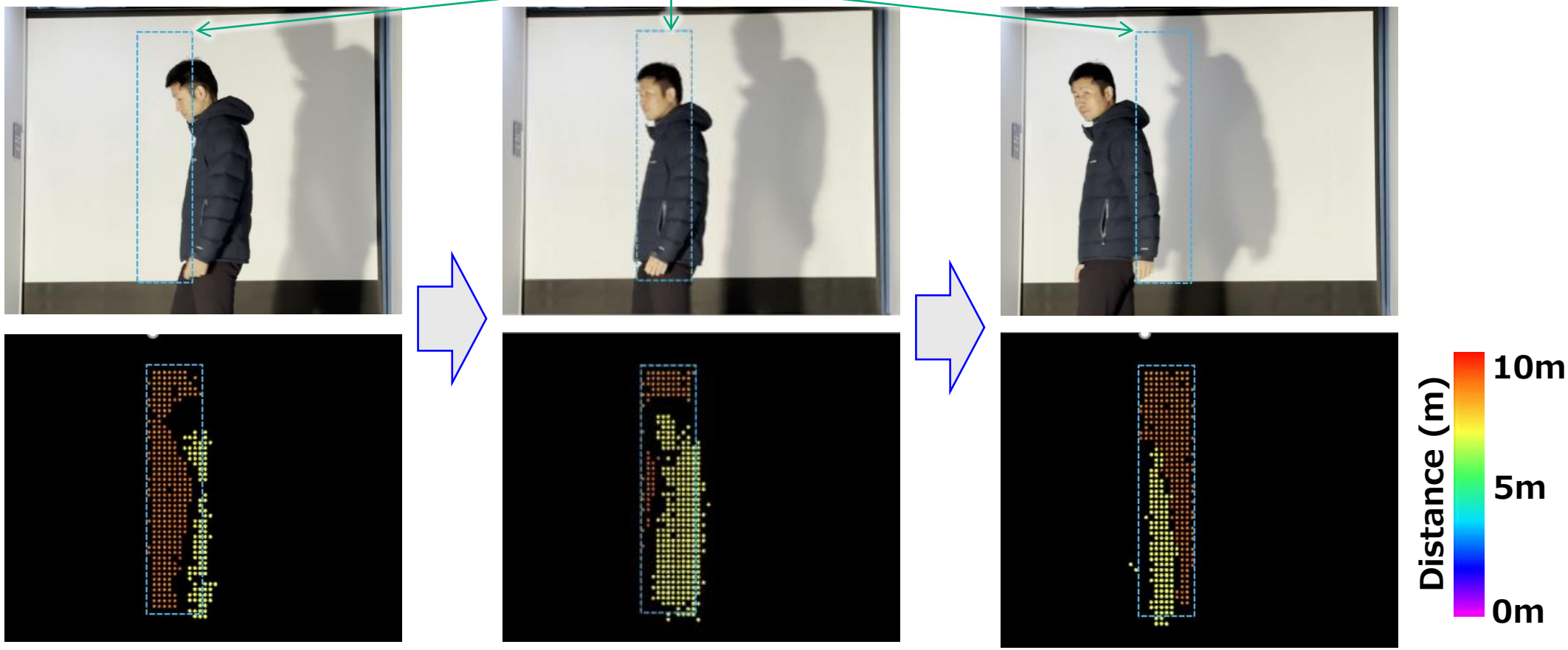


Initial Demonstration of Ranging by SPAD and PCSEL Array

Emission area of PCSEL array (2°x12°)

Camera images (snap shots from a video)

Ranging images (snap shots from a video)



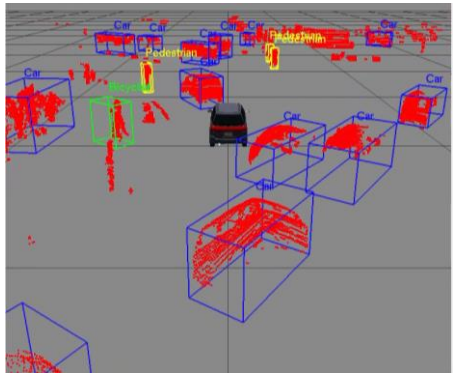
First success of ranging in a FOV of 2°x12° with all-semiconductor-chip PCSEL-LiDAR

Next step: Expand FOV by scanning beams of multiple PCSEL-array chips

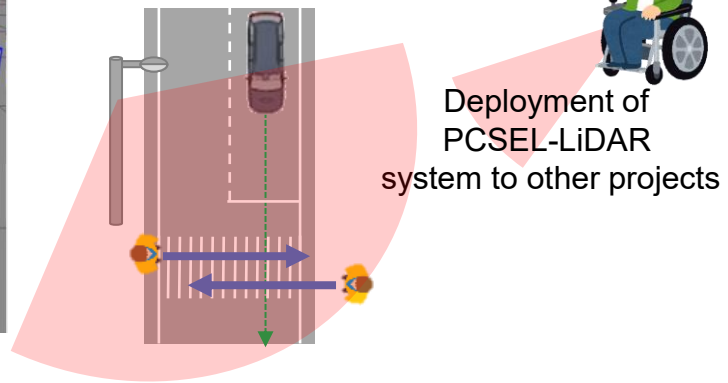
Development of Recognition Technology and Field-operational Test

*SIP Phase 2 (SIP-adus)

- Achievement of SIP Phase 2 (SIP-adus)*
  - Autonomous driving system
    - R&D of recognition technology using on-board sensors
  - Field-operational test using infrastructure
    - FOTs at Tokyo waterfront area
- R&D contents in this project
  - Development of recognition technology using LiDAR
    - Applying LiDAR to infrastructure sensor
      - Monitoring crossing pedestrians, etc.
    - Utilizing LiDAR as onboard sensor
      - Development of recognition technology and sensor evaluation
  - Field-operational test (FOT) using LiDAR
    - Deployment of PCSEL-LiDAR system to other projects
    - Testing of level 4-equivalent autonomous driving with cooperating infrastructure sensors



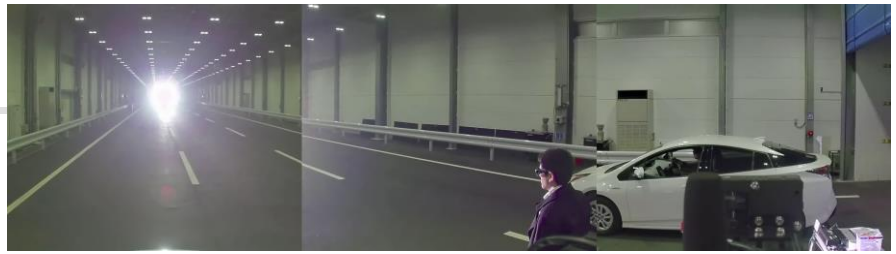
Development of recognition technology using LiDAR



Cooperate with infrastructure sensor and onboard sensor

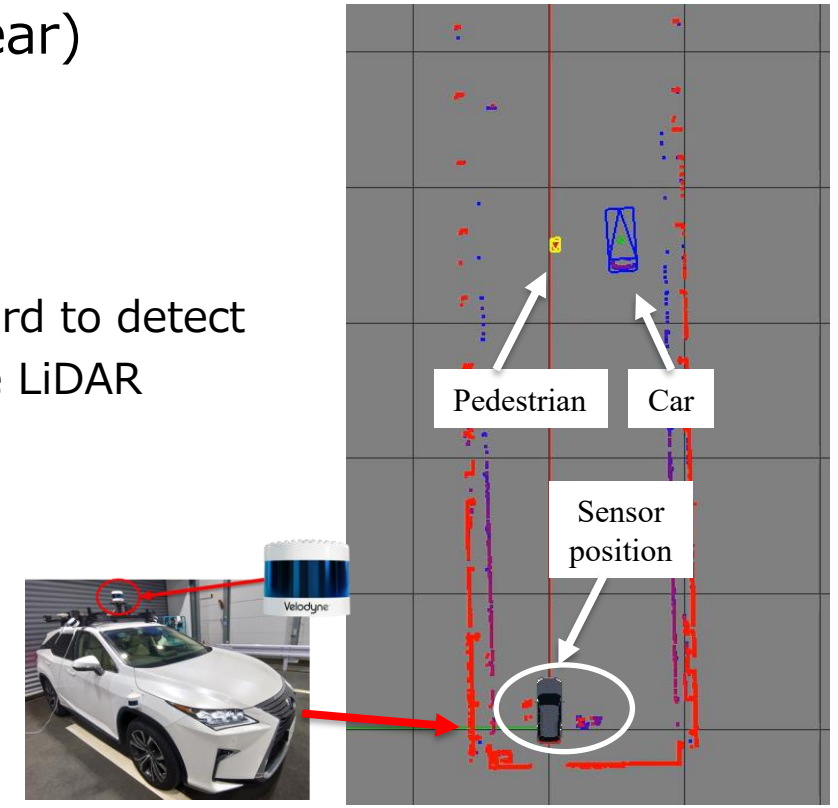
Deployment of PCSEL-LiDAR system to other projects

Activities for This Year



- **Detection experiments using LiDAR**
  - Under various weather conditions (was conducted last year)
    - JARI special environment testing center
    - Challenging conditions: backlight, rain, and fog
  - **Evaluation for low-reflectivity objects**
    - Observe the characteristics of low-reflectivity objects, which are hard to detect
      - Acquiring foundational data that is useful for developing future LiDAR
  - Acquiring real-world data by driving on public roads
    - In Tokyo, Ishikawa, Hokkaido, etc.
- **LiDAR-based recognition technology**
  - Status of development using deep learning (DNN*)
    - Evaluation detection performance using simulation data

    (Wide FOV PCSEL-LiDAR [Step 1] development planned for FY2025)
  - **Implementing the recognition model on small computing devices**

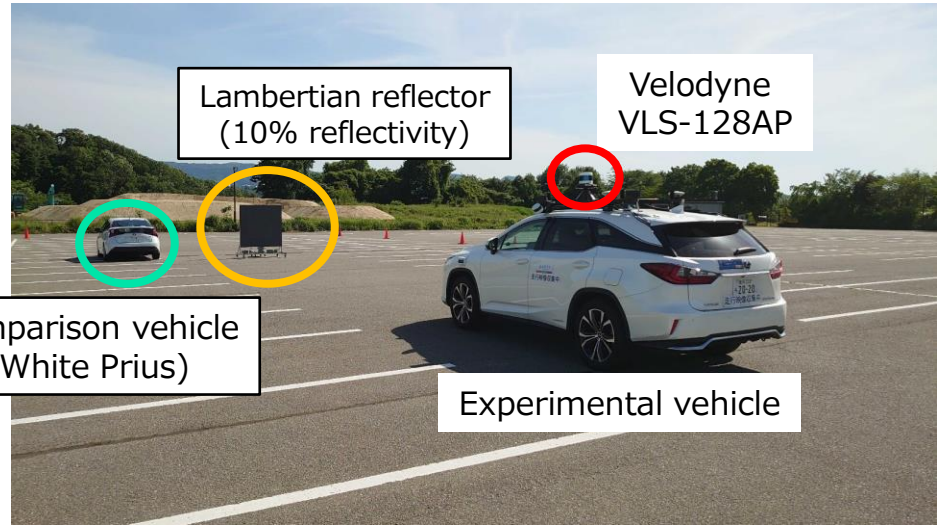


Examples of evaluations under various weather conditions in last year
(Backlight Impact Assessment)

* DNN: Deep Neural Network

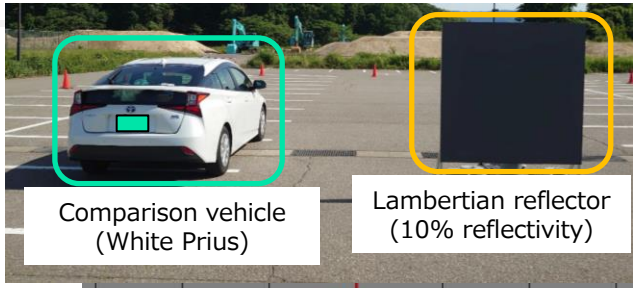
Overview of Evaluation of Maximum Detection Distance for Low-Reflectivity Objects

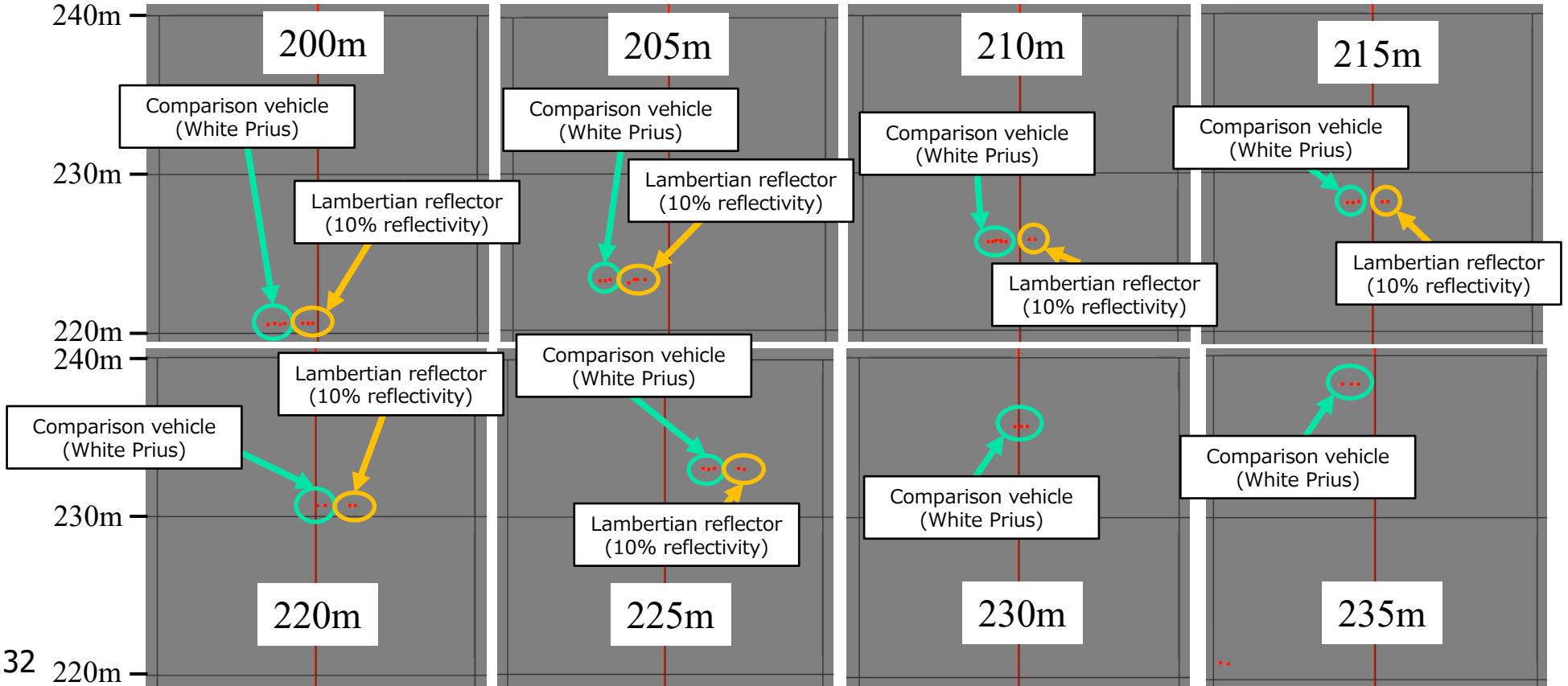
- **Experimental overview**
  - **Kanazawa university parking lot**
    - Weather : Sunny
  - **Measurement targets**
    - Lambertian reflector (10% reflectivity)
      - Difficult to measure due to low reflectivity
    - Comparison vehicle (White Prius)
      - Easier to measure due to high reflectivity (white)
  - **Evaluation method**
    - Position of the measurement targets were fixed.
    - LiDAR-equipped vehicle is driven backwards until the maximum detection distance was visually confirmed

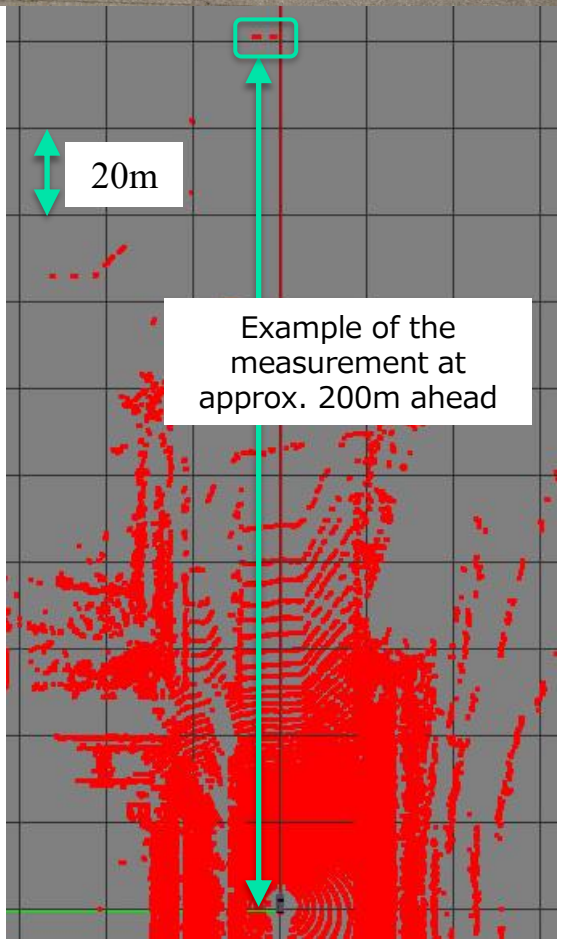


Results of Evaluation of Maximum Detection Distance for Low-Reflectivity Objects

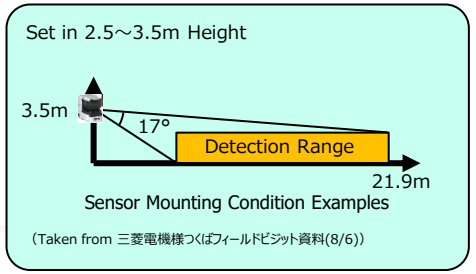
- **For the 10% reflectivity Lambertian reflector**
  - Detectable up to approx. 225m
- **For the comparison vehicle (White Prius)**
  - Detectable at all distances within the approx. 250m measurement range
  - At long distances, the low vertical resolution of LiDAR can prevent the laser from hitting the object, making detection impossible
    (Higher angular resolution is essential for long-range detection)



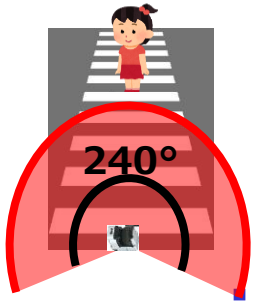




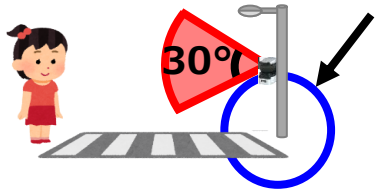
Developing a Virtual Environment for LiDAR Evaluation



- **Development of Wide-FOV LiDAR sensor model with the open-source simulator CARLA**
  - The laser is scanned in a zigzag pattern, while rotating to measure a wide area in 3D
- **Real-world use case simulation (informed by the site visit to the University of Tsukuba Consortium)**
  - Pedestrian observation on pedestrian walkway with Wide-FOV LiDAR mounted on a utility pole
    - Installed to acquire point clouds of pedestrians from 0m to 20m or more.



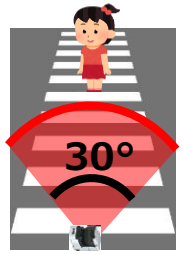
LiDAR【Step1】 FOV



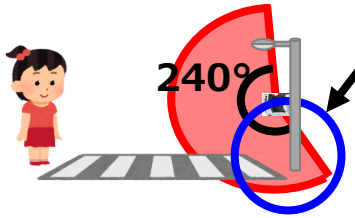
Impossible
to measure near and far simultaneously

Default Setting

Rotate 90° in roll



LiDAR【Step1】 FOV

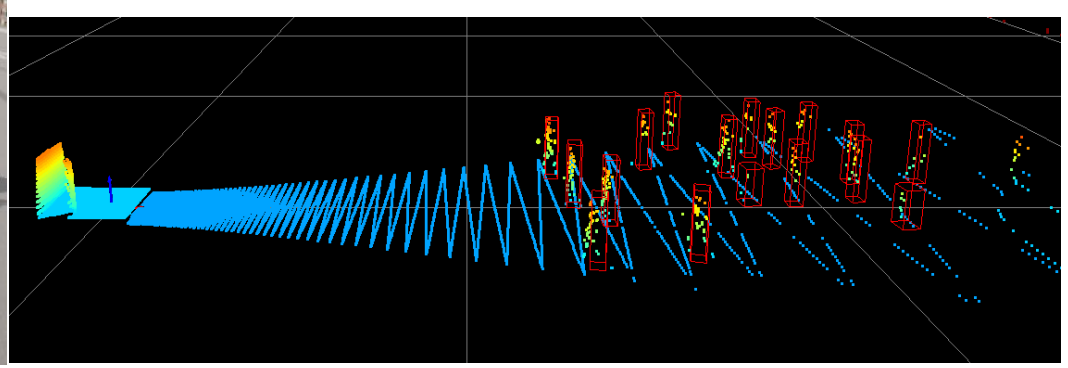


Possible
to measure near and far simultaneously

Setting for Infrastructure

Generating large amount of sensor data for implementing recognition models using deep learning

- Diverse data across multiple locations, crowd densities, and walking patterns (e.g., speed)
- Simulating point cloud noise of the real-world conditions



Height
Higher
Lower

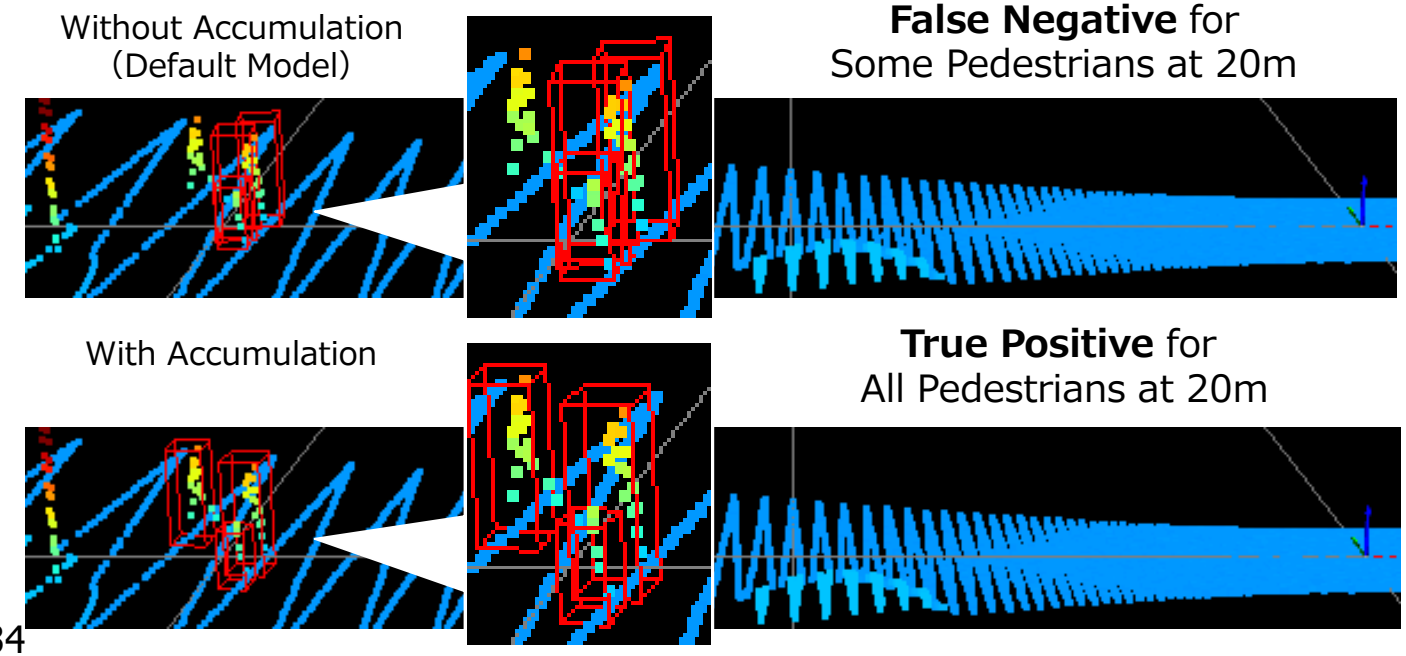
Example sensor data assuming the pedestrian walkway around Tsukuba Station
(left: camera image, right: LiDAR point cloud)

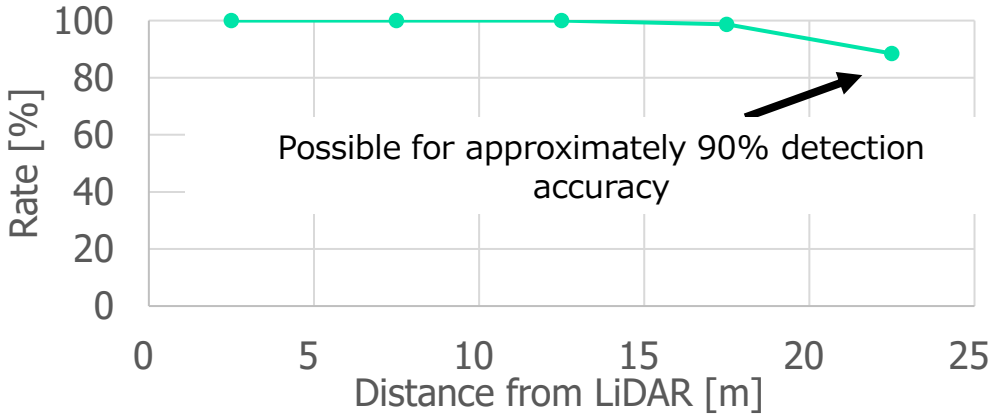
Conceptual model based on pedestrian walkway around Tsukuba Station ※

※ Further coordination is required for installation

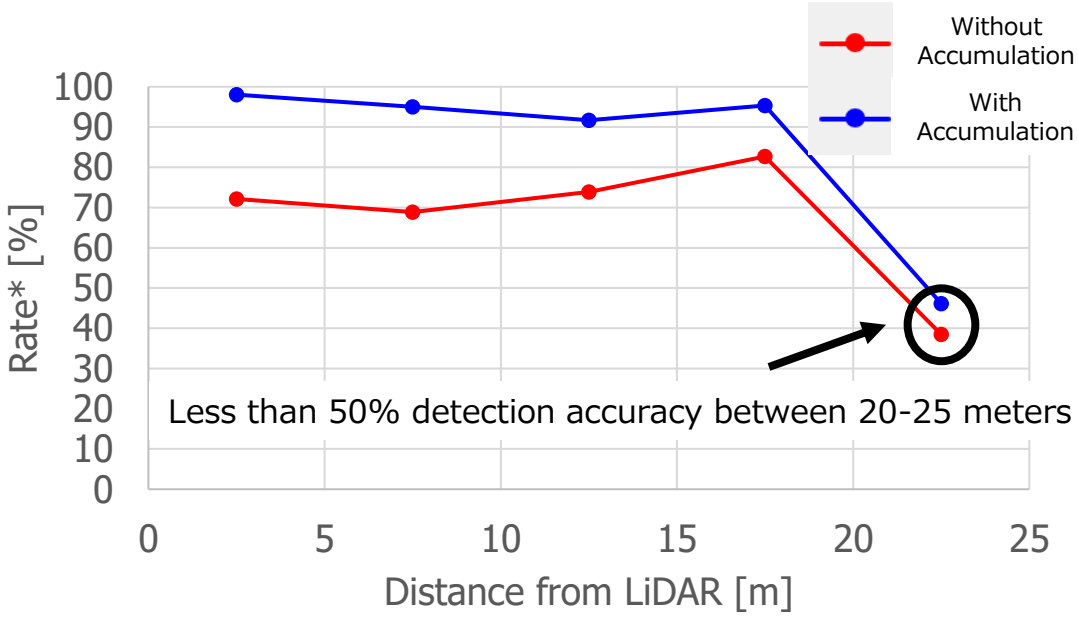
Development of a Recognition Model Aimed as Wide-FOV LiDAR Application

- **Key features of the Wide-FOV LiDAR Model**
  - Detecting pedestrian-sized objects up to the distance of approximately 25 meters
    - When the object class is not identified
- **Consideration of deep learning recognition models for object classification**
  - Development of the new recognition model that can accumulate the time-series point cloud features
    - Software-based improvement of point cloud resolution on pedestrian movement
    - Can detect from approximately 25m away and the continuous pedestrian identification is possible within 0-20m away



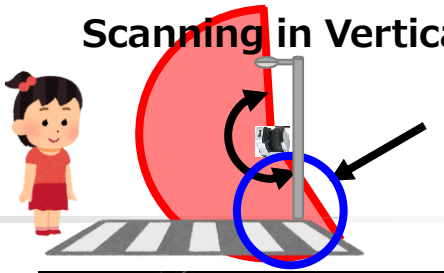


Observe 5 points or more in pedestrian areas



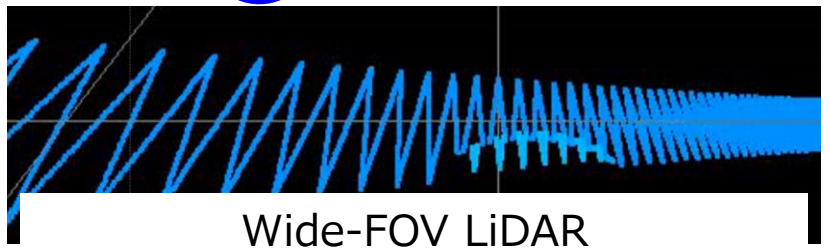
Detection accuracy for pedestrian category

Comparison with LiDAR from Other Manufacturers

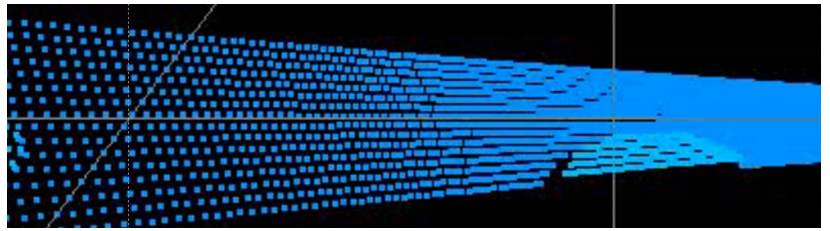


Rotate LiDAR in 90° in roll to observe point clouds in near and far simultaneously

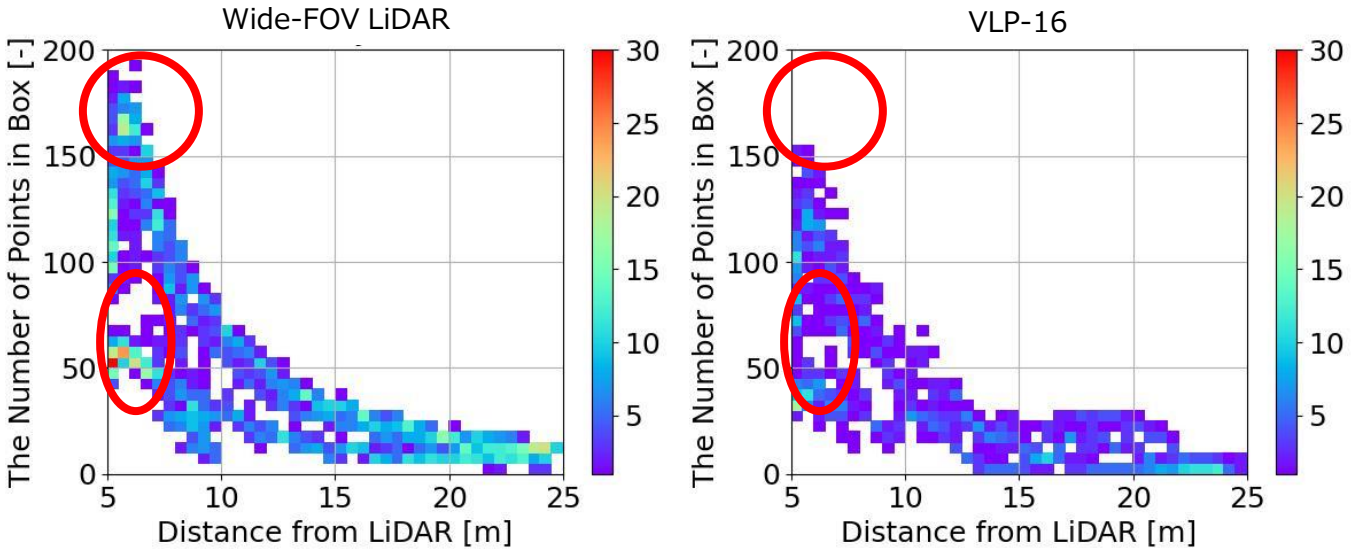
- **Comparison with LiDAR from other manufacturers**
  - Key features of the Wide-FOV LiDAR (Kyoto University, Hokuyo Automatic)
    - Scan over a wide area in a zigzag pattern (wedge-shaped scanning pattern)
    - Large number of point clouds is observable at close range
  - Key features of the third-party LiDAR (Velodyne VLP-16)
    - Point clouds are obtained by rotating layered lasers (layered scan pattern)
    - If pedestrians at long distances are between layers, point cloud acquisition is not possible.
- **Effective scanning pattern for small object recognition including pedestrians**



Wide-FOV LiDAR
(wedge-shaped scanning pattern)

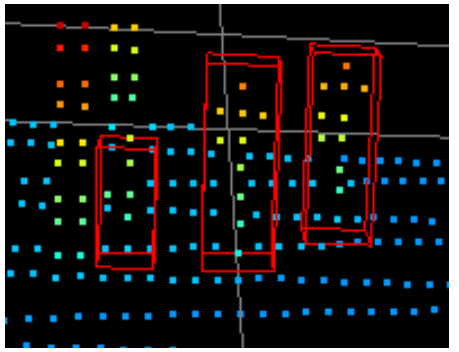


VLP-16 (layered scanning pattern)



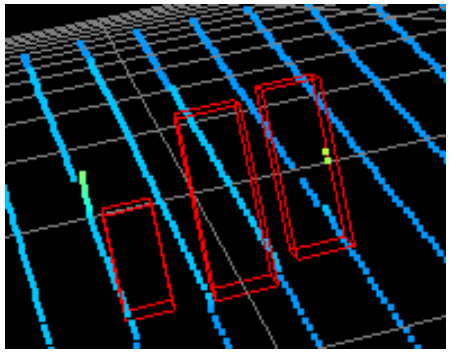
The Number of point clouds for pedestrian per distance from LiDAR

□ : Pedestrian



Wide-FOV LiDAR

Limited but possible for point cloud acquisition



VLP-16

No point cloud acquisition, when targets at long range fall between layers

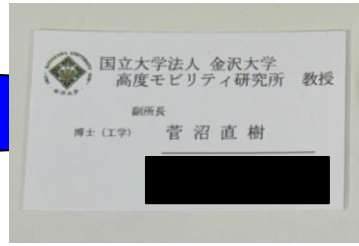
Consideration into Deploying Recognition Models on Compact Computing Devices

- **Miniaturization of computing devices for deployment as infrastructure sensors, etc. are also under consideration**
  - Preparation of small devices
    - Implementation on small devices (e.g., Anvil, Orin, and Raspberry Pi) are underway.
  - Consideration of lightweight recognition models
    - Implementation of real-time operation by using TensorRT* is underway.

* A Software Development Kit enables the acceleration of deep learning models by optimizing GPU utilization and reducing the model sizes.

Current Status

Business Card



Ultra-compact

AI Chip Add-on Board: Approx. ¥20,000
(Cost reduction possible with mass production)

Future

- Anvil @ConnectTech
  (Equipped with NVIDIA chip)
  - Embedded computer
- W x D x H =
  205mm x 136mm x 98mm
  - Area equivalent to approx. 5 business cards

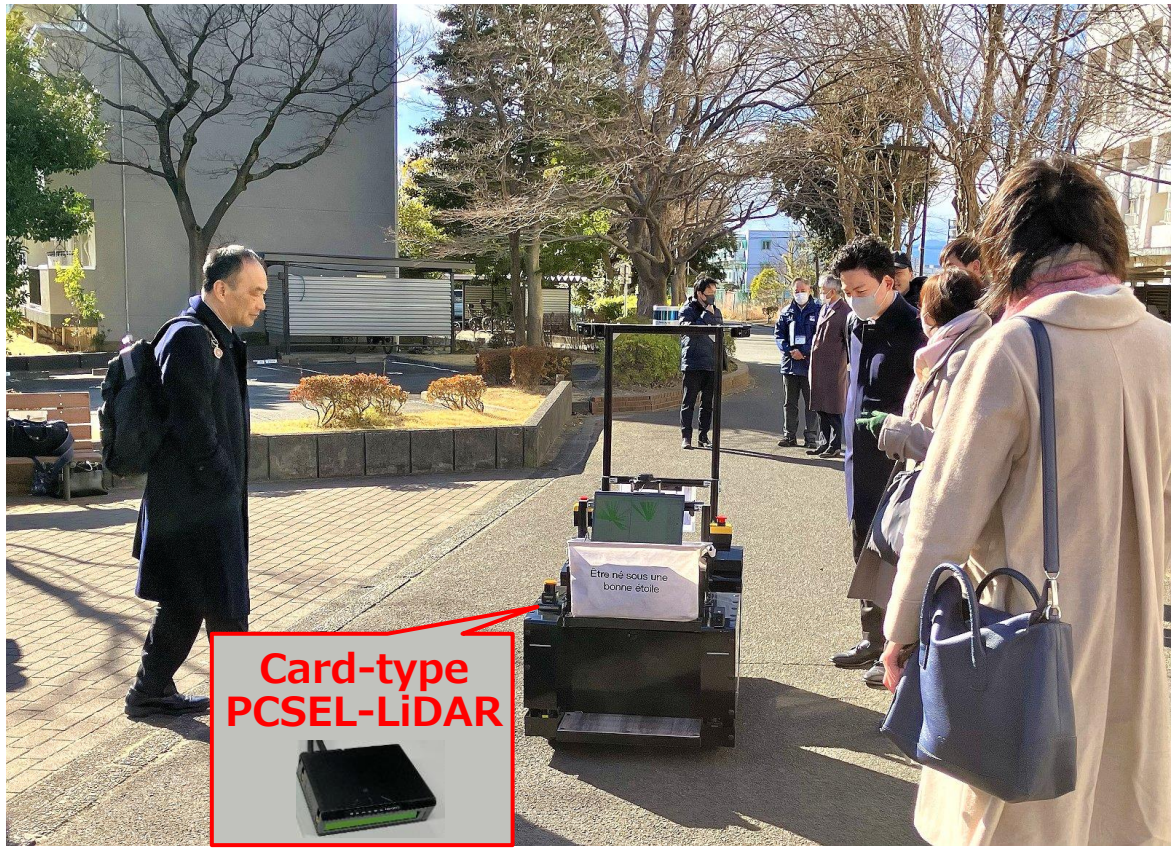
- Orin @NVIDIA
  - Compact development kit
- W x D x H =
  110mm x 110mm x 71.65mm
  - Area equivalent to approx. 2.5 business cards

- Raspberry Pi
  (Equipped with AI chip)
  - For IoT devices
- W x D x H =
  85mm × 56mm × 17mm
  - Area equivalent to approx. 1 business card

Efforts Toward Social Implementation (p.38~p.41)

Collaboration with SIP Inclusion Using Card-type PCSEL-LIDAR

Demonstration in Tama New Town (2025/2/19)

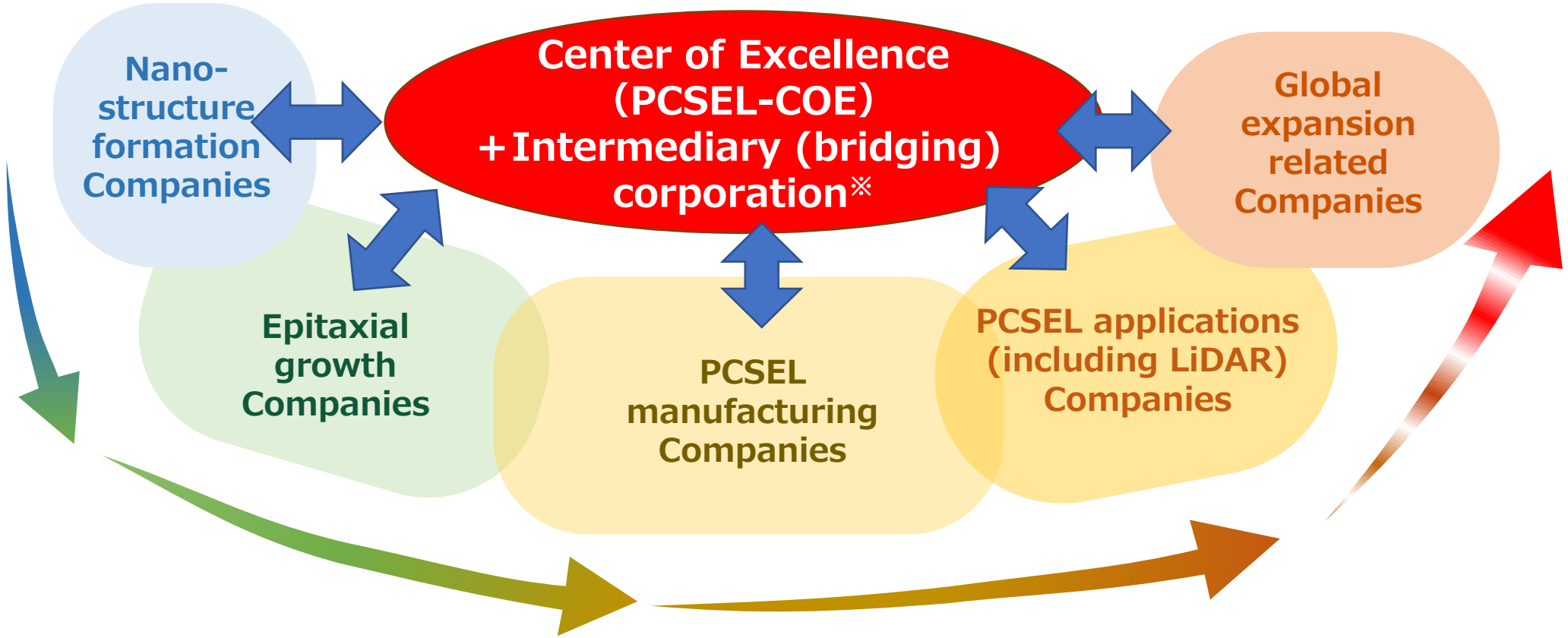


Comments from participants :

- **“With little space available, its compactness is very helpful.”**
- **“LiDAR that is not easily affected by the sun, especially at sunset, nor light and dark is vital.”**
- **“Its small size is appealing. I would love to give it a try.”**

Social Implementation Structure in STEPS 1 and 2

An ecosystem has been created in which companies for mass production of nanostructures, for semiconductor crystal growth, and for device manufacturing, user companies, and even overseas companies can work together in various ways, and a system has been established in which social implementations from many companies are expected



※『Kyoto University PCSEL Research Center』, a general incorporated association, was established on 2 December 2024 as an intermediary (bridging) corporation between the University and companies to support companies' social implementation activities

(Its roles: R&D on applications and social implementations of PCSELs, networking, promotional activities, supplying components, lending equipment, technical support and guidance, personnel training, etc.)

New Corporation『Kyoto University PCSEL Research Center』

Before

PCSEL CoE for accelerating development of PCSELs

Kyoto University
(previous organization)

PCSEL R&D Center (Light & Quantum CoE)

Close collab.

- Propose new concepts
- R&D of new technology
- Lend samples (MTA)
- Provide intel

- Various large-scale collaborative R&D projects
- But university is not suited to business ventures
- Growing beyond the bounds of a university

New corporation『Kyoto University PCSEL Research Center』

For the purpose of further accelerating the proliferation and social implementation of PCSELs

Separated from the university, so it also can serve as a business base

An independent bridging corporation, inspired by the style of Fraunhofer/IMEC

- R&D (applications, social implementations)
- Networking, proliferation
- Sample provision
- Equipment lending, tech support
- Personnel training

Can serve in various ways to contribute to the creation of a super-smart society

Measures to prevent outflow of government-sponsored results, ensure Japanese advantage, and contribute to economic security

Enable an ecosystem for mass production

Strengthen collaboration with various companies, construct bridges between companies, serve as a core of national projects, etc.

Reference material

Bridging Corporation: General Incorporated Association Establishment of「Kyoto University PCSEL Research Center」

Established on 2 December 2024 (Press release on 6 February 2025 / Posted on home page)

京都大学記者クラブ加盟各社 御中
在阪民放四社京都支局協議会加盟各社　御中

「一般社団法人 京都大学フォトニック結晶レーザー研究所」設立に関する記者レクのご案内について

京都大学は、フォトニック結晶レーザー（PCSEL : Photonic-Crystal Surface-Emitting Laser）研究において世界をリードしています。PCSEL は、フォトニック結晶（屈折率が異なる物質を光の波長と同程度の間隔で並べたナノ周期構造の人工結晶）を活用した半導体レーザーで、高出力・高ビーム品質動作が可能で、かつ様々な機能性をもつことを特長としています。センシング、レーザー加工、光通信、モバイル、医療・生命科学、宇宙（衛星間通信や宇宙計測、宇宙セイル推進等)、さらには極端紫外線（EUV）発生、核融合など、様々な分野への応用が期待されます。

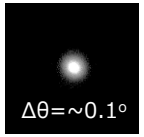
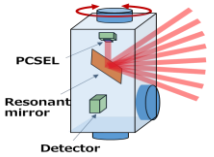
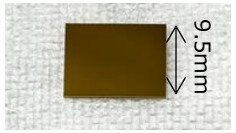
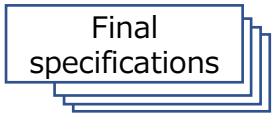
Also reported on Asahi Shimbun, Nihon Keizai Shimbun, Yomiuri Shimbun, Kansai TV News, etc.

Schedule･Level of Achievement (p.43~p.46)

Progress Schedule

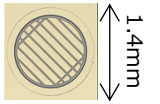
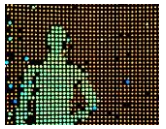
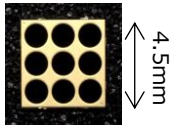
Working Items			2023				2024				2025				2026				2027			
			Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
① Development of 3D PCSEL-LiDAR system	STEP1.「Development of wide-FOV 3D PCSEL-LiDAR」	Improvement and fabrication of vertical-emission-type PCSEL																				
		Design and prototyping of wide-FOV 3D PCSEL-LiDAR																				
	STEP2.「Development of non-mechanical 3D PCSEL-LiDAR」	Design, fabrication, and deepening of multi-dot emission-type PCSEL																				
		Procurement of SPADs and development of a control unit																				
		Design and development of PCSEL driving circuit																				
		Design and prototyping of non-mechanical 3D PCSEL-LiDAR																				
Additional item	Development of card-type LiDAR	Prototyping of card-type wide-FOV 2D PCSEL-LiDAR																				
② Development of recognition technology and conducting field-operational test	A.「Development of recognition technology using LiDAR」	Survey of the latest recognition algorithms																				
		Building a virtual sensing environment																				
		Development of recognition algorithms with small-scale computing devices																				
		Improvement of recognition models for expanding detection range																				
		Construction of recognition models cooperated with infrastructure and on-vehicle sensors																				
	B.「Field-operational test (FOT) using LiDAR」	Evaluation of existing LiDAR sensor																				
		Public road experiment with existing LiDAR sensor																				
		FOT with wide-FOV LiDAR as infrastructure sensor																				
		FOT with wide-FOV LiDAR as on-vehicle sensor																				
		Construction of test vehicles equipped with multiple PCSEL-LiDAR, etc.																				
		FOT cooperated with infrastructure sensors and on-vehicle sensors																				

FY2024 R&D Achievement Status (Kyoto University)

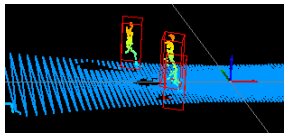
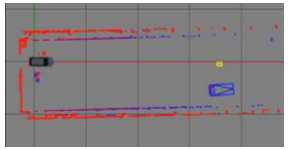
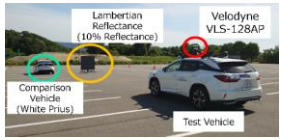
Implemented Items			Status of Development Items	Illustration	Completion Rate・Timeline
Development of 3D PCSEL-LiDAR system	**STEP1 : Development of wide-FOV 3D PCSEL-LiDAR**	Advancement of vertical-emission-type PCSEL	Completed: Vertical-emission-type PCSEL with ideal Gaussian beam Remaining: None		●
		Determining specifications for wide-FOV PCSEL-LiDAR	Completed: Basic specification of FOV, range, resolution, narrow bandpass filter, etc. Remaining: None		●
		Design・prototyping of wide-FOV PCSEL-LiDAR	Completed: Prototyping of light projector and receiver, mirrors, rotation system, circuitry, etc., evaluation of each component, and feedback Remaining: None		●
		Design・fabrication of narrow-bandpass filter to cut out background light	Completed: Design and prototyping of narrow bandpass filter (1/4 narrower than typical ones) leveraging PCSEL characteristics Remaining: None (although improvements will continue to be made)		●
	【Additional item】 Development of card-type PCSEL-LiDAR	Determining specifications for card-type PCSEL-LiDAR	Completed: Specification of FOV, range, resolution, weight, power consumption, operating temperature range, etc. Remaining: None		●
		Prototyping of card-type PCSEL-LiDAR	Completed: Fabrication, procurement, and evaluation of light projector and receiver, mirrors, rotation system, circuitry, etc., and introduction and assembly of narrow-bandpass filter Remaining: None		●

FY2024 R&D Achievement Status (Kyoto University)

Continued from previous page

Implemented Items			Status of Development Items	Illustration	Completion Rate・Timeline
	STEP2 : Development of non-mechanical 3D PCSEL-LiDAR	Fabrication・evaluation of single multi-dot-emission-type PCSEL	Completed: Design, fabrication, and evaluation of single PCSEL Remaining: None		●
		Procurement・initial evaluation of 2D SPAD array	Completed: Procurement of 2D SPAD array and initial evaluation of 3D ranging with PCSEL Remaining: None (although detailed evaluations will continue to be made)		●
		Development of PCSEL array (and combination with SPAD array)	Completed: Design, prototyping, implementation, and evaluation of PCSEL array Remaining: None (also started work on the later item of combining the PCSEL and SPAD arrays)		●

FY2024 R&D Achievement Status (Kanazawa University)

Implemented Items			Status of Development Items	Illustration	Completion Rate･Timeline
Development of infrastructure and onboard sensor systems that utilize compact LiDAR technology to understand the actual situations of streets in living areas and busy districts	**Development of recognition technology using LiDAR**	Construction of a sensing environment using a virtual platform	Completed : Construction of a LiDAR evaluation virtual platform using CARLA and development of the wide-FOV LiDAR sensor model【Step1】 Remaining : None		
		Evaluation and design of recognition algorithms	Completed: Implementation of PointPillars as a fundamental recognition model using deep learning, and conducted operational tests and quantitative evaluation with real data and in a virtual platform Remaining : None		
	Implementation of demonstration using LiDAR	Conducting evaluation tests for LiDAR sensor data	Completed: Measurement of LiDAR measurement characteristics in special environments such as rain, fog, and at long distances Remaining : None		
		Preparation for a demonstration using PCSEL-LiDAR as an on-vehicle sensor	Completed: Conducted sensor data acquisition tests for recognition evaluation using existing LiDAR in Kanazawa city, Ishikawa prefecture, and the coastal Areas of Tokyo Remaining : None (Planned to continue in the next FY)		
		Preparation for a demonstration using PCSEL-LiDAR as an infrastructure sensor	Completed: Generation of simulation data based on real use cases from field visits to the Tsukuba University Consortium Remaining: None		

Publications･Global Outreach (p.48~p.52)

Global Outreach

International conferences (plenaries, key notes, invited talks)

- S. Noda, "**[Invited]** A new light source: Photonic-crystal surface-emitting laser (PCSEL) - On the numerous possibilities for realizing a smart society -," The Optics and Photonics International Congress (OPIC) 2024/ BFSS, 2024/4/24.
- T. Inoue, S. Noda, et al., "**[Invited]** Short-pulse high-power photonic-crystal surface-emitting lasers," The Optics and Photonics International Congress (OPIC) 2024/ ALPS, 2024/4/23.
- M. Yoshida, S. Noda, et al., "**[Invited]** Kilowatt-class high-peak-power pulsed operation of large-area photonic-crystal surface-emitting lasers," The Conference on Lasers and Electro-Optics (CLEO) 2024, 2024/5/7.
- T. Inoue, S. Noda, et al., "**[Invited]** Temporal control of photonic-crystal surface-emitting lasers," Compound Semiconductor Week (CSW) 2024, 2024/6/5.
- S. Noda, "**[Invited]** Photonic-crystal surface-emitting lasers (PCSELs) for paradigm shift towards smart society (Society 5.0)," IEICE Distinguished Lecturer's Webinar, 2024/6/25.
- S. Noda, "**[Tutorial]** Photonic-crystal surface-emitting lasers - Tutorial," The 29th Opto-Electronics and Communications Conference (OECC 2024), 2024/7/3.
- S. Noda, "**[Invited]** Ultra-large area coherent lasing action through Hermitian/non-Hermitian control in photonic crystals," The 14th Conference on Metamaterials, Photonic Crystals and Plasmonics (META 2024), 2024/7/17.
- S. Noda, "**[Invited]** High-brightness scalable continuous-wave single-mode photonic-crystal laser (PCSEL)," The 16th Pacific Rim Conference on Lasers and Electro-Optics (CLEO-PR 2024), 2024/8/9.
- K. Aoki, S. Noda, et al., "**[Invited]** High-power CW/pulsed operations of 1.55-μm-wavelength photonic-crystal surface-emitting lasers," IEEE 29th International Semiconductor Laser Conference (ISLC 2024), 2024/9/29-10/2.
- S. Noda, "**[Plenary]** High-power, high-beam-quality, high-functionality photonic-crystal surface-emitting lasers－For paradigm shift towards realizing smart society," Advanced Solid State Lasers Conference (ASSL) 2024, 2024/10/20-24.
- S. Noda, "**[Keynote]** Recent Progress in High-Brightness and High-Functionality Photonic-Crystal Surface-Emitting Lasers," International Workshop on PCSELs 2024, 2024/11/7-8.
- S. Noda, "**[Tutorial]** Photonic-crystal surface-emitting lasers," The IEEE Photonics Conference (IPC) 2024, 2024/11/10-14.

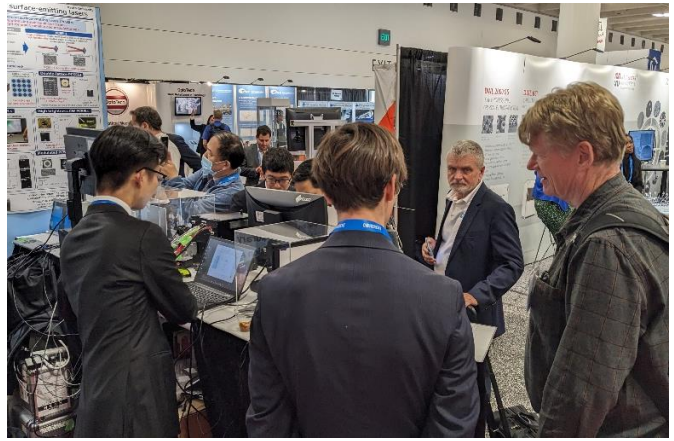
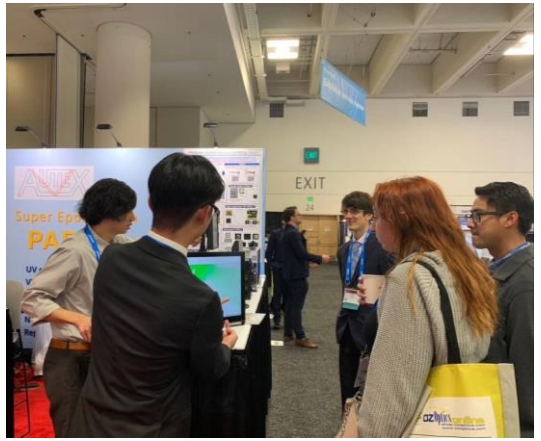
Global Outreach

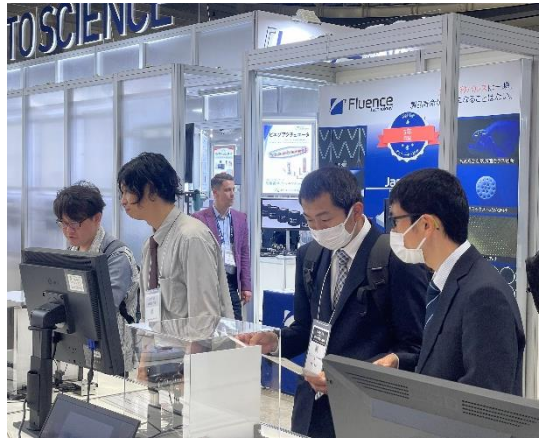
Seminars, tutorials (In Japan, Japanese presentation only)

- 野田進, “**[招待]** 超スマート社会(Society 5.0)実現に向けたフォトニック結晶レーザー技術の進展”, 第27回 KECテクノフォーラム, 2024年1月16日.
- 野田進, “**[チュートリアル]** フォトニック結晶レーザー：その基礎から最新動向まで”, 電子情報通信学会 レーザ・量子エレクトロニクス研究会（LQE), 2024年5月28日.
- 野田進, “**[招待]** 新たな光源技術：フォトニック結晶レーザー（PCSEL）–スマートモビリティ・スマート製造の発展に向けて–”, テクトロニクス・イノベーション・フォーラム2024, 2024年7月11日.
- メーナカ デ ゾイサ, 野田進, “**[招待]** フォトニック結晶レーザーとLiDARセンシングへの応用”, 光・レーザー関西2024 併設オープンセミナー, 2024年7月17日.

Exhibits

- SPIE Photonics WEST 2024 (30 January ~ 2 February 2024)
- OPIE 2024 (23~26 April 2024)



Global Outreach

International collaboration

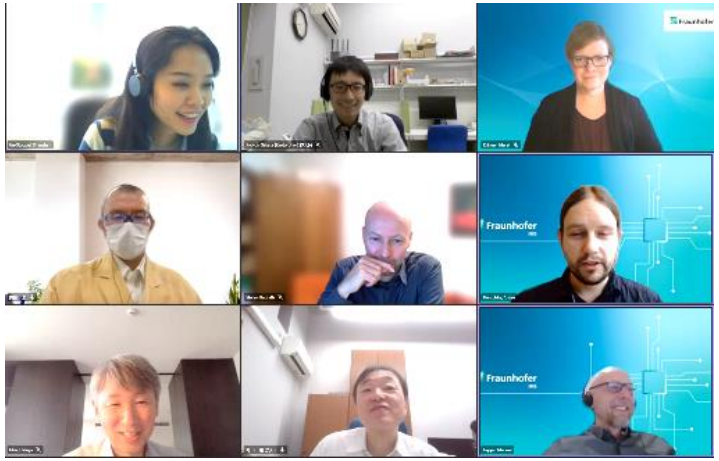
- **Germany-based Fraunhofer IMS & ISIT: Collaboration on PCSEL-SPAD sensing technology**

Visit to the PCSEL CoE at Kyoto University

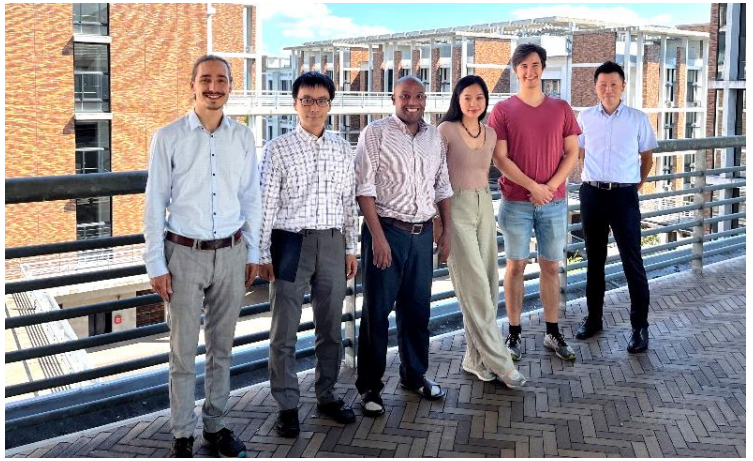
Meetings etc. with Fraunhofer from the start of SIP (October 2023) until now											
23/10	23/11	23/12	24/1	24/2	24/3	24/4	24/5	24/6	24/7	24/8	24/9

- **Netherlands-based nanoimprint company: Collaboration on technology for mass-production of nanoscale structures of PCSELs**

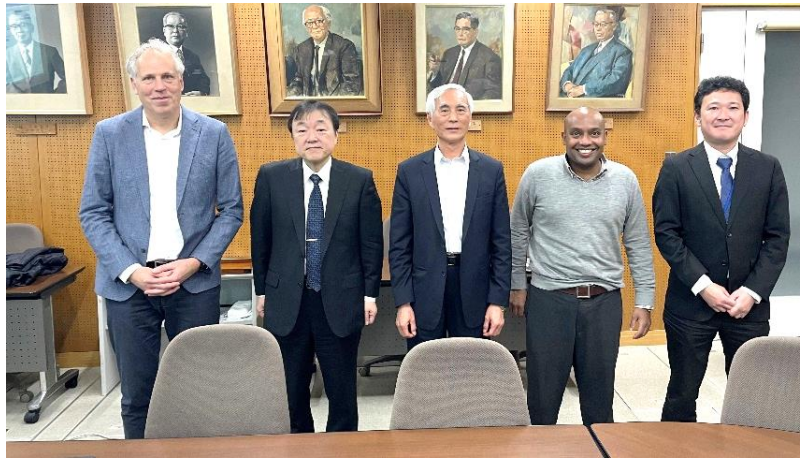
Meeting with Fraunhofer (DE)



Fraunhofer (DE) visiting Kyoto Uni.



Nanoimprint co. (NL) visiting Kyoto Uni.



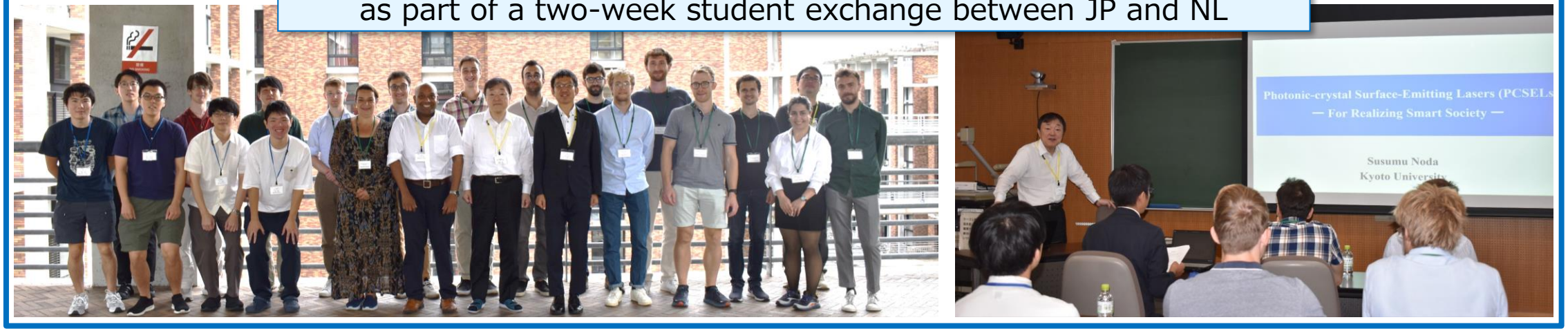
Global Outreach

International collaboration

- **Photon Delta ecosystem (NL): Events held under a MOU**

25-26 September 2024: International seminar with students from NL

27 September – 11 October 2024: First day of a group-work event as part of a two-week student exchange between JP and NL



Global Outreach

International collaboration

- **International Workshop on PCSEL (7-8th, November, 2024)**

Roadmap･Management Framework (p.54~p.55)

R&D Items & Roadmap

Collaboration with other projects

Results of SIP Phase 2

Infrastructure co-ordination demonstration
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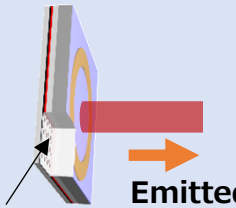
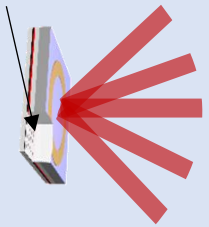


Photonic crystal

Emitted beam



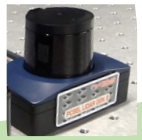
Photonic crystal laser (PCSEL)
京都大学 KYOTO UNIVERSITY PCSEL-COE

Field-operational test (FOT) by Kanazawa University

② Development of recognition technology and conducting field-operational test

Evaluation of applicability of PCSEL-based 2D LiDAR (SIP Phase 2)

Evaluation of applicability of 2D PCSEL-LIDAR



PCSEL-based 2D LiDAR

Additional item: Prototyping of 2D card-type PCSEL-LiDAR for inter-project collaboration scheduled for end of December 2024

(Note) Specifications of card-type LiDAR to be decided by October 2024

Kyoto University & Ecosystem + Hokuyo Automatic

① Development of 3D PCSEL-LiDAR system

Design of light source for 3D PCSEL-LiDAR

② A. Development of recognition technolog

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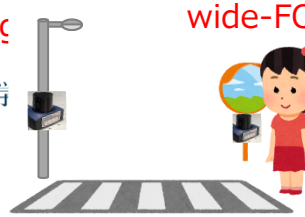


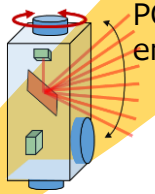
② B. Field-operational test (FOT) of infrastructure sensing

① STEP-1. Development of wide-FOV 3D PCSEL-LiDAR

京都大学 KYOTO UNIVERSITY PCSEL-COE

Operation test of wide-FOV 3D PCSEL-LiDAR

Test of wide-FOV 3D PCSEL-LiDAR prototype



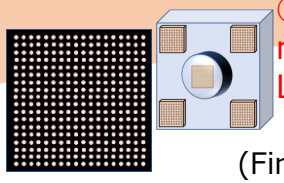
Prototyping of wide-FOV 3D PCSEL-LiDAR: Scheduled for end of September 2025

(Note) Specifications of wide-FOV LiDAR to be decided by March 2025

Fabrication of light source for 3D PCSEL-LiDAR

Prototyping of non-mechanical 3D PCSEL-LiDAR

Accelerate implementation of PCSEL/SPAD LiDAR in a separated configuration



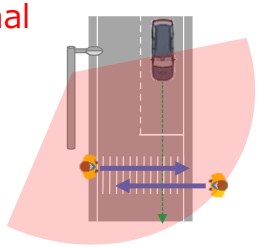
①STEP-2: Development of non-mechanical 3D PCSEL-LiDAR

(First, start with PCSEL/SPAD in a separated configuration)

京都大学 KYOTO UNIVERSITY PCSEL-COE

Development of 3D PCSEL-LiDAR for innovation of smart mobility

② B. Field-operational test (FOT) of on-board sensor
金沢大学



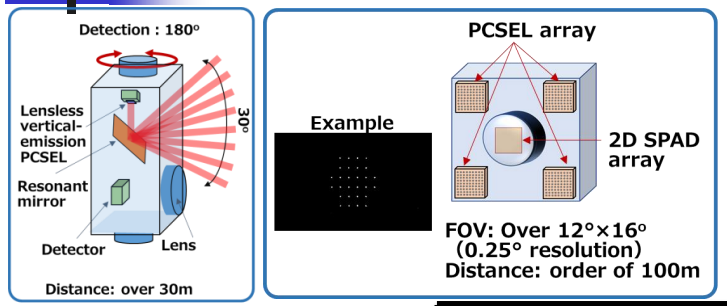
② B. Conduction of a level-4 equivalent demonstration that co-ordinates infrastructure and on-board sensing

Operation test of non-mechanical 3D PCSEL-LiDAR prototype

SIP Phase 3

Year 1 **Year 2** **Year 3** **Year 4** **Year 5**

Implementation Structure



Instructions & Discussion

NEDO

Head of R&D
- Affiliation: Kanazawa University Advanced Mobility Research Institute
- Title: Vice-director, Professor
- Name: Naoki Suganuma

Commissioning

Kyoto University
(① Development of 3D PCSEL-LiDAR system) Susumu Noda, Menaka De Zoysa, and others

PCSEL-LiDAR development

Feedback from demonstration

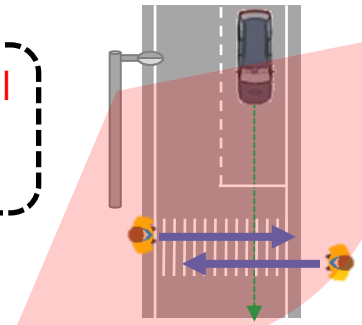
Kanazawa University
(②Development of recognition technology and conducting Field-operational test) Naoki Suganuma, Keisuke Yoneda, and others

Recommissioning

Hokuyo Automatic
Construction and basic evaluation of LiDAR system Naohiro Shimaji and others

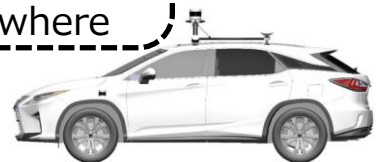
Collaboration

Fraunhofer (International collaborator)
PCSEL-COE ecosystem



Proof-of-concept demonstrations

<Demonstration sites>
- Tokyo waterfront area (Odaiba) Kanazawa City, Ishikawa Prefecture
- Abashiri City, Hokkaido, and elsewhere



This report partially includes the results of Cross-ministerial Strategic Innovation Promotion Program (SIP) 3rd Phase, Development of Smart Mobility Platform” promoted by Council for Science, Technology and Innovation, Cabinet Office. (Project Management Agency : New Energy and Industrial Technology Development Organization (NEDO) (Project Code JPNP23023)).