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# An Exciting Event in a Growing Industry

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# An Exciting Event in a Growing Industry

LASER World of PHOTONICS

After three years, Hamamatsu Photonics met again with the international photonics community at LASER World of PHOTONICS, in Munich from April 26 to 29. As one of the largest trade-shows for the photonics industry, we were delighted to be able to engage face-to-face with many of our customers and partners. The event was a huge success with over 900 exhibitors from more than 30 countries, and 15,000 visitors.

The world leading trade-fair organized for the second time an award ceremony for the top industry innovations selected by a jury of experts. We are very proud that our ORCA®-Quest qCMOS® camera won the “Laser Innovation Award” in the Biophotonics and Medical Engineering category.

For Hamamatsu Photonics, this is the perfect place to announce new technologies and meet new partners. Our booth not only showcased the best of our new products but also gave a preview of things to come. We created the ideal environment to connect with our customers. Our large booth was designed in an open space with interactive stations placed on every side. Each station, led by one of our experts, presented a specific technology so that each visitor could choose their preferred topic.

For those interested in learning, we offered three lectures attended by more than 120 participants about Mini-spectrometers, Low Light Measurement – Detection of Fluorescence and Laser-driven light sources. Another big success was The Hamamatsu Sushi Lounge, which attracted many hungry visitors. We offered our guests Japanese food and complementary drinks.

*“The event exceeded our expectations. We were originally concerned about the number of visitors due to the aftermath of the pandemic, but we were pleasantly surprised by the turnout. The industry is growing at a fast paste and the outcome of this event clearly demonstrated this. Not only did we get a large number of interested visitors but we also won an award. What a success!”*

*Oliver Roesler, Sales Director, Hamamatsu Photonics Deutschland*

Series Mitochondria

# The Little Giants Inside Cells That Maintain Life and Health

**Commentary:**
**Hideo Tsukada, Ph.D.,**
**Central Research Laboratory, Hamamatsu Photonics K.K.**

Part 2

## The challenge of PET to measure mitochondrial functions

**In Part 1 of this series, we explained the origin, shape and function of intracellular organelles known as mitochondria. You now likely understand that mitochondria play an important role for us not just in life itself but also in maintaining and improving our health. Here in Part 2 you will see the challenges we faced in developing PET (Positron Emission Tomography) probes needed for PET to measure the function of mitochondria in vivo in a living body.**

## What is PET?

Non-invasive imaging techniques such as X-ray CT (Computed Tomography) and MRI (Magnetic Resonance Imaging) are widely used not only in medical diagnosis but also in basic research fields due to their capability to measure in-vivo information as images from outside the body without damaging body tissues. Among those imaging techniques, PET has been the focus of much attention in recent years as an excellent nuclear medical diagnostic method. This stems from the fact that PET is capable of acquiring accurate physiological and biochemical information as quantitative functional images by measuring the in-vivo distributions and kinetics of a chemical compound labeled with positron-emitting nuclides from outside the body. This compound is called a PET probe, and in PET imaging it is essential to develop PET probes that specifically recognize and bind to target molecules in the body that must be examined.

Positron-emitting nuclides have one less neutron than stable isotopes with the same atomic number, which makes them energetically unstable, unless one positron is emitted.

Positrons have the same mass and spin as negatively charged electrons but are positively charged antimatter particles. Positrons are inherently extremely unstable and so eventually they combine with the surrounding electrons to cancel out their charges and annihilate each other. When a positron combines with an electron, a pair of annihilation gamma-rays of 511 keV is emitted at 180 degrees in opposite directions to each other (Figure 1). In PET imaging, the PET probes administered by intravenous injection flow along the bloodstream, circulate throughout the subject's body and accumulate in tissue reaching the target molecules. A pair of gamma-rays

Principle of PET imaging using positron-emitting nuclides

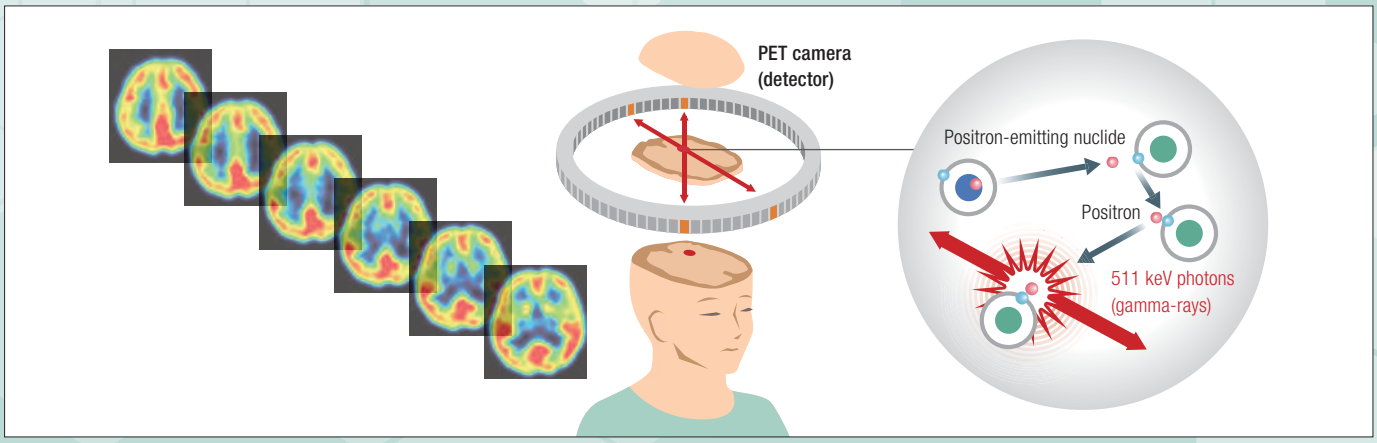


**Figure 1: Photodetectors surrounding the subject's body or brain are used to measure the location, kinetics and amount of the PET probes. They simultaneously detect a pair of gamma-rays emitted opposite of each other when the positron and the electron combine and annihilate.**

emitted from that location is then simultaneously detected by a pair of photodetectors positioned opposite one another among a large number of other photodetectors surrounding the body. The detected emissions reveal that the PET probe is somewhere along a straight line between the pair of photodetectors (Figure 1). This simultaneous or coincident measurement is also carried out by other pairs of photodetectors. Collecting all these data and performing image reconstruction provide multiple tomographic images that show "slices" or namely cross-sectional images giving fine internal views along with good quantitative performance.

## The Need for dedicated PET probes for mitochondria measurement

[$^{18}$F]FDG (Fluoro-2-deoxy-D-glucose) currently used for brain PET imaging is a derivative of glucose which is the only energy source for neuronal cells in the brain. It serves as a PET probe for measuring the energy metabolism of neuronal cells in diagnosis and research of various neurodegenerative diseases. Meanwhile, linked to many neuropsychiatric disorders including Alzheimer's disease, Parkinson's disease, schizophrenia, depression and autism, inflammation is reported to occur in the brain due to the activation of microglia which are a type of immune cell (Reference 1). Microglial cells accumulate at a damaged site while proliferating and becoming activated. Like cancer cells, these microglia produce ATP via enhanced cytoplasmic anaerobic glycolysis called a Warburg-like effect (see Figure 2 and Reference 2) rather than via mitochondrial oxidative phosphorylation. If a Warburg-like effect causes excessive uptake of [$^{18}$F]FDG into the activated microglia which require more glucose, then discriminating between intact and damaged regions that are expected to be detectable due to their lower accumulation of [$^{18}$F]FDG becomes extremely difficult. Thus making it impossible for PET imaging to accurately measure changes in neuronal cell functions. To deal with this problem, we took up the challenge of developing a new type of PET probes targeting mitochondria cells, which maintain activity in normal cells but have drastically reduced activity in inflammatory cells (Reference 3).

Differences in mitochondrial contribution to ATP synthesis

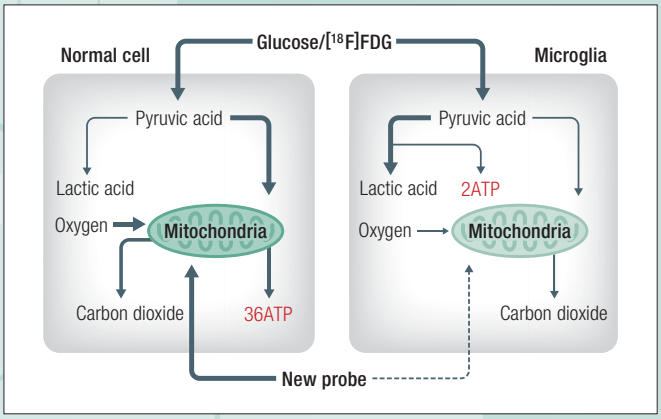


**Figure 2: ATP production via mitochondria is predominant in normal cells. But in activated microglia, ATP production via glycolysis is predominant because of low mitochondria activity.**

Over time we found that PET probes for mitochondria are not limited to discriminating inflammatory cells from neuronal cells but can also be applied to diagnosis and research of many neurodegenerative disorders. For example, Alzheimer's disease, which accounts for 40 % to 60 % of dementia cases, is thought to be caused by abnormal proteins called amyloid-β (Aβ) protein and phosphorylated tau protein that accumulate in the brain and damage neuronal cells leading to atrophy of the brain. What induces this accumulation of abnormal proteins is not currently known. Recent research using Alzheimer's disease model in mice suggest that the accumulation of highly toxic Aβ oligomers promoted by Aβ fibrils that change due to the impaired mitochondrial function which act as a scaffold for further Aβ aggregation and deposition (Reference 4).

Parkinson's disease is an intractable neurodegenerative disease accompanied not only by motor dysfunctions such as tremor, bradykinesia, muscle rigidity, and postural instability but also by mental symptoms and cognitive dysfunction. The cause of its onset is still unclear. Dopamine is an abundantly present neurotransmitter in the brain from the substantia nigra through to the striatum and it generates hydrogen peroxide ($H_2O_2$) when metabolized by monoamine oxidase. The hydrogen peroxide then reacts with divalent iron ions to produce hydroxyradical (·OH) which is a type of highly reactive ROS (Reactive Oxygen Species). When the brain is functioning normally, ROS are immediately removed by antioxidant enzymes and antioxidants. A recent report indicates that mutations in the Parkin protein gene *PARKIN,* responsible for the quality control of mitochondria and also mutations in the PTEN-inducible kinase 1 protein (PINK1) gene *PINK1* in collaboration with Parkin will increase the oxidative stress caused by ROS, leading to the onset of Parkinson's disease (Reference 5). Furthermore, another report suggests that abnormal accumulation of α-synuclein protein in Parkinson's disease is associated with mitochondrial dysfunction and excessive ROS production (Reference 6).

## Development of PET probes for mitochondria

Mitochondrial complex-I (MC-I) responsible for the first step in the electron transport chain has the largest molecular weight and is the least active among the five types of MC that make up mitochondria. It therefore indicates a rate-limiting step (or the slowest reaction) of the entire electron transport chain and is thought to reflect the whole mitochondrial activity. Around 2010 when we started our research, there was already a report about [$^{18}$F]BMS-747158-02 (hereinafter [$^{18}$F]BMS, Figure 3A) that was used as a PET probe targeting MC-I, exclusively for evaluating the myocardial function (Reference 7). Using rats as a model for study, we were able to confirm that [$^{18}$F]BMS accumulates at high levels not only in the myocardium with abundant MC-I but also in the brain (Figure 4A, Normal). However, we could not sufficiently displace the [$^{18}$F]BMS uptake in the heart and brain even by pre-administering an authentic specific inhibitor of MC-I (rotenone) (Figure 4A, Rotenone) (Reference 3). This means that PET measuring using [$^{18}$F]BMS can't achieve a sufficient dynamic range, because the ratio of its specific binding is too low for all the accumulated radioactivity. This issue is thought to be caused by the high non-specific binding, because of its high lipophilicity of BMS (lipophilic index LogP = 3.69) and the slow intracerebral kinetics, due to high affinity for MC-I (inhibition constant index Ki = 0.95 nM), both of which are not suitable for noninvasive quantitative analysis using PET.

Therefore, in order to create chemical compounds with more suitable characteristics for non-invasive measurement of MC-I activity in the brain using PET, we tried modifying the structure of the chemical formula of BMS while also considering conditions such as the labeling possibility by C-11 and F-18, the stability in blood, and the appropriate lipophilicity to have high blood-brain barrier permeability and low non-specific binding. Then we succeeded in creating two types of compounds as PET probes for MC-I, [$^{11}$C] BCPP-EM (LogP = 2.87, Ki = 2.87 nM, Figure 3B) and [$^{18}$F]BCPP-EF (LogP = 3.03, Ki = 2.31 nM, Figure 3C) (Reference 3). To confirm that each compound maintains its binding specificity to MC-I even after altering the chemical structural formula, we prepared sub-mitochondrial particles (SMP) containing a group of respiratory chain complexes extracted from a pig heart, and compared the binding specificity to MC-I of BCPP-EM and BCPP-EF with that of BMS which is the lead compound for these two novel PET probes. The respiratory chain complex present in SMP has substrate reaction sites facing outward, and each of MC-I, MC-II and MC-V can be specifically driven by adding NADH (electron carrier), succinate (succinic acid) and ATP, respectively, causing protons ($H^+$) to be transported into SMP by the electron transfer that occurs after each complex is driven. The proton transport activity can then be evaluated by combining it with a fluorescent reagent (ACMA; 9-Amino-6-chloro-2-methoxy acridine) that quenches its emission according to the proton concentration (Figure 5). Results from examining the effects of BCPP-EM and BCPP-EF on fluorescence quenching, reveal that MC-I-driven proton transport activity by NADH is inhibited at low concentrations just like in the case of BMS. However, MC-II and MC-V-driven proton transport activity by succinate and ATP is not inhibited even at high concentrations. This proves that BCPP-EM and BCPP-EF are compounds having reduced lipophilicity and proper binding affinity while maintaining the same binding specificity to MC-I as BMS (Reference 8).

PET probes

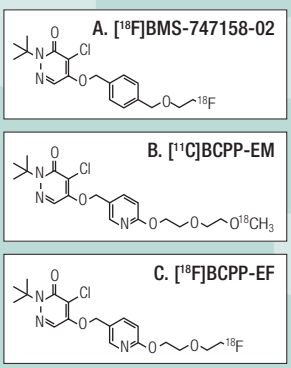


**Figure 3: PET probes for measurement of mitochondrial complex-I (MC-I).**

Effects of pre-administration of rotenone on uptake of [$^{18}$F]BMS and [$^{18}$F]BCPP-EF

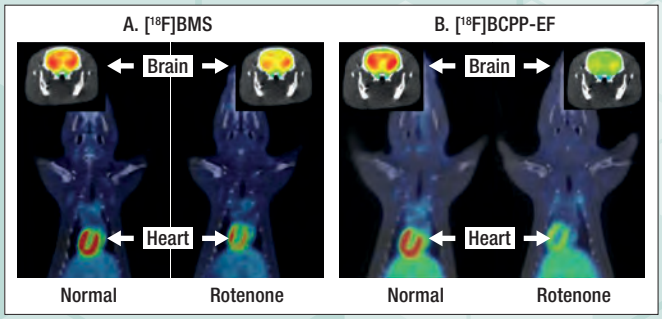


**Figure 4: Pre-administering the same amount of inhibitor (rotenone) caused a sufficient decrease in the radioactivity levels of [$^{18}$F]BCPP-EF in the brain and the myocardium, though the level of radioactivity in existing [$^{18}$F]BMS remained considerable.**

Principle of binding specificity evaluation using inside-out vesicles of inner mitochondrial membrane

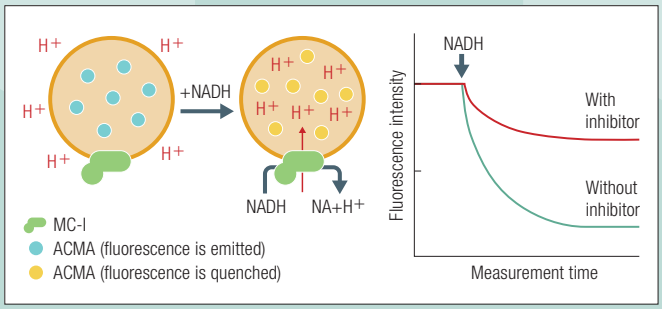


**Figure 5: When NADH (electron carriers) that drive MC-I acts on an inside-out vesicle, protons ($H^+$) are taken up into the vesicle via MC-I if there is no inhibitor, causing the ACMA fluorescence to extinguish (green line in the graph on the right). If the test substance specifically inhibits MC-I, it interferes with the influx of protons and prevents the ACMA fluorescence (red line in the graph on the right) from extinguishing.**

## Evaluation of PET probes for mitochondria using experimental animals

After in vitro evaluation of the compounds with the modified chemical structural formula, we pre-administered rotenone to rats under the same conditions as for [$^{18}$F]BMS (Figure 4A) to check for a displacement of accumulated [$^{18}$F]BCPP-EF in the myocardium and brain. We then confirmed that rotenone sufficiently reduced the radioactivity uptake as shown in Figure 4B. So we tried to verify that measuring MC-I as the target will overcome the issue of [$^{18}$F]FDG also being taken up into the inflammation site. Specifically, after developing an ischemic infarction in the rat brains, we measured it by PET 1 day and 7 days after the ischemic insult. One day later the damage region could be visualized as a low uptake site of [$^{18}$F]FDG, but after 7 days it showed a higher uptake of [$^{18}$F]FDG in the damage region (Figure 6A). Then, by using [$^{11}$C]PK11195 that specifically recognizes and binds to TSPO (Trans locator protein) which is a marker for activated inflammatory cells, we confirmed that this higher uptake of [$^{18}$F]FDG is due to an uptake into activated microglia accumulated in the damage region of the brain (Figure 6B). On the other hand, when we performed the same PET measurement using [$^{18}$F]BCPP-EF, the damage region could be visualized as a low uptake region using MC-I activity as an index not only 1 day, but also 7 days after the ischemic insult when a high [$^{18}$F]FDG uptake was exhibited (Figure 6C) (Reference 3).

The ultimate goal of developing novel PET probes is to help diagnose patients and monitor the therapeutic efficacy in clinical practice. In the early stages of the development process, it is essential to carry out evaluations with rodents (rats and mice). However, rodent pathological models are often emphasized by focusing only on particular aspects of human pathologic conditions and do not always reflect an overall picture of the more complex human conditions. Even in the rat cerebral infarction model described above, the collateral blood circulation pathways are not developed in the rat brain to the same extent as in the human brain. Therefore, occlusion of the middle cerebral artery on one side significantly reduces blood flow throughout the cerebral hemisphere on the same side, causing ischemia-reperfusion injury that is more serious than human cerebral infarction. We therefore proceeded with the evaluation of cynomolgus monkeys which are more human-like experimental animals. In this cerebral infarction model, one side of the middle cerebral artery was occluded with a clip for 3 hours to stop blood flow and the clip was then removed to resume blood flow, which caused a reperfusion injury resembling human cerebral infarction. One week after causing ischemia-reperfusion of the middle cerebral artery on the right side of the cynomolgus monkey, and after waiting for the local cerebral blood flow to return to normal, we made evaluations using [$^{18}$F]FDG, [$^{11}$C]PBR28 (inflammation marker TSPO) and [$^{18}$F]BCPP-EF. As Figure 7 shows, in the damage region corresponding to the area surrounded by the red line on the MRI image, there is a high [$^{18}$F]FDG uptake (A) in the region matching the high uptake region of [$^{11}$C]PBR28 (B) indicating accumulation of inflammatory cells (activated microglia), whereas [$^{18}$F]BCPP-EF (C) shows a low uptake in the same region (Reference 9).

Results from evaluations using these rat and monkey cerebral ischemic infarction models successfully demonstrate that, using MC-I as an evaluation target makes it possible to clearly discriminate between normal and damaged regions without being disturbed by inflammatory cells. In our next report, we will show results from applying [$^{18}$F]BCPP-EF to animal models of Alzheimer's disease and to human patients.

PET image of cerebral ischemic infarction disorder in a rat

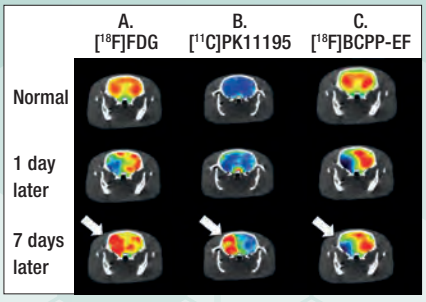


**Figure 6: At the site of ischemic injury indicated by the arrow in the cerebral hemisphere of a rat, neuronal cells were damaged and became dysfunctional showing a low uptake of [$^{18}$F]BCPP-EF, whereas activated microglia accumulated as seen by the high uptake of [$^{11}$C]PK11195, resulting in an abnormally high uptake of [$^{18}$F]FDG.**

PET image of cerebral ischemic infarction disorder in cynomolgus monkey

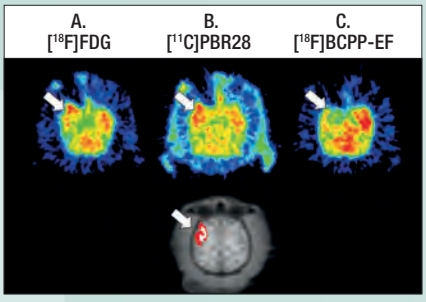


**Figure 7: At the site of ischemic injury indicated by the arrow in the cerebral hemisphere of a cynomolgus monkey, neuronal cells were damaged and became dysfunctional exhibiting a low uptake of [$^{18}$F]BCPP-EF, whereas activated microglia accumulated as seen by the high uptake of [$^{11}$C]PBR28, resulting in an abnormally high uptake of [$^{18}$F]FDG.**


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**An index calculator, quantitatively evaluating power device materials such as gallium nitride (GaN). A powerful tool that helps rate and improve semiconductor crystal quality.**

# ODPL Measurement System

Hamamatsu Photonics released a measurement system that accurately quantifies the quality of compound semiconductor crystals, which are critical for the development of electronic devices. It measures the efficiency of the photoluminescence generated inside a semiconductor crystal when it is excited with light. This system applies a new technique called ODPL spectroscopy, which will prove to be a breakthrough in material evaluation methods. Development of this new measurement technique started when a spectrum measured in a university laboratory was found to be significantly different in shape from the previously observed spectra. Let us hear more about the development approach from four of our project team members.

Planning and development:

***Kenichiro Ikemura***
*Product Planning Group, Systems Division*

Development:

***Kazuya Iguchi***
*Applied spectroscopy systems Department, Systems Division*

Development:

***Kengo Suzuki***
*Applied spectroscopy systems Department, Systems Division*

Sales:

***Hirohiko Watanabe***
*Business Promotion Department, Systems Division*

## A novel measurement technique that far exceeds conventional photoluminescence spectroscopy is now available!

First of all, what is the ODPL measurement system used for?

**Iguchi:** ODPL stands for Omni Directional Photo Luminescence. The ODPL measurement system plays an important role in the research and development of gallium nitride crystals, a material used for power devices, communication devices, and high brightness LEDs. This system will also prove useful to assert the quality of gallium nitride wafers found in those devices, helping to determine their performance.

**Suzuki:** Gallium nitride crystals are also used to make the common blue LED. In that application, a few defects in the crystal will not cause significant problems. However, when used as a material for power devices where high-conversion efficiency and reliability are crucial factors, the quality of the gallium nitride crystals becomes a prime factor affecting the device's characteristics.

**Iguchi:** The quality of gallium nitride crystals depends on the crystal defect density. In other words, reducing the defect density improves the overall quality, which calls for a reliable evaluation technique to accurately measure this.

Do you mean that finding a new evaluation method, unlike the ones currently used, was essential for viewing gallium nitride as a material for power devices?

**Iguchi:** That's right. Up to now, an evaluation method called photoluminescence spectroscopy or PL spectroscopy has been mainly used. PL is the light emission from a substance after being irradiated by light, which occurs when an excited electron returns to its original ground state. Since this light emission is affected by crystal defects, the crystal quality can be evaluated by measuring the PL.

**Suzuki:** PL spectroscopy allows for non-destructive and non-contact evaluations, but it is a qualitative evaluation method involving various factors such as the intensity and density of irradiation light. It also has the problem of being difficult to use in making quantitative evaluations.

**Iguchi:** The new system employs an integrating sphere to measure how much excitation light is absorbed by the crystal and how much of the absorbed light contributes to light emission. This provides quantitative evaluations that have been impossible to achieve up to now.

Well, it seems ideal for the quantitative evaluation of gallium nitride crystals. Are there similar measurement instruments available from other companies?

**Iguchi:** Many PL spectroscopy instruments exist. Ourselves, we already offer PL quantum yield spectrometers as measurement devices using an integrating sphere. However, at present, there are no other instruments that match our ODPL measurement system capable of providing an index of crystal internal quantum efficiency or IQE.

**Watanabe:** Although there are other instruments dedicated to evaluating defect density of semiconductor crystals, these are all intended for relative and qualitative evaluations. Our ODPL measurement system is unique in that it can make non-destructive, non-contact as well as quantitative evaluations.

## The reasons behind developing the ODPL measurement system

What led you to developing the ODPL measurement system?

**Iguchi:** About 15 years ago, we developed a PL quantum yield spectrometer and put it to practical use. It was initially developed for measuring the luminous efficiency of organic LED materials used in mobile phones and television displays and it has also been used in the R&D of luminous materials. It was from that point in time that we started thinking of measuring the luminous efficiency of semiconductor-based LED materials.

You mention thinking about it, but what was keeping you from acting?

**Iguchi:** We did not try doing it because the results obtained by measuring semiconductor materials with the PL quantum yield spectrometer were significantly smaller than the expected luminous efficiency. We could not identify its cause at that time, so we thought it would prove too difficult to evaluate semiconductor materials using a PL quantum yield spectrometer.

What made you decide to start?

**Iguchi:** We started developing the ODPL measurement system after obtaining interesting data from Professor Kazunobu Kojima of Tohoku University who was using our PL quantum yield spectrometer at that time to study gallium nitride. More specifically, the PL spectrum he measured with the PL quantum yield spectrometer was completely

different from the spectra measured with other equipment in his laboratory. Investigating the reason for this difference is what prompted us to start developing the ODPL measurement system.

**Ikemura:** Let me add one point: As a parameter for evaluating the quality of semiconductor materials, we had been considering using the internal quantum efficiency or IQE. However, to use the IQE, we first had to find a mathematical model expressing the process of luminescence in a crystal and compare it with actual experimental results to obtain a complementary understanding of these. Additionally the method for the experiment was a challenge, making our work even tougher while providing unsatisfactory results.

**Watanabe:** At the time, there was a growing demand for a simpler and better quantitative evaluation method for the quality of semiconductor materials throughout the industry. Professor Kojima was also one of those who sought out such a method. He gave us useful advice and cooperated by theoretically verifying the IQE measurement method, which in turn led to developing the ODPL measurement system.

## Calculating an index for quantitative quality evaluation

### What are the features of the ODPL measurement system?

**Suzuki:** One distinct feature is that this system uses "ODPL spectroscopy" – a novel measurement technique for acquiring the IQE of semiconductor materials. ODPL spectroscopy is a powerful measurement tool capable of non-contact, non-destructive and quantitative evaluation of semiconductor materials.

**Iguchi:** Besides compound semiconductor crystals such as gallium nitride, this system can also evaluate semiconductor materials called perovskite semiconductors.

**Suzuki:** Another feature I want to add is the use of a component called an integrating sphere. An integrating sphere consists of a hollow spherical shell with its inner wall covered with a highly reflective coating. In this spherical shell, a sample is excited to emit light which is then measured with a photodetector.

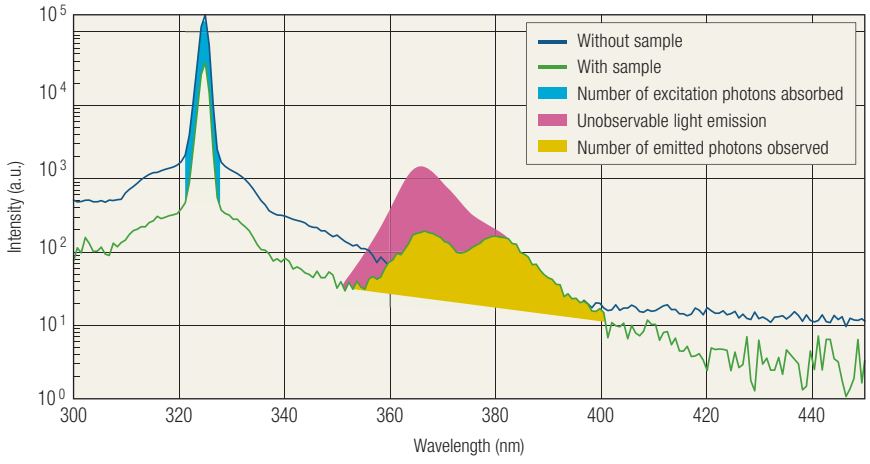
### How do you actually use it?

**Suzuki:** Let me explain this in a little bit more detail. A semiconductor crystal such as gallium nitride and perovskite crystal is placed inside the integrating sphere. The crystal is then irradiated with excitation light and the resulting PL from the crystal is measured. At this point, the PL is not emitted from part of the crystal but is instead emitted from all surfaces of the crystal in every direction and is uniformly scattered within the integrating sphere. Since the integrating sphere has very high reflectance, it uniformly scatters the PL along with the excitation light that was not absorbed by the crystal. A multichannel spectrum analyzer then measures a portion of this PL.

### How do you use the measured light to calculate the result?

**Suzuki:** The measurement results give information on external quantum efficiency or EQE. This EQE is easily calculated by dividing the number of emitted photons observed by the number of excitation photons absorbed. Finally, the IQE, which is an index parameter for quality evaluation, can then be calculated from this EQE.

ODPL measurement




**Calculation of EQE**

$$EQE = \frac{\text{Number of emitted photons observed}}{\text{Number of excitation photons absorbed}}$$

**Calculation of IQE**

IQE is calculated by analyzing the following information from EQE:

- **Light extraction efficiency:** Calculates the light emission amount absorbed by the sample
- **Photon Recycling:** Considers the process by which light emission is absorbed and emitted again in a GaN single crystal

[Ex.] **EQE 0.65 % → IQE 15 %**

## The integrating sphere: the turning point

You mentioned earlier that the data Professor Kojima measured on the PL quantum yield spectrometer was quite different from the data he previously measured. Did you find out why the difference occurred?

**Ikemura:** The PL quantum yield spectrometer that the Professor used included an integrating sphere. During standard PL measurements, optical lenses are used to measure light emitted in only one direction. In contrast, measurements using an integrating sphere allow the detection of light components emitted in all directions. When comparing these two measurements, we noticed that the spectrum obtained by measuring light emitted only in a certain direction appears hardly affected at all by absorption and transmission of light. However, when measuring components of light emitted in all directions, the ratio of absorption to transmission differs depending on the light emitting angle, causing a remarkable difference in the spectrum shape.

**Suzuki:** When measuring PL that is emitted from the surface of a semiconductor crystal irradiated with excitation light, the expected waveform can be obtained. But if an integrating sphere is instead used here, we can detect light emitted not only from the front surface of the crystal but also from the back surface and sides of the crystal. Unlike light emitted from the front surface of the crystal, the light emitted from the sides and the back surface is affected by absorption and transmission inside the crystal so the measured spectrum appears distorted. In the integrating sphere, the total emitted light is averaged by the integrating sphere and then detected, making the measured spectrum significantly different in shape from the spectrum obtained by measuring the light emitted only from the front surface. This is the reason for the difference between the spectrums.

You mean that Professor Kojima was first looking at light only emitted from the front surface. But utilizing the integrating sphere then allowed him to measure light emitted from all directions. This is the reason that the measured spectrum was different, isn't it?

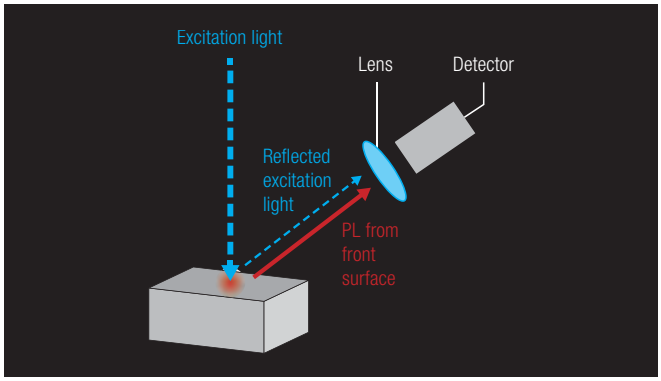
**Ikemura:** Exactly. The difference in spectrum gave us an opportunity to make a deeper study of the optical physics in semiconductors (the study of the property of light and its interaction with matter). Conducting this study helped us understand how and why these phenomena were occurring. This lead us to finally find the IQE and develop the ODPL measurement system.

## Compact design installable in a limited space

Can you tell me about the difficulties you faced during the development of the ODPL measurement system?

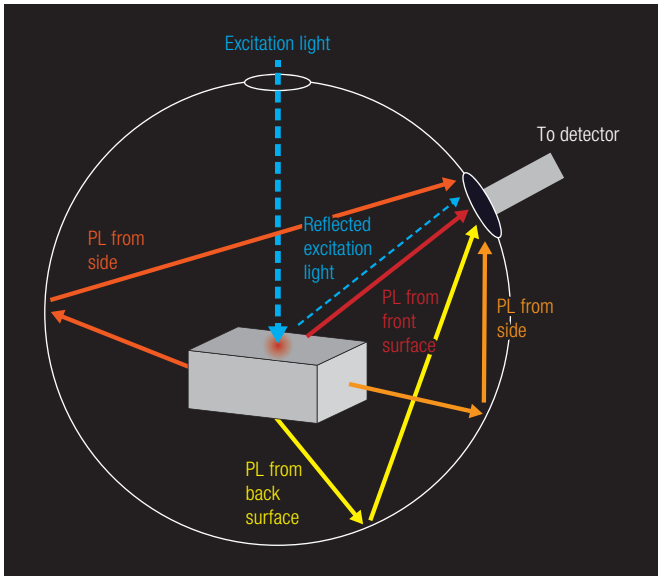
**Ikemura:** As I mentioned earlier, we started out developing the ODPL system by using a PL quantum yield spectrometer to make measurements of gallium nitride semiconductor material. Our greatest difficulty was understanding the physical phenomena inside the semiconductor and procuring samples. However, as I mentioned earlier, Professor Kojima's advice and collaboration got us through these challenges.

Ordinary PL measurement




**Detects PL emitted from the front surface irradiated with excitation light.**

PL measurement using an integrating sphere




**Averages and detects PL emitted not only from the front surface irradiated with excitation light but also from the back surface and sides after being absorbed or transmitted inside the crystal.**

It sounds like Professor Kojima was a great help providing you his insights about semiconductors. Did you have any other difficulties?

**Suzuki:** As Ikemura explained, we made a prototype based on Professor Kojima's requests and Ikemura's ideas. However, making it a reality was challenging, especially around fitting the prototype in a limited space.

**Watanabe:** Following on Suzuki's answer, researchers are mostly used to assembling their PL spectroscopy systems on their own using the entire lab space. However, our aim was to design such a compact and easy to use unit that they could make their measurements using only their desk area.

What is the final design size of the unit?

**Watanabe:** The width is 72 centimeters (about 28 inches), and the height is 41 centimeters (about 16 inches) including the mount base.

**Suzuki:** This unit must provide two essential functions. One is to calculate the EQE using an integrating sphere and the other is to obtain additional data for calculating IQE from the calculated EQE. To incorporate these functions into a unit of the required size, we devised a suitable optical system layout and an automatic control function.


*Kengo Suzuki*

**Watanabe:** This compact unit with all its integrated functions can be installed even if the laboratory is limited in space by all its testing instruments.

Did you make any new discoveries or encounter any surprises during the development process?

**Ikemura:** One thing that was surprising to me was that the measurement technique originally intended for gallium nitride was found to be a general method that is applicable to a variety of other semiconductor materials. We had to conduct a lot of testing before this became clear, but the key to all of this was that we were capable of finding out what was occurring inside a semiconductor crystal.

How do you feel about the current level of completion of the ODPL measurement system?

**Ikemura:** Up until now, measurement of compound semiconductor crystals used as materials for power devices has been considered difficult to do. However, we were able to show that our ODPL measurement system makes it very easy to measure the IQE of compound semiconductors, and this result will prove useful for scientific progress and dissemination.

**Watanabe:** From a business point of view, speedy research is essential even in university laboratories. This trend is even more pronounced in private enterprises. Because our ODPL measurement system can be installed in confined spaces and are able to produce quick and reliable results, we are confident that it will be highly rated by our customers.


*Hirohiko Watanabe*

## Aiming to expand the applications from laboratory to industrial use

What markets do you plan to target in the future?

**Watanabe:** In August 2021, we released our ODPL measurement system for research applications. We are currently promoting it at research institutes where the benefits from using such a system will be fully recognized.

We also aim to make this system known by publishing papers and other similar media. Quality evaluations of semiconductor materials and gallium nitride are now the focus of attention due to the increasing demand for gallium nitride semiconductor devices in the industry.

While doing market research in this field, we will deal with the future challenge of upgrading this system to make it more convenient for industrial tasks such as on-site testing.

How about the technical side?

**Iguchi:** Currently, this system is being sold for research use and cannot be used to measure wafers, which must be cut into small pieces before measurement. When performing industrial tasks, the wafer state and in-plane PL distribution must be accurately measured. If we achieve this, the system will prove successful in the quality improvement process at manufacturing sites.


*Kazuya Iguchi*

**Find more information about ODPL measurement system on page 24 of this issue.**


*Kenichiro Ikemura*

**Ikemura:** The quantitative capability of the ODPL measurement system is a very important aspect for industrial applications. Being able to measure quantitatively means that the effect on the measurement object can be calibrated. In the case of gallium nitride, the ODPL measurement system will likely be used, for example, to draw a calibration curve of the carbon impurity concentration. I hope it will be possible to use the IQE to calculate this parameter for other semiconductor materials.

**Suzuki:** I have similar thoughts to my colleagues. I would also like to make ODPL spectroscopy, known as an easy-to-use measurement technique.

To summarize, after first proving its usefulness in laboratories, you will then find new ways to expand sales to the industrial field while proceeding with the necessary development. Thank you for responding to all my questions. I look forward to seeing how its future progress will unfold.

***Professor Kazunobu Kojima***
*Graduate School of Engineering, Division of Electrical, Electronic and Infocommunications Engineering, Osaka University**

**Message from Professor Kazunobu Kojima, a research collaborator in ODPL spectroscopy**

ODPL spectroscopy is a technique for measuring the luminous quantum efficiency (QE) of semiconductor bulk crystals. People tend to think it has been around for a while but it is actually quite a novel technique. Luminous quantum efficiency is a useful index for evaluating the quality of substrate materials not only of optical devices but also electronic devices. It is measurable by a non-destructive and non-contact method not requiring any probe electrodes. In particular, ODPL spectroscopy is capable of quantitatively measuring internal quantum efficiency (IQE) to allow comparing quality between different crystals as well as between crystals of the same type. My sincere hope is that the ODPL measurement system based on ODPL spectroscopy will be effectively used in a broad range of applications including basic to applied research and mass production tasks.

To find detailed information on ODPL spectroscopy, please refer to my papers published in the Journal of Applied Physics (*J. Appl. Phys.* **120,** 015704 (2016)) and the Japanese Journal of Applied Physics *"Oyo Buturi"* (Dec. 2021).

* During the R&D collaboration, Professor Kazunobu Kojima was part of the Institute of Multidisciplinary Research for Advanced Materials, Tohoku University


Significantly reduces patient discomfort and paves the way for the expansion of clinical testing

# High-sensitivity Fluorescence Immunochromato Reader (Lateral Flow Reader)

C10066-60

Lateral flow immunoassay technology (LFIA) is widely used to test for infectious diseases such as influenza and coronavirus diseases. In this test, a sample is dripped onto a testing tool commonly called a lateral flow test strip that contains a reagent. The test result is then judged as positive if a line appears on the test strip when the target analyte in the sample reacts with the reagent. Until now, visual inspections have mainly been used to check these lines but recently there has been a large shift toward "lateral flow readers" that ensure higher accuracy and eliminate human judgement errors during visual inspections. This shift has also created demand for higher sensitivity in our immunochromato readers that serve as an industry standard for lateral flow readers. To meet this demand, an R&D team was set up with the goal of achieving significant improvements in sensitivity. Let's hear from some of these R&D team members about the development background for the new fluorescence immunochromato reader from Hamamatsu Photonics.

(From the left)

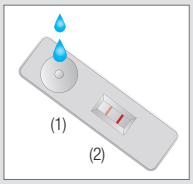
| | |
|---|---|
| ***Naokazu Morishita*** | *Manufacturing #1, Dept. #19* |
| ***Fusanori Kondo*** | *Manufacturing #1, Dept. #19* |
| ***Tomokazu Matsumura*** | *R&D Group #1* |
| ***Hideyuki Suzuki*** | *Business Promotion Group #1* |

## Higher sensitivity provides hope with new prospects for tackling infectious diseases

### First of all, what is an immunochromato reader?

**Suzuki:** This device reads the test line of a lateral flow test strip containing the reagent, which is why it is commonly called a lateral flow reader. Lateral flow test strips are widely used to make influenza and pregnancy tests, and also recently antigen tests for novel coronavirus. This test is simple and rapid. If a line appears on the test strip, the result is positive. If no line appears it is negative. More specifically, a sample is dripped onto the sample pad of the test strip (1), the sample reacts with the reagent in the test strip, and the test result is then judged as positive or negative depending on whether a line appears in the test window (2).

Lateral flow test strip




### How is this different from the PCR test we often hear about?

**Suzuki:** PCR is a very sensitive test that works by amplifying genes. But it takes time to get the results and the test procedure is complicated so it can only be done by experts. The lateral flow test is simple and rapid. The test results can be obtained within 5 to 15 minutes.

### Compared to the PCR test, the lateral flow test is simple and easy to use by anyone without training. Right?

**Morishita:** That's right. It's easy to visually check whether or not a line is present. But it's not easy to distinguish the color density of the line by visual inspection. Using an immunochromato reader allows not only judging if results are positive or negative, but also helps estimate how the disease will progress based on the color density of the line in some applications. This is possible because the immunochromato reader can quantify the relative color density of the line. This is a very useful feature when you need to quantify results.

### Are our immunochromato readers used in hospitals and laboratories?

**Suzuki:** Rather than being used in actual clinical environments, our immunochromato readers are mainly used by companies that develop and manufacture reagents for lateral flow tests. Those companies utilize our immunochromato readers for quality control to make sure that reagents under development react correctly with samples and also for quantifying reactions essential in the development stage. Our immunochromato readers in this way serve as an industry standard. However, improving their sensitivity has long been a challenge for us.

### The new immunochromato reader now offers significantly enhanced sensitivity, doesn't it?

**Suzuki:** Yes, it does. In commonly used lateral flow tests, the color of the line is checked by human eyes. This test is simple and rapid but sensitivity is low compared to the PCR test. This has created more demand from customers for higher sensitivity. The ongoing COVID-19 pandemic has triggered a wave of such requests from customers.

**Kondo:** There will always be limits on increasing sensitivity as long as we keep using lateral flow readers designed for checking the color of the line just by visual inspection. But we know that instead of just viewing the line color, we can enhance sensitivity by viewing fluorescence lines generated by irradiating a sample with ultraviolet light. However, this fluorescence is invisible to the human eyes so a specially designed lateral flow reader is required.

Fluorescent lateral flow test strip

Fluorescence line is invisible to human eyes.

Fluorescence line can be checked by irradiating the strip with ultraviolet light.

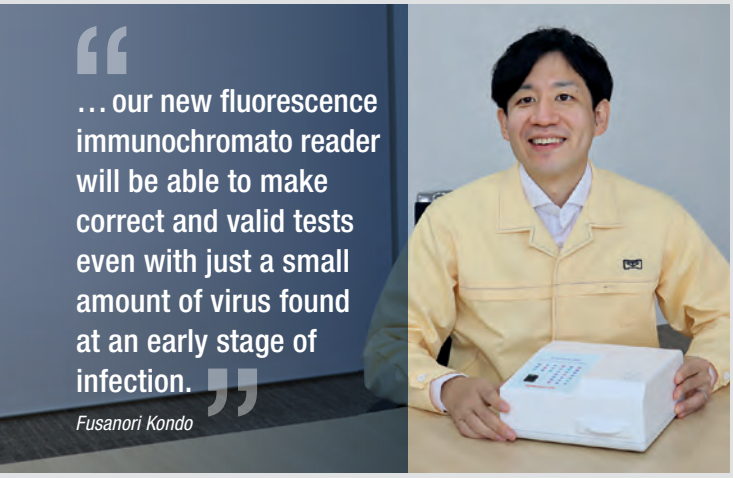
### So, did this situation lead you to developing the new fluorescence immunochromato reader?

**Suzuki:** Not exactly. We already had this type of immunochromato reader but its sensitivity was still not high enough, so we made steady efforts to boost its sensitivity.

## Reducing patient discomfort and improving development efficiency in reagent manufacturers

### Our early immunochromato readers could view fluorescence but their sensitivity was not really high enough for practical use. Is that right?

**Kondo:** Yes, that's right. When testing for influenza for example, a sample is collected from deep inside the nose where there is more virus content. However, if sensitivity is increased, the test can be made by using a nasal discharge sample easily taken from the bottom of




the nose or by using a saliva sample. This eases the subject's discomfort and also reduces false positives and false negatives. Moreover, when an influenza test is performed within 24 hours of the infection, the test often fails to detect it because the amount of the virus is low. However, our new fluorescence immunochromato reader will be able to make correct and valid tests even with just a small amount of virus found at an early stage of infection.

**Suzuki:** Also the enhanced sensitivity of our new fluorescence immunochromato reader can confirm the reaction that occurs from a reagent even when the virus content in the sample is low. This helps understand new issues with reagents that could not be dealt with so far, making it possible to concentrate on effective methods for increasing reagent sensitivity.

**Matsumura:** During the development phase of the creation of reagents, around 100 types of reagent candidates are produced. A fluorescence lateral flow reader is then used to test whether each one correctly emits fluorescence by reacting with the target such as the virus. This process is repeated to narrow down the promising reagents from a large number of reagent candidates. Our solution streamlines the reagent development process by finding ideal conditions for promising reagents from the early stages where the test line fluorescence is usually very weak.

Does the reader sensitivity affect the efficiency of the reagent development?

**Suzuki:** Yes, it does. In recent research on lateral flow test strips, there is a growing shift towards fluorescent reagents instead of visual detection reagents. This shift proves that our efforts on increasing fluorescence immunochromato reader sensitivity were lead at the right time.

## Responding to challenges by working closely with all departments

How did you go about increasing the sensitivity?

**Kondo:** The basic approach to increasing sensitivity is achieving a dedicated optical system with an optimal design. But we found there were limits on how far sensitivity can be increased just by improving the optical system. So, Matsumura teamed up with us to develop signal processing technology that reduces noise to a minimum.

**Matsumura:** The R&D Group which I am assigned to, worked jointly with the Manufacturing #1 to push ahead with the development work. We already had experience working together and had the opportunity to develop a good working relationship which was ideal to discuss various challenges. We feel lucky that at Hamamatsu Photonics we can build connections with various colleagues on site as well as with other departments. Kondo, who is part of Manufacturing #1 was working on increasing sensitivity via the optical system while discussing all the difficulties he encountered with us. Honestly speaking, I was concerned there were real limits to increasing the sensitivity with such a typical approach. He had to eliminate stray light in the compact optical system and also deal with cost restrictions.

Did you have other doubts?

**Matsumura:** Yes. At that time, the R&D Group I belong to was developing a unique signal processing technology. One day, I had a fellow engineer demonstrate it and I thought “This is amazing” but I also wondered, “what can it actually be used for?”

Did “that signal processing technology” help increase the sensitivity of the immunochromato readers?

**Matsumura:** Yes indeed. After a while, I was really impressed by it and thought, “This is perfect for removing noise from fluorescence immunochromato readers!” After this, the rest of the development work went ahead smoothly.

**Kondo:** We tried it out in a simple preliminary experiment and got good results so we then immediately started trial production.

Why did Mr. Matsumura think “that signal processing technology” would solve the challenges?

**Matsumura:** Well, we finally found out the cause of the low optical system sensitivity. It was the excitation light illuminating the lateral


flow strip and then leaking into the optical system. This light leakage seemed to appear as noise which lowered the sensitivity. If this was the true cause then what could we do to remove that excitation light signal during measurement? We then came up with the idea that the signal processing technology would prove effective.

So that is how you fixed the problem! The new technology created by the Engineering Department and the issues of the development group became linked across the departments and a solution finally appeared. That's really impressive!

## One day at a time, each issue was solved

What happened after you found the solutions?

**Kondo:** We first made a unit to verify the basic theory and to find out whether we could really obtain useful data from this combined technology and actually achieve the theory. At first, we couldn't get the results we expected, so all members spent most of their time in the darkroom for a couple of months and we worked each day to pinpoint what was wrong to improve it.

**Matsumura:** We had to make experiments in a closed darkroom because of the fluorescence device we were using. It was a simple room with no air conditioning. In the summer, it got hot and it lacked fresh air, making it a difficult place to work in.

While all of you were having such a hard time, were you confident you could complete the new immunochromato reader? Were there any times you felt like giving up?

**Kondo:** No, we really believed in what we were doing. Every day we found an issue to work on and in the process of solving it, we really felt like we were moving closer to our goal thanks to everyone's help.

Looking back now, what was the most difficult part of all this?

**Kondo:** Since the housing of the product is plastic, it was more difficult to take measures against electrical noise than in the preliminary experiments. Using a metallic material makes it relatively easy to eliminate the noise but the housing of the final product had to be made of plastic.

**Morishita:** Unlike metal, plastic allows noise to pass through. This means we first had to deal with external noise in order to increase the immunochromato reader sensitivity. I think that completely removing this noise was the most difficult thing we had to do to ensure reliable operations.

What specific measures did you take to deal with the noise?

**Matsumura:** During the development phase, we used something similar to shield tape to wrap around the housing as a noise countermeasure. We called this process: "Paint it gold" (laughter) because the housing, which was initially black, became shiny due to the amount of tape wound around.

**Kondo:** The final product now on sale has a housing properly designed to prevent noise intrusion, but no such housing was available in the development stage...

## Achieves 20 times higher sensitivity than the previous model!

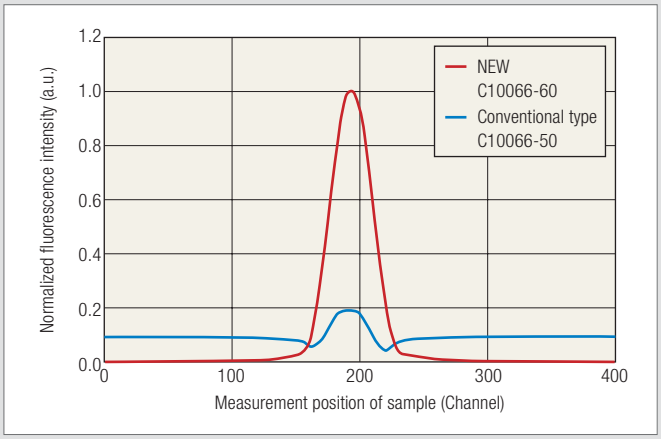
You finally completed the new immunochromato reader after a lot of hard work. How did customers react to it?

**Suzuki:** We released it in the fall of last year. Since then, we have received inquiries from many customers who were mainly reagent manufacturers. Most customers who used our demo unit eventually purchased the product, so we think this new immunochromato reader received high rating for its high sensitivity.

How much has the sensitivity increased?

**Morishita:** Compared to our previous fluorescence immunochromato reader, the sensitivity has increased by 9 times, and the signal-to-noise ratio by about 25 times. One customer's initial request was to increase the sensitivity by at least 4 times the amount previously obtained. Clearly, we exceeded our customer's expectations in terms of sensitivity.

Comparison of fluorescence intensity obtained by sample scanning




**Matsumura:** In addition to improving sensitivity, we upgraded other components. For example, we redesigned the lens of the optical system to enhance the beam focus and also modified complex algorithms for the digital section. I suppose the total result from all these small modifications contributed to enhancing the overall sensitivity.

Are there any points that customers have rated highly other than sensitivity?

**Suzuki:** Yes, there is. That point is measurement reproducibility. Since the same reliable result is obtained every time, the customers feel confident about the reagents they develop with our immunochromato reader.

## Helping to expand applications ranging from research to clinical use

Lastly, please tell us more about its future prospects.

**Morishita:** The fluorescence immunochromato reader we currently released is intended for research and development applications. As a next step, we are going to develop two models for clinical use. One is a general-purpose model that can be used in clinical environments. The other is a so-called reader engine that is a compact unit designed for installation into equipment yet has the minimum required functions ranging from fluorescence-reading to analysis. This reader engine will meet customer demands for in-house development of fluorescence lateral flow readers.

**Kondo:** If new models are released in these two market areas, then new lateral flow strips developed by reagent manufacturers can be made more quickly available to clinical sites.


**Morishita:** Let me add one point about reagents. Currently, europium (Eu) is mainly used for fluorescent reagents. If our immunochromato readers become able to support reagents other than europium, we believe this will contribute to expanding the range of useful reagents. There are also clinical test items that cannot be checked due to insufficient sensitivity. We hope our immunochromato readers will prove to be a breakthrough technology for those tests so we can contribute to achieving a healthier society.

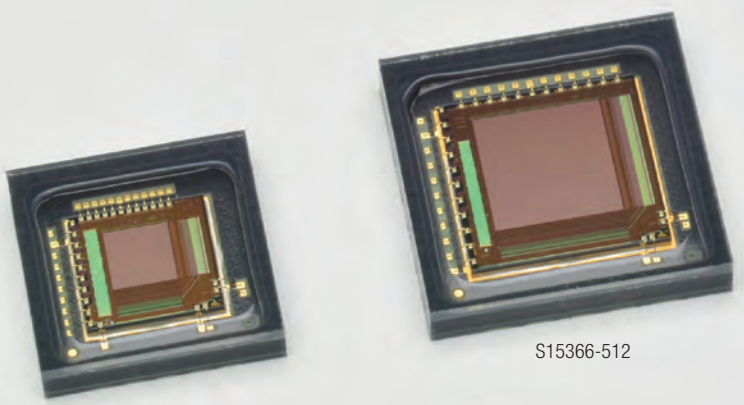
How about from a sales perspective?

**Suzuki:** The fluorescence immunochromato reader we released this time is designed for use with a PC to make detailed analyses ideal for quality control and R&D applications. However, for hospitals and clinics, where it necessary to operate easily while still maintaining a high performance, we would like our customers to entrust us with designing and developing OEM units specially made for their clinical needs.

**Our immunochromato readers primarily designed for R&D and quality control of reagents are now evolving to meet clinical usage needs. This will allow customers to set sight on wider markets while inheriting the high-sensitivity performance offered by our immunochromato readers. Let us keep looking forward to some really fast-paced future developments!**

NEW OPTO-SEMICONDUCTOR PRODUCTS

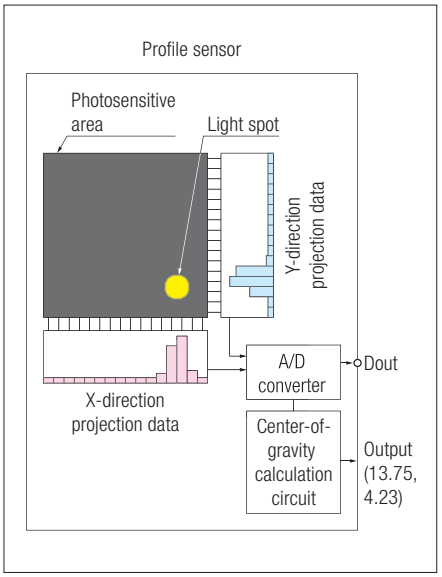
# Profile Sensors S15366-256/-512



S15366-256

S15366-512

Operation schematic




Comparison with CMOS area image sensors

| Parameter | Profile sensors NEW S15366-256/-512 | CMOS area image sensors |
|---|---|---|
| Image subject | Limited to bright spot (light spot, pattern, etc.) | General purpose (shape, color, pattern, etc.) |
| Photodiodes | X/Y-directions honeycomb array | Horizontal/vertical directions 2D array |
| Pixels | Pixels connected with the respective photodiodes in the X/Y-directions | Each pixel provided with a photodiode |
| Scanning method | Two lines readout by X/Y-directions scanning circuits | Area readout with vertical/horizontal scanning circuits |
| Center-of-gravity calculation circuit | Built-in | None |
| Output data | Center-of-gravity calculation results (X/Y-direction projection data) | Two-dimensional image |

## Outputs the Incident Position Coordinate Data of Light Spot, Built-in Center-of-Gravity Calculation Circuit

These profile sensors come with center-of-gravity calculation specialized in the function of calculating the incident signal of the light spot in its chip, and of outputting the incident position information. The photosensitive area is arranged in two dimensions in the X and Y directions, so projection data can be acquired by sequentially acquiring the sum of outputs from the photosensitive area of each line. With the built-in center-of-gravity calculation circuit, it is able to output the incident position of the light spot as coordinate data, eliminating the need for calculation with an external controller. It also comes equipped with a high-speed readout function and an automatic light spot tracking function.

### Differences from the previous product

The profile sensors are CMOS image sensors specialized in acquiring projection data (additional data of output in 1 vertical column and 1 horizontal row). Since the projection data size is small, position detection and moving object detection can be performed faster than normal CMOS area image sensors.

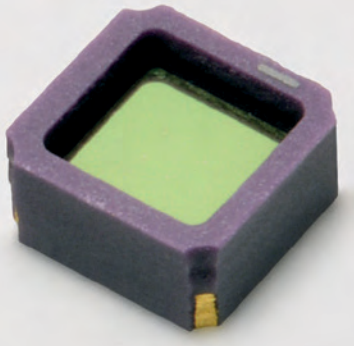
### Features

- Built-in center-of-gravity calculation circuit
- Enables partial readout and binning readout
- Low-power consumption
- Equipped with an automatic tracking mode
- Effective photosensitive area, number of pixels:
  2 × 2 mm, 256 + 256 pixels (S15366-256)
  4 × 4 mm, 512 + 512 pixels (S15366-512)
- High-speed frame rate:
  3156 frames/s max. (S15366-256)
  1602 frames/s max. (S15366-512)

### Applications

- Light spot position detection (printers, FA inspection equipment, amusement machines)
- Moving object detection (FA inspection equipment, amusement machines)
- 3D measurement (FA inspection equipment, medical measurement

# InAsSb Photovoltaic Detector P16612-011CA



## Specifications

| Parameter | Specifications | Unit |
|---|---|---|
| Photosensitive area | 0.7 × 0.7 | mm |
| Cutoff wavelength | 5.3 | µm |
| Peak sensitivity wavelength | 4.1 | µm |
| Photosensitivity | 4.5 | mA/W |
| Shunt resistance | 180 | kΩ |
| Detectivity | $1.0 \times 10^9$ | $cm \cdot Hz^{1/2}/W$ |
| Rise time | 15 | ns |

## Temperature Characteristics Was Greatly Improved by Using a Back-Illuminated Structure

The P16612-011CA is a photovoltaic type infrared detector that has high sensitivity in the spectral band up to 5 µm. This high sensitivity has been achieved due to Hamamatsu's unique crystal growth technology and process technology.

**Differences from the previous product**
Compared to the front-illuminated type P13243-013CA, the temperature coefficient of sensitivity has been improved from -0.9 %/°C to -0.1 %/°C in the wavelength range up to 4.5 µm.

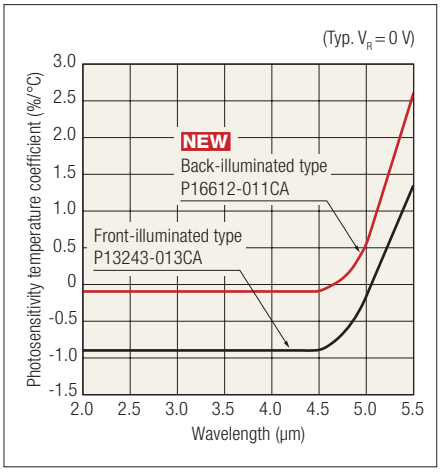
### Features

- High sensitivity
- Compact, surface mount type ceramic package
- Compatible with lead-free solder reflow

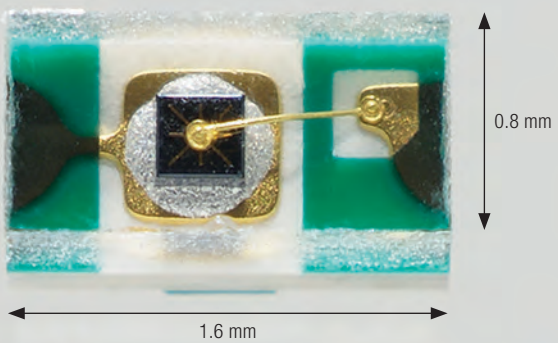
### Applications

- Gas detection ($CH_4$, $CO_2$, CO, etc.)
- Radiation thermometers
- Flame detection ($CO_2$ resonance radiation)

Photosensitivity temperature characteristics



# Infrared LED L13072-0120G, L12771-0130G




## Compact, Surface Mount Type Package Peak Emission Wavelength: 1.2 µm, 1.3 µm

These are high-power infrared LEDs made using InGaAs material. They are used in combination with an InGaAs photodiode for the applications of analysis and measurement. Lower prices have been achieved by the use of a surface mount type package.

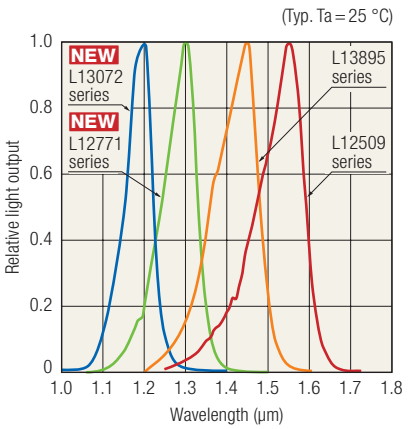
**Differences from the previous product**

We have added 1.2 µm and 1.3 µm surface mount types to our 1 µm band near infrared LED lineup.

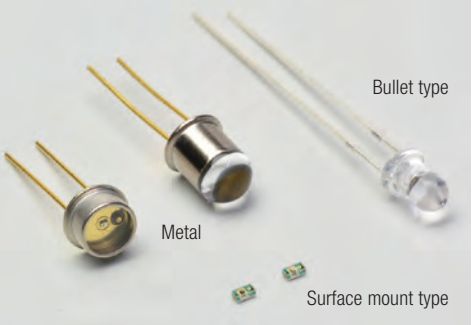
**Features**

- Peak emission wavelength:
  1.2 µm (L13072-0120G)
  1.3 µm (L12771-0130G)
- Compact, surface mount type package:
  $1.6 \times 0.8 \times 0.7^{t}$ mm
- Compatible with lead-free solder reflow

Emission spectrum




We have a lineup of near infrared LEDs that support various wavelength bands (1.2 µm/1.3 µm/1.45 µm/1.55 µm). In addition to the surface mount type, we also offer a highly reliable metal package and a narrow directivity bullet type.



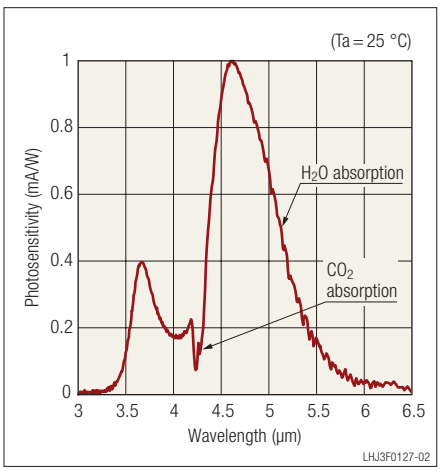
# Quantum Cascade Photodetector P16309-01

## Specifications

| Parameter | Value | Unit |
|---|---|---|
| Peak sensitive wavelength | 4.65 | µm |
| Photosensitivity | 1.0 | mA/W |
| Detectivity | $1.5 \times 10^{9}$ | cm·Hz$^{1/2}$/W |
| Noise equivalent power | $3.0 \times 10^{-10}$ | W/Hz$^{1/2}$ |
| Cut-off frequency | 20 | GHz |
| Connector type | SMA | – |
| Aperture | $\phi$4.5 | mm |

Ambient temperature: Ta = 25 °C

## Spectral response (example)




# Ultrafast Infrared Detector with a Gigahertz Optical Response

This is a ultrafast mid-infrared photodetector with a response bandwidth of 20 GHz. QCD explores the application such the high frequency and high time resolved measurement like a Heterodyne detection in mid-infrared region.

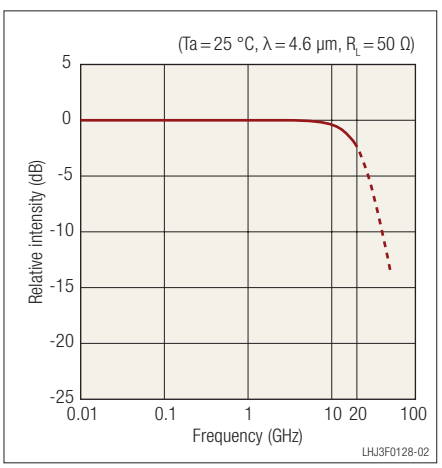
### Features

- Ultrafast infrared detector with a gigahertz optical response
- Response frequency range (-3 dB): DC to 20 GHz
- Peak sensitive wavelength: 4.65 µm
- Photosensitivity: 1.0 mA/W (typ.)
- No cooling, and no operation bias are required

### Applications

- Heterodyne detection
- High frequency/high time resolved measurement

## Response frequency (example)



# Image Intensifier Unit C16031

Specifications

| Parameter | Specification | Unit |
|---|---|---|
| Photocathode type | Multialkali | – |
| Spectral response range | 185 to 900 | nm |
| Input/Output faceplate size | $\phi$24/$\phi$16 | mm |
| Luminous gain (typ.) | $1 \times 10^5$ | $(lm/m^2)/lx$ |
| Limiting resolution (typ.) | 38 | Lp/mm |
| Gate maximum repetition frequency | 200 | kHz |

## Compatible with High-Speed Cameras Ideal for High Frame Rate Image Capture

The C16031 consists of an image intensifier (I.I.), a high-voltage power supply circuit, a gate drive circuit, and an image booster. Using the image booster increases the output brightness by two orders of magnitude to obtain a bright image required for high-speed cameras. Its compact cuboid shape allows easy connection to the body of most high-performance readout cameras, which is not so easily obtained by the standard product (C10880 series) with its "L" shaped configuration.

### Features

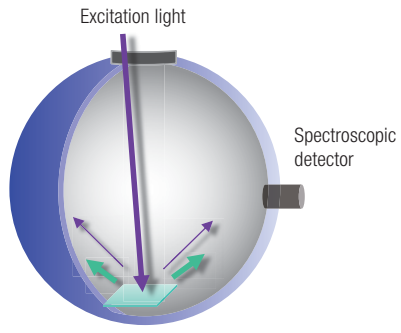
- Compact: 100 mm × 100 mm × 120 mm (W x H x D)
- Cuboid shape easily connectable to camera
- Gate function: 10 ns to DC
- Excessive light protection
- C-mount or F-mount selectable

### Applications

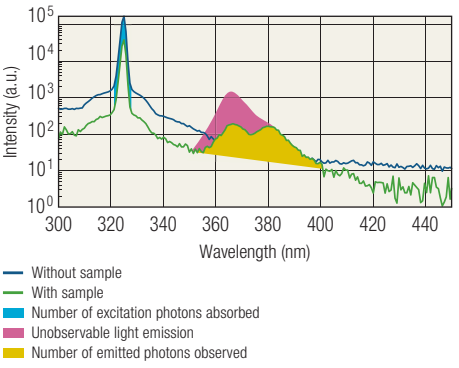
- Observation of high-speed moving objects and phenomena
  - Electrical discharge
  - Invisible phenomena in UV and near IR regions
  - Fluorescence from cells
  - Engine combustion

# ODPL Measurement System C15993-01


Structure of integrating sphere




ODPL measurement




**Calculation of EQE**

$$EQE = \frac{\text{Number of emitted photons observed}}{\text{Number of excitation photons absorbed}}$$

**Calculation of IQE**

IQE is calculated by analyzing the following information from EQE.

- Light extraction efficiency: Calculates the light emission amount absorbed by the sample
- Photon Recycling: Considers the process by which light emission is absorbed and emitted again in a GaN single crystal

[Ex.] **EQE 0.65 %** → **IQE 15 %**

## Easy and Instant Measurement of IQE, Which Is Necessary to Evaluate GaN Single Crystals and Perovskite Crystals

The ODPL measurement system uses an integrating sphere to measure the spectrum of omnidirectional photoluminescence and determine the emission efficiency of samples. Instant measurement of IQE (internal quantum efficiency) contributes to quantitative quality evaluation with a non-destructive and non-contact process.

### What is ODPL measurement?

ODPL measurement is a method of photoluminescence measurement using an integrating sphere to obtain the ratio of the number of photons emitted from a sample to the number of photons of excitation light absorbed by the sample. Semiconductor crystals have a wavelength region where photon absorption and emission overlap. Some light emission cannot be observed due to light extraction efficiency and photon recycling in that region. Thesefore only EQE (emission external quantum efficiency) can be observed among emitted light.* The ODPL measurement system can calculate IQE instantly by combining the measured EQE with analysis taking into consideration the unobservable light.

### Measurement target

- GaN single crystal
- Perovskite crystal

### Measurement/analysis items

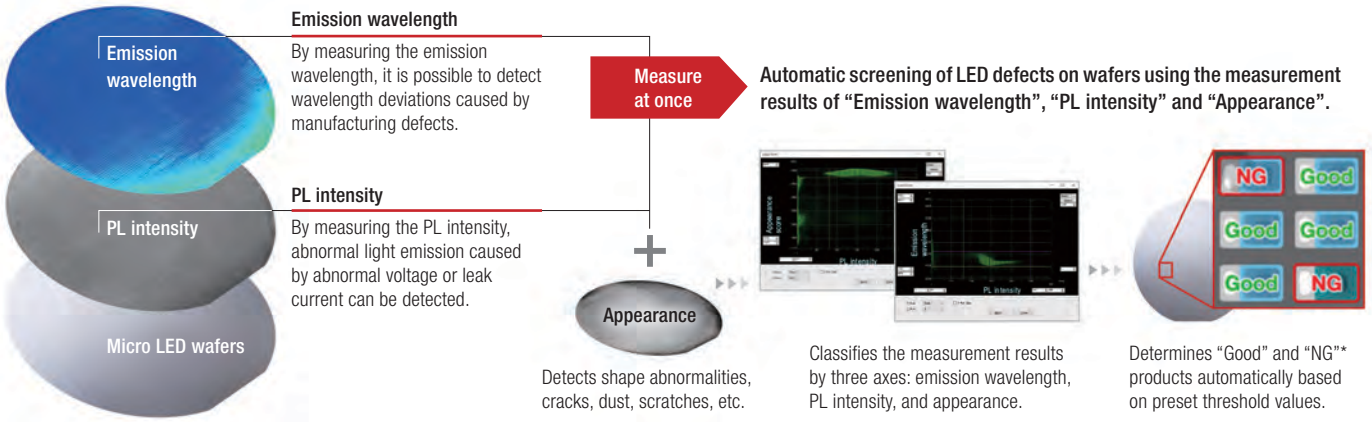
- EQE measurement
- IQE calculation
- Absorption ratio measurement
- PL spectrum measurement

*Except when IQE is 100 %.

NEW SYSTEMS PRODUCTS

# MiNY® PL Micro LED PL Inspection System C15740-01

## Screening mechanism




*NG stands for Not Good.

# High-Speed, Non-Contact, Non-Destructive, Automatic Inspection of the Entire Wafer for Micro LEDs

MiNY® PL is an inspection system for micro LED wafers using the photoluminescence measurement method that enables a full inspection, which is not possible with electroluminescence (EL) inspection. This system screens LED defects on wafers using the measurement results of "Emission wavelength", "PL intensity" and "Appearance".

### Features

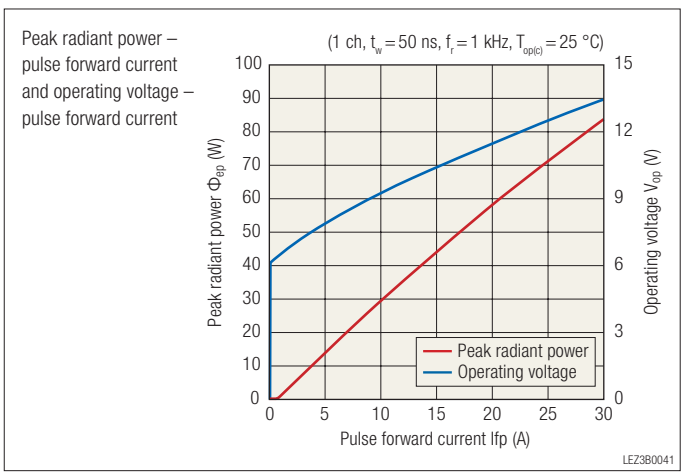
- Detects abnormalities in luminescence and wavelength that cannot be detected by Automated Optical Inspection (AOI)
- High-speed, non-contact, non-destructive full inspection
- Enables inspection in the front-end of the manufacturing process, contributing to higher yields

## Specifications

| Parameter | Specifications |
|---|---|
| Supported wafer size | 100 mm (4 inches) or 150 mm (6 inches) (other sizes negotiable) |
| Measurement time | Approx. 12 minutes (objective lens 10×, PL measurement, 4 inch wafers) |
| PL measurement wavelength | R, G, B |
| Spatial resolution | 1 µm/pixel (standard mode), 0.5 µm/pixel (high resolution mode) |
| Measurement items | Shape abnormality, PL intensity, PL wavelength abnormality |

# Pulsed Laser Diode
# L15326-01

Peak radiant power (example)




NEP emitting pattern (example)

## 4-Channel Array Surface-Mount Type Ideal for LiDAR

4-channel array surface-mount pulsed laser diode (PLD) ideal for high-reliability LiDAR. LD is mounted on a highly reliable hollow ceramic package, it facilitates short pulse operation and high peak power output. The anodes in the 3 stack structure are independent electrodes and the cathode is a common electrode, this enables both simultaneous and individual operation of the PLD.

**Differences from the previous product**

Compared with conventional can packages, low inductance and low thermal resistance are realized.This facilitates short pulse operation and high output.

### Features

- Wavelength: 905 nm
- Emission width: 230 µm
- High-reliability hollow ceramic packages
- Sharp NFP light emitting emissions pattern
- Narrow non-light emitting area (narrow GAP)

### Applications

- LiDAR
- 3D sensing

# SPOLD® LD Irradiation Light Source L14140-55


## Specifications

| Parameter | Specification |
|---|---|
| Radiant power (at ouput end of the irradiation unit with maximum current setting) (min.) | 2.3 W |
| Laser type | LD |
| Oscillation type | CW |
| Peak emission wavelength | 448 nm ± 5 nm |
| Cooling method | Air cooling |
| Dimensions (W x H x D) | 280 mm × 100 mm × 300 mm protrusions (excluding) |
| Light condensing diameter | $\phi$0.1 ~ $\phi$1.6* |

*Depends on the fiber core diameter and condensing magnification

## Application examples

**Figure 1: Soldering**

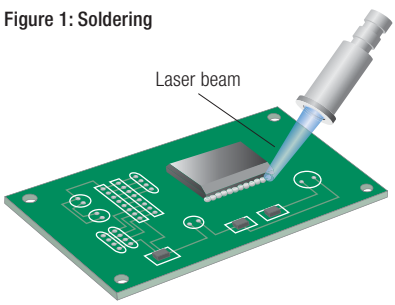
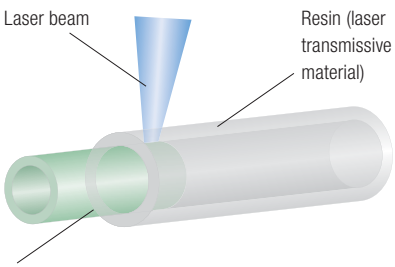



**Figure 2: Plastic welding of medical devices**




# Compact LD Irradiation Light Source with an Oscillation Wavelength of 448 nm

Copper absorption efficiency is better than infrared laser, which enables more precise welding, such as soldering of medical devices.

It can be used for joining medical devices such as catheters and fittings. It can be joined without the use of adhesives or other materials.

Ideal for copper processing, we have recently added 448 nm to our lineup of conventional products (only for near-infrared wavelength).

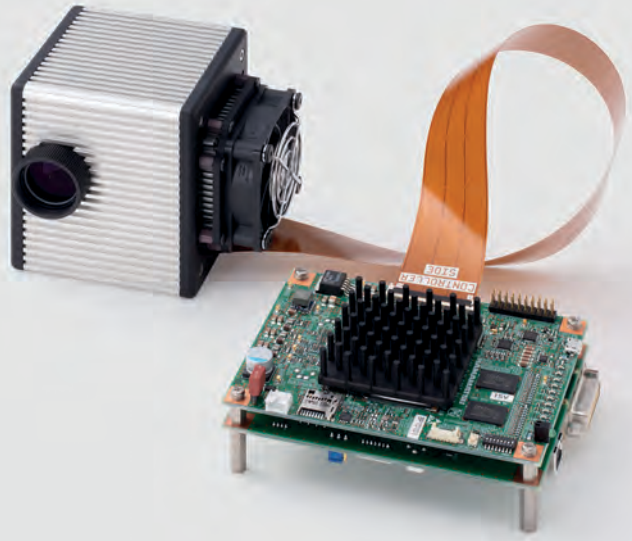
### Features

- Wavelength: 448 nm
- Energy saving/space saving
- Welding of plastic and copper which do not absorb infrared light
- Easy external control
- Specially designed for embedded use in equipment

### Applications

- Soldering of tiny parts
- Plastic welding of medical devices

# Wavefront Shaper C16353 Series

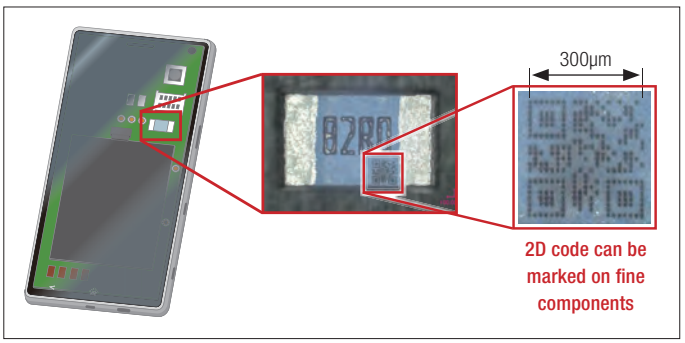


Specifications

| Type.no | Wavelength range | Unit |
|---|---|---|
| C16353-04M | 460 ~ 560 | nm |
| C16353-02 | 750 ~ 850 | nm |
| C16353-12 | 850 ~ 1000 | nm |
| C16353-03 | 1000 ~ 1100 | nm |

For other wavelengths, contact our sales office separately

2D code marking processing image




## Phase Control Modules for Industrial Applications Suitable for Laser Processing and Microscope Observation

This is a spatial optical phase modulation module designed for embedding in equipment, such as laser processing equipment and microscopes. It is configured to connect the LCOS-SLM head and the controller with a flexible cable. In addition, since it is equipped with DLL (dynamic link libraries) and application software to make a phase data for beam shaping, it is possible to add a computer hologram creation function, etc. to the software.

**Differences from the previous product**

Compared to a reflection type LCOS-SLM (X15223 series), the wavefront shaper has a pseudo-transmittance configuration and allows direct mounting of optical components.

### Features

- Easy connections to optical components/systems
- Simple control (with various DLL for control)
- Number of pixel: 1272 × 1024 pixels
- Pixel pitch: 12.5 µm
- Construction of high functioning laser machining/microscopic observation systems
- Temperature control function (for high-power laser processing applications)

### Applications

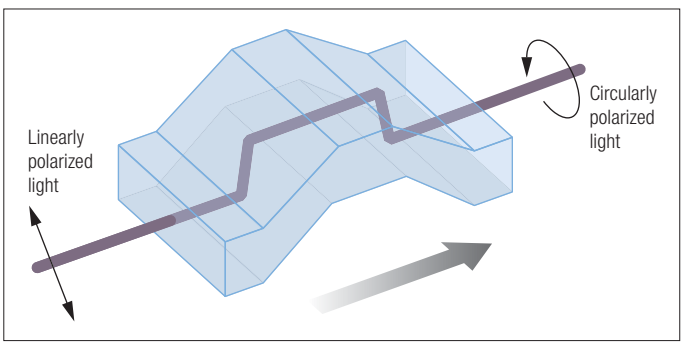
- Optical beam shaping
- Optical manipulation/Aberration correction
- Repair/trimming
- 3D simulataneous multipoint laser beam generation

# Terahertz Wave Plate
# A16394-02/-04

Specifications

| Parameter | A16394-02 | A16394-04 | Unit |
|---|---|---|---|
| Phase delay amount | λ/2 | λ/4 | – |
| Material | Sillicon | | – |
| Effective aperture | ϕ20 | | mm |
| Dimensions (D × L) | 50.8 × 50 | 50.8 × 31 | mm |

Polarization control with total reflection prism (example)




## Large-Diameter, High-Transmittance Terahertz Wave Plate

This is a Fresnel rhomb wave plate for controlling terahertz (THz) wave polarization. The adoption of Fresnel rhomb makes it possible to handle a THz wave over a broad band. In addition, stacking total reflection prisms simultaneously achieves a large aperture and a small size of the component. The prisms are made of high-resistivity silicon, which highly transmits a THz wave.

### Features

- Optical element for polarization control of terahertz wave
- Fresnel rhomb wave plate with co-axial design for input and output terahertz beams
- Broadband (typical value: 0.5 THz to 2.5 THz)

### Applications

- THz wave phase control
- THz polarization imaging
- THz-STM (scanning tunnel microscope)

# Selection Guide
Series

## Select your ideal photonics **solution**

We compiled a complete new series of Selection Guides to make it easier for our customers to find and choose the most suitable solution for their application.

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- Infrared detectors
- InGaAs
- LED
- Mini-spectrometers
- Si APD
- Si photodiodes

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These were designed to ensure an easy navigation through the range of options such as wavelength, sensitivity, resolution and more. Many of our products can be customized based on your needs, so please contact us if you wish to discuss this option further.

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